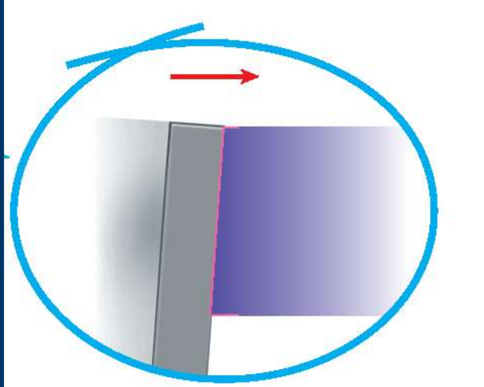
Preview

Objectives

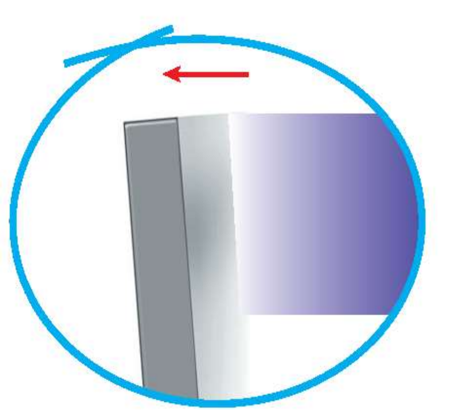
- **Explain** how sound waves are produced.
- **Relate** frequency to pitch.
- **Compare** the speed of sound in various media.
- **Relate** plane waves to spherical waves.
- **Recognize** the Doppler effect, and **determine** the direction of a frequency shift when there is relative motion between a source and an observer.

What is Sound?

- Sound is a longitudinal wave.
- All sound waves are produced by vibrating objects.
  - Tuning forks, guitar strings, vocal cords, speakers
- The vibrating object pushes the air molecules together, forming a *compression*.
- It then spreads them apart, forming a *rarefaction*.

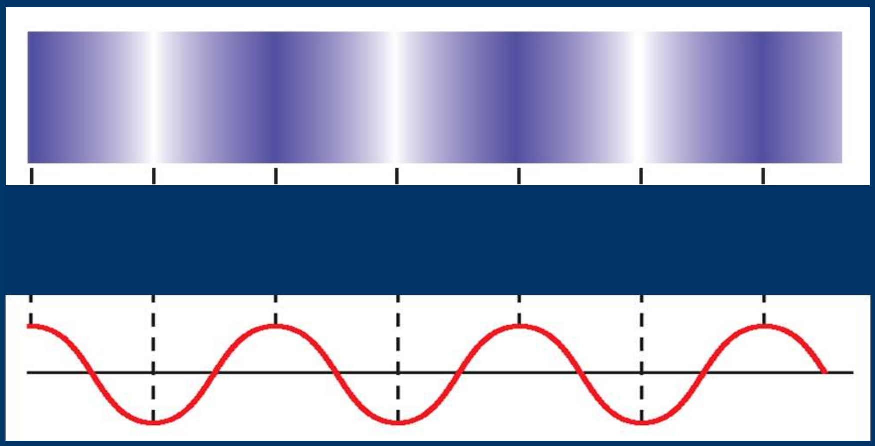


(c) Compression



(d) Rarefaction

Graphing Sound Waves



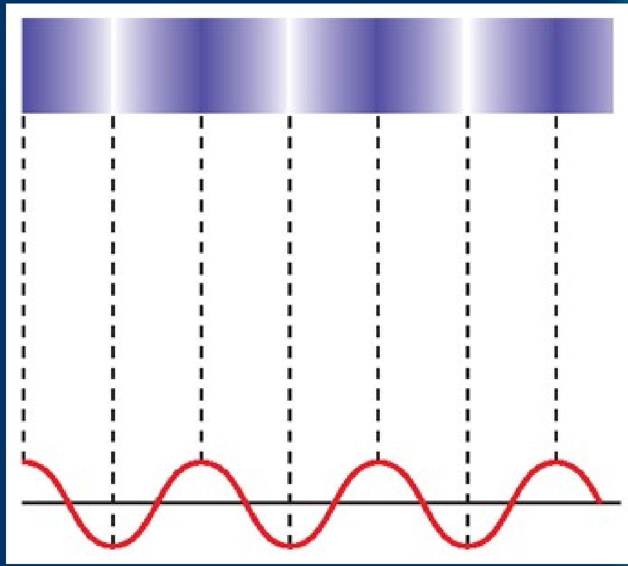
- The diagram shows compressions (dark) and rarefactions(white). If you measured the pressure or density of the air and plotted these against position, how would the graph appear?

The Production of Sound Waves

- Every sound wave begins with a **vibrating object,** such as the vibrating prong of a tuning fork.
- A **compression** is the region of a longitudinal wave in which the density and pressure are at a maximum.
- A **rarefaction** is the region of a longitudinal wave in which the density and pressure are at a minimum.

The Production of Sound Waves, *continued*

- Sound waves are **longitudinal.**
- The simplest longitudinal wave produced by a vibrating object can be represented by a **sine curve.**
- In the diagram, the **crests** of the sine curve correspond to **compressions,** and the **troughs** correspond to **rarefactions.**



Characteristics of Sound

- Frequency is the number of waves per second.
- You have heard of *ultrasound*. What is it?
- Frequencies audible to humans are between 20 Hz and 20 000 Hz.
  - Middle C on a piano is 262 Hz.
  - The emergency broadcast signal is 1 000 Hz.
- Infrasound frequencies are lower than 20 Hz.
- Ultrasound frequencies are greater than 20 000 Hz.

Frequency of Sound Waves

- As discussed earlier, **frequency** is defined as the number of cycles per unit of time.
- Sound waves that the average human ear can hear, called **audible** sound waves, have frequencies between **20 and 20 000 Hz.**
- Sound waves with frequencies **less than 20 Hz** are called **infrasonic** waves.
- Sound waves with frequencies **above 20 000 Hz** are called **ultrasonic** waves.

End of Slide

Frequency and Pitch

- The **frequency** of an audible sound wave determines how **high or low** we perceive the sound to be, which is known as **pitch.**
- As the frequency of a sound wave **increases,** the pitch **rises.**
- The frequency of a wave is an objective quantity that can be measured, while pitch refers to how different frequencies are perceived by the human ear.

End of Slide

Pitch

- Pitch is the human perception of how high or low a sound appears to be.
  - Pitch is primarily determined by frequency.
  - Pitch also depends slightly on other factors.
    - Higher frequencies appear to have a higher pitch when played loudly, even though the frequency does not change.

Speed of Sound

- Sound waves travel though solids, liquids and gases.
  - In which would the speed generally be greatest? Why?
    - Solids. Because the molecules are more closely packed, the particles respond more rapidly to compressions.
  - How might the temperature of air affect the speed of sound waves? Why?
    - Higher temperature increases the speed of the waves because the particles are moving faster and colliding more often.

The Speed of Sound

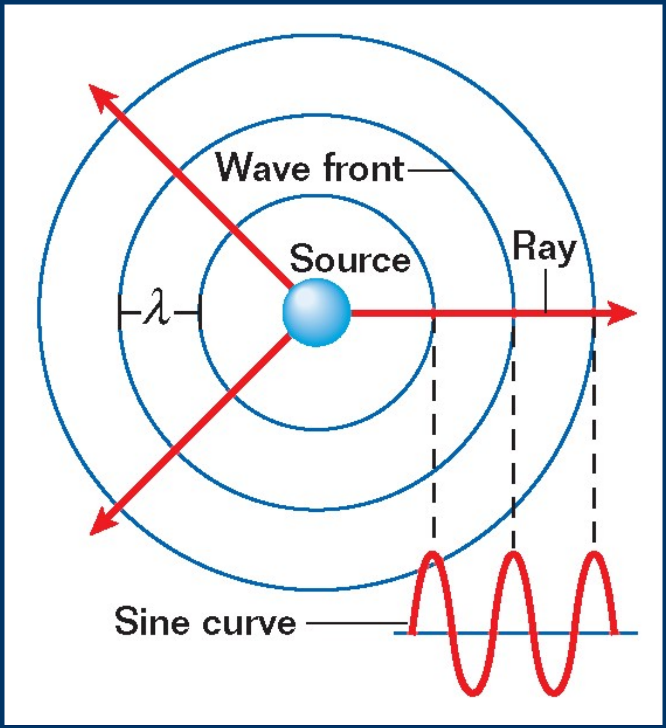
- The speed of sound depends on the **medium.**
  - Because waves consist of particle vibrations, the speed of a wave depends on how quickly one particle can transfer its motion to another particle.
  - For example, sound waves generally travel faster through solids than through gases because the molecules of a solid are closer together than those of a gas are.
- The speed of sound also depends on the **temperature** of the medium. This is most noticeable with gases.

The Speed of Sound in Various Media

Medium	v (m/s)
Gases	
air (0°C)	331
air (25°C)	346
air (100°C)	366
helium (0°C)	972
hydrogen (0°C)	1290
oxygen (0°C)	317
Liquids at 25°C	
methyl alcohol	1140
sea water	1530
water	1490
Solids	
aluminum	5100
copper	3560
iron	5130
lead	1320
vulcanized rubber	54

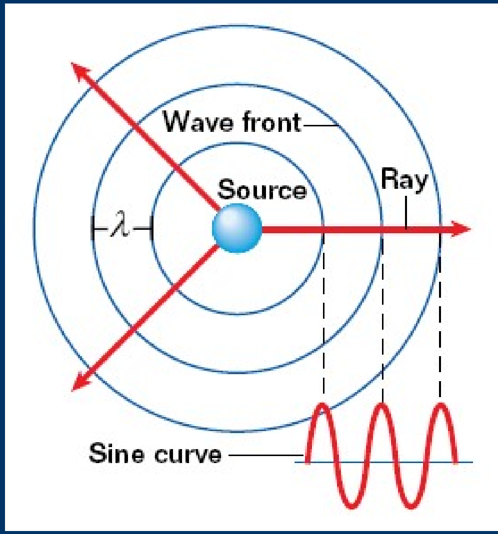
Spherical Waves

- Sound propagates in three dimensions.
- The diagram shows:
  - Crests or wave fronts (blue circles)
  - Wavelength (λ)
  - Rays (red arrows)
- Rays indicate the direction of propagation.
- How would these wave fronts appear different if they were much farther from the source?

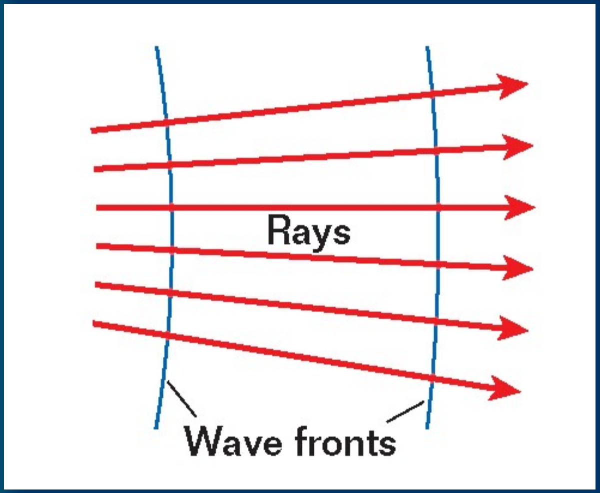


The Propagation of Sound Waves

- Sound waves propagate in three dimensions.
- Spherical waves can be represented graphically in two dimensions, as shown in the diagram.
- The circles represent the centers of compressions, called **wave fronts.**
- The radial lines perpendicular to the wave fronts are called **rays.**
- The **sine curve** used in our previous representation corresponds to a single ray.



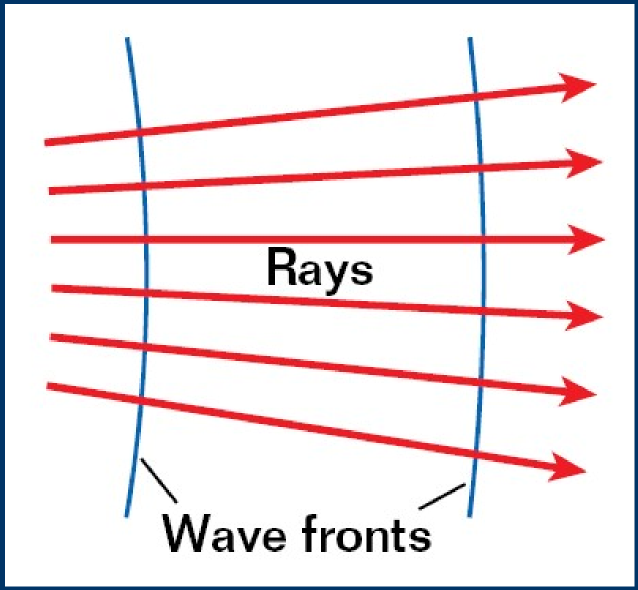
Spherical Waves



- Wave fronts and rays become more nearly parallel at great distances.
- Plane waves are simply very small segments of a spherical wave a long distance from the source.

The Propagation of Sound Waves, *continued*

- At distances from the source that are great relative to the wavelength, we can approximate **spherical wave fronts** with **parallel planes.**
- Such waves are called **plane waves.**
- Plane waves can be treated as one-dimensional waves all traveling in the same direction.



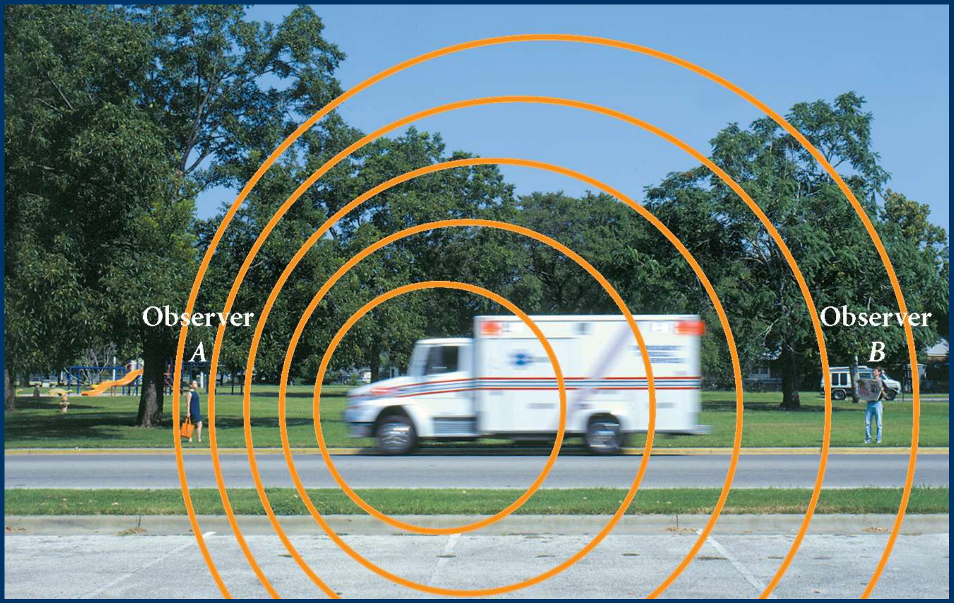
The Doppler Effect

- The **Doppler effect** is an observed change in frequency when there is **relative motion** between the source of waves and an observer.
- Because frequency determines pitch, the Doppler effect affects the **pitch** heard by each listener.
- Although the Doppler effect is most commonly experienced with sound waves, it is a phenomenon common to all waves, including electromagnetic waves, such as visible light.

End of Slide

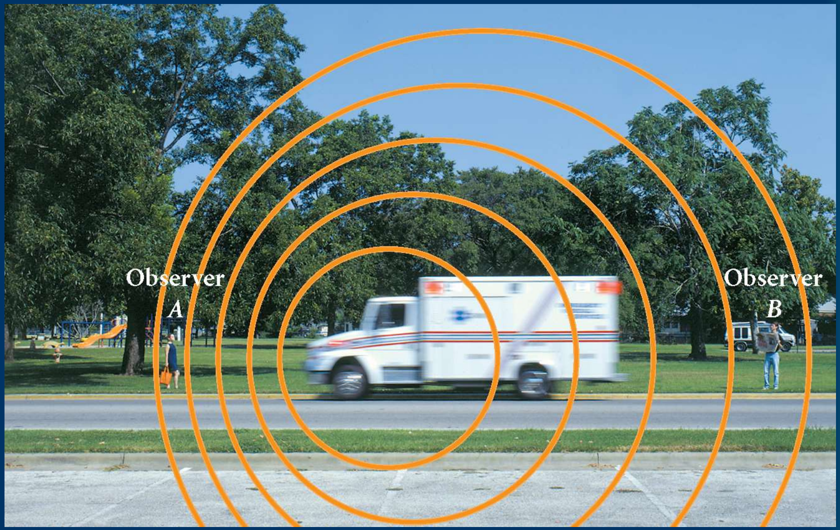
Doppler Effect

- Why are the waves closer together on the left?
  - Waves are closer because the vehicle moves to the left along with the previous wave.
- How will the sound be different for observer *A* and observer *B*?
  - Higher frequency (pitch) for observer A
- *Continued on the next slide….*



Doppler Effect

- How would the wave pattern change if the vehicle moved at a faster speed? How would it sound different?
  - At a higher speed, waves would be even closer together and the pitch difference would be even greater.



- The *Doppler effect* is the observed change in frequency due to the motion of the source or observer.

Preview

- Objectives
- Sound Intensity
- Forced Vibrations and Resonance
- The Human Ear

Objectives

- **Calculate** the intensity of sound waves.
- **Relate** intensity, decibel level, and perceived loudness.
- **Explain** why resonance occurs.

End of Slide

Sound Intensity

- Vibrating objects do work on the air as they push against the molecules.
- Intensity is the rate of energy flow through an area.
  - What is “rate of energy flow” called?
    - $\Delta E/t$ is called power (P).
  - Since the waves spread out spherically, you must calculate the area of a sphere. How?
    - $A = 4\pi r^2$
  - So, what is the equation for intensity?

Sound Intensity

- As sound waves travel, energy is transferred from one molecule to the next. The rate at which this energy is transferred through a unit area of the plane wave is called the **intensity** of the wave.
- Because **power (*P*)** is defined as the rate of energy transfer, intensity can also be described in terms of power.

$$\text{intensity} = \frac{\Delta E / \Delta t}{\text{area}} = \frac{P}{4\pi r^2}$$

$$\text{intensity} = \frac{\text{power}}{(4\pi)(\text{distance from the source})^2}$$

End of Slide

Sound Intensity

INTENSITY OF A SPHERICAL WAVE

$$\text{intensity} = \frac{P}{4\pi r^2}$$

$$\text{intensity} = \frac{(\text{power})}{(4\pi)(\text{distance from the source})^2}$$

- SI unit: W/m^2
- This is an *inverse square* relationship.
  - Doubling *r* reduces intensity by ¼.
  - What happens if *r* is halved?
    - Intensity increases by a factor of 4.

Sound Intensity, *continued*

- Intensity has units of **watt per square meter (W/m^2).**
- The intensity equation shows that the **intensity decreases** as the **distance (*r*) increases.**
- This occurs because the same amount of energy is spread over a larger area.

Sound Intensity, *continued*

- The **intensity** of a wave approximately determines its perceived **loudness.**

- However, loudness is not directly proportional to intensity. The reason is that the sensation of loudness is approximately **logarithmic** in the human ear.

- **Relative intensity** is the ratio of the intensity of a given sound wave to the intensity at the threshold of hearing.

Sound Intensity, *continued*

- Because of the logarithmic dependence of perceived loudness on intensity, using a number equal to **10 times the logarithm of the relative intensity** provides a good indicator for human perceptions of loudness.
- This is referred to as the **decibel level.**
- A dimensionless unit called the **decibel (dB)** is used for values on this scale.

End of Slide

Intensity and Decibels

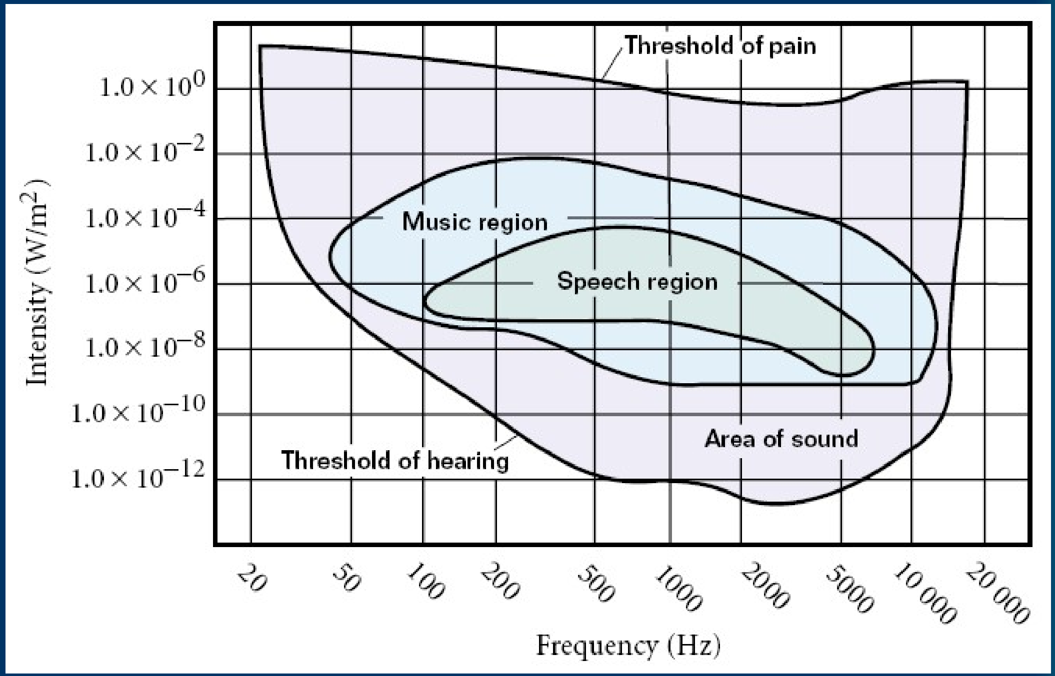
- An intensity scale based on human perception of loudness is often used.
- The base unit of this scale is the *bel*. More commonly, the *decibel* (dB) is used.
  - 0.1 bel = 1 dB,1 bel = 10 dB, 5 bels = 50 dB, etc.
  - The lowest intensity humans hear is assigned a value of zero.
- The scale is logarithmic, so each increase of 1 bel is 10 times louder.
  - An increase in intensity of 3 bels is 1 000 times louder.

Audible Sounds

- The softest sound humans can hear is called the *threshold of hearing*.
  - Intensity = 1×10^{-12} W/m^2 or zero dB
- The loudest sound humans can tolerate is called the *threshold of pain*.
  - Intensity = 1.0 W/m^2 or 120 dB
- Human hearing depends on both the frequency and the intensity.

Sound Intensity, *continued*

- Human hearing depends on both the **frequency** and the **intensity** of sound waves.
- Sounds in the middle of the spectrum of frequencies can be heard more easily (at lower intensities) than those at lower and higher frequencies.



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Conversion of Intensity to Decibel Level

Intensity (W/m^2)	Decibel level (dB)	Examples
1.0×10^{-12}	0	threshold of hearing
1.0×10^{-11}	10	rustling leaves
1.0×10^{-10}	20	quiet whisper
1.0×10^{-9}	30	whisper
1.0×10^{-8}	40	mosquito buzzing
1.0×10^{-7}	50	normal conversation
1.0×10^{-6}	60	air conditioning at 6 m
1.0×10^{-5}	70	vacuum cleaner
1.0×10^{-4}	80	busy traffic, alarm clock
1.0×10^{-3}	90	lawn mower
1.0×10^{-2}	100	subway, power motor
1.0×10^{-1}	110	auto horn at 1 m
1.0×10^{0}	120	threshold of pain
1.0×10^{1}	130	thunderclap, machine gun
1.0×10^{3}	150	nearby jet airplane

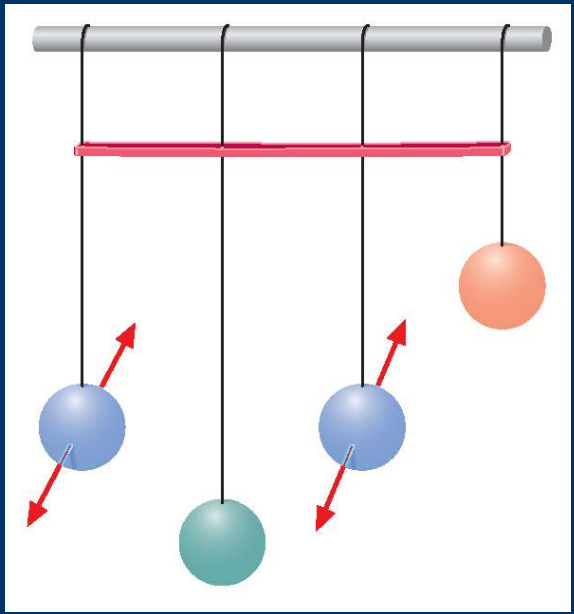
Classroom Practice Problems

- The intensity of the sound from an explosion is 0.10 W/m^2 at a distance of 1.0×10^3 m. Find the intensity of the sound at a distance of 5.0×10^2 m, 1.0×10^2 m and 10.0 m.
  - Answers: 0.41 W/m^2, 1.0×10^1 W/m^2, 1.0×10^3 W/m^2
- Find the approximate decibel equivalents of these sound intensities using Table 2.
  - Answers: 110 dB, 130 dB, 150 dB

Forced Vibrations

- Sympathetic vibrations occur when a vibrating object forces another to vibrate as well.
  - A piano string vibrates the sound board.
  - A guitar string vibrates the bridge.
- This makes the sound louder and the vibrations die out faster.
  - Energy is transferred from the string to the sound board or bridge.

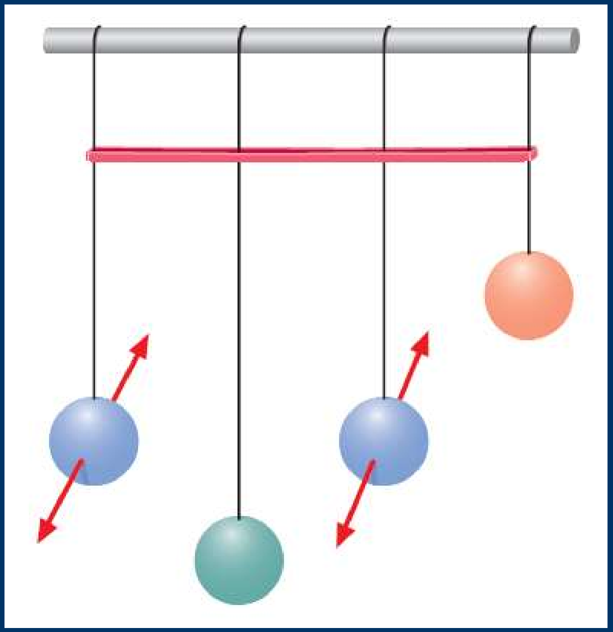
Resonance



- The red rubber band links the 4 pendulums.
- If a blue pendulum is set in motion, only the other blue pendulum will have large-amplitude vibrations.
  - The others will just move a small amount.
- Since the vibrating frequencies of the blue pendulums match, they are *resonant.*

Forced Vibrations and Resonance

- If one of the pendulums is set in motion, its vibrations are transferred by the rubber band to the other pendulums, which will also begin vibrating. This is called a **forced vibration.**
- Each pendulum has a **natural frequency** based on its length.



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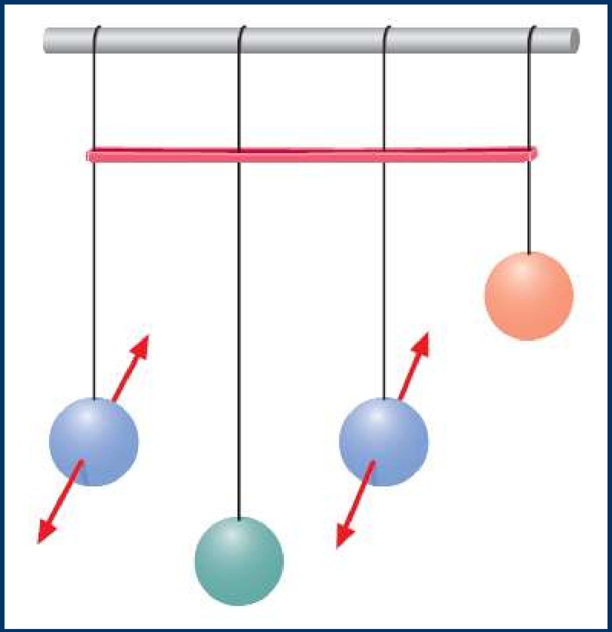
Forced Vibrations and Resonance, *continued*

- **Resonance** is a phenomenon that occurs when the frequency of a force applied to a system matches the **natural frequency** of vibration of the system, resulting in a **large amplitude of vibration.**
- If one blue pendulum is set in motion, only the other blue pendulum, whose length is the same, will eventually resonate.



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Resonance

- Large amplitude vibrations produced when the frequency of the applied force matches the natural frequency of receiver
  - One blue pendulum was the driving force and the other was the receiver.
- Bridges have collapsed as a result of structural resonance.
  - Tacoma Narrows in the wind
  - A freeway overpass during an earthquake

The Human Ear

- The human ear is divided into three sections—outer, middle, and inner.
- Sound waves travel through the three regions of the ear and are then transmitted to the brain as impulses through nerve endings on the basilar membrane.