Waves: More than a Simple Oscillation

A 5 E learning cycle presented by
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AMERICAN ASSOCIATION OF PHYSICS TEACHERS
PHYSICS TEACHING RESOURCE AGENTS

AAPT PTRA

Waves

LO: Students will:

- Compare the motions of transverse, longitudinal, and combined waves.
- Identify and measure the amplitude, wavelength, and frequency of waves.
- Explore how amplitude, frequency, tension, and density of the medium affect wavelength and wave speed.
- Determine that wave speed is equal to frequency multiplied by wavelength.
- Explore the factors that affect wave power, including amplitude, frequency, tension, and density of the medium.
- Explore the characteristics of combined waves.

Waves

LO: Students will:

- Observe how sound waves of the same frequency interact.
- State the relationship between amplitude and volume.
- Describe how constructive and destructive interference occurs.
- Explain the origin of sound beats.
- Investigate the relationship between the frequency difference and the number of sound beats that occur each second. Observe diffraction and explain why diffraction occurs.
- Determine the relationship between wavelength, gap width, and diffraction.
- Apply the principle of superposition to understand interference patterns.
- Observe refraction and understand that refraction occurs when wave speed changes.

Standards Alignment

MS-PS4-1 Waves and their Applications in Technologies for Information Transfer

- Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.

MS-PS4-2 Waves and their Applications in Technologies for Information Transfer

- Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

HS-PS4-1 Waves and their Applications in Technologies for Information Transfer

- Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS-PS4-3 Waves and their Applications in Technologies for Information Transfer

- Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

Standards Alignment

- MP.2 Reason abstractly and quantitatively.
- MP.4 Model with mathematics.
- HSA-SSE.A.1 Interpret expressions that represent a quantity in terms of its context.
- HSA-SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- HSA.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Common Misconceptions

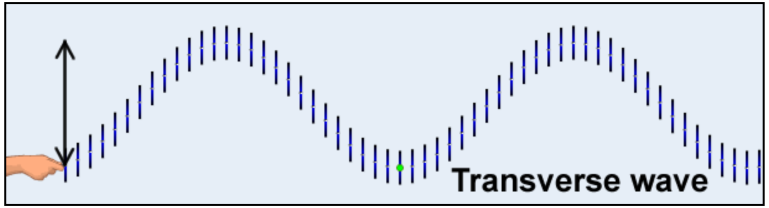
- All waves travel the same way.
- There must be a medium for wave propagation.
- Light and sound have the same wave nature.
- Wave speed and frequency are the same.
- Pitch is related to loudness.
- Large amplitude waves travel faster than small amplitude waves in the same medium.
- Waves transport matter from one place to another.
- Changes in wave speeds produce the Doppler effect.
- Only waves of light can refract
- The law of reflection works for special angles or plane surfaces.

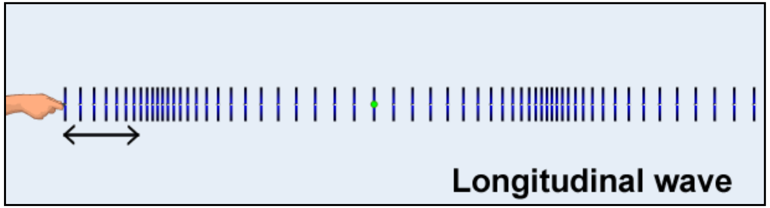
Teacher background information

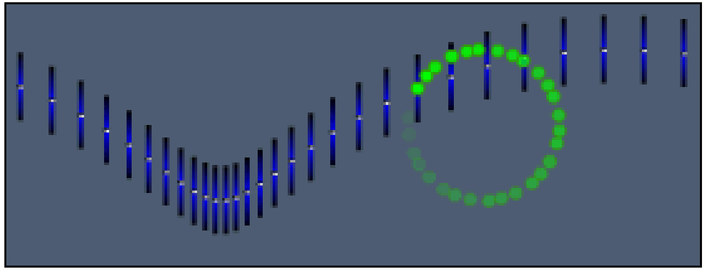
A wave is a transmission of energy that usually occurs without permanently displacing the particles of the medium the wave travels through. There are four main types of waves. Mechanical waves involve the motion of particles in a medium. Electromagnetic waves (including visible light) involve perturbations in electric and magnetic fields. The other types of waves are quantum mechanical waves and gravitational waves.

Mechanical waves involve two types of motion: transverse and longitudinal. In a transverse wave, the vibration of particles in the medium is perpendicular to the direction of the wave. Examples of transverse waves include seismic secondary waves (S-waves) and waves in a rope or guitar string. (Light waves also involve transverse motion.) In a longitudinal wave, the vibration of particles is parallel to the direction of the wave. This results in an alternating series of compressions (where particles are pushed together) and rarefactions (where particles are spread apart.) Sound waves and seismic primary waves (P-waves) are longitudinal waves.

Teacher background information







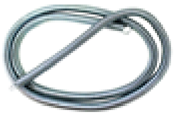
Many mechanical waves involve both transverse and longitudinal motion. In this case, individual particles in the medium will move in a circular or elliptical orbit, as shown by the green trace in the image to the right. Ocean waves and seismic surface waves are examples of combined waves.

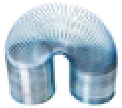
Wave at Me Engage:

How do we measure and describe waves?

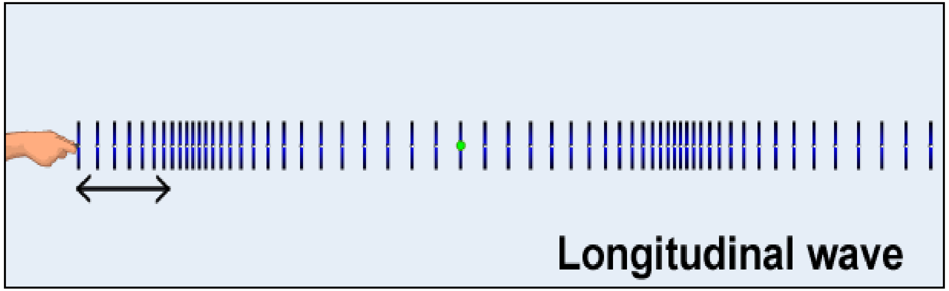
Materials:

meterstick, stopwatch, spring, slinky, cord or rope.





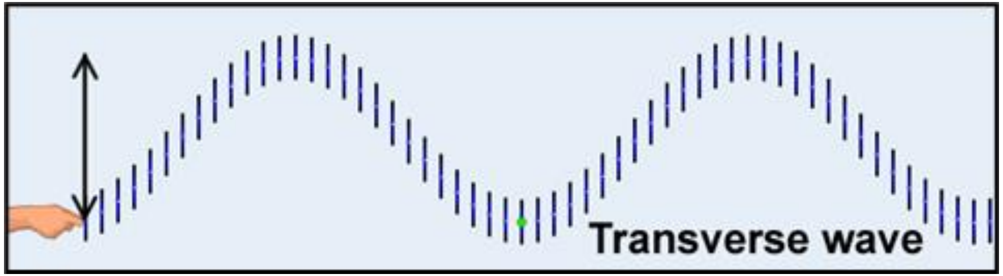
Send a pulse down the spring or Slinky™ by pinching together several coils of the spring or Slinky and then releasing them. Sketch the pulse. What happens to the shape of the pulse as it travels down the spring? What is the motion of your hand? How does the compression (pinched coils of the spring/ Slinky™) move?



Wave at Me Engage:

How do we measure and describe waves?

Quickly pull an end of the spring or Slinky to one side and then release it. Sketch the pulse. What happens to the shape of the pulse as it travels down the spring? What is the motion of your hand? Follow the motion of a single crest of the wave. How does the crest move?
Compare the speed of a longitudinal wave (pinched coils) to the speed of a transverse wave (pulled to the side) for the same stretch



Wave at Me Explore:

What factors affect wave motion?

Using a cord, or rope measure the time it takes a pulse to travel down the medium.

________seconds.

Change the size (amplitude) of the pulse (4x), time the pulses, and record the respective times.

How does changing the amplitude affect the speed of the pulse for 1 significant figure?

Waves Explore: Boundary Interactions

Attach a spring (Snaky/spring) and a Slinky™ using duct tape, string, wire or twist tie

Send a pulse from the Snaky/spring to the Slinky™.

Make 2 sketches of the observations: 1 before the pulse reaches the boundary and 2 after the pulse reaches the boundary.

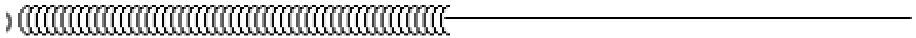
Observe and record when the pulse arrives at the junction(boundary) where the two media join.

Repeat, sending the pulse from the Slinky™ to the Snaky/spring paying attention to the phase (side of the Snaky/spring or Slinky™ the pulse before the boundary and after the pulse passes through the boundary

Is the result the same when the pulse is sent from the Slinky™ to the Snaky? Make a new drawing if it is not.

Summarize your observations about the phases of the original and transmitted pulses.

Waves Explore: Reflections



Using the Snaky/spring attach approximately 2 m of string or rope to one end.

Send a pulse from the Snakey/spring while holding the opposite end of the string tightly to simulate a rigid barrier.

How do the phases of the original and reflected pulses compare when a wave is reflected from a rigid or fixed barrier?

Send a pulse from the Snakey/spring while holding the opposite end of the string loosely to simulate a non-rigid barrier.

How do the phases of the original and reflected pulses compare when a wave is reflected from a non-rigid barrier?

Which type of barrier was represented by the pulse going from the Snaky to the Slinky™?

Waves Explore: Superposition and Interference

From both ends of the spring send simultaneous pulses (one pinched, one pulled to the side)

What happens when they meet?

Do the pulses appear to pass through each other or do the pulses "bounce back" from the collision with another pulse?

Place small paper cups approximately in the middle of the spring, approximately 50 cm to the side of the spring. Send an individual pulse separately from each end of the stretched spring and observe what happens to the cups as the pulse passes.

Send transverse pulses simultaneously using pulses that are both pulled to the same side (pulses in phase) and record what happens to the cups as the pulses pass. Repeat with transverse pulses pulled to opposite sides of the spring (pulses out of phase) and record what happens to the cups as the pulses pass.

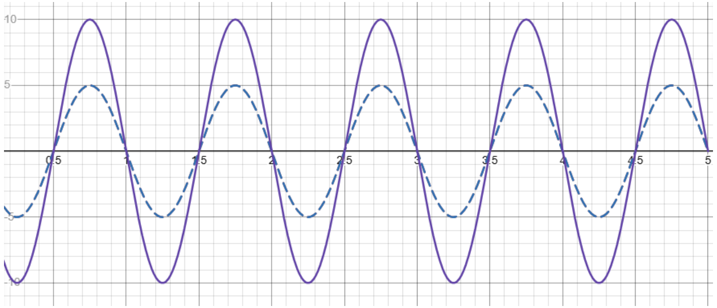
How does the maximum displacement where the pulses meet compare with the displacement of each pulse?

Waves Interactions Explain

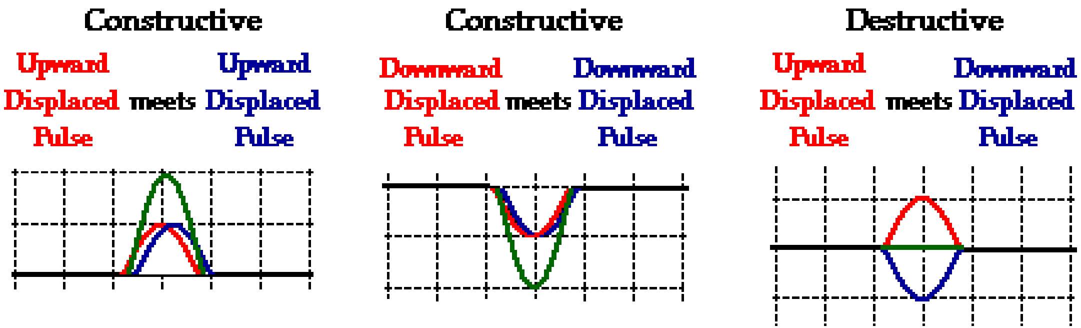
In Breakout rooms Open the Desmos Standing Waves Simulation https://www.desmos.com/calculator/nk2gqsfk9k on your screen or phone and capture different interference patterns. The Red Wave is #1, the Blue Wave is #2 and the purple wave is the superposition of the two waves. Vary the frequency (i.e. change the wavelength) of one wave, run the simulation, pause the simulation and sketch the resulting waveform due to the superposition of the red and blue waves. Repeat at least 3 times

Discuss with your group where there was constructive and destructive interference in the activity and drawings.

https://www.desmos.com/calculator/nk2gqsfk9k



Waves Interactions Explain



The diagrams show two waves (i.e. similar to in a Snaky/spring where one is blue and the other is red. The waves are interfering in such a way as to produce a resultant shape in a medium; the **resultant** is shown in green. In two cases (on the left and in the middle), constructive interference occurs and in the third case (on the far right, destructive interference occurs.

Waves Summary Explain

After the exploration activities, students should be able to define the variables investigated such as:

Longitudinal wave/pulse the vibration of particles is parallel to the direction of the wave.

Transverse wave/pulse vibration of particles is perpendicular to the direction of the wave.

A **Wave** is a disturbance that carries energy through matter or space without transferring matter.

Amplitude: The greatest distance from equilibrium. The bigger the amplitude of the wave, the more energy the wave has.

Crest: The top point of a wave.

Trough: The bottom point of a wave.

Wavelength: The shortest distance between points where the wave pattern repeats itself. Symbol is λ

Phase: Any two points on a wave that are one or more whole wavelengths apart are said to be "in phase".

Waves Summary Explain

After the exploration activities, students should be able to define the variables investigated such as:

Frequency: Is the number of complete oscillations a point on that wave makes each second.

Frequency: f is measured in Hertz (Hz), its units are $\frac{1}{s}$.

Period: is the time required for one cycle or phase of a wave or pulse

Period: T is measured in seconds $T = \frac{1}{f}$

The **speed or velocity** of a wave is how fast the energy is moved. For most waves, wave speed does not depend on amplitude, frequency, or wavelength. Speed depends only on the medium through which it moves $v = f\lambda$

Waves Summary Explain

After the exploration activities, students should be able to define the variables investigated such as:
The 3 waves/pulses that interact at the boundaries:

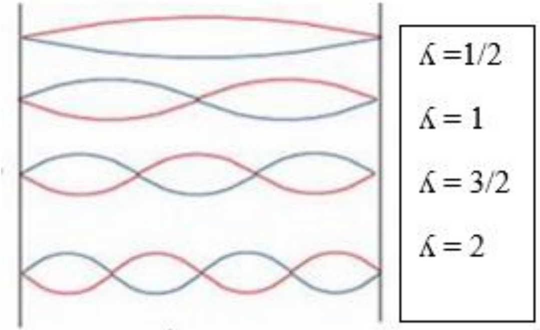
- **Incident wave/pulse:** the wave/pulse that strikes a boundary
- **Reflected wave/pulse:** the wave/pulse that reflects or bounces back from the boundary.
- **Transmitted wave/pulse:** the wave/pulse that continues past/through the boundary.

- **Wave Interference or the Principle of Superposition of wave/pulse:** when two or more waves/pulses add their displacement/amplitudes in a media
- **Constructive interference:** two or more waves/pulses are in phase: crest on crest, energies add and form an **antinode**
- **Destructive interference:** two or more waves/pulses are out of phase: crest on trough, energies subtract and form a **node**

Wave at Me: Extension

Wave At Me: Standing Waves

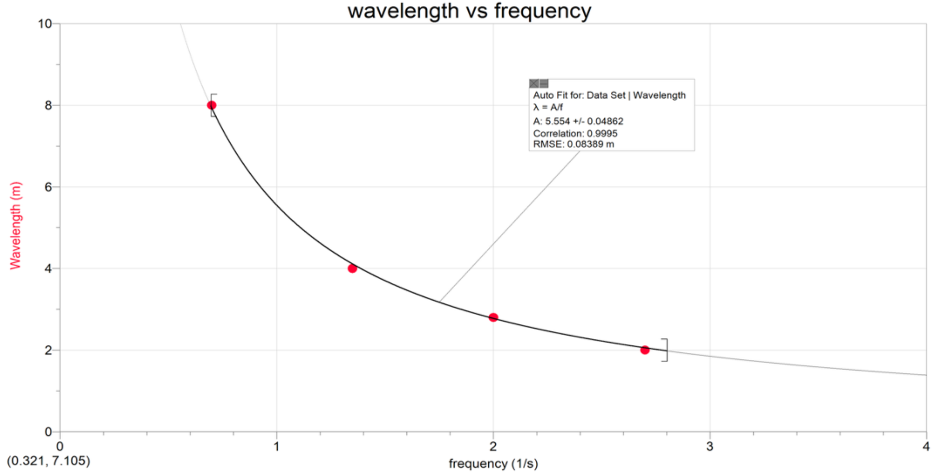
Produce a periodic or standing wave by shaking the spring horizontally, back and forth at a uniform rate. For each oscillation, measure the wavelength, ʎ, and determine the frequency *f*. To determine the frequency of a wave, time for 10 seconds and count the number of waves in 10 seconds. Frequency is the number of waves per second. Complete the data table. Have students graph wavelength vs frequency. How are wavelength and frequency in a given medium related?



Wave segments	Wavelength (m)	Frequency Waves/sec	Wavelength x frequency m/s
1			
2			
3			
4			

Sample Data for Lab

Wave segments	Wavelength (m)	Frequency Waves/sec	Wavelength x frequency m/s
1	8	.7	5.6
2	4	1.4	5.6
3	2.7	2	5.4
4	2	2.8	5.6



Standing Wave Generator: Extension #2

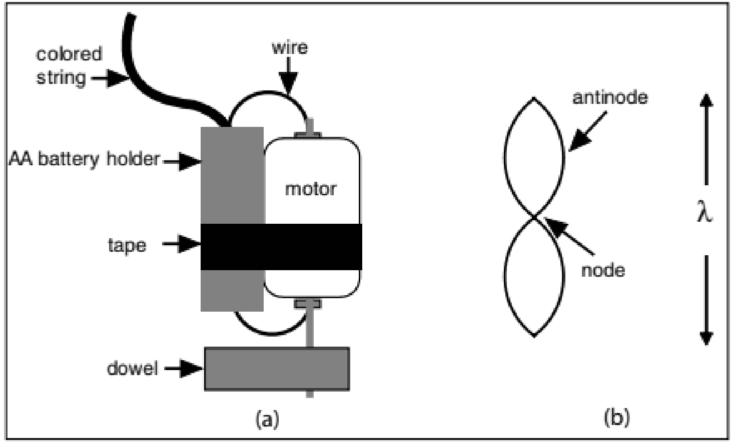


Fig. 14.7. (a) Standing wave demonstrator and (b) standing wave.

Materials and Construction

small electric motor (1.5 volts), AA battery, 1.5 length of 3/8-inch dowel, approximately 1-meter length of string or yarn (brightly colored cord shows better), insulated wire, electrical or other tape

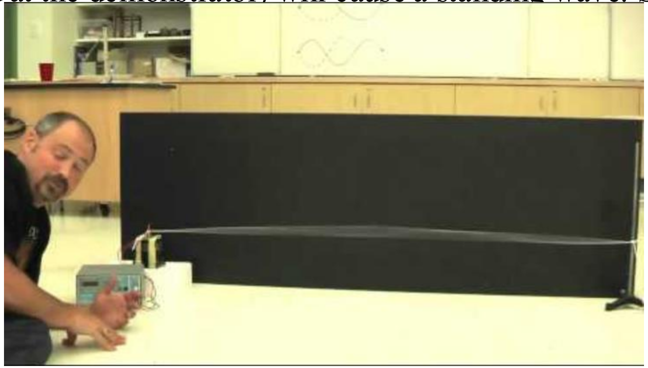
1. Cut the dowel to a length of about 1-1/4 inches. Drill a hole crosswise through the dowel close to one end. The size of the hole should be just slightly smaller than the shaft of the motor.
2. Press the dowel onto the shaft of the motor.
3. Feed the yarn through the end of the battery holder where the spring is located. Tie a knot in the yarn, and then pull back the yarn so it is inside the spring and doesn't interfere with electrical contact.

Standing Wave Generator Extension #2

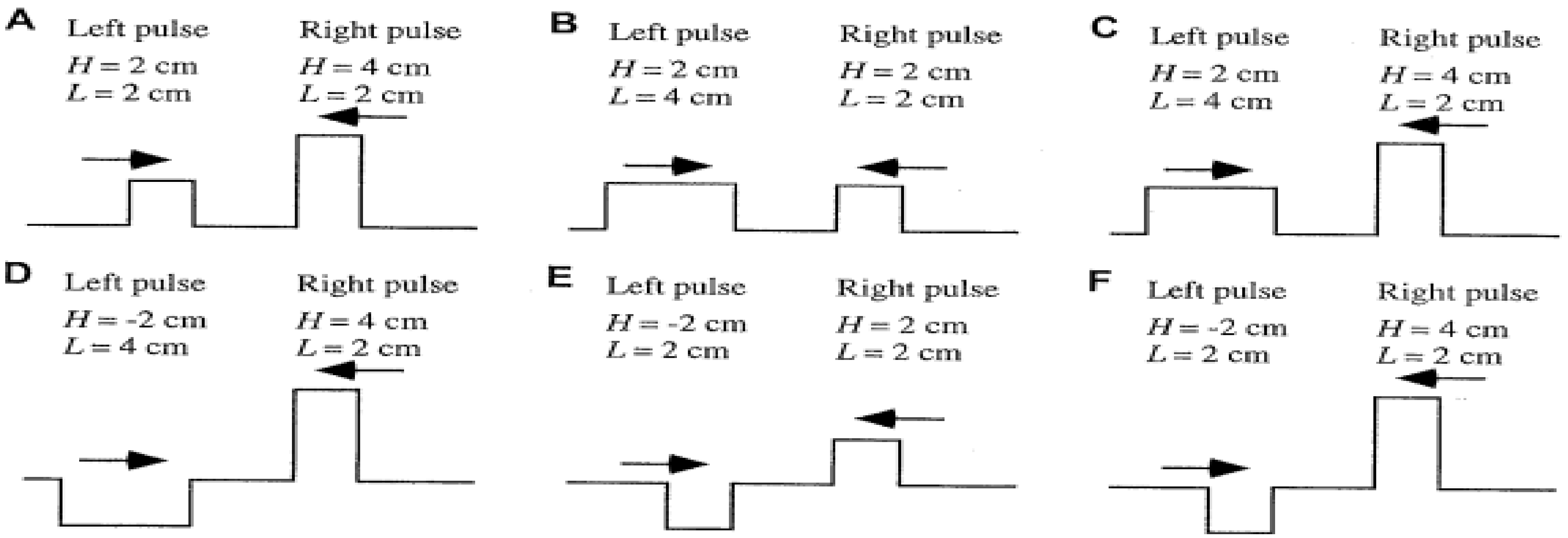
Hold the apparatus by the end of the brightly colored string. Connect the battery so that the motor runs. The apparatus will vibrate, causing the string to vibrate. Adjust the length of the string until a standing wave is produced. Changing the length will produce waves with different frequencies and therefore a different number of loops on the standing wave. See how many loops can be produced. The loops can be viewed with a stroboscope. Holding the apparatus in front of the blue screen will also cause it to strobe.

Standing waves are produced by constructive and destructive interference. A wave from a fixed point reflects back 180^{o} out of phase, so the incident wave and the reflected wave will have equal wavelength and amplitude. If the incident wave and reflected wave are in phase, a standing wave will be set up. The vibrations of the demonstrator produce waves that are reflected back and forth between the hand and the demonstrator. Any string length that will cause a node to be set up at the hand (and at the demonstrator) will cause a standing wave. Several different lengths will work to produce different numbers of loops.

An example of a larger than life standing wave generator.



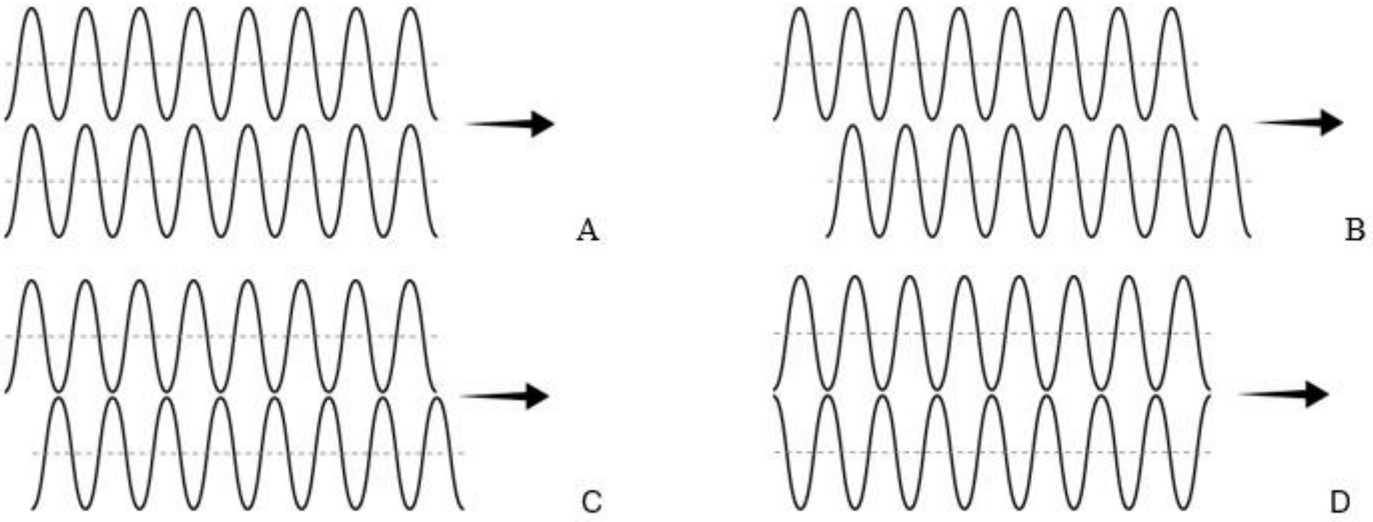
Waves Interactions Evaluate



Using the 6 rectangular transverse pulses, rank order from highest to slowest maximum peak when the pulses interfere/superimpose. Justify the ranking

Waves Interactions Evaluate

Identify the type of superposition (constructive, destructive)



Sound Waves: Engage

Play the YouTube video and explain the methods the Blue Man Group uses to produce sound. Record your responses in the chat

https://tinyurl.com/3z3zypyc

Sound Waves: Explore

Provide students with a variety of objects that produce sound and have students catagorize the objects based on how the objects produce sound. In the chat identify 3 of the objects and state how the objects produce sound.

Fore Golf & the Speed of Sound: Explain

Using resonance to calculate the speed of sound with an open tube and a closed tube? How does speed of sound identify an overtone? Sound is a longitudinal wave with a wavelength, a frequency, and the speed of sound. $v=f\lambda$

Materials: resonating tubes, large graduated cylinder, meter stick, tuning forks

Points to Ponder:

- What fraction of a wave resonates as the fundamental in a closed tube?
- What is an overtone? How would the speed of an overtone compare to that of a fundamental?

1. Using a 500- to 1000-ml graduated cylinder, a plastic golf shaft cover, a meterstick, and assorted tuning forks, design an experiment to determine the speed of sound in air, based on closed tube resonance.
2. Strike the tuning fork with a rubber heel, or rubber hammer, to prevent damaging the tuning fork and changing its frequency. Raise the tube out of the water until the sound is a maximum. The length of the tube is ¼ λ Collect the necessary data to calculate the speed of sound for three tuning forks from frequency 256 Hz to 512 Hz.
3. Determine % error for each of the three calculated speeds of sound knowing that v of sound = [332 + (0.6 x°C)] m/s.

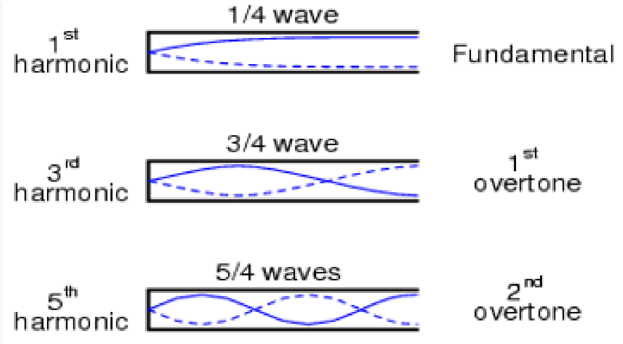
Tuning fork frequency Hz	Length of column of air that resonates (m)	Wavelength of sound wave (m)	Speed of sound from data	% error

Fore Golf & the Speed of Sound: Explain

Closed tube

1. How does your calculation for the speed of sound compare with the accepted value?
2. When timing at a track meet, why are you instructed to watch for the smoke from the starter's pistol as opposed to listening for the crack of the shot?
3. When you are attempting to estimate the distance to a lightning strike what do you do?

Frequency (Hz)	Length of tube (m)	Estimated wave-length (m)	Calculated speed of sound (m/s) $V = f\lambda$	Error for the speed of sound (%)
265	0.34	1.36	348	1.2%
320	0.25	1.00	320	5.8%
480	0.18	0.72	346	5.8%



Fore Golf & the Speed of Sound: Explain

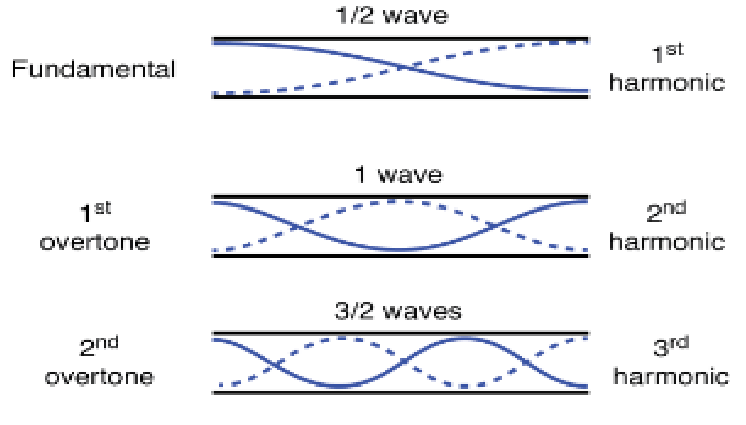
1. Using an open pvc tube with cardboard tubes that can slide, a meter stick and assorted tuning forks, design an experiment to determine the speed of sound in air based on open tube resonance.

1. An open tube has sound escaping from both ends of the tube.
2. Strike the tuning fork with a rubber heel, or with a rubber hammer to prevent damaging the tuning fork and changing its frequency.
3. Place the tuning fork at one end of the pvc/cardboard tube and slide the cardboard tube to maximize the sound.

Fore Golf & the Speed of Sound: Explain

4. Measure the length of the tube. This measurement will be ½ λ
5. Collect the necessary data to calculate the speed of sound for three tuning forks from frequency 256Hz to 512 Hz.
6. Determine % error for the three calculated speeds of sound knowing that v = [332 + (0.6 x °C)] m/s.

Tuning fork frequency Hz	Length of column of air that resonates (m)	Wavelength of sound wave (m)	Speed of sound from data	% error



Makey Makey Extend

The Makey Makey is a simple device. On the front of the board are holes for alligator clips to plug into, and on the back is a USB plug. Plug an alligator clip into anything conductive and attach the 'Earth's lead to your body to turn anything into a touch sensor or touchpad and connect to the internet. On the back of the board, there are several of easily-breadboarded headers that expand the six inputs on the front to 16 inputs that can send any input to a PC. Have students watch https://www.youtube.com/watch?v=rfQqh7iCcOU before beginning their constructions.The developers of Makey Makey also made Scratch - https://scratch.mit.edu

Doppler Effect Background

A sound wave is an example of a *longitudinal wave*, which consists of a series of high- and low-pressure regions called *compressions* and *rarefactions*.

Sound is perceived when the compressions and rarefactions strike the eardrums. The greater the frequency of waves, the higher-pitched the sound will be. Shortening the distance between compressions (wavelength) will increase the frequency of the waves and raise the pitch.

The Doppler shift applies to other types of waves, including light waves. Changing the wavelength shifts the color of a light wave. In the visible spectrum, light from an object moving toward the observer is *blueshifted*, while light moving away is *redshifted*. Scientists use this information to tell if a galaxy is moving towards or away from our galaxy, or to detect small movements that may indicate the presence of planets around a distant star.

AAPT PTRA

Doppler Shifting: Extension 2

The **pitch** of a sound, or how shrill or deep the ear perceives the sound, is related to the **frequency** of the sound waves.

The Doppler effect is the apparent shift in frequency due to the motion of the source, the observer of both.

The greater the number of sound waves passing by a point each second, the higher the frequency and the pitch will be. The unit of frequency is the *hertz* (Hz).

Doppler Shifting: Extension 2

The Doppler Effect can be demonstrated using a buzzer and battery in a tennis ball at the end of a long string. Whirl the buzzer in a horizontal circle over your head. Point out the difference in frequency between the moving and the stationary buzzer. An alternate demonstration is to provide students with a tuning fork. A vibrating tuning fork moved back and forth near their ear produces' a Doppler shift in frequency. Ask students for examples they may have heard outside the classroom Ambulances or fire engines approaching and then passing. Cars honking horns, or motorcycles and cars as the vehicles approach and then pass them.

A common misconception among students concerns the frequency shift due to the Doppler effect. Many students intuitively think amplitude changes rather than frequency. This demonstration is simple and clearly shows the frequency shift of the Doppler effect. The Doppler effect is a frequency shift of the original tone due to the relative motion between a moving source and observer. For a source moving toward an observer, the observer perceives a shorter wavelength, because wavefronts reach the observer at shorter time intervals than would be the case with a stationary source of the same frequency. As a result, the frequency heard by the observer is greater (higher pitched) than the frequency being emitted by the source. Similarly, when the source is moving away from the observer, the observer perceives longer wavelengths and hears a lower pitch tone. Pitch is what the ear hears as a result of frequency.

Doppler Shifting: Extension 3

How to Make a Doppler Ball

Materials: one old tennis ball or a small Nerf ®-type football or soccer ball, or any other type of stuffed soft ball, one electric buzzer suitable for 9-V battery, one 9-V battery cap with leads
one 9-V battery, soldering gun and solder, switch (optional), masking or duct tape

Instructions:

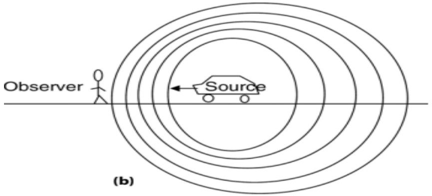
1. Solder battery cap (and switch if desired) to buzzer. 2. Split the ball and "dig out" a section of the inside to provide a pocket for the buzzer/battery assembly. 3. Connect the battery, insert the buzzer assembly, and tape the ball shut with masking or duct

Discussion Questions for Evaluations

1. As a wave passes through the spring, does any matter move from one end of the spring to the other? Explain
2. Where are transverse, longitudinal, and combined waves found in nature?
3. Why does increasing the tension increase the speed of a wave?
4. How is the equation $v = f \cdot \lambda$ derived from the standard speed equation, $v = d \div t$?
5. Why are the sound waves compressed in front of the moving sound source, and stretched out behind the sound source?
6. Why does the magnitude of the Doppler shift increase when the speed of sound is reduced?
7. Would you observe a Doppler shift if you were moving toward a stationary sound source? Explain why or why not.

Discussion Answers for Evaluations

1. No. As the wave passes through, individual coils of the spring will move up and down and/or back and forth, but no part of the spring moves from one end to the other.
2. Light waves are transverse waves, sound waves are longitudinal, and ocean waves are combined. Seismic (earthquake) waves may be transverse, longitudinal, or combined.
3. Rigid materials will respond more quickly to force than elastic materials.
4. The wavelength (λ) is a distance, and frequency is the reciprocal of the period, which is the amount of time required for one wavelength to pass
5. The source emitting the sound is moving into the sound wave compressing the wavelength.



6. As the velocity of the sound source approaches the speed of sound, the Doppler shift increases. This can be achieved by increasing the speed of the sound source or decreasing the speed of sound
7. *Y*es—the frequency of sound waves would be higher as you approach the source, and lower and you move away

Additional Resources

Types of waves: http://www.physicsclassroom.com/class/waves/Lesson-1/Categories-of-Waves
Wave motion: http://www.acs.psu.edu/drussell/demos/waves/wavemotion.html
Transverse and longitudinal waves (video): https://www.youtube.com/watch?v=jAXx0018QCc
Ocean waves: http://hyperphysics.phy-astr.gsu.edu/hbase/waves/watwav2.html
Wave power: http://hyperphysics.phy-astr.gsu.edu/hbase/waves/powstr.html
Doppler shift videos and clips:
http://www.wfu.edu/physics/demolabs/demos/3/3b/3B40xx.html,
http://www.sciencechannel.com/video-topics/space-videos/time-doppler-effect/,
https://www.youtube.com/watch?v=I1ykNQijOC8
Doppler shift demonstrations: http://molebash.com/doppler/home.htm
Doppler movies: http://molebash.com/doppler/horn/horn1.htm
How to make a Doppler ball: http://molebash.com/doppler/pitch/dopplerball.htm