SOUND

Objectives

• State what the source of sound

 is. (26.1)

• Describe the movement of

 sound through air. (26.2)

• Compare the transmission of

 sound through air with that

 through solids, liquids, and a

 vacuum. (26.3)

• Describe factors that affect the

 speed of sound. (26.4)

• Describe loudness and sound

 intensity. (26.5)

• Describe natural frequency.

 (26.6)

• Describe the purpose of a

 sounding board in a stringed

 musical instrument. (26.7)

• Describe resonance. (26.8)

• Describe how sound waves

 interfere with one another.

 (26.9)

• Describe beats. (26.10)

6 SOUND

THE BIG

........

IDEA

Sound is a form of energy that

spreads out through space.

W

discover!

MATERIALS

tuning forks

 Students

will hear a change in sound

intensity as they rotate a

vibrating tuning fork.

EXPECTED OUTCOME

ANALYZE AND CONCLUDE

 hen a singer sings, the vocal chords in the singer’s

 throat vibrate to and fro, causing adjacent air mol-

 ecules to vibrate. This air, in turn, vibrates against

neighboring air molecules. A series of ripples in the form of

a longitudinal wave travels through the air. The frequency

of the ripples matches the frequency of the singer’s

vibrating vocal chords. When the ripples hit your

eardrum, the eardrum is pushed and then pulled

with the same frequency as the singer’s vibrat-

ing vocal chords. Vibrations in the eardrum send

rhythmic electrical impulses into your brain. And

you hear the voice of the singer.

 Molecules of air behave like tiny table-tennis

balls. If you place a tuning fork in the middle of

a room and then strike the tuning fork with a

rubber hammer, the prongs of the vibrating

tuning fork set the surrounding air mol-

ecules into motion in the same way that

the moving paddle sets the table-tennis

balls into motion.

1. The intensity of the sound

 varies.

2. Alternating loud and

 soft sounds occur more

 frequently with a tuning

 fork with a higher

 frequency.

3. Each of the tuning fork’s

 tines has a front and a

 back surface. Sounds from

 these surfaces interfere

 with each other in the

 area surrounding the tines,

 producing an audible

 interference pattern.

discover!

What Is Acoustical Interference?

1. Strike a tuning fork with a rubber hammer or

 on the heel of your shoe. (Do not strike the

 tuning fork on the edge of the table.)

2. Place the vibrating tuning fork near your ear.

3. Slowly rotate the vibrating tuning fork.

 Make certain that you rotate the tuning fork

 through 360 degrees.

Analyze and Conclude

1. Observing What do you hear as you rotate

 the tuning fork?

2. Predicting What do you think you would hear

 if you were to use a tuning fork with a higher

 pitch? A lower pitch?

3. Making Generalizations What causes the

 changes in sound intensity produced by rotat-

 ing a tuning fork?

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26.1 The Origin

26.1 The Origin of Sound

 All sounds originate in the vibrations of material objects. In a

piano, violin, or guitar, a sound wave is produced by vibrating strings;

in a saxophone, by a vibrating reed; in a flute, by a fluttering column

of air at the mouthpiece. The prongs of the tuning fork in Figure 26.1

vibrate when the fork is struck. Your voice results from the vibration

of your vocal chords.

 In each of these cases, the original vibration stimulates the vibra-

tion of something larger or more massive—the sounding board of

a stringed instrument, the air column within a reed or wind instru-

ment, or the air in the throat and mouth of a singer. This vibrating

material then sends a disturbance through a surrounding medium,

usually air, in the form of longitudinal waves. Under ordinary con-

ditions, the frequency of the sound waves produced equals the fre-

quency of the vibrating source.

 We describe our subjective impression about the frequency of

sound by the word pitch. A high-pitched sound like that from a pic-

colo has a high vibration frequency, while a low-pitched sound like

that from a foghorn has a low vibration frequency.

 A young person can normally hear pitches with frequencies

from about 20 to 20,000 hertz. As we grow older, our hearing range

shrinks, especially at the high-frequency end. Sound waves with

frequencies below 20 hertz are called infrasonic, and those with

frequencies above 20,000 hertz are called ultrasonic. We cannot

hear infrasonic or ultrasonic sound waves. Dogs can hear frequencies

of 40,000 Hz or more. Bats can hear sounds at over 100,000 Hz.

CONCEPT

of Sound

Key Terms

pitch, infrasonic, ultrasonic

 Teaching Tip State that

sound is the only thing that the

ear can hear. Then state that

the source of sound or any wave

motion is a vibrating object.

Demonstrations

Tap a large tuning fork and

show that it is vibrating

by dipping the vibrating

prongs in a cup of water.

The splashing water shows

that the prongs are moving.

(Small forks do not work well

because the frequency is too

high for the eyes to see.)

Show a large radio speaker

without its cover. Play low

frequencies with an audio

oscillator (or other source) so

students gathered around can

see the diaphragm vibrating.

Rub some pine pitch or rosin

on your fingers and stroke

an aluminum rod. If you do it

properly, it will “sing” quite

loudly. Do this while holding

the rod at its midpoint, and

then at different places to

show harmonics. (Of course

you have practiced this first!)

FIGURE 26.1

The source of all sound

waves is vibration.

......

CHECK

What is the source of all sound?

26.2 Sound in Air

Clap your hands and you produce a sound pulse that goes out in

all directions. The pulse vibrates the air somewhat as a similar

pulse would vibrate the coiled spring shown in Figure 26.2. Each

particle moves back and forth along the direction of motion of the

expanding wave.

FIGURE 26.2

A compression travels

along the spring.

 All sounds originate

CHECK in the vibrations of

material objects.

CONCEPT

Teaching Resources

Conceptual Physics Alive!

 DVDs

 Vibrations and Sound I, II

CHAPTER 26

SOUND

......

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26.2 Sound in Air

Key Terms

compression, rarefaction

 Teaching Tip Vibrate a

Slinky transversely to show a

transverse wave. Then vibrate

it longitudinally to show a

longitudinal wave. Call attention

to the compressions and

rarefactions of the longitudinal

wave and relate them to the

compressions and rarefactions

that occur in air as sound passes

through it.

 For a clearer picture of this process, consider the long room

shown in Figure 26.3. At one end is an open window with a curtain

over it. At the other end is a door.

FIGURE 26.3

Opening and closing a door

produces compressions and rar-

efactions. a. When the door is

opened, a compression travels

across the room. b. When the

door is closed, a rarefaction

travels across the room.

a

b

 As a source of sound

CHECK vibrates, a series of

compressions and rarefactions

travels outward from the source.

CONCEPT

Teaching Resources

• Reading and Study

 Workbook

• PresentationEXPRESS

• Interactive Textbook

FIGURE 26.4

The vibrating cone of the

speaker produces the

pleasing sound of music.

 When you quickly open the door as in Figure 26.3a, you can

imagine the door pushing the molecules next to it away from their

initial positions, and into their neighbors. Neighboring molecules, in

turn, push into their neighbors, and so on, like a compression wave

moving along a spring, until the curtain flaps out the window. A

pulse of compressed air has moved from the door to the curtain. This

pulse of compressed air is called a compression.

 When you quickly close the door as in Figure 26.3b, the door

pushes neighboring air molecules out of the room. This produces an

area of low pressure next to the door. Neighboring molecules then

move into it, leaving a zone of lower pressure behind them. We say

the air in this zone of lower pressure is rarefied. Other molecules far-

ther from the door, in turn, move into these rarefied regions, result-

ing in a pulse of rarefied air moving from the door to the curtain.

This is evident when the lower-pressure air reaches the curtain, which

flaps inward. This pulse of low-pressure air is called a rarefaction.

 For all wave motion, it is not the medium that travels across the

room, but a pulse that travels. In both cases the pulse travels from the

door to the curtain. We know this because in both cases the curtain

moves after the door is opened or closed.

 If you swing the door open and closed in periodic fashion, you

can set up a wave of periodic compressions and rarefactions that

will make the curtain swing in and out of the window. On a much

smaller but more rapid scale, this is what happens when a tuning fork

is struck or when the speaker in Figure 26.4 produces music. As

a source of sound vibrates, a series of compressions and rarefac-

tions travels outward from the source. The vibrations of the tuning

fork and the waves it produces are considerably higher in frequency

and lower in amplitude than in the case of the swinging door. You

don’t notice the effect of sound waves on the curtain, but you are well

aware of them when they meet your sensitive eardrums.

516

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26.3 Media That

Transmit Sound

FIGURE 26.5

Compressions and rarefactions

travel from the tuning fork

through the tube.

Demonstration

Place a bell or ringing alarm

clock in a bell jar. Using a

vacuum pump, remove the air

from the jar while the bell is

ringing. Students will notice

how the sound diminishes as

the air is removed from the

jar.

 Consider sound waves in the tube shown in Figure 26.5. For sim-

plicity, only the waves that travel in the tube are shown. When the

prong of the tuning fork next to the tube moves toward the tube, a

compression enters the tube. When the prong swings away, in the

opposite direction, a rarefaction follows the compression. It is like the

table-tennis paddle moving back and forth in a room packed with

table-tennis balls. As the source vibrates, a series of compressions and

rarefactions is produced.

CONCEPT

CHECK

How does a sound wave travel through air?

26.3 Media That Transmit Sound

Most sounds you hear are transmitted through the air, but put your

ear to the ground as Native Americans did, and you can hear the

hoofbeats of distant horses through the ground before you can hear

them through the air. More practically, put your ear to a metal fence

and have a friend tap it far away. The sound is transmitted louder and

faster by the metal than by the air. Sound travels in solids, liquids,

and gases.

 Or click two rocks together underwater while your ear is sub-

merged. You’ll hear the clicking sound very clearly. If you’ve ever

been swimming in the presence of motorized boats, you’ve probably

noticed that you can hear the boats’ motors much more clearly under

water than above water. Solids and liquids are generally good conduc-

tors of sound—much better than air. The speed of sound differs in

different materials. In general, sound is transmitted faster in liquids

than in gases, and still faster in solids.

 The boy in Figure 26.6 cannot hear the ringing bell when air is

removed from the jar because sound cannot travel in a vacuum. The

transmission of sound requires a medium. If there is nothing to com-

press and expand, there can be no sound. There may still be vibra-

tions, but without a medium there is no sound.

 Teaching Tip While the

loudness of sound from the

ringing doorbell diminishes,

discuss the movement of sound

through different media—gases,

liquids, and solids (vibrating table

tennis balls analogy). Ask why

sound moves faster in warm air.

(Faster-moving balls take less

time to bump into one another.)

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CONCEPT

CHECK

gases.

Sound travels in

solids, liquids, and

Teaching Resources

FIGURE 26.6

Sound can be heard from

the ringing bell when air is

inside the jar, but not when

the air is removed.

• Reading and Study

 Workbook

• PresentationEXPRESS

• Interactive Textbook

CONCEPT

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CHECK

What media transmit sound?

......

CHAPTER 26

SOUND

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26.4 Speed of Sound

 Common Misconception

The speed of sound is the same in all

media.

 The speed of sound

depends on the medium, its

temperature, and its elasticity.

FACT

26.4 Speed of Sound

think!

How far away is a storm

if you note a 3-second

delay between a lightning

flash and the sound of

thunder? Answer: 26.4

 Teaching Tip Discuss

the speed of sound through

different media—four times as

fast in water as in air—about

fifteen times as fast in steel.

The elasticity of these materials

accounts for the different speeds.

Explain why Native Americans

used to place their ears to the

ground to hear distant hoof

beats and how one could (but

should not) put an ear to a track

to listen for distant trains.

 Teaching Tip Explain that

sound travels faster in moist

air than in dry air because H2O

molecules move faster than N2 or

O2 molecules. This shortens the

time between the collisions that

transmit the sound energy. H2O

molecules move faster because

they have less mass (18 amu) than

O2 (32 amu) and N2 (28 amu). At

the same temperature, molecules

have the same KE, so the less

massive ones move faster.

 Teaching Tip Point out that

light travels quite fast, nearly one

million times faster through air

than sound travels.

 The speed of sound

CHECK in a gas depends on

the temperature and the mass of

the particles. The speed of sound

in a material depends on

elasticity.

CONCEPT

Have you ever watched a distant person chopping wood or hammer-

ing, and noticed that the sound of the blow takes time to reach your

ears? You see the blow before you hear it. This is most noticeable in

the case of lightning. You hear thunder after you see the lightning.

These experiences are evidence that sound is much slower than light.

 The speed of sound in a gas depends on the temperature of

the gas and the mass of the particles in the gas. The speed of sound

in dry air at 0°C is about 330 meters per second, or about 1200 kilo-

meters per hour, about one-millionth the speed of light. Water vapor

in the air and increased temperatures increase this speed slightly. This

makes sense, for the faster-moving molecules in warm air bump into

each other more often and therefore can transmit a pulse in less time.

For each degree increase in air temperature above 0°C, the speed of

sound in air increases by about 0.60 m/s. So in air at a normal room

temperature of about 20°C, sound travels at about 340 m/s. The

speed of sound in a gas also depends on the mass of its particles.

Lighter particles such as hydrogen molecules and helium atoms move

faster and transmit sound much more quickly than heavier gases

such as oxygen and nitrogen, found in air.

 The speed of sound in a solid material depends not on the mate-

rial’s density, but on its elasticity. Elasticity is the ability of a material

to change shape in response to an applied force, and then resume its

initial shape once the distorting force is removed. The speed of

sound in a material depend on the material’s elasticity. Steel is very

elastic; putty is inelastic.26.4 In elastic materials, the atoms are relatively

close together and respond quickly to each other’s motions, transmit-

ting energy with little loss. Sound travels about fifteen times faster in

steel than in air, and about four times faster in water than in air.

CONCEPT

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CHECK

What determines the speed of sound in a medium?

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Link to TECHNOLOGY

Ultrasound Imaging A technique for harmlessly “seeing” inside

a body uses high-frequency sound (ultrasound) instead of X-rays.

Ultrasound that enters the body is reflected more strongly from

the outside of an organ than from its inside, and we get a picture

of the outline of the organ. When ultrasound is incident upon

a moving object, the reflected sound has a slightly different

frequency. Using this Doppler effect, a physician can “see” the

beating heart of a developing fetus that is only 11 weeks old.

Teaching Resources

• Concept-Development

 Practice Workbook 26-1

• Next-Time Question 26-1

• Laboratory Manual 72

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26.5 Loudness

FIGURE 26.7

The loudspeaker at the left is a paper

cone that vibrates in rhythm with an

electric signal. The sound sets up

similar vibrations in the microphone,

which are displayed on the screen

of an oscilloscope. The wave on

the oscilloscope reveals information

about the sound.

Demonstration

Play mono music from a tape

recorder through a pair of

enclosed stereo speakers

placed side by side facing the

class. First, play one speaker.

Then play both in phase. The

resulting sound is slightly

louder than with one speaker.

Reverse the speaker wires to

one of the speakers to reverse

its phase. (Speaker systems

for stereos have polarity

indications on their terminals.)

The sound is much less intense

than from the single speaker.

With the speakers still facing

forward, vary the separation

distance and illustrate the

wavelength dependence

of the interference. (As the

distance between the speakers

becomes greater, so does the

loudness of the sound. Sound

with wavelengths greater than

the distance between speakers

is canceled. Note the variations

in the quality of the sound.

Finally, face the speakers

toward each other with only a

small gap between them. Play

one, and then both, in phase.

Then reverse the polarity of

one of the speakers. The result

is almost total silence. Sound

at virtually all wavelengths is

being canceled by destructive

interference. As you increase

the distance between the

speakers, shorter wavelengths

avoid total destructive

interference, and the sound

level increases. Spectacular!

26.5 Loudness

The intensity of a sound is proportional to the square of the amplitude

 The decibel scale for

of a sound wave. Sound intensity is objective and is measured

 loudness is logarithmic.

by instruments. Loudness, on the other hand, is a physiological

sensation sensed in the brain. It differs for different people. Loudness

is subjective but is related to sound intensity. The unit of intensity for

sound is the decibel (dB), after Alexander Graham Bell, inventor of the

telephone. The oscilloscope shown in Figure 26.7 measures sound.

 Some common sources and sound levels are given in

 Table 26.1 Sound Levels

Table 26.1. Starting with zero at the threshold of hearing

for a normal ear, an increase of each 10 dB means thatSource of SoundLevel (dB)

sound intensity increases by a factor of 10. A sound of

 Jet engine, at 30 m140

10 dB is 10 times as intense as sound of 0 dB; 20 dB is

 Threshold of pain120

not twice but 10 times as intense as 10 dB, or 100 times as

 Loud rock music115

intense as the threshold of hearing. A 60-dB sound is

 Old subway train100100 times as intense as a 40-dB sound.

 Average factory90Roughly, the sensation of loudness follows this decibel

scale. We hear a 100-dB sound to be about as much louderBusy street trafﬁc70

than a 70-dB sound as the 70-dB sound is louder than a

 Normal speech60

40-dB sound because there is a 30-dB difference between

 Library40

the pairs of sound each time.

 Close whisper20

 Physiological hearing damage begins at exposure to

 Normal breathing10

85 decibels. The extent of damage depends on the length

 Hearing threshold0of exposure and on frequency characteristics. A single

burst of sound can produce vibrations intense enough

to tear apart the organ of Corti, the receptor organ in

the inner ear. Less intense, but severe, noise can interfere with cel-

lular processes in the organ and cause its eventual breakdown.

Unfortunately, the cells of the Corti do not regenerate.

CHECK

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CONCEPT What is the difference between sound

intensity and loudness?

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SOUND

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 Teaching Tip The loudest

sounds emitted by a creature

are those from the Blue Whale.

They can emit sounds at a volume

greater than 180 dB in water,

but pitched too low for humans

to detect without sensitive

equipment.

 Sound intensity is

CHECK objective and is

measured by instruments.

Loudness is a physiological

sensation sensed in the brain.

CONCEPT

26.6 Natural Frequency

Drop a wrench and a baseball bat on the floor, and you hear dis-

tinctly different sounds. Objects vibrate differently when they strike

the floor. Tap a wrench, and the vibrations it makes are different from

the vibrations of a baseball bat, or of anything else.

 When any object composed of an elastic material is dis-

turbed, it vibrates at its own special set of frequencies, which

together form its special sound. We speak of an object’s natural

frequency, which is the frequency at which an object vibrates when

it is disturbed. An object’s natural frequency depends on the elastic-

ity and shape of the object. The bells shown in Figure 26.8 and tun-

ing forks vibrate at their own characteristic frequencies. Interestingly

enough, most things—from planets to atoms and almost everything

else in between—have a springiness to them and vibrate at one or

more natural frequencies. A natural frequency is one at which mini-

mum energy is required to produce forced vibrations. It is also the

frequency that requires the least amount of energy to continue this

vibration.

CONCEPT

......

FIGURE 26.8

The natural frequency of the

smaller bell is higher than

that of the big bell, and it

rings at a higher pitch.

26.6 Natural

Frequency

Key Term

natural frequency

 Teaching Tip Compare the

sounds of a couple of pennies

dropped on a hard surface—one

dated before 1982 and one after.

The old penny is made of 95%

copper and 5% zinc, and sounds

noticeably different than the

newer pure zinc core pennies

plated with copper.

 Teaching Tip Note that the

human ear can discriminate

among more than 300,000 tones!

 When an object

CHECK composed of an

elastic material is disturbed, it

vibrates at is own special set of

frequencies.

CONCEPT

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CHECK

What happens when an elastic material is disturbed?

26.7 Forced Vibration

When you strike an unmounted tuning fork, the sound it makes is

faint. Strike a tuning fork while holding its base on a tabletop, and

the sound is relatively loud. Why? It is because the table is forced to

vibrate, and its larger surface sets more air in motion. The tabletop

becomes a sounding board, and can be forced into vibration with

forks of various frequencies. This is a case of a forced vibration.

A forced vibration occurs when an object is made to vibrate by

another vibrating object that is nearby.

 The washtub in Figure 26.9 serves as a sounding board.

 Sounding boards are an important part of all stringed musical

instruments because they are forced into vibration and produce the

sound. The vibration of guitar strings in an acoustical guitar would

be faint if they weren’t transmitted to the guitar’s wooden body. The

mechanism in a music box is mounted on a sounding board. Without

the sounding board, the sound the music box mechanism makes is

barely audible.

CONCEPT Why are sounding boards an important part of

26.7 Forced

Vibration

Key Term

forced vibration

 Sounding boards are

CHECK an important part of

all stringed musical instruments

because they are forced into

vibration and produce the sound.

CONCEPT

......

FIGURE 26.9

When the string is plucked,

the washtub is set into

forced vibration and serves

as a sounding board.

......

CHECK

stringed instruments?

520

520

26.8 Resonance

26.8 Resonance

Resonance is a phenomenon that occurs when the frequency of a

vibration forced on an object matches the object’s natural frequency

and a dramatic increase in amplitude occurs. Resonance means to

re-sound, or sound again. Putty doesn’t resonate because it isn’t

elastic, and a dropped handkerchief is too limp. An object

resonates when there is a force to pull it back to its starting

position and enough energy to keep it vibrating.

 A common experience illustrating resonance occurs on a swing

like the one shown in Figure 26.10. When pumping a swing, you

pump in rhythm with the natural frequency of the swing. More

important than the force with which you pump is the timing. Even

small pumps, or even small pushes from someone else, if delivered in

rhythm with the natural frequency of the swinging motion, produce

large amplitudes.

FIGURE 26.11

The stages of resonance are shown for a tuning fork. a. The first

compression meets the fork and gives it a tiny and momentary push.

b. The fork bends. c. The fork returns to its initial position just at the

time a rarefaction arrives. d. It keeps moving and overshoots in the

opposite direction. e. When it returns to its initial position, the next

compression arrives to repeat the cycle.

Key Term

resonance

Demonstration

Show resonance using a long

stove pipe. Put three layers

of wire window screen on

crossed wires 1/4 of the way

up from the bottom of the

stove pipe. Heat gently over

a Bunsen burner (not so hot

as to melt the screen). The

screen becomes a white-noise

generator, while the tube is

the frequency selector that

resonates at the fundamental

frequency of the tube. When

the tube is removed from the

flame, it continues to sound

as the wire screen cools. Turn

the pipe horizontal until the

sound subsides for a few

seconds, and then turn it back

to vertical—the sound returns.

Very impressive!

FIGURE 26.10

Pumping a swing in rhythm

with its natural frequency

produces larger amplitudes.

 Teaching Tip Give other

examples of resonance; the

chattering vibration of a glass

shelf when a radio placed on it

plays a certain note; the loose

front end of a car that vibrates at

only certain speeds; crystal glass

shattered by a singer’s voice;

troops marching in step across a

bridge.

 A common classroom demonstration of resonance uses a pair

of tuning forks adjusted to the same frequency and spaced about a

meter apart. When one of the forks is struck, it sets the other fork

into vibration as shown in Figure 26.11. This is a small-scale ver-

sion of pushing a friend on a swing—it’s the timing that’s important.

When a sound wave impinges on the fork, each compression gives the

prong a tiny push. Since the frequency of these pushes corresponds to

the natural frequency of the fork, the pushes successively increase the

amplitude of the fork’s vibration. This is because the pushes occur at

the right time and are repeatedly in the same direction as the instan-

taneous motion of the fork.

Like humans, we

parrots use our

tongues to craft and

shape sound. Tiny

changes in the position

of my tongue produce

big differences in the

sound I make.

Forced vibrations, resonance,

and interference provide a

useful background for the same

concepts applied to light in

following chapters.

CHAPTER 26

SOUND

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 An object resonates

CHECK when there is a force

to pull it back to its starting

position and enough energy to

keep it vibrating.

CONCEPT

......

26.9 Interference

 Common Misconception

Sound cannot cancel sound.

 Sound waves, like

any waves, can interfere

constructively or destructively.

FACT

 Teaching Tip Review

interference by sketching

overlapping sine curves on the

board (Figure 26.13, or

Figure 25.10 on p. 498).

 If the forks are not adjusted for matched frequencies, the timing

of pushes will be off and resonance will not occur. When you tune

your radio set, you are similarly adjusting the natural frequency of

the electronics in the set to match one of the many incoming signals.

The set then resonates to one station at a time, instead of playing all

the stations at once.

 Resonance occurs whenever successive impulses are applied to a

vibrating object in rhythm with its natural frequency. English infan-

try troops marching across a footbridge in 1831 inadvertently caused

the bridge to collapse when they marched in rhythm with the bridge’s

natural frequency. Since then, it is customary for troops to “break

step” when crossing bridges. The Tacoma Narrows Bridge disaster

in 1940, shown in Figure 26.12, is attributed to wind-generated

resonance. A mild 40-mile-per-hour wind gale produced a fluctuat-

ing force that resonated with the natural frequency of the bridge,

steadily increasing the amplitude over several hours until the bridge

collapsed.

CONCEPT

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Now you’re ready for a series

of fantastic demonstrations—

perhaps the most unforgettable

of your course!

CHECK

What causes resonance?

26.9 Interference

Sound waves, like any waves, can be made to interfere. A comparison

of interference for transverse waves and longitudinal waves is shown

in Figure 26.13. For sound, the crest of a wave corresponds to a com-

pression, and the trough of a wave corresponds to a rarefaction.

In either case, when the crests of one wave overlap the crests of

another wave, there is constructive interference and an increase in

amplitude. Or when the crests of one wave overlap the troughs of

another wave, there is destructive interference and a decrease in

amplitude. When constructive interference occurs with sound

waves, the listener hears a louder sound. When destructive interfer-

ence occurs, the listener hears a fainter sound or no sound at all.

The listener in Figure 26.14a is equally distant from two sound speak-

ers that simultaneously trigger identical sound waves of constant

frequency. The listener hears a louder sound because the waves add.

The compressions and rarefactions arrive in phase, that is, in step.

 In Figure 26.14b, the listener moved to the side so that paths from

the speakers differ by a half wavelength. The rarefactions from one

speaker reach the listener at the same time as compressions from the

other. It’s like the crest of one water wave exactly filling in the trough

of another water wave—destructive interference. (If the speakers emit

many frequencies, not all wavelengths destructively interfere for a

given difference in path lengths.)

Demonstration

Remove the foam cover

from a small speaker (a few

centimeters in diameter).

Connect the speaker to the

auxiliary output of a portable

tape recorder. Play music

through the speaker. The

music will sound quite tinny.

Then produce a baffle (large

flat piece of cardboard or

whatever) with a hole slightly

smaller than the size of the

speaker cut in its middle. Place

the speaker behind the hole

and note the much-improved

sound quality. (The baffle

reduces the interference

between the back and front

waves.) Place the same

speaker behind a hole in a

small closed box to show even

better quality.

FIGURE 26.12

In 1940, four months after

being completed, the

Tacoma Narrows Bridge in

the state of Washington was

destroyed by a 40-mile-per-

hour wind.

For: Links on interference

Visit: www.SciLinks.org

Web Code: csn – 2609

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FIGURE 26.13

Both transverse and longi-

tudinal waves display wave

interference when they are

superimposed.

a. Two identical transverse waves in phase produce a wave of increased

amplitude.

b. Two identical longitudinal waves in phase produce a wave of increased

amplitude.

c. Two identical transverse waves that are out of phase destroy each other.

 Teaching Tip Explain that

a speaker produces waves from

both its front and its rear. These

waves are 180° out of phase.

As it produces a compression in

front, it produces a rarefaction in

back, and vice versa. When sound

reaches your ears from both the

front and back of a speaker,

destructive interference occurs.

This is most pronounced for long

waves where the difference in

the distances traveled from the

speaker to you is relatively small.

An uncovered speaker sounds

tinny because it produces little

sound energy for wavelengths

much longer than its diameter.

The long-wavelength bass notes

are canceled. This cancellation is

notably reduced when the baffle

is introduced.

d. Two identical longitudinal waves that are out of phase destroy each other.

 Destructive interference of sound waves is usually not a problem

because there is usually enough reflection of sound to fill in canceled

spots. Nevertheless, “dead spots” are sometimes evident in poorly

designed theaters and gymnasiums, where sound waves reflected off

walls interfere with unreflected waves to form zones of low ampli-

tude. Often, moving your head a few centimeters in either direction

can make a noticeable difference.

 Destructive sound interference is a useful property in antinoise

technology. Noisy devices such as jackhammers are being equipped

with microphones that send the sound of the device to electronic

microchips. The microchips create mirror-image wave patterns of

the sound signals. For the jackhammer, this mirror-image sound

signal is fed to earphones worn by the operator. Sound compressions

(or rarefactions) from the hammer are neutralized by mirror-image

rarefactions (or compressions) in the earphones. The combination

of signals neutralizes the jackhammer noise. Noise-canceling ear-

phones, shown in Figure 26.15, are already common for pilots. Some

automobiles enjoy quiet riding due to noise cancellation. Noise-

detecting microphones inside the car pick up engine or road noise.

Speakers in the car then emit an opposite signal that cancels out

those noises, so the human ear can’t detect them. Similarly, the cab-

ins of some airplanes are now quieted with antinoise technology.

a

b

 When constructive

CHECK interference occurs

with sound waves, the listener

hears a louder sound. When

destructive interference occurs,

the listener hears a fainter sound

or no sound at all.

CONCEPT

FIGURE 26.14

The sound waves from two

speakers interfere. a. Waves

arrive in phase. b. Waves

arrive out of phase.

Teaching Resources

• Reading and Study

 Workbook

• Transparency 54

• PresentationEXPRESS

• Interactive Textbook

CHAPTER 26

SOUND

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CONCEPT What are the effects of constructive and

destructive interference?

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26.10 Beats

Key Term

beats

 Teaching Tip Tell students

they can produce beats next

time they are in a room with a

ventilation fan. If they hum at

the same frequency as the hum

of the fan, they will hear beats.

 Teaching Tip You can show

interference and beats with an

oscilloscope trace of a pair of

sound sources slightly out of sync.

26.10 Beats

 When two tones of slightly different frequency are sounded

together, a regular fluctuation in the loudness of the combined

sounds is heard. The sound is loud, then faint, then loud, then

faint, and so on. This periodic variation in the loudness of sound is

called beats. Beats are an interesting and special case of interference.

 Beats can be heard when two slightly mismatched tuning forks,

like the ones shown in Figure 26.16, are sounded together. Because

one fork vibrates at a frequency different from the other, the vibra-

tions of the forks will be momentarily in step, then out of step, then

in again, and so on. When the combined waves reach your ears in

step—say when a compression from one fork overlaps a compression

from the other—the sound is a maximum. A moment later, when

the forks are out of step, a compression from one fork is met with a

rarefaction from the other, resulting in a minimum. The sound that

reaches your ears throbs between maximum and minimum loudness

and produces a tremolo effect.

FIGURE 26.15

Ken Ford tows gliders in

quiet comfort when he

wears his noise-canceling

earphones.

FIGURE 26.16

A sound wave traveling

through the ear canal

vibrates the eardrum,

which vibrates three

tiny bones, which

vibrate the fluid-filled

cochlea. Inside the

cochlea, tiny hair cells

convert the pulse into

an electrical signal to

the brain. Ear plugs

typically reduce noise

by about 30 dB.

The interference of two sound sources of slightly different

frequencies produces beats.

 If you walk side by side with someone who has a different stride,

there will be times when you are both in step, and times when you

are both out of step. Suppose, for example, that you take exactly 70

steps in one minute and your friend takes 72 steps in the same time.

Your friend gains two steps per minute on you. A little thought will

show that you two will be momentarily in step twice each minute.

In general, when two people with different strides walk together, the

number of times they are in step in each unit of time is equal to the

difference in the frequencies of their steps. This applies also to a pair

of tuning forks. When one fork vibrates 264 times per second, and

the other fork vibrates 262 times per second, they are in step twice

each second. A beat frequency of 2 hertz is heard.

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Demonstration

 Beats can be nicely displayed on an oscilloscope. When sound

signals of slightly different frequencies are fed into an oscilloscope,

graphical representations of their pressure patterns can be displayed

both individually and when the sounds overlap. Figure 26.17 shows

the wave forms for two waves separately, and superposed. Although

the separate waves are of constant amplitude, we see amplitude varia-

tions in the superposed wave form. Careful inspection of the figure

shows this variation is produced by the interference of the two super-

posed waves. Maximum amplitude of the composite wave occurs

when both waves are in phase, and minimum amplitude occurs when

both waves are completely out of phase. Like the walkers in the pre-

vious example, the waves are in step twice each second, producing a

beat frequency of 2 Hz. The 10- and 12-Hz waves, chosen for con-

venience here, are infrasonic, so they and their beats are inaudible.

Higher-frequency audible waves behave exactly the same way and can

produce audible beats.

 If you overlap two combs of different teeth spacings as shown in

Figure 26.18, you’ll see a moiré pattern that is related to beats. The

number of beats per length will equal the difference in the number of

teeth per length for the two combs.

Show beats by bouncing laser

light off a pair of vibrating

tuning forks as shown below.

FIGURE 26.17

Sinusoidal representations

of a 10-Hz sound wave and

a 12-Hz sound wave dur-

ing a 1-second time inter-

val. When the two waves

overlap, they produce a

composite wave with a beat

frequency of 2 Hz.

FIGURE 26.18

The unequal spacings of the combs produce a moiré

pattern that is similar to beats.

 Beats can occur with any kind of wave and are a practical way to

compare frequencies. To tune a piano, a piano tuner listens for beats

produced between a standard tuning fork and a particular string on

the piano. When the frequencies are identical, the beats disappear.

The members of an orchestra tune up by listening for beats between

their instruments and a standard tone produced by an oboe.

CONCEPT

 When two tones of

CHECK slightly different

frequency are sounded together,

a regular fluctuation in the

loudness of the combined sounds

is heard.

CONCEPT

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What causes beats?

Teaching Resources

• Reading and Study

 Workbook

• Transparency 55

• PresentationEXPRESS

• Interactive Textbook

CHAPTER 26

SOUND

think!

What is the beat frequency when a 262-Hz and a 266-Hz tuning fork are

sounded together? A 262-Hz and a 272-Hz?

Answer: 26.10

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Science, Technology,

 and Society

CRITICAL THINKING

 Students’

examples may vary. Accept all

reasonable responses. Hearing

can be protected by limiting

(or avoiding) time spent in

excessively noisy environments

or by wearing ear protectors

such as ear plugs.

Science, Technology, and Society

Noise and Your Health

Most of us try to protect

our eyes from excess light,

but few give the same

care to our ears. Near

loudspeakers during her

first time at a concert,

Allison was alarmed at

the pain in her ears. Her

friends meant to reassure

her when they told her

she’d get used to it. But

what they didn’t tell her

was that after the fine

tuning of her ears was

blasted, she wouldn’t

know the difference.

 Teaching Tip The loudest

sounds emitted by a creature

are those from the Blue Whale.

They can emit sounds at a volume

greater than 180 db in water, but

the sounds are pitched too low

for humans to detect without

sensitive equipment.

Industrial noise is even

more damaging to the

ears than amplified music

because of its sudden

high-energy peaks. Loud

motorcycles, jackhammers,

chain saws, and power

tools not only produce

steady high-volume sound, but also produce sporadic peaks of energy

that can destroy tiny hair cells in the inner ear. When these tiny sensory

cells in the inner ear are destroyed they can never be restored. Noise-

induced hearing loss is insidious.

Fortunately for music devotees, damage caused by energetic peaks is

somewhat limited by an inadequate response of electronic amplifiers

and loudspeakers. Similarly for live music where most of the sound

comes from amplifying equipment. If amplifying equipment were more

responsive to sudden sound bursts, hearing loss at concerts would be

more severe.

The impact of hearing loss isn’t fully apparent until compounded by age.

Today’s young people will be tomorrow’s old people—probably the hardest

of hearing ever. Start now to care for your ears and prevent further hearing

loss!

Critical Thinking Describe some situations you might find yourself

in that could cause hearing loss. What can you do to protect your

hearing?

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