تجميع هيكل الفيزياء -10 متقدم - انسباير

عمل الطالب : حمد خالد العبدولي 9-A2

مدرسه خليفه بن زايد للتعليم الثانوي .

1	Apply the equation (T=2π√(l/g)) to calculate the period of a simple pendulum for small-angle oscillations.	Student Book	P.(7-8)
		Q.(5-8 & 11)	P.8

Pendulums

Simple harmonic motion also occurs in the swing of a pendulum. A **simple pendulum** consists of a massive object, called the bob, suspended by a string or a light rod of length ℓ. The bob swings back and forth, as shown in **Figure 4.** The string or rod exerts a tension force (F_T), and gravity exerts a force (F_g) on the bob. Throughout the pendulum's path, the component of the gravitational force in the direction of the pendulum's circular path is a restoring force. At the left and right positions, the restoring force is at a maximum and the velocity is zero. At the equilibrium position, the restoring force is zero and the velocity is maximum.

For small angles (less than about 15°), the restoring force is proportional to the displacement from equilibrium. Similar to the motion of the mass on a spring discussed earlier, the motion of the pendulum is simple harmonic motion. The period of a pendulum is given by the following equation.

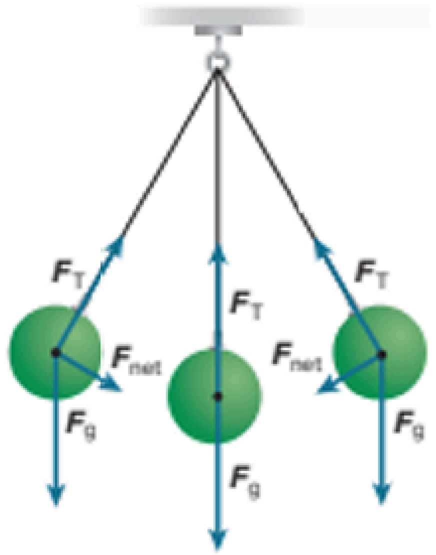


Figure 4 The pendulum's motion is an example of simple harmonic motion because the restoring force is directly proportional to the displacement from equilibrium.

Period of a Pendulum

The period of a pendulum is equal to 2π times the square root of the length of the pendulum divided by the gravitational field.

$$T = 2\pi\sqrt{\frac{\ell}{g}}$$

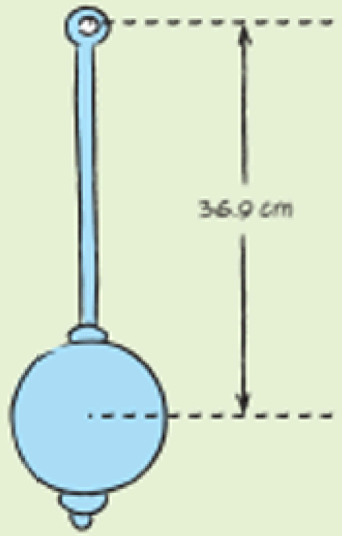
Resonance

To get a playground swing going, you can "pump" it by leaning back and pulling the chains at the same point in each swing. Another option is to have a friend give you repeated pushes at just the right times. **Resonance** occurs when forces are applied to a vibrating or oscillating object at time intervals equal to the period of oscillation. As a result, the amplitude of the vibration increases. Other familiar examples of resonance include rocking a car to free it from a snow bank and jumping rhythmically on a trampoline or a diving board to go higher.

Resonance in simple harmonic motion systems causes a larger and larger displacement as energy is added in small increments. As a child you may have been told to hold a seashell such as a conch up to your ear to "hear the sound of the ocean." The sound you hear when you hold a seashell or other similar-shaped object up to your ear actually comes from resonance. Sound waves resulting from background noise in the room interact with the seashell. Sounds with frequencies matching one of the natural frequencies at which the seashell vibrates result in resonance, and the sound becomes amplified and loud enough to hear. The large amplitude oscillations caused by resonance can also produce useful results. Resonance is used in musical instruments to amplify sounds and in clocks to increase accuracy.

EXAMPLE Problem 2

FINDING *g* USING A PENDULUM A pendulum with a length of 36.9 cm has a period of 1.22 s. What is the gravitational field at the pendulum's location?



1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Label the length of the pendulum.

Known	Unknown
ℓ = 36.9 cm	g = ?
T = 1.22 s	

2 SOLVE FOR THE UNKNOWN

$T = 2\pi\sqrt{\frac{\ell}{g}}$ Solve for g.

$g = (2\pi)^2\frac{\ell}{T^2}$

$= \frac{4\pi^2(0.369\text{ m})}{(1.22\text{ s})^2}$ Substitute l = 0.369 m, T = 1.22 s.

$= 9.78\text{ m/s}^2 = 9.78\text{ N/kg}$

3 EVALUATE THE ANSWER

- **Are the magnitudes realistic?** N/kg is the correct unit for gravitational field.
- **Is the magnitude realistic?** The calculated value of g is quite close to the accepted value of g, 9.8 N/kg. This pendulum could be at a higher elevation above sea level.

1	Apply the equation (T=2π√(l/g)) to calculate the period of a simple pendulum for small-angle oscillations.	Student Book	P.(7-8)
		Q.(5-8 & 11)	P.8

5. What is the period on Earth of a pendulum with a length of 1.0 m?

Known:

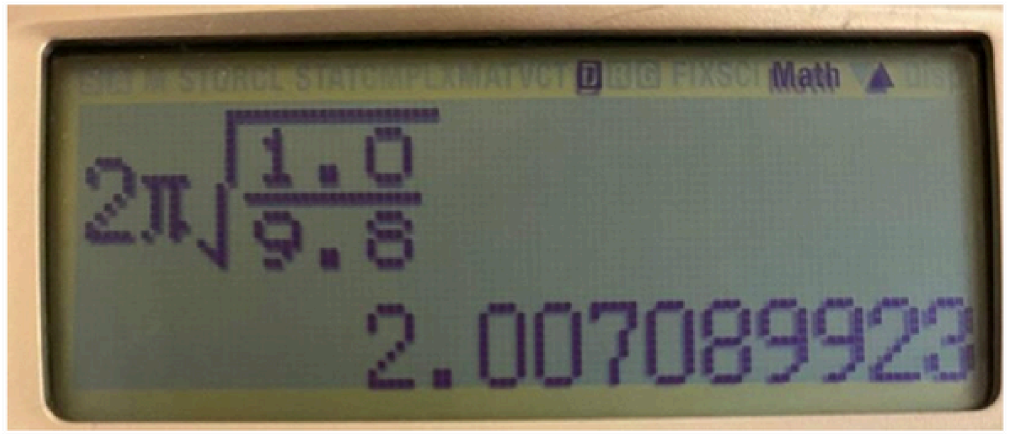
π = 3.14

g = 9.8

ℓ = 1.0

Unknown:

T = ?



6. How long must a pendulum be on the Moon, where g = 1.6 N/kg, to have a period of 2.0 s?

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where:

- T is the period of the pendulum,
- L is the length of the pendulum,
- g is the acceleration due to gravity.

2 = 2π√(x / 1.6) → 0.162

Problem 6: Pendulum on the Moon

We are given:

- $T = 2.0\,\mathrm{s}$
- $g = 1.6\,\mathrm{N/kg}$ (on the Moon)

7. CHALLENGE On a certain planet, the period of a 0.75-m-long pendulum is 1.8 s. What is g for this planet?

$$g = \frac{4\pi^2 \cdot 0.75}{(1.8)^2} = 9.14$$

8. Periodic Motion Explain why a pendulum is an example of periodic motion.

A pendulum is an example of periodic motion because it swings back and forth in a regular, repeated pattern over equal intervals of time. This repeated motion occurs due to the restoring force (gravity) that pulls the pendulum back toward its equilibrium position, making the pendulum's motion predictable and cyclical.

9. Energy of a Spring The springs shown in **Figure 5** are identical. Contrast the potential energies of the bottom two springs.

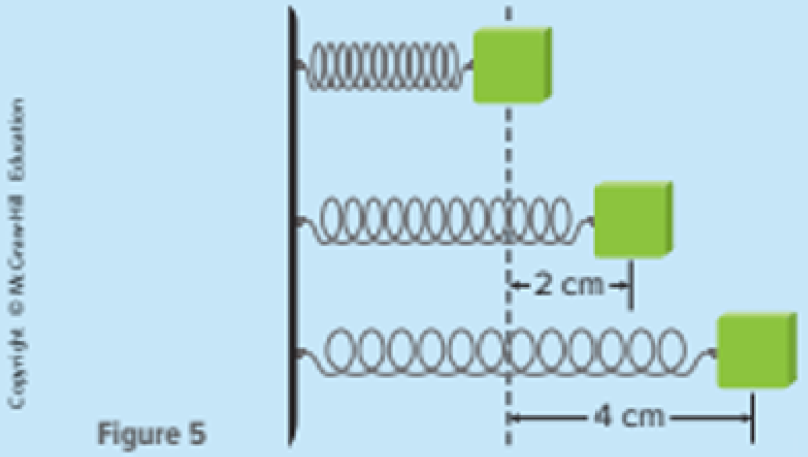


Figure 5

$$PE = \frac{1}{2}kx^2$$

1. **For the Middle Spring:**

$$PE_{\text{middle}} = \frac{1}{2}k(2\,\text{cm})^2$$

2. **For the Bottom Spring:**

$$PE_{\text{bottom}} = \frac{1}{2}k(4\,\text{cm})^2$$

Comparing the Energies:

The displacement in the bottom spring (4 cm) is twice that of the middle spring (2 cm). Since potential energy depends on the square of the displacement, we find that:

$$(4\,\text{cm})^2 = 4 \times (2\,\text{cm})^2$$

Thus, the potential energy of the bottom spring will be four times that of the middle spring:

$$PE_{\text{bottom}} = 4 \times PE_{\text{middle}}$$

Final Answer:

The potential energy in the bottom spring is four times the potential energy in the middle spring.

تعليم

1	Apply the equation (T=2π√(l/g)) to calculate the period of a simple pendulum for small-angle oscillations.	Student Book	P.(7-8)
		Q.(5-8 & 11)	P.8

10. **Hooke's Law** Objects of various weights are hung from a rubber band that is suspended from a hook. The weights of the objects are plotted on a graph against the stretch of the rubber band. How can you tell from the graph whether the rubber band obeys Hooke's law?

Hooke's Law states that the force FFF exerted by a spring or elastic object is proportional to its displacement xxx from equilibrium, expressed as:

F=−kxF = -kxF=−kx

If a rubber band obeys Hooke's law, a graph of force (or weight) versus displacement (stretch) should show a straight line, indicating a constant proportional relationship. The slope of this line represents the rubber band's effective spring constant kkk. If the graph is linear, the rubber band obeys Hooke's law. If it is nonlinear (curves), the rubber band does not obey Hooke's law.

11. **Pendulum** How must the length of a pendulum be changed to double its period? How must the length be changed to halve the period?

The period T of a pendulum is given by:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

To double the period:

- Since $T \propto \sqrt{L}$, to double T, L must be increased by a factor of 4 (since T depends on the square root of L). Therefore, the length must be quadrupled to double the period.

To halve the period:

- To halve T, L must be reduced by a factor of 4, so the length must be one-fourth of its original length to halve the period.

2	Apply Hooke's law to calculate the force exerted by a spring, the spring constant, or the distance by which a spring is stretched or compressed.	Student Book	P.(4-6)
		Q.(1-4)	P.6

Table 1 **Force Magnitude-Stretch Distance in a Spring**

Stretch Distance (m)	Magnitude of Force Exerted by Spring (N)
0.0	0.0
0.030	1.9
0.060	3.7
0.090	6.3
0.12	7.8

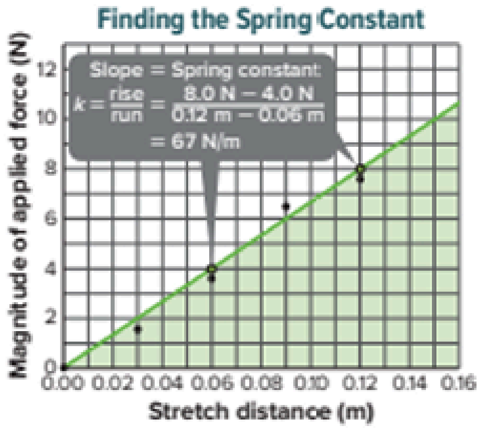


Figure 2 The spring constant can be determined from the slope of the force magnitude-stretch distance graph. The area under the curve is equal to the potential energy stored in the spring.

Hooke's Law

Table 1 shows the relationship between the magnitude of the force exerted by a spring and the distance the spring stretches. **Figure 2** is a graph of the data with the line of best fit. The linear relationship indicates that the magnitude of the force exerted by the spring is directly proportional to the amount the spring is stretched. A spring that exerts a force directly proportional to the distance stretched obeys **Hooke's law.**

Hooke's Law

The magnitude of the force exerted by a spring is equal to the spring constant times the distance the spring is stretched or compressed from its equilibrium position.

$$F = -kx$$

In this equation, k is the spring constant, which depends on the stiffness and other properties of the spring, and x is the distance the spring is stretched from its equilibrium position. Notice that k is the slope of the line in the magnitude of the force v. stretch distance graph. A steeper slope—a larger k—indicates that the spring is harder to stretch. The constant k has the same units as the slope, newtons/meter (N/m). The negative sign in Hooke's law indicates that the force is in the direction opposite the stretch or compression direction. The force exerted by the spring on the mass is always directed toward the spring's equilibrium position.

Hooke's law and real springs Not all springs obey Hooke's law. For example, rubber bands do not. Those that do obey Hooke's law are called elastic springs. Even for elastic springs, Hooke's law only applies over a limited range of distances. If a spring is stretched too far, it can become so deformed that the force is no longer proportional to the displacement.

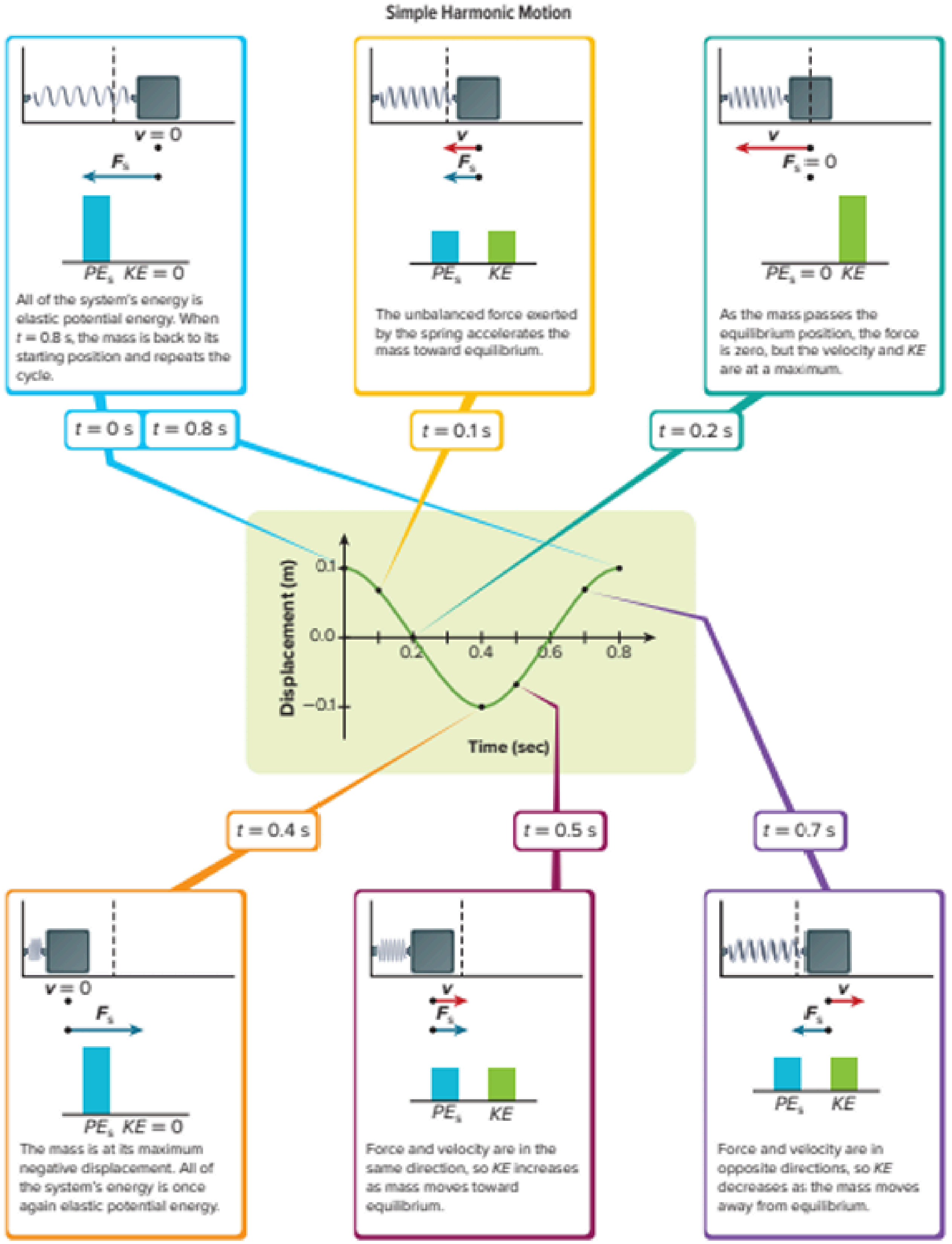
Potential energy When you stretch a spring you transfer energy to the spring, giving it elastic potential energy. The work done by an applied force is equal to the area under a force v. distance graph like the one shown in **Figure 2.** This work is equal to the elastic potential energy stored in the spring. To calculate this stored energy, find the area of the triangle by multiplying one-half the base of the triangle, which is x, by the height of the triangle. According to Hooke's law, the height of the triangle—the magnitude of the force—is equal to kx.

Potential Energy in a Spring

The potential energy in a spring is equal to one-half times the product of the spring constant and the square of the displacement.

$$PE_{\text{spring}} = -\frac{1}{2}kx^2$$

This mathematical expression, which quantifies how the stored energy in a spring depends on its configuration, together with kinetic energy calculated from mass and speed data, allows the concept of the conservation of energy to be used to predict and describe system behavior. As shown in **Figure 3** on the next page, during horizontal simple harmonic motion the spring's elastic potential energy is converted to kinetic energy and then back to potential energy.



2	Apply Hooke's law to calculate the force exerted by a spring, the spring constant, or the distance by which a spring is stretched or compressed.	Student Book	P.(4-6)
		Q.(1-4)	P.6

1. What is the spring constant of a spring that stretches 12 cm when an object weighing 24 N is hung from it?

x = 12cm .. F = 24N

اول شي بنحول الـcm للـm

يعني بنقسم 12 على 100

بيكون الناتج 0.12

يعني بنقسم 24 على 0.12

بيكون الناتج 200 N/m

2. What is the elastic potential energy of a spring with $k = 144$ N/m that is compressed by 16.5 cm?

Known:

K = 144 N/m

x = 16.5 cm

unknown:

PE = ?

16.5/100 = 0.165m

$\frac{1}{2}kx^2 \Rightarrow \frac{1}{2} \times 144 \times 0.165^2 = 1.9602$

3. A spring has a spring constant of 56 N/m. How far will a block weighing 18 N stretch it?

f=18N

k=5N/M

x = distance stretched

x=f/k=0.32m

4. CHALLENGE A spring has a spring constant of 256 N/m. How far must it be stretched to give it an elastic potential energy of 48 J?

u=48j

k=256N/m

$\sqrt{\frac{2u}{k}}$

$\sqrt{\frac{2 \times 48}{256}} = 0.61$

3	Sketch snapshots for the superposition of two overlapping wave pulses (same wavelength) traveling in opposite directions showing the resultant wave.	Student Book	P.(16-17)
		Q.31	P.20

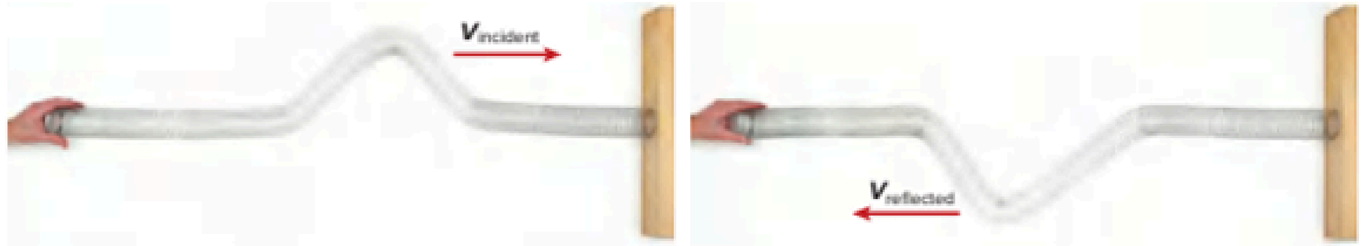


Figure 13 When a wave encounters a rigid boundary, the reflected wave is inverted. Note that the amplitude is not affected by the rigid boundary.

Rigid boundaries When a wave pulse hits a rigid boundary, the energy is reflected back, as shown in **Figure 13.** The wall is the boundary of a new medium through which the wave attempts to pass. Instead of passing through, the pulse is reflected from the wall with almost exactly the same amplitude as the pulse of the incident wave. Thus, almost all the wave's energy is reflected back. Very little energy is transmitted into the wall. Also note that the pulse is inverted.

Superposition of Waves

Suppose a pulse traveling along a spring meets a reflected pulse that is coming back from a boundary, as shown in **Figure 14.** In this case, two waves exist in the same place in the medium at the same time. Each wave affects the medium independently. The **principle of superposition** states that the displacement of a medium caused by two or more waves is the algebraic sum of the displacements caused by the individual waves. In other words, two or more waves can combine to form a new wave. If the waves move in the same medium, they can cancel or add or subtract to form a new wave of lesser or greater amplitude. They emerge unaffected by each other. The result of the superposition of two or more waves is called **interference.**

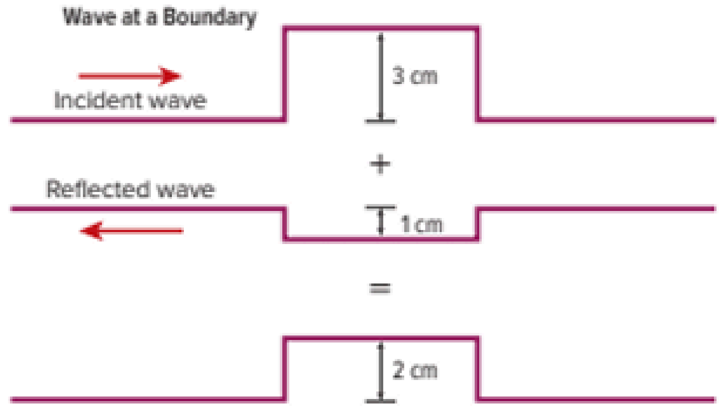


Figure 14 Waves add algebraically during superposition.

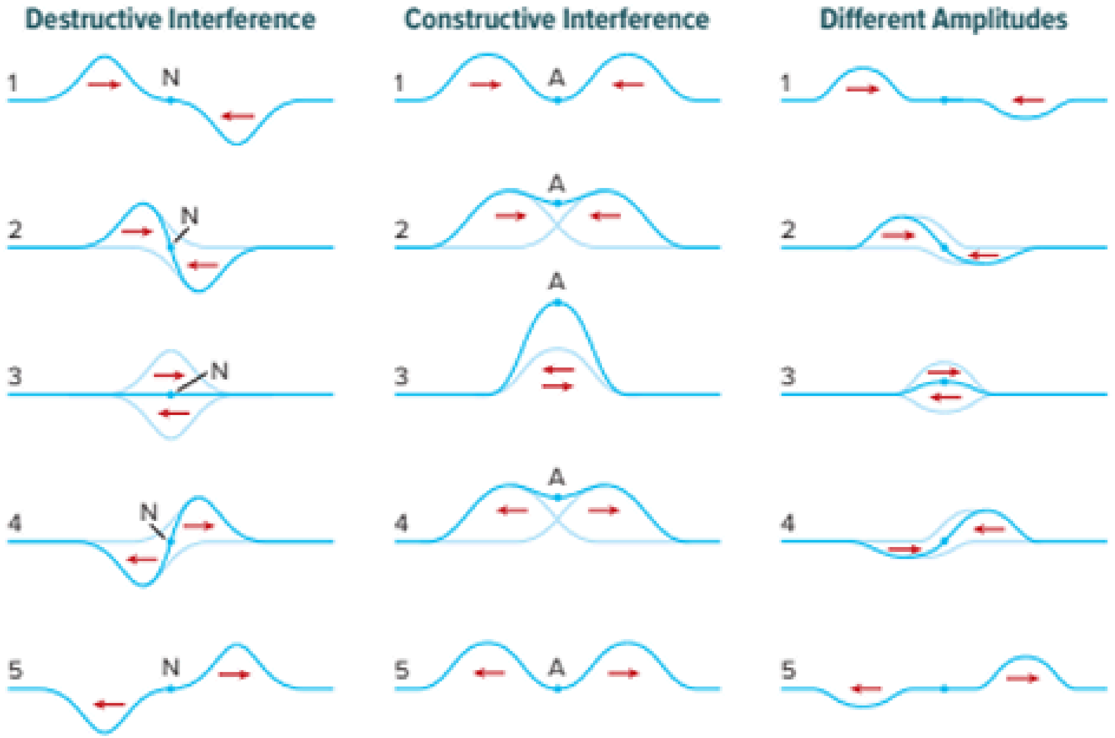


Figure 15 When waves add algebraically, the resulting combined waves can be quite different from the individual waves. **Summarize** *how waves behave during and after superposition.*

Wave interference Wave interference can be either constructive or destructive. The first panel in **Figure 15** shows the superposition of waves with equal but opposite displacements, causing destructive interference. When the pulses meet and are in the same location, the displacement is zero. Point N, which does not move at all, is called a **node.** The pulses travel horizontally and eventually emerge unaffected by each other.

Constructive interference occurs when wave displacements are in the same direction. The result is a wave that has an amplitude greater than those of the individual waves. A larger pulse appears at point A when the two waves meet. Point A has the largest displacement and is called the **antinode.** The two pulses pass through each other without changing their shapes or sizes. Even if the pulses have unequal amplitudes, the resultant pulse at the overlap is still the algebraic sum of the two pulses, as shown in the final panel of **Figure 15.**

Get It?
Compare the wave medium's displacement at a node and at an antinode.

Two reflections You can apply the concept of superimposed waves to the control of large-amplitude waves. Imagine attaching one end of a rope to a fixed point, such as a doorknob, a distance *L* away. When you vibrate the free end, the wave leaves your hand, travels along the rope toward the fixed end, is reflected and inverted at the fixed end, and returns to your hand. When it reaches your hand, the reflected wave is inverted and travels back down the rope. Thus, when the wave leaves your hand the second time, its displacement is in the same direction as it was when it left your hand the first time.

3	Sketch snapshots for the superposition of two overlapping wave pulses (same wavelength) traveling in opposite directions showing the resultant wave.	Student Book	P.(16-17)
		Q.31	P.20

31. **Superposition of Waves** Sketch two wave pulses whose interference produces a pulse with an amplitude greater than either of the individual waves.

Draw the First Pulse: Sketch a wave pulse traveling to the right with a certain amplitude.
Draw the Second Pulse: Sketch a second wave pulse of the same amplitude traveling to the left.
Interference Result: When the two waves meet, they will add up to form a larger pulse with an amplitude equal to the sum of their individual amplitudes. This combined pulse will be twice the amplitude of either pulse.
This setup visually demonstrates constructive interference, where the overlap of two wave pulses creates a new wave with greater amplitude than either original pulse.

Mechanical Waves

A **wave** is a disturbance that carries energy through matter or space without transferring matter. You have learned how Newton's laws of motion and the law of conservation of energy govern the behavior of particles. These laws also govern the behavior of waves. Water waves, sound waves, and the waves that travel along a rope or a spring are mechanical waves. Mechanical waves pass through a physical medium, such as water, air, or a rope.

Transverse waves A **wave pulse** is a single bump or disturbance that passes through a medium. In the left panel of **Figure 6**, the wave pulse disturbs the rope in the vertical direction, but the pulse travels horizontally. A wave that disturbs the particles in the medium perpendicular to the direction of the wave's travel is called a **transverse wave.** If the disturbances continue at a constant rate, a **periodic wave** is generated.

Longitudinal waves In a coiled spring toy, you can produce another type of wave. If you squeeze together several turns of the coiled spring toy and then suddenly release them, pulses will move away in both directions. The result is called a **longitudinal wave** because the disturbance is parallel to the direction of the wave's travel. Sound waves are longitudinal waves in which the molecules are alternately compressed or decompressed along the path of the wave.

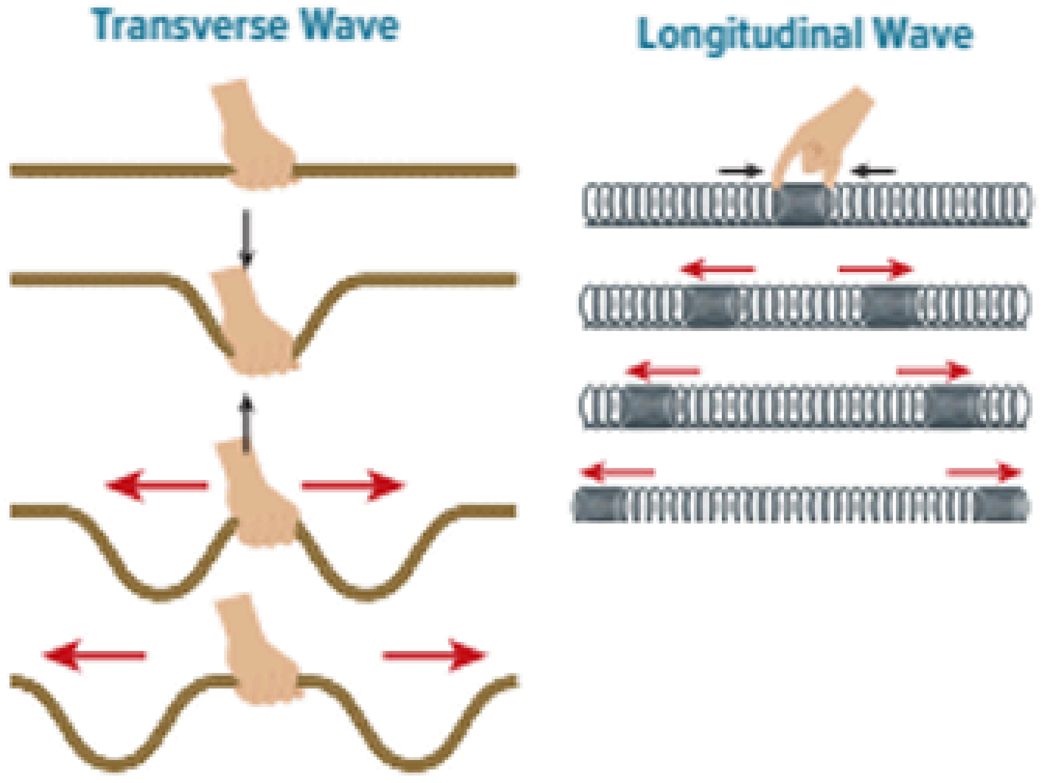


Figure 6 Shaking a rope up and down produces transverse wave pulses traveling in both directions. Squeezing and releasing the coils of a spring produces longitudinal wave pulses in both directions.

Explain *the difference between transverse and longitudinal waves.*

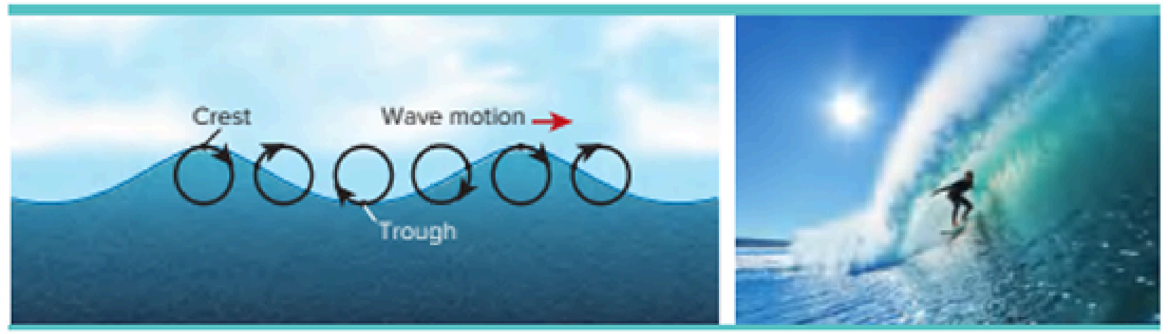


Figure 7 Surface waves in water cause movement both parallel and perpendicular to the direction of wave motion. When these waves interact with the shore, the regular, circular motion is disrupted and the waves break on the beach.

Surface waves Waves that are deep in a lake or an ocean are longitudinal. In a **surface wave,** however, the medium's particles follow a circular path that is at times parallel to the direction of travel and at other times perpendicular to the direction of wave travel, as shown in **Figure 7.** Surface waves set particles in the medium, in this case water, moving in a circular pattern. At the top and bottom of the circular path, particles are moving parallel to the direction of the wave's travel. This is similar to a longitudinal wave. At the left and right sides of each circle, particles are moving up or down. This up-and-down motion is perpendicular to the wave's direction, similar to a transverse wave.

> **Real-World Physics**
> **Tsunamis**
> On March 11, 2011, a wall of water estimated to be ten meters high hit areas on the east coast of Japan—tsunami! A tsunami is a series of ocean waves that can have wavelengths over 100 km, periods of one hour, and wave speeds of 500–1000 km/h.

Wave Properties

Many types of waves share a common set of wave properties. Some wave properties depend on how the wave is produced, whereas others depend on the medium through which the wave is passing.

Amplitude How does the pulse generated by gently shaking a rope differ from the pulse produced by a violent shake? The difference is similar to the difference between a ripple in a pond and an ocean breaker—they have different amplitudes. You read earlier that the amplitude of periodic motion is the greatest distance from equilibrium. Similarly, as shown in **Figure 8,** a transverse wave's amplitude is the maximum distance of the wave from equilibrium. Since amplitude is a distance, it is always positive. You will learn more about measuring the amplitude of longitudinal waves when you study sound.

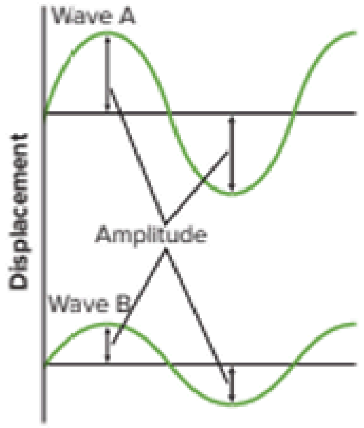


Figure 8 A wave's amplitude is measured from the equilibrium position to the highest or lowest point on the wave.

Energy of a wave Waves, including water waves, are examples of the many ways that energy manifests at the macroscopic scale. The energy of a wave is related to its amplitude, and a wave's amplitude depends on how the wave is generated. More energy must be added to the system to generate a wave with a greater amplitude. For example, strong winds produce larger water waves than those formed by gentle breezes. Waves with greater amplitudes transfer more energy. Whereas a wave with a small amplitude might move sand on a beach a few centimeters, a giant wave can uproot and move a tree.

For waves that move at the same speed, the rate at which energy is transferred is proportional to the square of the amplitude. Thus, doubling the amplitude of a wave increases the amount of energy that wave transfers each second by a factor of four.

4	Differentiate between transverse, longitudinal, and surface waves and give examples.	Student Book	P.(9-10)
		Q.(25-27)	P.14

25. **Transverse Waves** Suppose you and your lab partner are asked to demonstrate that a transverse wave transports energy without transferring matter. How could you do it?

26. **Wave Characteristics** You are creating transverse waves on a rope by shaking your hand from side to side. Without changing the distance your hand moves, you begin to shake it faster and faster. What happens to the amplitude, wavelength, frequency, period, and velocity of the wave?

27. **Longitudinal Waves** Describe longitudinal waves. What types of mediums transmit longitudinal waves?

5	Explore through an experiment, like using a number of musical instruments, the perception of sound depending on its different physical quantities like amplitude and frequency, and relate them to loudness and pitch.	Student Book	P. (29-30)
		Q.6	P.33

Perceiving Sound

How humans perceive sound depends partly on the physical characteristics of sound waves, such as frequency and amplitude.

Pitch Marin Mersenne and Galileo first determined that the pitch we hear depends on the frequency of vibration. **Pitch** is the highness or lowness of a sound, and it can be given a name on the musical scale. For instance, the note known as middle C has a frequency of 262 Hz. The highest note on a piano has a frequency of 4186 Hz. The human ear is not equally sensitive to all frequencies. Most people cannot hear sounds with frequencies below 20 Hz or above 16,000 Hz. Many animals, such as dogs, cats, elephants, and bats, are capable of hearing frequencies that humans cannot hear.

Get It?
Identify What characteristic of waves is pitch most closely linked to?

Loudness Frequency and wavelength are two physical characteristics of sound waves. Another physical characteristic of sound waves is amplitude. Amplitude is the measure of the variation in pressure in a wave. The **loudness** of a sound is the intensity of the sound as perceived by the ear and interpreted by the brain. This intensity depends primarily on the amplitude of the pressure wave.

The human ear is extremely sensitive to variations in the intensity of sound waves. Recall that 1 atmosphere of pressure equals 1.01×10^5 Pa. The ear can detect pressure-wave amplitudes of less than one-billionth of an atmosphere, or 2×10^{-5} Pa. At the other end of the audible range, pressure variations of approximately 20 Pa or greater cause pain. It is important to remember that the ear detects pressure variations only at certain frequencies. Driving over a mountain pass changes the pressure on your ears by thousands of pascals, but this change does not take place at audible frequencies.

Because humans can detect a wide range of intensities, it is convenient to measure these intensities on a logarithmic scale called the **sound level.** The most common unit of measurement for sound level is the **decibel** (dB). The sound level depends on the ratio of the intensity of a given sound wave to that of the most faintly heard sound. This faintest sound is measured at 0 dB. A sound that is ten times more intense registers 20 dB. A sound that is another ten times more intense is 40 dB.

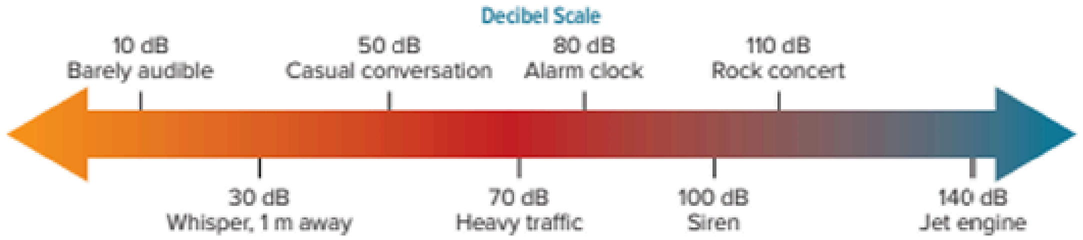


Figure 4 This decibel scale shows the sound level for a variety of sounds.
Infer *About how many times louder does an alarm clock sound than heavy traffic?*

Most people perceive a 10-dB increase in sound level as about twice as loud as the original level. **Figure 4** shows the sound level for a variety of sounds. In addition to intensity, pressure variations and the power of sound waves can be described by decibel scales.

The ear can lose its sensitivity, especially to high frequencies, after exposure to loud sounds in the form of noise or music. The longer a person is exposed to loud sounds, the greater the effect. A person can recover from short-term exposure in a period of hours, but the effects of long-term exposure can last for days or weeks. Long exposure to 100-dB or greater sound levels can produce permanent damage. Hearing loss also can result from loud music being transmitted to stereo headphones from personal music devices. In some cases, the listeners are unaware of just how high the sound levels really are. Cotton earplugs reduce the sound level only by about 10 dB. Special ear inserts can provide a 25-dB reduction. Specifically designed earmuffs and inserts, as shown in **Figure 5**, can reduce the sound level by up to 45 dB.

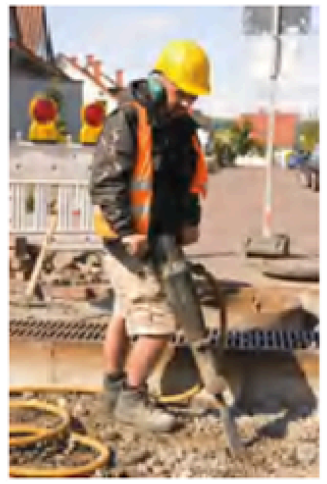


Figure 5 Hearing loss can occur with continuous exposure to loud sounds. Workers in many occupations, such as construction, wear ear protection. The jackhammer this worker is operating has a sound level of 130 dB.

The Doppler Effect

Have you ever noticed that the pitch of a fast car changed as the vehicle sped past you? The pitch was higher when the vehicle was moving toward you, then it dropped to a lower pitch as the vehicle moved away. The change in frequency of sound caused by the movement of either the source, the detector, or both is called the **Doppler effect.** The Doppler effect is illustrated in **Figure 6.**

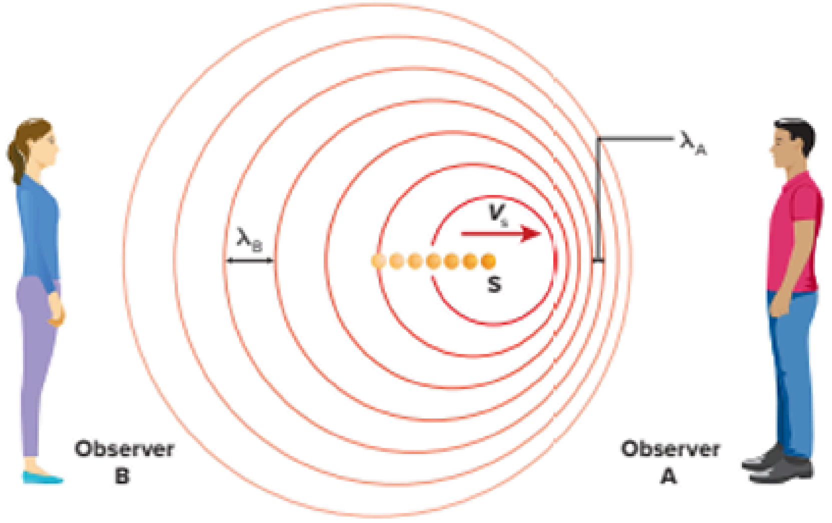


Figure 6 As a sound producing source moves toward observer A, the wavelength is shortened to λ_A. As the source moves away from observer B, the wavelength is lengthened to λ_B.
Describe *What is the relative difference in the frequency of the detected sound for each observer?*

5	Explore through an experiment, like using a number of musical instruments, the perception of sound depending on its different physical quantities like amplitude and frequency, and relate them to loudness and pitch.	Student Book	P. (29-30)
		Q.6	P.33

6. **Wave Characteristics** What physical characteristic of a sound wave should be changed to alter the pitch? The loudness?

Perceiving Sound

How humans perceive sound depends partly on the physical characteristics of sound waves, such as frequency and amplitude.

Pitch Marin Mersenne and Galileo first determined that the pitch we hear depends on the frequency of vibration. **Pitch** is the highness or lowness of a sound, and it can be given a name on the musical scale. For instance, the note known as middle C has a frequency of 262 Hz. The highest note on a piano has a frequency of 4186 Hz. The human ear is not equally sensitive to all frequencies. Most people cannot hear sounds with frequencies below 20 Hz or above 16,000 Hz. Many animals, such as dogs, cats, elephants, and bats, are capable of hearing frequencies that humans cannot hear.

Get It?

Identify What characteristic of waves is pitch most closely linked to?

Loudness Frequency and wavelength are two physical characteristics of sound waves. Another physical characteristic of sound waves is amplitude. Amplitude is the measure of the variation in pressure in a wave. The **loudness** of a sound is the intensity of the sound as perceived by the ear and interpreted by the brain. This intensity depends primarily on the amplitude of the pressure wave.

The human ear is extremely sensitive to variations in the intensity of sound waves. Recall that 1 atmosphere of pressure equals 1.01×10^5 Pa. The ear can detect pressure-wave amplitudes of less than one-billionth of an atmosphere, or 2×10^{-5} Pa. At the other end of the audible range, pressure variations of approximately 20 Pa or greater cause pain. It is important to remember that the ear detects pressure variations only at certain frequencies. Driving over a mountain pass changes the pressure on your ears by thousands of pascals, but this change does not take place at audible frequencies.

Because humans can detect a wide range of intensities, it is convenient to measure these intensities on a logarithmic scale called the **sound level.** The most common unit of measurement for sound level is the **decibel** (dB). The sound level depends on the ratio of the intensity of a given sound wave to that of the most faintly heard sound. This faintest sound is measured at 0 dB. A sound that is ten times more intense registers 20 dB. A sound that is another ten times more intense is 40 dB.

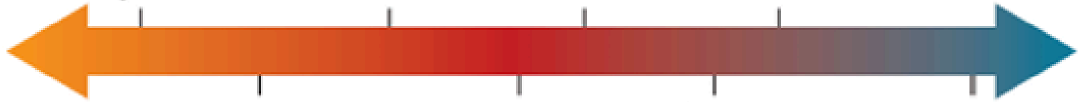


Figure 4 This decibel scale shows the sound level for a variety of sounds.
Infer *About how many times louder does an alarm clock sound than heavy traffic?*

Most people perceive a 10-dB increase in sound level as about twice as loud as the original level. **Figure 4** shows the sound level for a variety of sounds. In addition to intensity, pressure variations and the power of sound waves can be described by decibel scales.

The ear can lose its sensitivity, especially to high frequencies, after exposure to loud sounds in the form of noise or music. The longer a person is exposed to loud sounds, the greater the effect. A person can recover from short-term exposure in a period of hours, but the effects of long-term exposure can last for days or weeks. Long exposure to 100-dB or greater sound levels can produce permanent damage. Hearing loss also can result from loud music being transmitted to stereo headphones from personal music devices. In some cases, the listeners are unaware of just how high the sound levels really are. Cotton earplugs reduce the sound level only by about 10 dB. Special ear inserts can provide a 25-dB reduction. Specifically designed earmuffs and inserts, as shown in **Figure 5**, can reduce the sound level by up to 45 dB.

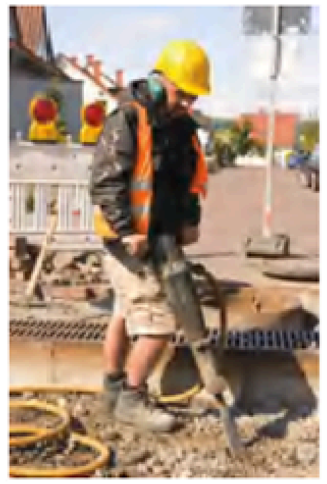


Figure 5 Hearing loss can occur with continuous exposure to loud sounds. Workers in many occupations, such as construction, wear ear protection. The jackhammer this worker is operating has a sound level of 130 dB.

The Doppler Effect

Have you ever noticed that the pitch of a fast car changed as the vehicle sped past you? The pitch was higher when the vehicle was moving toward you, then it dropped to a lower pitch as the vehicle moved away. The change in frequency of sound caused by the movement of either the source, the detector, or both is called the **Doppler effect.** The Doppler effect is illustrated in **Figure 6.**

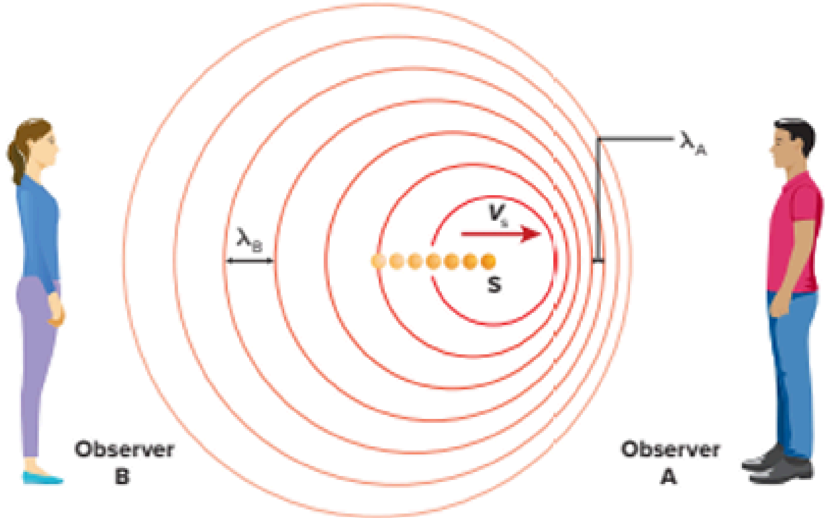


Figure 6 As a sound producing source moves toward observer A, the wavelength is shortened to λ_A. As the source moves away from observer B, the wavelength is lengthened to λ_B.
Describe *What is the relative difference in the frequency of the detected sound for each observer?*

6	Describe the sound level and define the decibel (dB) as a unit of measuring sound level.	Student Book	P.(29-30)
		Figure 4	P.30

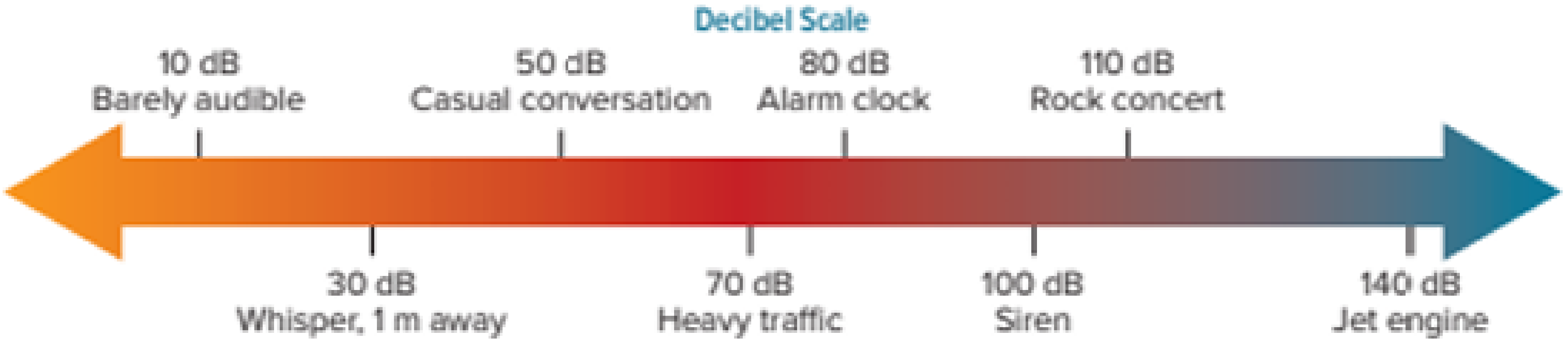


Figure 4 This decibel scale shows the sound level for a variety of sounds.

Infer *About how many times louder does an alarm clock sound than heavy traffic?*

7	Explore the meaning of resonance and understand how musical instruments work.	student Book	P.(35-40)
		Q.(13-16)	P.40

Stringed instruments, such as the piano, the guitar, and the violin, work by setting wires or strings into vibration. In the piano, the wires are struck; for the guitar, they are plucked; and for the violin, the friction of the bow causes the strings to vibrate. The strings are attached to a sounding board that vibrates with the strings. The vibrations of the sounding board cause the pressure oscillations in the air that we hear as sound. Electric guitars use electronic devices to detect and amplify the vibrations of the guitar strings.

A loudspeaker has a cone that is made to vibrate by electrical currents. The surface of the cone creates the sound waves that travel to your ear and allow you to hear music. Musical instruments such as gongs, cymbals, and drums are other examples of vibrating surfaces that are sources of sound.

The human voice is produced by vibrations of the vocal cords, which are two membranes located in the throat. Air from the lungs rushing through the throat starts the vocal cords vibrating. The frequency of vibration is controlled by the muscular tension placed on the vocal cords. The more tension on the vocal cords, the more rapidly they vibrate, resulting in a higher pitch sound. If the vocal cords are more relaxed, they vibrate more slowly and produce lower-pitched sounds.

Get It?

Describe How does a vocalist sing higher pitched notes?

Resonance in Air Columns

If you have ever used just the mouthpiece of a brass or wind instrument, you know that while the vibration of your lips or the reed alone makes a sound, it is difficult to control the pitch. The long tube that makes up the instrument must be attached if music is to result. When the instrument is played, the air within this tube vibrates at the same frequency, or in resonance, with a particular vibration of the lips or reed. Remember that resonance increases the amplitude of a vibration by repeatedly applying a small external force to the vibrating air particles at the natural frequency of the air column. The length of the air column determines the frequencies of the vibrating air that will resonate. For wind and brass instruments, such as flutes, trumpets, and trombones, changing the length of the column of vibrating air varies the pitch of the instrument. The mouthpiece simply creates a mixture of different frequencies, and the resonating air column acts on a particular set of frequencies to amplify a single note, turning noise into music. A tuning fork above a hollow tube can provide resonance in an air column, as shown in **Figure 10.**

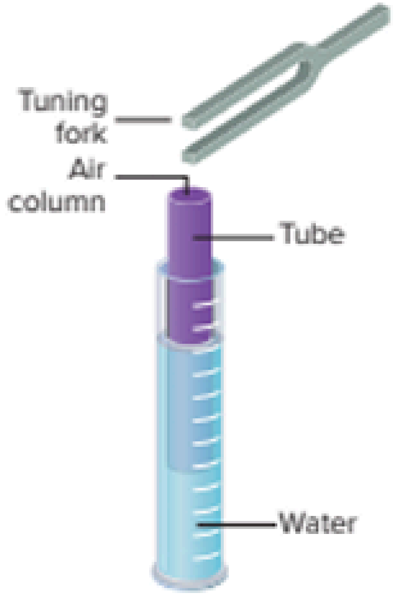


Figure 10 As the tube is raised or lowered, the length of the air column changes, which causes the sound's volume to change.

7	Explore the meaning of resonance and understand how musical instruments work.	student Book	P.(35-40)
		Q.(13-16)	P.40

13. A 440-Hz tuning fork is used with a resonating column to determine the velocity of sound in helium gas. If the spacing between resonances is 110 cm, what is the velocity of sound in helium gas?

Resonance spacing $= \frac{\lambda}{2} = 1.1$ m

so $\lambda = 2.2$ m

$v = \lambda f = (2.2 \text{ m})(440 \text{ Hz}) = 970 \text{ m/s}$

14. The frequency of a tuning fork is unknown. A student uses an air column at 27°C and finds resonances spaced by 20.2 cm. What is the frequency of the tuning fork? Use the speed calculated in Example Problem 2 for the speed of sound in air at 27°C.

$v = 347$ m/s at 27°C

Resonance spacing gives $\frac{\lambda}{2} = 0.202$ m,

or $\lambda = 0.404$ m

$$f = \frac{v}{\lambda} = \frac{347 \text{ m/s}}{0.404 \text{ m}} = 859 \text{ Hz}$$

15. A 440-Hz tuning fork is held above a closed pipe. Find the spacing between the resonances when the air temperature is 20°C.

Resonance spacing $= \frac{\lambda}{2}$ so using $\lambda = \frac{v}{f}$

the resonance spacing is

$$\frac{\lambda}{2} = \frac{v}{2f} = \frac{343 \text{ m/s}}{(2)(440 \text{ Hz})} = 0.39 \text{ m}$$

16. CHALLENGE A bugle can be thought of as an open pipe. If a bugle were straightened out, it would be 2.65-m long.

a. If the speed of sound is 343 m/s, find the lowest frequency that is resonant for a bugle (ignoring end corrections).

b. Find the next two resonant frequencies for the bugle.

A $\lambda_1 = 2L = (2)(2.65 \text{ m}) = 5.30 \text{ m}$

The lowest frequency is

B

$f_2 = 2f_1 = (2)(370 \text{ Hz}) = 740 \text{ Hz}$

$f_3 = 3f_1 = (3)(370 \text{ Hz}) = 1110 \text{ Hz} = 1100 \text{ Hz}$

$f_4 = 4f_1 = (4)(370 \text{ Hz}) = 1480 \text{ Hz} = 1500 \text{ Hz}$

مغلطين فيه الوزاره

10	Demonstrate an understanding that the work performed in moving a charged particle in an electric field can result in the particle gaining electric potential energy or kinetic energy or both.	Student Book	P. (74 - 75)
		Q.(43 - 52)	P. (74 - 75)

Figure 25 A model of an electric field between two oppositely charged parallel plates is shown. Grass seed is used to model the electric field lines.

Electric Potential in a Uniform Field

You can produce a uniform electric field by placing two large, flat conducting plates parallel to each other. One plate is charged positively, and the other plate is charged negatively. The magnitude and the direction of the electric field are the same at all points between the plates, except at the edges of the plates, and the electric field points from the positive plate to the negative plate. The pattern formed by the grass seeds pictured in **Figure 25** represents the electric field between parallel plates.

Imagine that you move a positive test charge (q') a distance (d) in the direction opposite the electric field direction. Because the field is uniform, the force from that field on the charge is constant. As a result, you can use the relationship $W_{on\ q'} = Fd$ to find the work done on the charge. Then, the electric potential difference, the work done per unit charge, is $\Delta V = \frac{Fd}{q'} = \left(\frac{F}{q'}\right)d$. Remember that electric field intensity is force per unit charge $\left(E = \frac{F}{q'}\right)$. Therefore, you can represent the electric potential difference (ΔV) between two points a distance (d) apart in a uniform field (E) with the following equation.

Electric Potential Difference in a Uniform Field

The potential difference between two locations in a uniform electric field equals the product of electric field intensity and the distance between the locations parallel to the direction of the field.

$$\Delta V = Ed$$

The electric potential is higher near the positively charged plate and lower near the negatively charged plate.

EXAMPLE Problem 4

WORK REQUIRED TO MOVE A PROTON BETWEEN CHARGED PARALLEL PLATES Two charged parallel plates are 1.5 cm apart. The magnitude of the electric field between the plates is 1800 N/C.

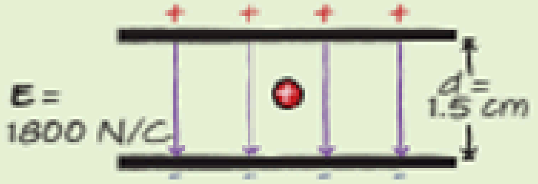
a. What is the electric potential difference between the plates?

b. How much work is required to move a proton from the negative plate to the positive plate?

1 ANALYZE AND SKETCH THE PROBLEM

- Draw the plates separated by 1.5 cm.
- Label one plate with positive charges and the other with negative charges.
- Draw uniformly spaced electric field lines from the positive plate to the negative plate.
- Indicate the electric field strength between the plates.
- Place a proton in the electric field.

Known	Unknown
$E = 1800$ N/C	$\Delta V = ?$
$d = 1.5$ cm	$W = ?$
$q = 1.602\times10^{-19}$ C	



2 SOLVE FOR THE UNKNOWN

a. $\Delta V = Ed$

$= (1800\text{ N/C})(0.015\text{ m})$ — Substitute $E = 1800$ N/C, $d = 0.015$ m.

$= 27$ V

b. $\Delta V = \frac{W}{q}$

$W = q\Delta V$

$= (1.602\times10^{-19}\text{ C})(27\text{ V})$ — Substitute $q = 1.602\times10^{-19}$ C, $\Delta V = 27$ V.

$= 4.3\times10^{-18}$ J

3 EVALUATE THE ANSWER

- **Are the units correct?** (N/C)(m) = N·m/C = J/C = V. The units work out to be volts. C·V = C(J/C) = J, the unit for work.
- **Does the sign make sense?** You must do positive work to move a positive charge toward a positive plate.
- **Is the magnitude realistic?** When you move such a small charge through a potential difference of less than 100 volts, the work done is small.

10	Demonstrate an understanding that the work performed in moving a charged particle in an electric field can result in the particle gaining electric potential energy or kinetic energy or both.	Student Book	P. (74 - 75)
		Q.(43 - 52)	P. (74 - 75)

43. The electric field intensity between two large, charged parallel metal plates is 6000 N/C. The plates are 0.05 m apart. What is the electric potential difference between them?

44. A voltmeter reads 400 V across two charged, parallel plates that are 0.020 m apart. What is the magnitude of the electric field between them?

45. What electric potential difference is between two metal plates that are 0.200 m apart if the electric field between those plates is 2.50×10^3 N/C?

46. When you apply a potential difference of 125 V between two parallel plates, the field between them is 4.25×10^3 N/C. How far apart are the plates?

47. **CHALLENGE** You apply a potential difference of 275 V between two parallel plates that are 0.35 cm apart. How large is the electric field between the plates?

48. What work is done on a 3.0-C charge when you move that charge through a 1.5-V electric potential difference?

49. What is the magnitude of the electric field between the two plates shown in **Figure 26**?

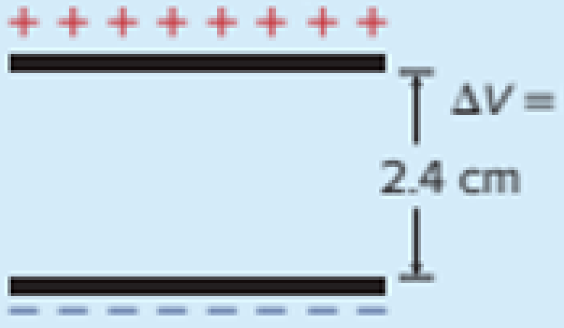


Figure 26

50. An electron in an old television picture tube passes through a potential difference of 18,000 V. How much work is done on the electron as it passes through that potential difference?

51. The electric field in a particle accelerator has a magnitude of 4.5×10^5 N/C. How much work is done to move a proton 25 cm through that field?

52. **CHALLENGE** A 12-V car battery has 1.44×10^6 C of usable charge on one plate when it is fully energized. How much work can this battery do before it needs to be energized again?

تعليم

10	Demonstrate an understanding that the work performed in moving a charged particle in an electric field can result in the particle gaining electric potential energy or kinetic energy or both.	Student Book	P. (74 - 75)
		Q.(43 - 52)	P. (74 - 75)

43

$$\Delta V = Ed = (6000\ \text{N/C})(0.05\ \text{m})$$
$$= 300\ \text{J/C} = 3\times10^{2}\ \text{V}$$

44

$$\Delta V = Ed$$
$$E = \frac{\Delta V}{d} = \frac{400\ \text{V}}{0.020\ \text{m}} = 2\times10^{4}\ \text{N/C}$$

45

$$\Delta V = Ed = (2.50\times10^{3}\ \text{N/C})(0.200\ \text{m})$$
$$= 5.00\times10^{2}\ \text{V}$$

46

$$\Delta V = Ed$$
$$d = \frac{\Delta V}{E} = \frac{125\ \text{V}}{4.25\times10^{3}\ \text{N/C}} = 2.94\times10^{-2}\ \text{m}$$

47

$$E = \frac{\Delta V}{d} = \frac{275\ \text{V}}{3.5\times10^{-3}\ \text{m}} = 7.9\times10^{4}\ \text{N/C}$$

48

$$W = q\Delta V = (3.0\ \text{C})(1.5\ \text{V}) = 4.5\ \text{J}$$

50

$$E = \frac{\Delta V}{d} = \frac{5.00\times10^{2}\ \text{V}}{0.024\ \text{m}} = 2.1\times10^{4}\ \text{N/C}$$

51

$$W = q\Delta V = qEd$$
$$= (1.60\times10^{-19}\ \text{C})(4.5\times10^{5}\ \text{N/C})(0.25\ \text{m})$$
$$= 1.8\times10^{-14}\ \text{J}$$

52

$$W = q\Delta V = (1.44\times10^{6}\ \text{C})(12\ \text{V})$$
$$= 1.7\times10^{7}\ \text{J}$$

49

$$E = \frac{\Delta V}{d} = \frac{5.00\times10^{2}\ \text{V}}{0.024\ \text{m}} = 2.1\times10^{4}\ \text{N/C}$$

11	1. Use vector addition to calculate the net force on a charge due to other point charges. 2. Solve problems involving the electrostatic force acting on charged particles by making use of Coulomb's Law.	Student Book	P.(59-62)
		Q.(15-17, 22-23)	P.63

Coulomb's Law

In your investigations with tape, you demonstrated that a force acts between two or more charged objects. You probably found that the strength of the force depended on distance. The force also gets stronger as the strength of the charge on the object increases.

How can you vary the quantity of charge in a controlled way? In the late 1770s, Charles Coulomb devised an apparatus that enabled him to determine the amount of charge between two objects. The type of apparatus Coulomb used is shown in **Figure 11.** An insulating rod with a small conducting sphere at one end (A) was suspended from the top by a thin wire that was free to rotate. An equal-sized conducting sphere (B) at the end of another rod was placed in contact with sphere A. When Coulomb touched the rod attached to B with a charged object, the charge spread evenly over the two spheres. Because the two spheres were the same size, they received an equal amount of charge. The symbol for charge is q. We can represent the amount of charge on the spheres as q_A for sphere A and q_B for sphere B; in this case, $q_A = q_B$.

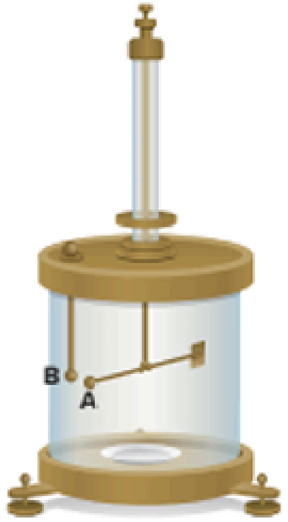


Figure 11 Coulomb used an apparatus similar to this one to measure the electrostatic force between two charged spheres. He observed differences in the amount of deflection of the spheres while varying the distance between them.

Force depends on distance Coulomb found that the force between two charged spheres depends on the distance between them. First, he measured the amount of force needed to twist the suspending wire through a given angle. He then placed equal charges on spheres A and B and varied the distance (r) between them. The force moved A, which twisted the suspending wire. By measuring the deflection of A, Coulomb could calculate the force of repulsion. He showed that the magnitude of the force (F) varies inversely with the square of the distance between the centers of the spheres.

$$F \propto \frac{1}{r^2}$$

Force depends on charge To investigate the way in which the force depends on the amount of charge, Coulomb had to change the charges on the spheres in a measured way. He first charged spheres A and B equally, as before. Then he selected an uncharged sphere (C) of the same size as spheres A and B. When C was placed in contact with B, the spheres shared the charge that had been on B alone. Because the two were the same size, B then had only half of its original charge. Therefore, the charge on B was only one-half the charge on A. After Coulomb adjusted the position of B so that the distance (r) between A and B was the same as before, he found that the force between A and B was half of its former value. That is, he found that the force varies directly with the charge of the bodies.

$$F \propto q_A q_B$$

After many similar measurements, Coulomb summarized the results in a law now known as **Coulomb's law:** the magnitude of the force between point charge q_A and point charge q_B, separated by a distance r, is proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them. Coulomb's law provides a mathematical model to describe and predict the effects of electrostatic forces between distant objects.

$$F \propto \frac{q_A q_B}{r^2}$$

Using Coulomb's law As you use the Coulomb's law equation, keep in mind that Coulomb's law is valid only for point charges or for charges that are spread uniformly over a sphere. A charged sphere may be treated as if all the charge were located at its center if the charge is spread evenly across its entire surface or throughout its volume.

If the sphere is a conductor and another charge is brought near it, the charges on the sphere will be attracted or repelled and will move, making the sphere no longer uniformly charged. The charge no longer will act as if it were at the sphere's center. Therefore, it is important to consider how large and how far apart two charged spheres are before applying Coulomb's law.

The problems in this textbook assume that charged spheres are small enough and far enough apart to be considered point charges, unless otherwise noted. When you consider shapes such as long wires or flat plates, you must modify Coulomb's law to account for the non-point charge distributions. To do this, you must model the charge distribution as an additive collection of point charges.

Applications of Electrostatic Forces

There are many commercial and industrial applications that take advantage of electrostatic forces. For example, tiny paint droplets can be charged by induction. When sprayed on automobiles and other objects, the droplets repel each other and paint spreads uniformly. Photocopy machines take advantage of static electricity to place black toner on a page so that a precise reproduction of the original document is achieved. Laser printers use static electricity in a similar way. Toner particles are attracted to charged characters on a drum.

11	1. Use vector addition to calculate the net force on a charge due to other point charges. 2. Solve problems involving the electrostatic force acting on charged particles by making use of Coulomb's Law.	Student Book	P.(59-62)
		Q.(15-17, 22-23)	P.63

15. **Charge and Distance** What is Coulomb's law and how does it allow you to describe and predict the effects of electrostatic forces between distant objects?

17. **Force and Distance** How are electrostatic force and distance related? How would the force change if the distance between two charges were tripled?

22. **Electrostatic Forces** Two charged spheres are held a distance *r* apart, as shown in **Figure 14.** Compare the force of sphere A on sphere B with the force of sphere B on sphere A.

Figure 14

23. **Critical Thinking** Suppose you are testing Coulomb's law using a small, positively charged plastic sphere and a large, positively charged metal sphere. According to Coulomb's law, the force depends on $1/r^2$, where *r* is the distance between the centers of the spheres. As you bring the spheres close together, the force is smaller than expected from Coulomb's law. Explain.

12	1. State and apply Coulomb's law to charges separated by finite distances. 2. Conduct an experiment to demonstrate charging of objects and the electrostatic force between charged objects.	Student Book	P.(59-62)
		Physics Challenge, Q.(9-17, 22-23)	P.(62-63)

Coulomb's Law

In your investigations with tape, you demonstrated that a force acts between two or more charged objects. You probably found that the strength of the force depended on distance. The force also gets stronger as the strength of the charge on the object increases.

How can you vary the quantity of charge in a controlled way? In the late 1770s, Charles Coulomb devised an apparatus that enabled him to determine the amount of charge between two objects. The type of apparatus Coulomb used is shown in **Figure 11.** An insulating rod with a small conducting sphere at one end (A) was suspended from the top by a thin wire that was free to rotate. An equal-sized conducting sphere (B) at the end of another rod was placed in contact with sphere A. When Coulomb touched the rod attached to B with a charged object, the charge spread evenly over the two spheres. Because the two spheres were the same size, they received an equal amount of charge. The symbol for charge is q. We can represent the amount of charge on the spheres as q_A for sphere A and q_B for sphere B; in this case, $q_A = q_B$.

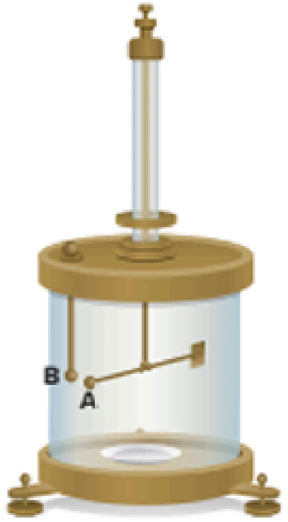


Figure 11 Coulomb used an apparatus similar to this one to measure the electrostatic force between two charged spheres. He observed differences in the amount of deflection of the spheres while varying the distance between them.

Force depends on distance Coulomb found that the force between two charged spheres depends on the distance between them. First, he measured the amount of force needed to twist the suspending wire through a given angle. He then placed equal charges on spheres A and B and varied the distance (r) between them. The force moved A, which twisted the suspending wire. By measuring the deflection of A, Coulomb could calculate the force of repulsion. He showed that the magnitude of the force (F) varies inversely with the square of the distance between the centers of the spheres.

$$F \propto \frac{1}{r^2}$$

Force depends on charge To investigate the way in which the force depends on the amount of charge, Coulomb had to change the charges on the spheres in a measured way. He first charged spheres A and B equally, as before. Then he selected an uncharged sphere (C) of the same size as spheres A and B. When C was placed in contact with B, the spheres shared the charge that had been on B alone. Because the two were the same size, B then had only half of its original charge. Therefore, the charge on B was only one-half the charge on A. After Coulomb adjusted the position of B so that the distance (r) between A and B was the same as before, he found that the force between A and B was half of its former value. That is, he found that the force varies directly with the charge of the bodies.

$$F \propto q_A q_B$$

After many similar measurements, Coulomb summarized the results in a law now known as **Coulomb's law:** the magnitude of the force between point charge q_A and point charge q_B, separated by a distance r, is proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them. Coulomb's law provides a mathematical model to describe and predict the effects of electrostatic forces between distant objects.

$$F \propto \frac{q_A q_B}{r^2}$$

Using Coulomb's law As you use the Coulomb's law equation, keep in mind that Coulomb's law is valid only for point charges or for charges that are spread uniformly over a sphere. A charged sphere may be treated as if all the charge were located at its center if the charge is spread evenly across its entire surface or throughout its volume.

If the sphere is a conductor and another charge is brought near it, the charges on the sphere will be attracted or repelled and will move, making the sphere no longer uniformly charged. The charge no longer will act as if it were at the sphere's center. Therefore, it is important to consider how large and how far apart two charged spheres are before applying Coulomb's law.

The problems in this textbook assume that charged spheres are small enough and far enough apart to be considered point charges, unless otherwise noted. When you consider shapes such as long wires or flat plates, you must modify Coulomb's law to account for the non-point charge distributions. To do this, you must model the charge distribution as an additive collection of point charges.

Applications of Electrostatic Forces

There are many commercial and industrial applications that take advantage of electrostatic forces. For example, tiny paint droplets can be charged by induction. When sprayed on automobiles and other objects, the droplets repel each other and paint spreads uniformly. Photocopy machines take advantage of static electricity to place black toner on a page so that a precise reproduction of the original document is achieved. Laser printers use static electricity in a similar way. Toner particles are attracted to charged characters on a drum.

12	1. State and apply Coulomb's law to charges separated by finite distances. 2. Conduct an experiment to demonstrate charging of objects and the electrostatic force between charged objects.	Student Book	P.(59-62)
		Physics Challenge, Q.(9-17, 22-23)	P.(62-63)

9. A negative charge of -2.0×10^{-4} C and a positive charge of 8.0×10^{-4} C are separated by 0.30 m. What is the force between the two charges?

17. **Force and Distance** How are electrostatic force and distance related? How would the force change if the distance between two charges were tripled?

22. **Electrostatic Forces** Two charged spheres are held a distance r apart, as shown in **Figure 14.** Compare the force of sphere A on sphere B with the force of sphere B on sphere A.

Figure 14

23. **Critical Thinking** Suppose you are testing Coulomb's law using a small, positively charged plastic sphere and a large, positively charged metal sphere. According to Coulomb's law, the force depends on $1/r^2$, where r is the distance between the centers of the spheres. As you bring the spheres close together, the force is smaller than expected from Coulomb's law. Explain.

13	1. Explain how electric charges are distributed on a spherical conductor, and the effect of this on both the electric field and the electric potential. 2. Explain the meaning of equipotential.	Student Book	P.78
		Figure 28; Q. 61	P.80

Conducting Sphere

A

On a conducting sphere, the charge is evenly distributed around the surface.

Hollow Sphere

B

The charges on a hollow sphere are entirely on the outer surface.

Irregular Surface

C

On an irregular conducting surface, the charges are closest together at sharp points.

Figure 28 Charges on a conducting sphere spread far apart to minimize their potential energy.

Electric Fields Near Conductors

Recall that many of the electrons in a conductor are free to move. Consider the charges on the conducting sphere in **Figure 28.** Because these electrons have like charges, they repel each other. They spread far apart in a way that minimizes their potential energy. The result is these charges come to rest on the surface of the conductor. It does not matter if the conducting sphere is solid or hollow. The excess charges move to the outer surface of the conductor.

Closed metal containers What happens if a closed metal container, such as a box, is charged? You can use a voltmeter to measure the electric potential difference between any two points inside the container. You will find that this potential difference is zero no matter which two points you choose inside the container. What are the consequences of this measurement for the electric field inside of the closed, metal container?

Recall that potential difference is equal to the product of the electric field and distance, or $\Delta V = Ed$. Because the potential difference between any two points inside the container is zero, the equation implies that the field is zero everywhere inside a closed, charged metal container.

Cars are a good example of this scenario. A car is a closed metal box that protects passengers from electric fields generated by lightning. On the outside of the conductor, the electric field often is not zero. The field is always perpendicular to the surface of the conductor. This makes the surface an equipotential; the potential difference between any two locations on the surface is zero.

Irregular surfaces The electric field at the surface does depend on the shape of the conductor, as well as on the electric potential difference between it and other objects. Free charges are closer together at the sharp points of a conductor, as indicated in **Figure 28.** Therefore, the field lines are closer together, and the field is stronger. This field can become so strong that when electrons are knocked off of atoms, the electrons and resulting ions are accelerated by the field, causing them to strike other atoms, resulting in more ionization of atoms. This chain reaction produces the pink glow seen inside a gas discharge sphere.

Lightning rods If an electric field is strong enough, when the particles hit other molecules they will produce a stream of ions and electrons that form a plasma, which is a conductor. The result is a spark or, in extreme cases, lightning. In order to protect buildings from lightning, builders install lightning rods. The electric field is strong near the pointed end of a lightning rod. As a result, charges in the clouds spark to the rod, rather than to another point on the building. From the rod, a conductor takes the charges to the ground. A lightning rod safely diverts lightning into the ground and away from the building.

61. A sphere is charged by a 12 V battery and suspended above Earth as shown in **Figure 31.** What is the net charge on the sphere?

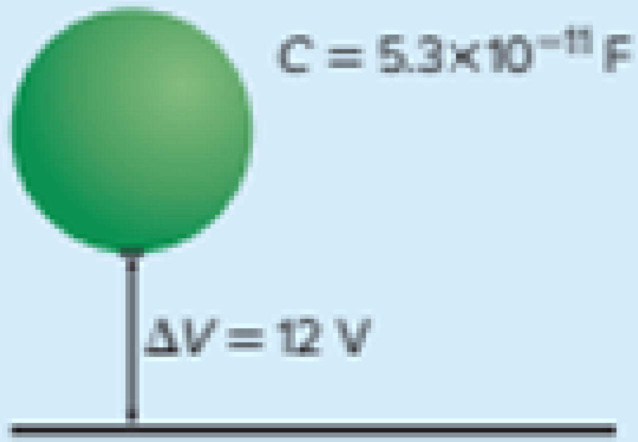
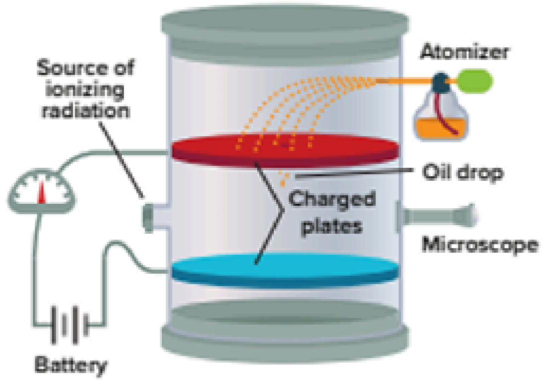


Figure 31

14	Describe Millikan's oil-drop experiment and explain how it confirms that charge exists in discrete amounts, which are integral multiples of the elementary charge.	Student Book	P.(76-77)
		Q.(53-56); Q.66	P.81

Figure 27 The American physicist Robert A. Millikan used an apparatus similar to this one to determine the charge of a single electron in 1909.



Millikan's Oil-Drop Experiment

You have read that the magnitude of the elementary charge is $e = 1.602\times10^{-19}$ C. The net charge on an object must be some integer multiple of this value. In other words, the net charge on an object can be 2e, −5e, 7e, or even −3157e. The net charge cannot be a fractional charge, such as 0.5e, −23.7e, 6.2e, or −31,524.6e. How do we know?

In 1909, Robert Millikan performed an experiment to test whether charge exists in discrete amounts. Millikan was able to measure the magnitude of the elementary charge with his experiment. A diagram of Millikan's apparatus for this experiment is shown in **Figure 27.** Notice that Millikan used two parallel plates to produce a uniform electric field in his apparatus. How did Millikan perform his experiment?

First, Millikan sprayed fine oil drops from an atomizer into the air. These drops were charged by friction as they were sprayed from the atomizer. Earth's gravitational force pulled the drops downward, and a few of those drops entered the hole in the top plate of Millikan's apparatus. Millikan then adjusted the electric field between the plates until he had suspended a negatively charged drop. At this point, the downward force from Earth's gravitational field and the upward force from the electric field were equal in magnitude.

Get It?
Explain why the following net charges are impossible: 0.66e, 1.554e, and 3.504e.

Calculating charge Millikan calculated the magnitude of the electric field (E) from the electric potential difference between the plates $\left(E = \frac{\Delta V}{d}\right)$. Millikan had to make a second measurement to find the weight (mg) of the tiny drop. To find the weight of a drop, Millikan first suspended it. Then, he turned off the electric field and measured the rate of the fall of the drop.

Because of friction with air molecules, the oil drop quickly reached terminal velocity, which was related to the weight of the drop by a complex equation. Millikan was then able to calculate the charge (q) on the drop from the weight of the drop (mg) and the electric field (E). He found that the net charge on an oil drop was always some integer multiple of a number close to 1.6×10^{-19} C. In later experiments, others have refined this result to 1.60217662×10^{-19} C.

66. **Millikan Experiment** When the net charge on an oil drop suspended in a Millikan apparatus is changed, the drop begins to fall. How should you adjust the potential difference between the conducting plates to bring the drop back into balance?

15	1. Define capacitance as the ratio of the net charge on one plate of a capacitor to the potential difference across the plates, and it is measured in Farads. 2. Apply the equation for capacitance to solve numerical problems.	Student Book	P.(79-81)
		Q.(57-62, 68)	P.(80-81)

Capacitors

When you lift a book, you increase the gravitational potential energy of the book-Earth system. You can interpret this as storing energy in a gravitational field. In a similar way, you can store energy in an electric field. In 1746, Dutch physician and physicist Pieter Van Musschenbroek invented a device to store electrical energy. In honor of the city in which he worked, he called it a Leyden jar. The modern, much smaller device for storing electrical energy is called a **capacitor.** Manufacturers make capacitors from two conducting plates separated by a thin insulator. They often roll these layers into a cylinder. Capacitors are key components in computers and other electronic devices, as shown in **Figure 29.**

Figure 29 A computer circuit board uses many capacitors in its operation. The gray cylinders, the disk-shaped objects, and the tiny colored tear-drop shaped objects are all capacitors.

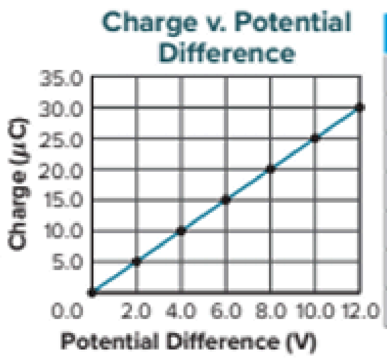
Capacitance Suppose you connect the positive terminal of a 1-V power source to one of the conducting plates of a capacitor and connect the negative terminal of that power source to the other plate of that capacitor. What happens? The power source would produce a potential difference (ΔV) of 1 V between the two plates. This would result in a net positive charge ($+q$) on one plate and a net negative charge of equal magnitude ($-q$) on the other plate.

Now suppose that you increase the voltage of the power source. What happens to the amount of net charge on each plate? **Figure 30** shows the results of an experiment in which the experimenter increases the potential difference across a capacitor's plates from 0 V to 12 V. Notice that the graph of q v. ΔV is a straight line. The slope of the line in a net charge versus potential difference graph is a constant and is called the **capacitance** (C) of the capacitor. You can measure the capacitance of a capacitor in farads (F), where 1 F = 1 C/V.

Capacitance

Capacitance is the ratio of the magnitude of the net charge on one plate of the capacitor to the potential difference across the plates.

$$C = \frac{q}{\Delta V}$$



Data Table

Potential Difference (V)	Charge on a Plate (μC)
0.0	0.0
2.0	5.2
4.0	9.7
6.0	15.0
8.0	20.3
10.0	24.7
12.0	30.1

Varieties of capacitors Capacitors have many shapes and sizes. Some are large enough to fill whole rooms and can store enough electrical energy to create artificial lightning or power giant lasers that release thousands of joules of energy in a few billionths of a second. Capacitors are also used in computers, televisions, and digital cameras. These capacitors store much less energy than those used to make artificial lightning, but they can still be dangerous. Charge can remain for hours after the device is turned off. This is why many electronic devices carry warnings not to open the case.

15	1. Define capacitance as the ratio of the net charge on one plate of a capacitor to the potential difference across the plates, and it is measured in Farads. 2. Apply the equation for capacitance to solve numerical problems.	Student Book Q.(57-62, 68)	P.(79-81) P.(80-81)

57. A 27-μF capacitor has an electric potential difference of 45 V across it. What is the amount the net charge on the positively charged plate of the capacitor?

62. CHALLENGE You increase the potential difference across a capacitor from 12.0 V to 14.5 V. As a result, the magnitude of the net charge on each plate increases by 2.5×10^{-5} C. What is the capacitance of the capacitor?

68. **Capacitance** What is the magnitude of net charge on each conductor plate of a 0.47-μF capacitor when a potential difference of 12 V is applied across that capacitor?

الجزء الكتابي :

Q1	1. Determine wave properties such as wavelength, period, frequency, amplitude, and speed using a graphical or a visual representation of a periodic mechanical wave. 2. Explain that transverse and longitudinal waves transfer energy without transferring matter during their propagation.	Student Book	P.(10-14); P.9
		Q.(14-23); Q.25	P.14

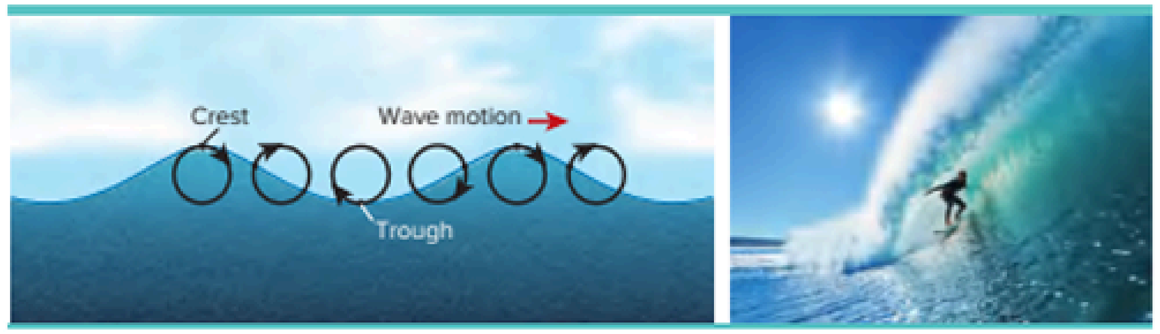


Figure 7 Surface waves in water cause movement both parallel and perpendicular to the direction of wave motion. When these waves interact with the shore, the regular, circular motion is disrupted and the waves break on the beach.

Surface waves Waves that are deep in a lake or an ocean are longitudinal. In a **surface wave,** however, the medium's particles follow a circular path that is at times parallel to the direction of travel and at other times perpendicular to the direction of wave travel, as shown in **Figure 7.** Surface waves set particles in the medium, in this case water, moving in a circular pattern. At the top and bottom of the circular path, particles are moving parallel to the direction of the wave's travel. This is similar to a longitudinal wave. At the left and right sides of each circle, particles are moving up or down. This up-and-down motion is perpendicular to the wave's direction, similar to a transverse wave.

Real-World Physics

Tsunamis

On March 11, 2011, a wall of water estimated to be ten meters high hit areas on the east coast of Japan—tsunami! A tsunami is a series of ocean waves that can have wavelengths over 100 km, periods of one hour, and wave speeds of 500–1000 km/h.

Wave Properties

Many types of waves share a common set of wave properties. Some wave properties depend on how the wave is produced, whereas others depend on the medium through which the wave is passing.

Amplitude How does the pulse generated by gently shaking a rope differ from the pulse produced by a violent shake? The difference is similar to the difference between a ripple in a pond and an ocean breaker—they have different amplitudes. You read earlier that the amplitude of periodic motion is the greatest distance from equilibrium. Similarly, as shown in **Figure 8,** a transverse wave's amplitude is the maximum distance of the wave from equilibrium. Since amplitude is a distance, it is always positive. You will learn more about measuring the amplitude of longitudinal waves when you study sound.

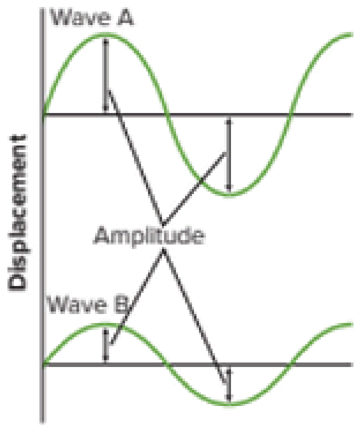


Figure 8 A wave's amplitude is measured from the equilibrium position to the highest or lowest point on the wave.

Energy of a wave Waves, including water waves, are examples of the many ways that energy manifests at the macroscopic scale. The energy of a wave is related to its amplitude, and a wave's amplitude depends on how the wave is generated. More energy must be added to the system to generate a wave with a greater amplitude. For example, strong winds produce larger water waves than those formed by gentle breezes. Waves with greater amplitudes transfer more energy. Whereas a wave with a small amplitude might move sand on a beach a few centimeters, a giant wave can uproot and move a tree.

For waves that move at the same speed, the rate at which energy is transferred is proportional to the square of the amplitude. Thus, doubling the amplitude of a wave increases the amount of energy that wave transfers each second by a factor of four.

Mechanical Waves

A **wave** is a disturbance that carries energy through matter or space without transferring matter. You have learned how Newton's laws of motion and the law of conservation of energy govern the behavior of particles. These laws also govern the behavior of waves. Water waves, sound waves, and the waves that travel along a rope or a spring are mechanical waves. Mechanical waves pass through a physical medium, such as water, air, or a rope.

Transverse waves A **wave pulse** is a single bump or disturbance that passes through a medium. In the left panel of **Figure 6,** the wave pulse disturbs the rope in the vertical direction, but the pulse travels horizontally. A wave that disturbs the particles in the medium perpendicular to the direction of the wave's travel is called a **transverse wave.** If the disturbances continue at a constant rate, a **periodic wave** is generated.

Longitudinal waves In a coiled spring toy, you can produce another type of wave. If you squeeze together several turns of the coiled spring toy and then suddenly release them, pulses will move away in both directions. The result is called a **longitudinal wave** because the disturbance is parallel to the direction of the wave's travel. Sound waves are longitudinal waves in which the molecules are alternately compressed or decompressed along the path of the wave.

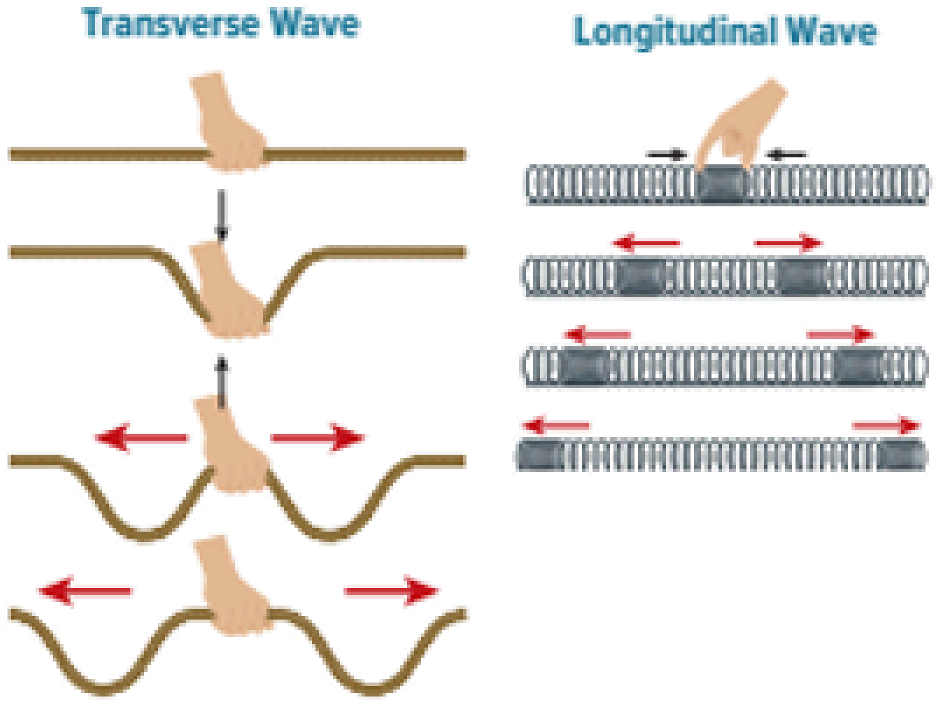


Figure 6 Shaking a rope up and down produces transverse wave pulses traveling in both directions. Squeezing and releasing the coils of a spring produces longitudinal wave pulses in both directions.

Explain *the difference between transverse and longitudinal waves.*

Q1	1. Determine wave properties such as wavelength, period, frequency, amplitude, and speed using a graphical or a visual representation of a periodic mechanical wave. 2. Explain that transverse and longitudinal waves transfer energy without transferring matter during their propagation.	Student Book	P.(10-14); P.9
		Q.(14-23); Q.25	P.14

14. A sound wave produced by a clock chime is heard 515 m away 1.50 s later.
    a. Based on these measurements, what is the speed of sound in air?
    b. The sound wave has a frequency of 436 Hz. What is the period of the wave?
    c. What is its wavelength?
15. How are the wavelength, frequency, and speed of a wave related? How do they depend on the medium through which the wave is passing and the type of wave?
16. What is the speed of a periodic wave disturbance that has a frequency of 3.50 Hz and a wavelength of 0.700 m?
17. How does increasing the wavelength by 50 percent affect the frequency of a wave on a rope?
18. The speed of a transverse wave in a string is 15.0 m/s. If a source produces a disturbance that has a frequency of 6.00 Hz, what is its wavelength?
19. Five wavelengths are generated every 0.100 s in a tank of water. What is the speed of the wave if the wavelength of the surface wave is 1.20 cm?
20. A periodic longitudinal wave that has a frequency of 20.0 Hz travels along a coiled spring toy. If the distance between successive compressions is 0.600 m, what is the speed of the wave?
21. How does the frequency of a wave change when the period of the wave is doubled?
22. Describe the change in the wavelength of a wave when the period is reduced by one-half.
23. If the speed of a wave increases to 1.5 times its original speed while the frequency remains constant, how does

Q2	1. Use the relation between resonance length and wavelength to solve problems for closed and open pipes. 2. Define sound pitch and relate it to the frequency of a sound wave. 3. Define resonance and list some examples and consequences. 4. Explain resonance in air columns and give examples on different instruments. 5. Apply the Doppler effect equation to calculate different frequencies and velocities.	Student Book	P.29; P.37; P8; P.(30-33)
		Q.15; Q.(1-12)	P.40

Perceiving Sound

How humans perceive sound depends partly on the physical characteristics of sound waves, such as frequency and amplitude.

Pitch Marin Mersenne and Galileo first determined that the pitch we hear depends on the frequency of vibration. **Pitch** is the highness or lowness of a sound, and it can be given a name on the musical scale. For instance, the note known as middle C has a frequency of 262 Hz. The highest note on a piano has a frequency of 4186 Hz. The human ear is not equally sensitive to all frequencies. Most people cannot hear sounds with frequencies below 20 Hz or above 16,000 Hz. Many animals, such as dogs, cats, elephants, and bats, are capable of hearing frequencies that humans cannot hear.

Get It?
Identify What characteristic of waves is pitch most closely linked to?

Loudness Frequency and wavelength are two physical characteristics of sound waves. Another physical characteristic of sound waves is amplitude. Amplitude is the measure of the variation in pressure in a wave. The **loudness** of a sound is the intensity of the sound as perceived by the ear and interpreted by the brain. This intensity depends primarily on the amplitude of the pressure wave.

The human ear is extremely sensitive to variations in the intensity of sound waves. Recall that 1 atmosphere of pressure equals 1.01×10^5 Pa. The ear can detect pressure-wave amplitudes of less than one-billionth of an atmosphere, or 2×10^{-5} Pa. At the other end of the audible range, pressure variations of approximately 20 Pa or greater cause pain. It is important to remember that the ear detects pressure variations only at certain frequencies. Driving over a mountain pass changes the pressure on your ears by thousands of pascals, but this change does not take place at audible frequencies.

Because humans can detect a wide range of intensities, it is convenient to measure these intensities on a logarithmic scale called the **sound level.** The most common unit of measurement for sound level is the **decibel** (dB). The sound level depends on the ratio of the intensity of a given sound wave to that of the most faintly heard sound. This faintest sound is measured at 0 dB. A sound that is ten times more intense registers 20 dB. A sound that is another ten times more intense is 40 dB.

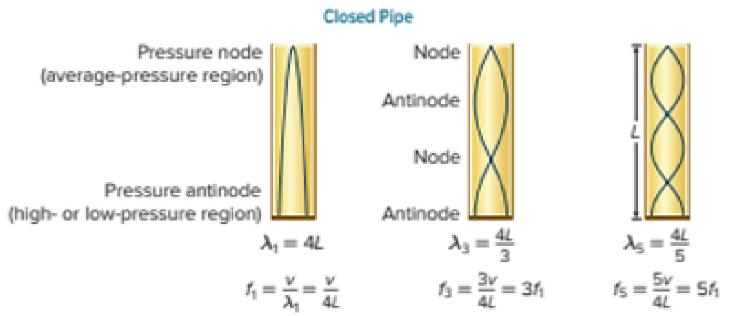


Figure 13 A closed pipe resonates when its length is an odd number of quarter wavelengths.

In the pressure graphs, the nodes are regions of mean atmospheric pressure. At the antinodes, the pressure oscillates between its maximum and minimum values. In the case of the displacement graph, the antinodes are regions of high displacement and the nodes are regions of low displacement. In both cases, two adjacent antinodes (or two nodes) are separated by one-half wavelength.

Get It?
Explain the difference between a node and an antinode on a displacement graph.

Resonance frequencies in a closed pipe If a closed end must act as a node, and an open end must act as an antinode, what is the shortest column of air that will resonate in a closed pipe? **Figure 13** shows that it must be one-fourth of a wavelength. As the frequency is increased, additional resonance lengths are found at half-wavelength intervals. Thus, columns of length $\frac{\lambda}{4}$, $\frac{3\lambda}{4}$, $\frac{5\lambda}{4}$, $\frac{7\lambda}{4}$, and so on will all be in resonance with a tuning fork that produces sound of wavelength λ.

In practice, the first resonance length is slightly longer than one-fourth of a wavelength. This is because the pressure variations do not drop to zero exactly at the open end of the pipe. Actually, the node is approximately 0.4 pipe diameters beyond the end. Additional resonance lengths, however, are spaced by exactly one-half of a wavelength. Measurements of the spacing between resonances can be used to find the velocity of sound in air, as in Example Problem 2.

Resonance frequencies in an open pipe The shortest column of air that can have nodes at both ends is one-half of a wavelength long, as shown in **Figure 14.** As the frequency is increased, additional resonance lengths are found at half-wavelength intervals. Thus, columns of length $\frac{\lambda}{2}$, λ, $\frac{3\lambda}{2}$, 2λ, and so on will be in resonance with a tuning fork.

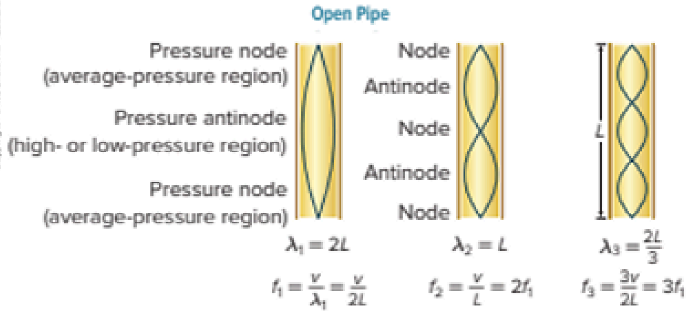


Figure 14 An open pipe resonates when its length is an even number of quarter wavelengths.

Explain How does the length at which an open pipe resonates differ from the length at which a closed pipe resonates?

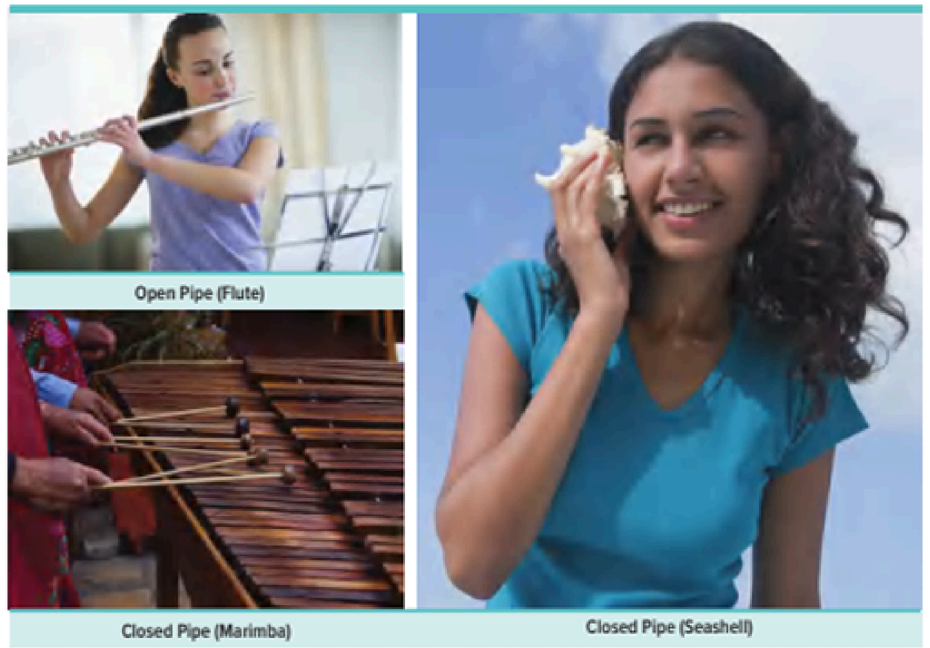


Figure 15 A flute is an example of an open-pipe resonator. The hanging pipes of a marimba and seashells are examples of closed-pipe resonators.

If open and closed pipes of the same length are used as resonators, the wavelength of the resonant sound for the open pipe will be half as long as that for the closed pipe. Therefore, the frequency will be twice as high for the open pipe as for the closed pipe. For both pipes, resonance lengths are spaced by half-wavelength intervals.

Get It?
Predict A tuning fork plays a sound that has a wavelength of 0.78 m. A pipe that is 0.39 m long resonates with the tuning fork. Is the pipe open or closed? Explain your reasoning.

Real-World Physics
HEARING AND FREQUENCY The human auditory canal acts as a closed-pipe resonator that increases the ear's sensitivity for frequencies between 2000 and 5000 Hz, but the full range of frequencies that people hear extends from 20 to 20,000 Hz. A dog's hearing extends to frequencies as high as 45,000 Hz, and a cat's extends to frequencies as high as 100,000 Hz.

Hearing resonance Musical instruments use resonance to increase the loudness of particular notes. Open-pipe resonators include flutes, shown in **Figure 15.** Clarinets and the hanging pipes under marimbas and xylophones are examples of closed-pipe resonators. If you shout into a long tunnel, the booming sound you hear is the tunnel acting as a resonator. The seashell in **Figure 15** also acts as a closed-pipe resonator.

Q2	1. Use the relation between resonance length and wavelength to solve problems for closed and open pipes. 2. Define sound pitch and relate it to the frequency of a sound wave. 3. Define resonance and list some examples and consequences. 4. Explain resonance in air columns and give examples on different instruments. 5. Apply the Doppler effect equation to calculate different frequencies and velocities.	Student Book	P.29; P.37; P8; P.(30-33)
		Q.15; Q.(1-12)	P.40

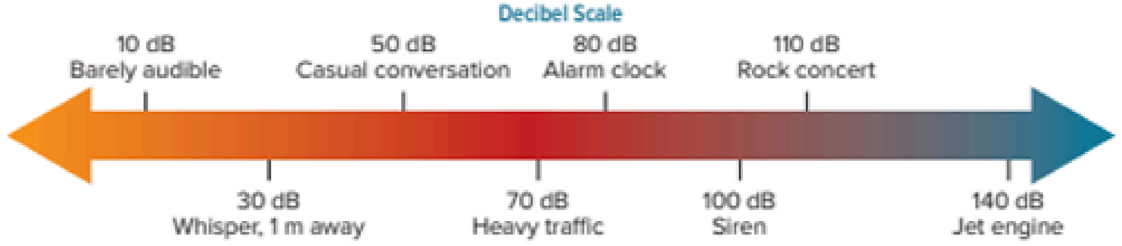


Figure 4 This decibel scale shows the sound level for a variety of sounds.

Infer *About how many times louder does an alarm clock sound than heavy traffic?*

Most people perceive a 10-dB increase in sound level as about twice as loud as the original level. **Figure 4** shows the sound level for a variety of sounds. In addition to intensity, pressure variations and the power of sound waves can be described by decibel scales.

The ear can lose its sensitivity, especially to high frequencies, after exposure to loud sounds in the form of noise or music. The longer a person is exposed to loud sounds, the greater the effect. A person can recover from short-term exposure in a period of hours, but the effects of long-term exposure can last for days or weeks. Long exposure to 100-dB or greater sound levels can produce permanent damage. Hearing loss also can result from loud music being transmitted to stereo headphones from personal music devices. In some cases, the listeners are unaware of just how high the sound levels really are. Cotton earplugs reduce the sound level only by about 10 dB. Special ear inserts can provide a 25-dB reduction. Specifically designed earmuffs and inserts, as shown in **Figure 5**, can reduce the sound level by up to 45 dB.

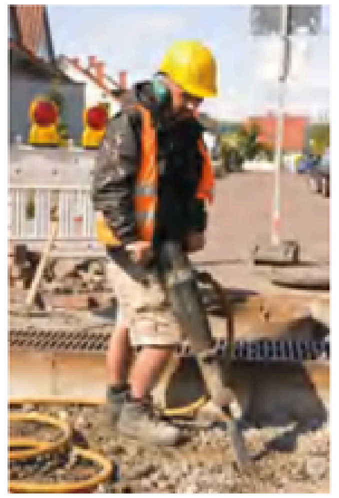


Figure 5 Hearing loss can occur with continuous exposure to loud sounds. Workers in many occupations, such as construction, wear ear protection. The jackhammer this worker is operating has a sound level of 130 dB.

The Doppler Effect

Have you ever noticed that the pitch of a fast car changed as the vehicle sped past you? The pitch was higher when the vehicle was moving toward you, then it dropped to a lower pitch as the vehicle moved away. The change in frequency of sound caused by the movement of either the source, the detector, or both is called the **Doppler effect.** The Doppler effect is illustrated in **Figure 6.**

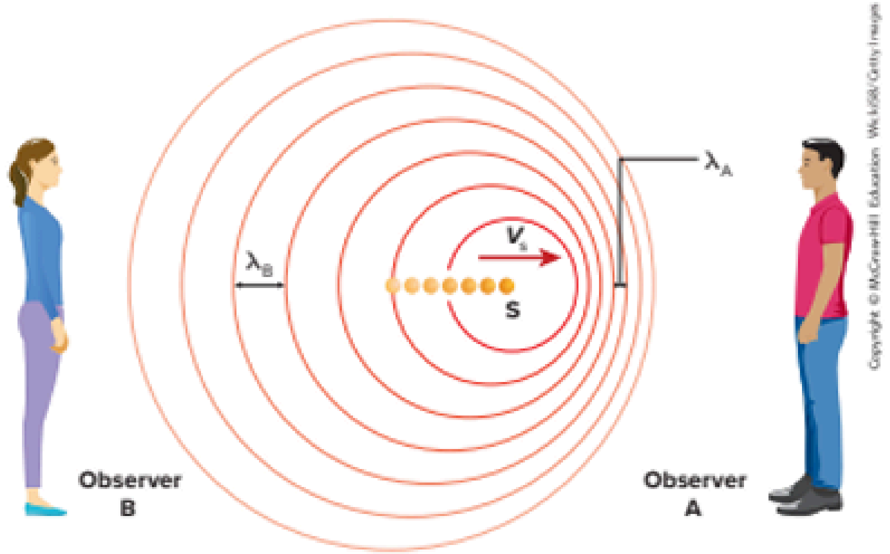


Figure 6 As a sound producing source moves toward observer A, the wavelength is shortened to λ_A. As the source moves away from observer B, the wavelength is lengthened to λ_B.

Describe *What is the relative difference in the frequency of the detected sound for each observer?*

Applications of the Doppler effect The Doppler effect occurs in all wave motion, both mechanical and electromagnetic. It has many applications. Radar detectors use the Doppler effect to measure the speed of baseballs and automobiles. Astronomers observe light from distant galaxies and use the Doppler effect to measure their speeds. Physicians can detect the speed of the moving heart wall in a fetus by means of the Doppler effect in ultrasound.

BIOLOGY Connection Bats use the Doppler effect to detect and catch flying insects. When an insect is flying faster than a bat, the reflected frequency is lower, but when the bat is catching up to the insect, as in **Figure 8,** the reflected frequency is higher. Not only do bats use sound waves to navigate and locate their prey, but they often must do so in the presence of other bats. This means they must discriminate their own calls and reflections against a background of many other sounds of many frequencies. Scientists continue to study bats and their amazing abilities to use sound waves.

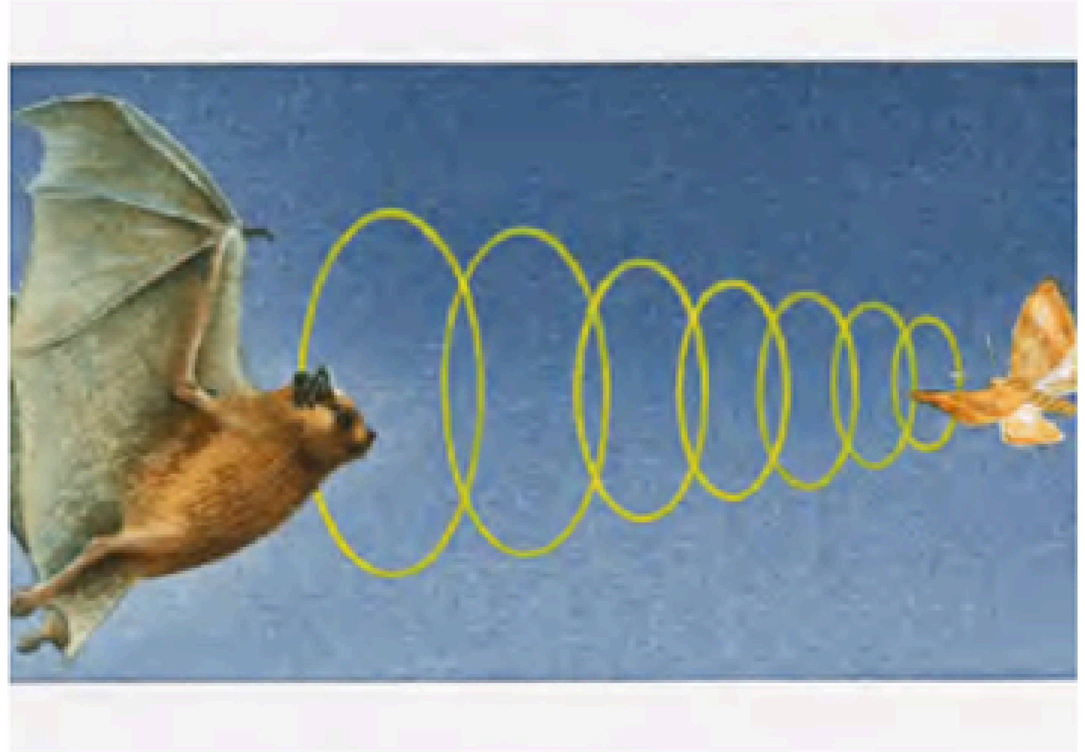


Figure 8 Bats use the Doppler effect to locate and catch flying insects, such as the moth shown here. As the bat catches up to the moth, the frequency of reflected sound waves increases.

Q2	1. Use the relation between resonance length and wavelength to solve problems for closed and open pipes. 2. Define sound pitch and relate it to the frequency of a sound wave. 3. Define resonance and list some examples and consequences. 4. Explain resonance in air columns and give examples on different instruments. 5. Apply the Doppler effect equation to calculate different frequencies and velocities.	Student Book	P.29; P.37; P8; P.(30-33)
		Q.15; Q.(1-12)	P.40

15. A 440-Hz tuning fork is held above a closed pipe. Find the spacing between the resonances when the air temperature is 20°C.

Resonance spacing $= \frac{\lambda}{2}$ so using $\lambda = \frac{v}{f}$ the resonance spacing is

$$\frac{\lambda}{2} = \frac{v}{2f} = \frac{343\ \text{m/s}}{(2)(440\ \text{Hz})} = 0.39\ \text{m}$$

Q3	1. Describe the charge distribution on a solid conducting sphere, a hollow conducting sphere and an irregular conducting surface. 2. Calculate the electric field strength at a point close a single point charge / a conducting charged sphere.	Student Book	P.(65-67), P.78
		Q.(24 - 37)	P.(66-67)

The strength of an electric field You might wonder how you can detect an electric field if you cannot see it. You can envision the force from an electric field by modeling its effects on a small, charged object—a test charge (q')—at some location. If there is an electrostatic force on the object, then there is an electric field at that point. **Figure 16** illustrates a charged object with a net charge of q. Suppose you place the positive test charge at point (A) and measure a force (F_A). According to Coulomb's law, the force is directly proportional to the strength of the test charge (q'). That is, if the charge on the test charge is doubled, so is the force $\left(\frac{2F}{2q'} = \frac{F}{q'}\right)$. Therefore, the ratio of the force to the strength of the test charge is a constant. When you divide force (F) by the strength of the test charge (q'), you obtain a vector quantity $\left(\frac{F}{q'}\right)$. The electric field at point A, the location of q', is represented by the following equation.

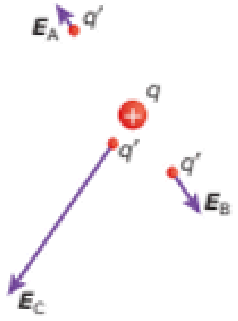


Figure 16 An electric field surrounds particle q. The forces exerted on a positively charged test particle (q') at locations A, B, and C are represented by force vectors. The vectors represent the magnitude and direction of the force from the electric field on the test particle at that point.

Electric Field Strength

The strength of an electric field is equal to the force on a positive test charge divided by the strength of the test charge.

$$E = \frac{F_{\text{on } q'}}{q'}$$

The direction of an electric field is the direction of the force on a positive test charge. The magnitude of the electric field is measured in newtons per coulomb, N/C.

COLOR CONVENTION

Electric field line (E)	⟷	purple
Positive charge	●	red
Negative charge	●	blue

Get It?

Explain how the strength of an electric field can be determined.

Field vectors You can make a model of an electric field by using arrows to represent the field vectors at various locations, as shown in **Figure 16.** The length of the arrow represents the field strength. The direction of the arrow represents the field direction. To find the field from two charges, add the fields from the individual charges through vector addition. Some typical electric field strengths are shown in **Table 1.**

You also can use a test charge to map the electric field resulting from any collection of test charges. A test charge should be small enough so that its effect on the charge you are testing (q) is negligible. Remember that, according to Newton's third law, the test charge exerts forces back on the charges that produce the electric field. It is important that these forces do not redistribute the charges that you are trying to measure, thereby affecting the electric field you are mapping.

Table 1 Typical Electric Field Strengths (Approximate)

Field	Value (N/C)
Near a charged, hard-rubber rod	1×10^{3}
Needed to create a spark in air	3×10^{6}
At an electron's orbit in a hydrogen atom	5×10^{11}

Coulomb's law and electric fields When two charges interacting through a field change relative position, the energy stored in the field is changed. If, and only if, the charge q is a point charge or a uniformly charged sphere, you can calculate its electric field from Coulomb's law. Use Coulomb's law in the electric field equation above to find the magnitude of the force exerted on the test charge ($F_{\text{on } q'}$):

$$E = \frac{F_{\text{on } q'}}{q'} = F_{\text{on } q'} \times \frac{1}{q'} = \frac{Kqq'}{r^2} \times \frac{1}{q'} = \frac{Kq}{r^2}$$

On a conducting sphere, the charge is evenly distributed around the surface.

The charges on a hollow sphere are entirely on the outer surface.

On an irregular conducting surface, the charges are closest together at sharp points.

Figure 28 Charges on a conducting sphere spread far apart to minimize their potential energy.

Electric Fields Near Conductors

Recall that many of the electrons in a conductor are free to move. Consider the charges on the conducting sphere in **Figure 28.** Because these electrons have like charges, they repel each other. They spread far apart in a way that minimizes their potential energy. The result is these charges come to rest on the surface of the conductor. It does not matter if the conducting sphere is solid or hollow. The excess charges move to the outer surface of the conductor.

Closed metal containers What happens if a closed metal container, such as a box, is charged? You can use a voltmeter to measure the electric potential difference between any two points inside the container. You will find that this potential difference is zero no matter which two points you choose inside the container. What are the consequences of this measurement for the electric field inside of the closed, metal container?

Recall that potential difference is equal to the product of the electric field and distance, or $\Delta V = Ed$. Because the potential difference between any two points inside the container is zero, the equation implies that the field is zero everywhere inside a closed, charged metal container.

Cars are a good example of this scenario. A car is a closed metal box that protects passengers from electric fields generated by lightning. On the outside of the conductor, the electric field often is not zero. The field is always perpendicular to the surface of the conductor. This makes the surface an equipotential; the potential difference between any two locations on the surface is zero.

Irregular surfaces The electric field at the surface does depend on the shape of the conductor, as well as on the electric potential difference between it and other objects. Free charges are closer together at the sharp points of a conductor, as indicated in **Figure 28.** Therefore, the field lines are closer together, and the field is stronger. This field can become so strong that when electrons are knocked off of atoms, the electrons and resulting ions are accelerated by the field, causing them to strike other atoms, resulting in more ionization of atoms. This chain reaction produces the pink glow seen inside a gas discharge sphere.

Lightning rods If an electric field is strong enough, when the particles hit other molecules they will produce a stream of ions and electrons that form a plasma, which is a conductor. The result is a spark or, in extreme cases, lightning. In order to protect buildings from lightning, builders install lightning rods. The electric field is strong near the pointed end of a lightning rod. As a result, charges in the clouds spark to the rod, rather than to another point on the building. From the rod, a conductor takes the charges to the ground. A lightning rod safely diverts lightning into the ground and away from the building.

Q3	1. Describe the charge distribution on a solid conducting sphere, a hollow conducting sphere and an irregular conducting surface. 2. Calculate the electric field strength at a point close a single point charge / a conducting charged sphere.	Student Book	P.(65-67), P.78
		Q.(24 - 37)	P.(66-67)

24. A positive test charge of 5.0×10^{-6} C is in an electric field that exerts a force of 2.0×10^{-4} N on it. What is the magnitude of the electric field at the location of the test charge?

37. **CHALLENGE** You place a small sphere with a net charge of 5.0×10^{-6} C at one corner of a square that measures 5.0 m on each side. What is the magnitude of the electric field at the opposite corner of the square?

Q4	Demonstrate knowledge of electrostatic charge, differentiate materials based on their electrical conductivity, and describe the methods of electrical charging of objects.	Student Book	P.(52-58),
		Q.(2-7), Q.(18-21)	P.54; P.63

Types of charge From your investigations with two strips of tape, you have discovered that there are only two types of charge. Benjamin Franklin called them positive charges and negative charges. Matter normally contains both types of charges. Materials have varying degrees of ability to acquire charge. Hard rubber and plastic have a tendency to become negatively charged. Glass and wool have a tendency to become positively charged. Rubbing materials together separates the two types of charge. To explore this further, consider a microscopic view.

Get It?
Predict the type of charge on the pen shown at the beginning of the module.

A Microscopic View of Charge

Electric charges exist within atoms. In 1897 J.J. Thomson discovered that all materials contain low-mass, negatively charged particles. These particles are called electrons. Between 1909 and 1911, Ernest Rutherford, who had earlier worked as Thomson's assistant, discovered that the atom has a massive, positively charged nucleus surrounded by a cloud of orbiting electrons. From these experiments and many others, scientists know that atoms are normally neutral. For a **neutral** object, the amount of negative charge exactly balances the amount of positive charge.

Transfer of electrons With the addition of energy, the outer electrons of an atom can be removed from the atom. An atom that is missing electrons has a net positive charge, and matter that has electron-deficient atoms is positively charged. The electrons can remain unattached or can attach to other atoms, resulting in atoms with net negative charge. From a microscopic viewpoint, acquiring charge is a process of transferring electrons, as modeled in **Figure 3.**

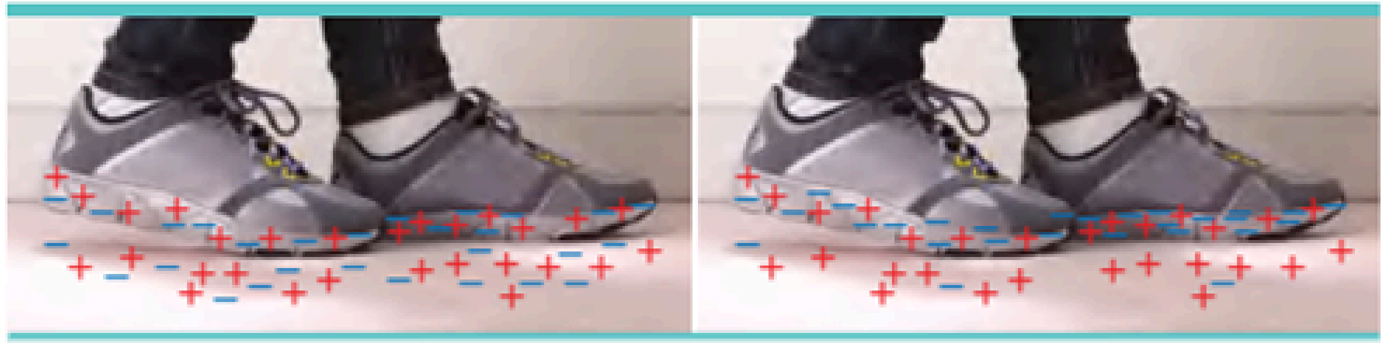


Figure 3 Electrons can be transferred from the wool rug to the rubber shoe.

COLOR CONVENTION

Positive charge	+	red
Negative charge	−	blue

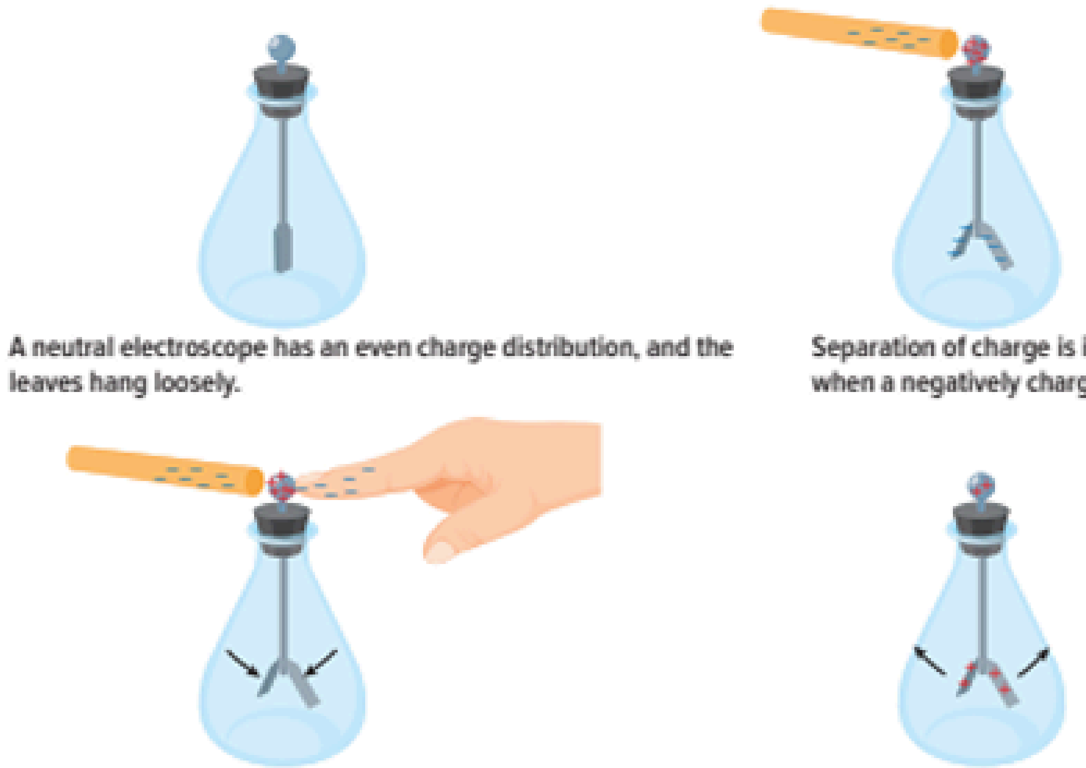


Figure 10 Grounding an electroscope charges the electroscope by induction.

Grounding **Figure 10** shows how to charge an electroscope by induction through **grounding,** which is the process of removing excess charge by connecting an object to Earth. Because Earth is very large, it can absorb great amounts of charge without becoming noticeably charged itself.

If you bring a negatively charged rod close to the knob of the electroscope in **Figure 10,** as in the top-right image, the rod repels electrons onto the leaves. If you ground the knob on the side opposite the charged rod by touching it, electrons will be pushed from the electroscope through your hand and into the ground until the leaves are neutral. If you then remove your hand, leaving the charging rod in place, the electroscope will have a deficit of electrons and a positive charge.

You also can use the ground as a source of electrons. If you bring a positive rod near the knob of a grounded electroscope, electrons will be attracted from the ground and the electroscope will obtain a negative charge. When you employ this process, the charge induced on the electroscope is opposite that of the object used to charge it. Because the charged rod never touches the electroscope, no electrons are transferred between the rod and the electroscope, and the rod can be used many times to charge objects by induction.

Q4	Demonstrate knowledge of electrostatic charge, differentiate materials based on their electrical conductivity, and describe the methods of electrical charging of objects.	Student Book	P.(52-58),
		Q.(2-7), Q.(18-21)	P.54; P.63

2. **Charged Objects** After you rub a comb on a wool sweater, you can use the comb to pick up small pieces of paper. Why does the comb lose this ability after a few minutes?
3. **Types of Charge** A pith ball is a small sphere made of a light material, such as plastic foam, that is often coated with a layer of graphite or aluminum paint. How could you determine whether a pith ball suspended from an insulating thread is neutral, charged positively, or charged negatively?
4. **Charge Separation** You can give a rubber rod a negative charge by rubbing the rod with wool. What happens to the charge of the wool? Why?
6. **Charging a Conductor** Suppose you hang a long metal rod from silk threads so that the rod is electrically isolated. You then touch a charged glass rod to one end of the metal rod. Describe the charges on the metal rod.
7. **Charging by Friction** You can charge a rubber rod negatively by rubbing it with wool. What happens when you rub a copper rod with wool?
8. **Critical Thinking** Some scientists once proposed that electric charge is a type of fluid that flows from objects with an excess of the fluid to objects with a deficit. How is the current two-charge model more accurate than the single-fluid model?

18. **Charging by Induction** In an electroscope being charged by induction, what happens when the charging rod is moved away before the ground is removed from the knob?
19. **Electroscopes** Why do the leaves of a charged electroscope rise to a certain angle and no farther?
20. **Attraction of Neutral Objects** What properties explain how both positively charged objects and negatively charged objects can attract neutral objects?

21. **Charging an Electroscope** How can you charge an electroscope positively using a positively charged rod? Using a negatively charged rod?

Q4	Demonstrate knowledge of electrostatic charge, differentiate materials based on their electrical conductivity, and describe the methods of electrical charging of objects.	Student Book	P.(52-58),
		Q.(2-7), Q.(18-21)	P.54; P.63

الله يوفقنا ويوفقكم - الاساله الي مب محلوله بتنحل قريب