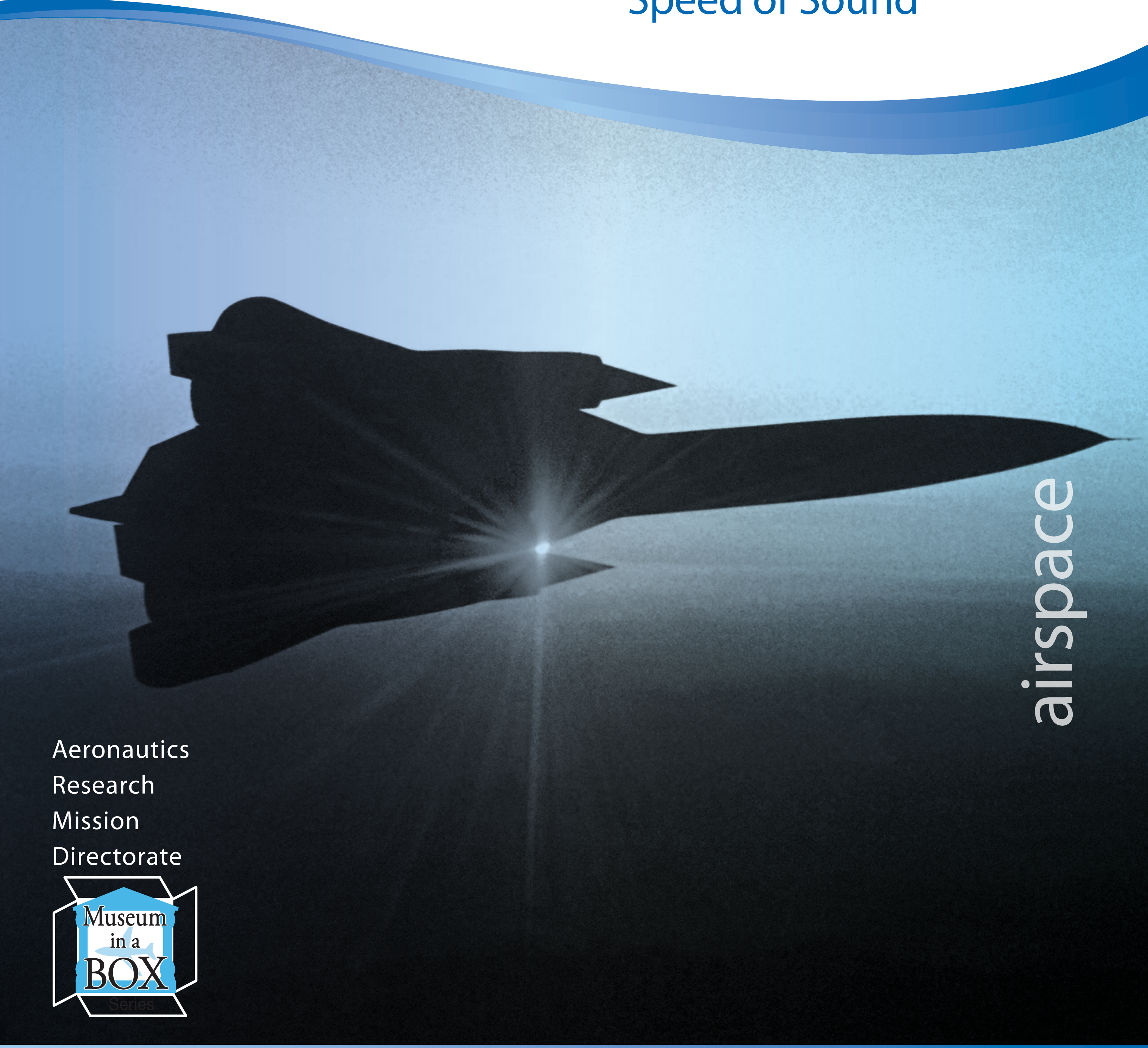
National Aeronautics and Space Administration

GRADES 9-12

Speed of Sound



airspace

Aeronautics
Research
Mission
Directorate

Museum in a BOX Series

www.nasa.gov

Speed of Sound

Lesson Overview

As scientists and engineers work to reduce aircraft noise, a thorough understanding of the physics of sound is necessary. The speed of sound and how that speed depends on certain variables are important concepts related to the physics of sound. Engineers who design every aspect of an airplane, from the airframe through the engines, must have a thorough understanding of the speed of sound, since noise affects each component of an aircraft. In this lesson, participants will learn about motions and forces and the interactions of energy and matter as they use the principle of resonance to set up an experiment in the classroom to measure the speed of sound in air. The speed of sound will be calculated using the standard relationship between velocity, frequency and wavelength. A second activity challenges students to produce longitudinal and transverse waves in a spring. They will measure wavelength, amplitude and the period of a transverse wave. The speed of a wave in a spring will be determined.

Objectives

Students will:

1. Use experimental procedures to determine the speed of sound in a gas (air).
2. Better understand some of the principles of sound.
3. Become familiar with the wave equation: velocity = wavelength · frequency ($v = \lambda \cdot f$).
4. Measure amplitude, wavelength and the period of a wave in a spring.
5. Understand that noise from aircraft is a growing problem and that NASA is working to reduce the amount of noise.

Materials:

In the Box

Plastic tube, clear, 1″ diameter, 2 ft.

PVC tube, white, ½″ diameter, 2 ft.

Rubber stopper

Stop watches

Eye protection

Meter stick

Container to hold water

Tuning forks set of 4

Tuning fork, 256 Hz

Rubber activator block

Provided by User

Water, 1 gallon

Calculator

Pencils

Pertroleum jelly

GRADES 9-12

Time Requirements: 1 hour 45 minutes

Background

As scientists and engineers work to reduce noise pollution from aircraft, a thorough understanding of the physics of sound is necessary. The speed of sound and how it depends on certain variables are important concepts related to the physics of sound. Sound is one of the most important ways we have of sensing our surroundings and communicating with others. Sound itself is a sensation created in the human brain in response to sensory inputs from the inner ear. However, not all sounds are desirable or beneficial. The following information is presented to help the reader develop a better understanding of sound, including how it is made and how it travels:

- Sound is produced by vibrating objects.
- Sound is transmitted through the air and can travel through solids, liquids, or gases.
- Sound cannot travel through a vacuum.
- Air is a gas, and a very important property of any gas is the speed at which sound travels through it. The speed of "sound" is actually the speed of the transmission of a small disturbance through a medium.
- The speed of sound in air is slower than it is in solids and liquids. To some this may seem counterintuitive.

	Solid Steel	Sea Water	Air
Speed of sound in m/sec at 21° C (70°F)	5,180 m/s	1,524 m/s	331 m/s
Speed of sound in mph at 21° C (70°F)	11,600 mph	3,414 mph	740 mph

Fig. 1 Speed of sound in different mediums

Given normal atmospheric conditions, the temperature, and thus speed of sound, varies with altitude:

Altitude	Temperature	m/sec	Km/h	mph	knots
Sea level	15°C (59°F)	340	1225	761	661
11,000m - 20,000m (Cruising altitude of commercial jets)	-57°C (-70°F)	295	1062	660	573
29,000m (Flight of X-43A)	-48°C (-53°F)	301	1083	673	585

Fig. 2 Speed of sound at different altitudes

- The speed of sound is dependent on temperature. As the temperature of the air increases, the speed of sound in air increases.
- Sound waves are longitudinal. They move by alternately squeezing (compression) and stretching (rarefaction).
- Wave science: frequency = number of waves/sec.
- Hertz (Hz) is a unit of frequency where one Hertz equals one cycle, or wave, per second.
- Velocity = wave length (meters) X frequency (Hz or cycles/sec).
- Frequency of sound and pitch are related. The higher the pitch, the greater the frequency.
- Frequency and pitch depend on the length of the object that is vibrating. For example, a short string vibrates faster than a long string resulting in a higher frequency and a higher pitch.
- Multiple sound waves can reinforce or interfere with each other.
- Sound insulation is designed to absorb sound energy. Many of the same materials used in temperature insulation can be used to reduce sound as well.
- The normal range of sound that a human can hear is between 40 – 18,000 Hertz (Hz).
- Many animals can detect a wider range of sound frequencies than humans can.
- Sound can be reflected (bounced off) or refracted (bent) or absorbed.
- Sound levels decrease rapidly as the distance from the point of origin to the receiver increases. If the distance from the source is doubled, then the intensity decreases about one-fourth.
- The decibel is a unit that expresses the relative intensity of sound.

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

Fig. 3 Examples of sound intensity

As an aircraft moves through the air, the air molecules near the aircraft are disturbed and begin to move around the aircraft. If the aircraft passes through the air at a low speed, typically less than 250 mph, the density of the air remains the same. But when aircraft travel at higher speeds, some of the energy from the aircraft goes into compressing the air and locally changes the density of the air. This compressibility effect alters the amount of resulting force on the aircraft. The effect becomes more important as speed increases. Near and beyond the speed of sound, about 330 m/s or 760 mph, small disturbances in the flow are transmitted to other locations on the aircraft. But a sharp disturbance generates a shock wave that affects both the lift and drag of an aircraft. The ratio of the speed of the aircraft to the speed of sound in the gas determines the magnitude of the many compressibility effects. Because of the importance of this speed ratio, aerodynamicists have designated it with a special parameter called the Mach number in honor of Ernst Mach, the late 19th century physicist who studied gas dynamics. The Mach number (M) allows us to define flight conditions in which compressibility effects vary.

1. Subsonic conditions occur for Mach numbers less than one ($M < 1$). For the lowest subsonic conditions, compressibility can be ignored.
2. As the speed of the object approaches the speed of sound, the flight Mach number is nearly equal to one ($M \approx 1$), and the flow is said to be transonic. At some places on the object, the local speed exceeds the speed of sound. Compressibility effects are most important in transonic flows and led to the early conclusion that a sound barrier existed. Historically, a flight faster than the speed of sound was thought to be impossible. Some engineers thought that the aircraft would self-destruct in this region of flight. We now know that there is no "sound barrier". In fact, the sound barrier is only an increase in the drag near sonic conditions because of compressibility effects. Because of the high drag associated with compressibility effects along with the variability of the aircraft's performance due to fluctuations in airflow around different components on the aircraft (for example, some sections

of the plane experiencing effects of air faster than the speed of sound while others are experiencing subsonic conditions), aircraft do not cruise near Mach 1.

3. Supersonic conditions occur for Mach numbers greater than one, $(1 < M < 5)$. Compressibility effects are important for supersonic aircraft, and shock waves are generated by the surface of the object. For high supersonic speeds $(3 < M < 5)$, aerodynamic heating also becomes very important in aircraft design. Even at $(M=2)$ heating was an issue for the Concorde. During supersonic flight, the fuselage expanded by a foot due to heating. The nose of any supersonic aircraft is generally the hottest part of the aircraft other than the engines. During supersonic flight, the nose temperature of an aircraft can approach 260^0 F, almost 50^0 hotter than boiling water.
4. For speeds greater than five times the speed of sound $(M > 5)$, the flow is said to be hypersonic. At these speeds, some of the energy of the object goes into exciting the chemical bonds, which hold together the nitrogen and oxygen molecules of the air. At hypersonic speeds, the chemistry of the air must be considered when determining the forces on the object. The Space Shuttle re-enters the atmosphere at high hypersonic speeds, $(M \sim 25)$. Under these conditions, the heated air becomes ionized gas, or plasma, and the spacecraft must be insulated from the high temperatures of the plasma.

Fig. 4 Mach number divisions

Standing Waves and Resonance

Imagine that you have a long rope attached to a wall. If you vibrate the end of the rope by shaking it, you can send a wave down the rope. When the wave reaches the other end of the rope it will be reflected back, but it will interfere with the oncoming wave. In most cases there will be a jumble. If you shake the rope at just the right frequency, a standing wave will be created as shown in Fig. 9. A standing wave is produced when two waves traveling in opposite directions interfere with each other and produce a large amplitude wave. When a standing wave is created, then resonance occurs. Another form of resonance occurs when one object is vibrating at the same natural frequency of a second object, which forces that second object into vibration. The frequency at which you are shaking the rope is called the resonant frequency .

In Activity 1: Measuring the Speed of Sound Using Resonance, you will use this wave principle as it applies to sound waves. Instead of vibrating a rope, you will vibrate a column of air in a closed pipe.

Activity 1 Measuring the Speed of Sound Using Resonance

GRADES 9-12

Time Requirements: 60 minutes

Materials:

In the Box

None

Provided by User

Water, 1 gallon
Pertroleum jelly (optional)
Calculator
Pencils
Copies of the worksheet

Worksheets

None

Reference Materials

None

Key Terms:

Amplitude
Frequency
Inteference
Resonance
Sound wave
Standing wave
Wavelength

Objective:

The purpose of this activity is for students to learn about motion and forces and interactions of energy and matter as they measure the speed of sound in air. Students will become familiar with some of the variables that affect the speed of sound in air. The concepts of resonance and interference will also be introduced.

Activity Overview:

Using a closed pipe and a tuning fork, students will determine the speed of sound in air using a classic physics experiment. In this experiment the tuning fork produces a sound wave that travels down a closed pipe. As the sound wave is reflected off the top of the water in the pipe and returns to the open end, interference between the two sound waves occurs. If the length of the closed pipe is one-fourth of a wavelength, then a standing wave is set up and resonance occurs. The velocity of sound is then calculated using the following equation:

$v = \text{wavelength} \cdot \text{frequency} = 4\,(l + .3d) \cdot \text{frequency}$

where:

l = length (meters) of the closed tube (Fig. 5) when resonance occurs
d = inside diameter (meters) of the clear plastic tube
frequency = 256 Hz, or the number inscribed on the tuning fork

Activity:

1. **A minimum of two people are needed for this activity.**

2. **Place a rubber stopper in the bottom of the clear plastic tube.**

3. **Secure the apparatus so that it will not fall over.**

4. **Pour a small amount of water into the tube and make sure that no leaks occur.** Petroleum jelly around the part of the stopper that contacts the glass will stop leaks if they happen.

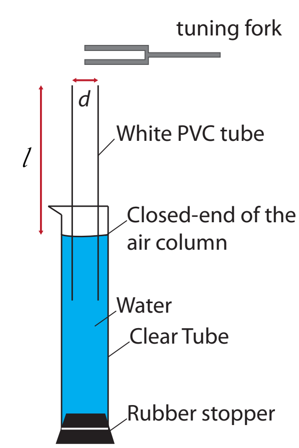


Fig. 5 Apparatus setup

5. **Fill the tube with water as shown in Fig. 5.** The water should be near the top but not overflowing.

6. **Place the white PVC tube in the water (Fig. 5).**

7. **Strike the tuning fork (256 Hz) on your knee or the rubber block activator that comes with the tuning fork kit.** Striking the tuning fork on hard objects produces higher pitched vibrations called harmonics, which will interfere with the experiment. When properly activated, you should have to bring the vibrating tuning fork within a few inches of your ear to hear it well.

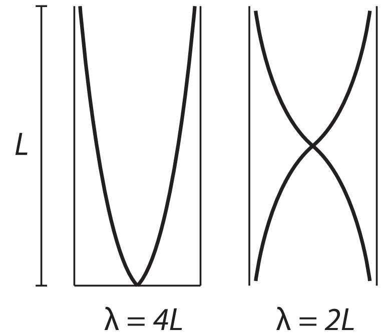


Fig. 6 Resonance in closed and open pipes (λ = wavelength)

8. **Hold the vibrating tuning fork as shown in Fig. 5.** It is important to keep the vibrating tuning fork directly over the opening of the PVC tube.

9. **Slowly move the white PVC tube AND the tuning fork up and down and listen for the volume of the sound to change.** When you think you've found the length of the tube that produces the loudest sound (resonance), strike the tuning fork again and check your results. You may need to repeat this step several times.

10. **Hold the white PVC tube in the position where resonance is heard.**

11. **Measure the length *l* (centimeters) and record in the worksheet.** Note: the length *l* is the distance from the top of the white PVC tube to the top of the water (Fig. 5).

12. **For the 256 Hz tuning fork the volume should increase somewhere near *l* = .32 meters.**

13. **You have just determined ¼ of a wavelength for a sound that has a frequency of 256 Hz (see Fig. 6).**

14. **Measure d (Fig. 5) and record on the worksheet.**

15. **Measure the air temperature inside the PVC tube.** Record on the worksheet.

16. **Use the formula given above to calculate the speed of sound in air.**

17. **If time permits, repeat the experiment using tuning forks with different frequencies (320-E, 385-G and 512-C).** Predict how a higher frequency tuning fork will affect. (If the frequency increases, then *l* should decrease)

18. **Again, if time permits, predict how a change in temperature will affect the speed of sound in air.** Find an environment with a significant change in temperature. Allow sufficient time for the air temperature inside the PVC tube to adjust to the new environment.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 2 Determining the Speed of a Wave in a Spring

GRADES 9-12

Time Requirements: 45 minutes

Materials:

In the Box

Safety glasses

Wave modeling spring (one per group)

Stopwatch (one per group)

Masking tape

Provided by User

Gloves (for holding the spring)

Calculator

Worksheets

None

Reference Materials

None

Key Terms:

Amplitude

Frequency

Period

Longitudinal wave

Sound wave

Standing wave

Transverse wave

Wavelength

Objective:

This activity will show students how to determine the speed of a wave using the wave equation. Students will be introduced to the following wave terms: amplitude, wavelength, period, stand waves and frequency. Transverse and longitudinal waves will be demonstrated and compared.

Activity Overview:

Participants are introduced to motions and forces and interactions of energy and matter through standing waves in a wave modeling spring. They will measure the amplitude, wavelength and period of a standing wave. The wave equation will be used to calculate the speed of the wave in the spring. The spring will be used to demonstrate longitudinal and transverse waves.

Caution: Safety glasses should be worn by participants and any students nearby. This activity involves using a stretched spring. If released while stretched, personal and/or property damage could result. Caution should be maintained while holding a stretched spring.

Activity:

Demonstrating a Transverse Wave (Requires at least two people)

1. **Person One will hold one end of the spring (Fig. 7).** Person One should grasp their end of the spring with both hands and hold the spring against their body. The idea is to keep their end of the spring from moving as little as possible. Using a piece of masking tape, mark the spot where Person One stands. Person One should always stand in this spot.

2. **Person Two will provide the up-and-down motion to produce the standing wave**.

3. **Person Two should take two or three steps backward to stretch the spring**.

4. **Person Two will then begin moving their hands up and down to produce a transverse standing wave.**

5. **Have students try to produce all of the harmonics shown in Figs. 9, 10, 11.**

6. **Let the spring come to a rest.** Have Person Two flick their wrist up-and-down once. This will produce a small transverse wave that will travel down the spring.

7. **Observe the wave when it reaches Person One.**

8. **Record your observations on the worksheet.**

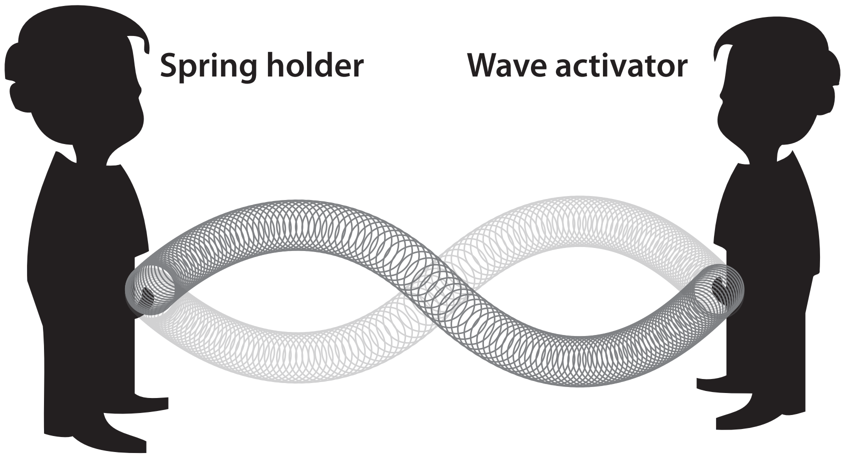


Fig. 7 Transverse wave

Demonstrating a Longitudinal Wave (Requires at least two people per group)

1. **Lay the spring flat on the floor and have Person One and Person Two slightly stretch the spring.**

2. **Have Person One compress a short portion of the spring, then release it.**

3. **Watch the wave travel down the spring.**

4. **Observe the wave when it reaches the Person Two.**

5. **Record your observations on the worksheet.**

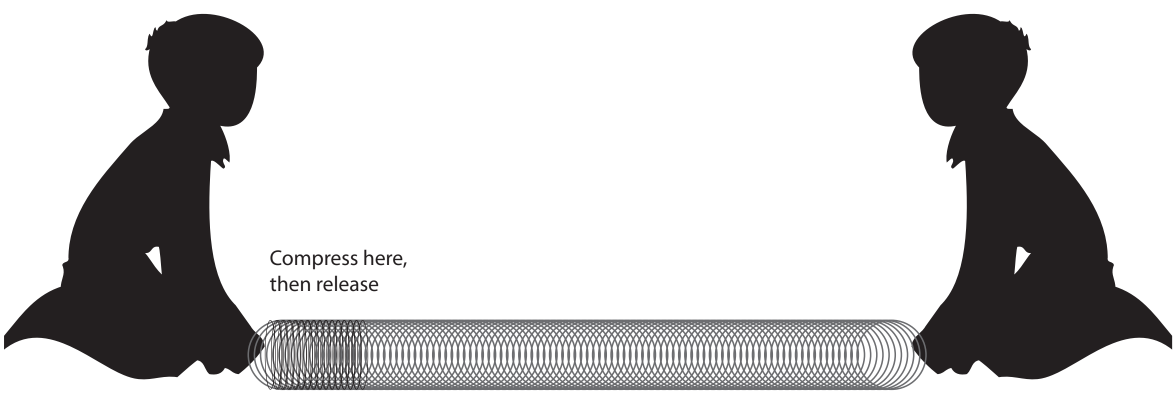


Fig. 8 Longitudinal wave

Measuring Wave Speed (Requires at least three people per group.)

1. **Begin with the fundamental (first harmonic) standing wave as shown in Fig. 9.** The first harmonic is the simplest resonant frequency of a standing wave.

2. **Measure the distance between the hands of Person One and Person Two.** Mark the distance on the floor with pieces of masking tape. This is one-half of the wave length. Multiply by two to find the wavelength.

3. **Record the wavelength on the worksheet**.

4. **A third person will use a stopwatch to time ten periods of oscillation (a period is the time it takes for any part of the spring to go through one complete cycle).** One way to do this is to watch the hands of Person One. Begin when the hands are at the highest point. One cycle is completed when the hands return to that same point.

5. **Record the time for ten cycles on the worksheet.**

6. **Calculate the period, T, for the standing wave by dividing the time for ten cycles by ten.**

7. **Record the period, T, on the worksheet.**

8. **The frequency is the reciprocal of T, or 1/T where T is in seconds.**

9. **Record the frequency on the worksheet.**

10. **Calculate speed, V (meters/second) of the wave using the wave equation:**
    $v = \text{wavelength} \cdot \text{frequency}$

11. **If time permits, repeat the above procedure using a first overtone (second harmonic) and second overtone (third harmonic) as shown in Fig. 10 and 11.** The second harmonic is a resonant frequency of a standing wave that has three nodes. In Fig. 10 the hand is a node. A third harmonic has four nodes, Fig. 11.

12. **It will be helpful to time 20 periods for the second harmonic and 30 periods for the third harmonic.**

13. **For the second harmonic the distance between the hands of Person One and the hands of Person Two is the wavelength.**

14. **For the third harmonic the distance between hands is 1.5 wavelengths.** To find the wavelength multiply the distance between the hands of Person One and the hands of Person Two by 2/3.

A = Antinode   N = Node

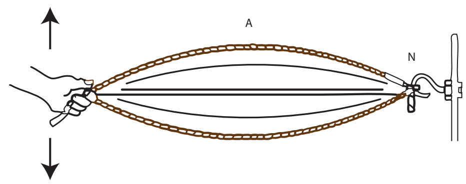


Fig. 9 Fundamental or First Harmonic

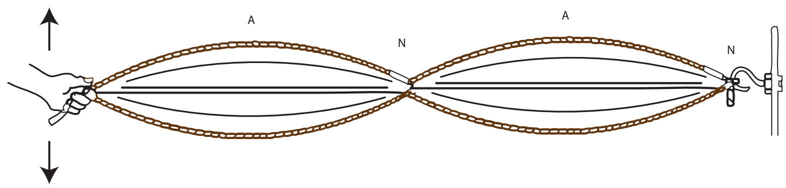


Fig. 10 First Overtone or Second Harmonic

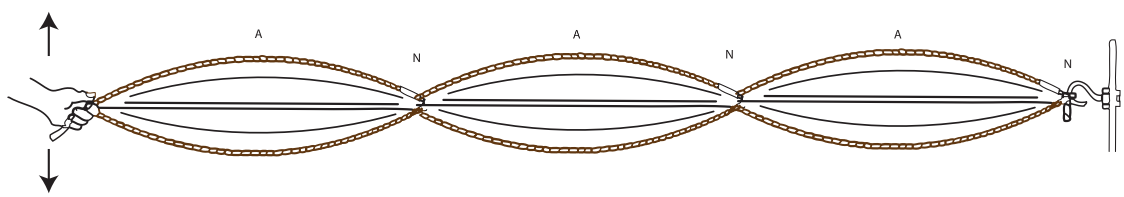


Fig. 11 Second Overtone or Third Harmonic

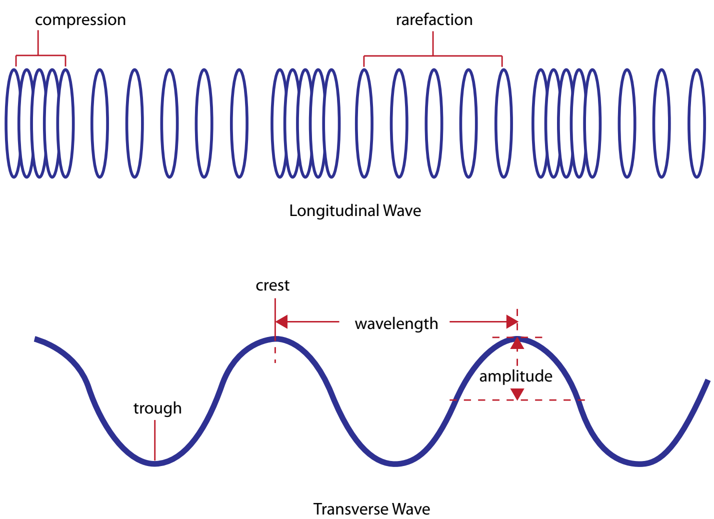


Fig. 12 Longitudinal and Transverse waves

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Reference Materials

Glossary

Acoustics:
The study of sound

Amplitude:
The height of a wave; the amplitude determines the amount of energy a wave carries; high volume sounds have large amplitudes

Antinode:
A point of destructive interference in a standing wave

Decibel:
A unit that expresses the relative intensity of sound

Frequency:
The periodic change in sound pressure; frequency is measured in cycles per second or in Hertz (Hz); in music it is called pitch; in music pitch can be high (soprano) or low (bass) or somewhere in between

Hertz:
Hertz (Hz) is a unit of frequency where one Hertz equals one cycle, or wave, per second second

Intensity:
The average rate at which sound energy is transmitted through an area between a source and a receiver. Sound energy is measured in watts/cm2 or in decibels (dB)

Interference:
Occurs when two waves interact with each other; in some cases the waves will reinforce one another and the volume or intensity will increase (constructive interference); at other times the waves will cancel each other out and little or no sound will be heard (destructive interference)

Longitudinal wave:
The oscillations are in the same direction as the line of travel; a sound wave is an example

Node:
A point of constructive interference in a standing wave

Noise:
Sound with no set patterns in rhythm or frequency

Period:
The time it takes for two successive wave crests to pass a given point; also given as the reciprocal of the frequency

Pitch:
The highness or lowness of a sound

Resonance:
The vibration of an object when exposed to sound at its own natural frequency, as in a window pane vibrating when a helicopter flies overhead; also occurs when two sound waves reinforce one another

Sound wave:
Produced whenever a vibrating object creates changes in the pressure of a medium, such as air

Speed:
How fast an object is moving with respect to another object; for example, how fast an airplane moves with respect to the ground

Standing wave:
Produced when two waves traveling in opposite directions interfere with each other and produce a large amplitude wave

Transverse wave:
The oscillations are perpendicular to the direction of travel

Ultrasound:
Sound that is too high in frequency to be heard by the human ear

Wavelength:
The distance between two successive crests in a wave

Velocity
Speed and direction; for example, an airplane moving at 350 kilometers per hour going East

Fig. 1 Speed of sound in different mediums

	Solid Steel	Sea Water	Air
Speed of sound in m/sec at 21° C (70°F)	5,180 m/s	1,524 m/s	331 m/s
Speed of sound in mph at 21° C (70°F)	11,600 mph	3,414 mph	740 mph

Fig. 2 Speed of sound at different altitudes

Altitude	Temperature	m/sec	Km/h	mph	knots
Sea level	15°C (59°F)	340	1225	761	661
11,000m - 20,000m (Cruising altitude of commercial jets)	-57°C (-70°F)	295	1062	660	573
29,000m (Flight of X-43A)	-48°C (-53°F)	301	1083	673	585

Fig. 3 Examples of sound intensity

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

Fig. 4 Mach number divisions

Fig. 5 Apparatus setup

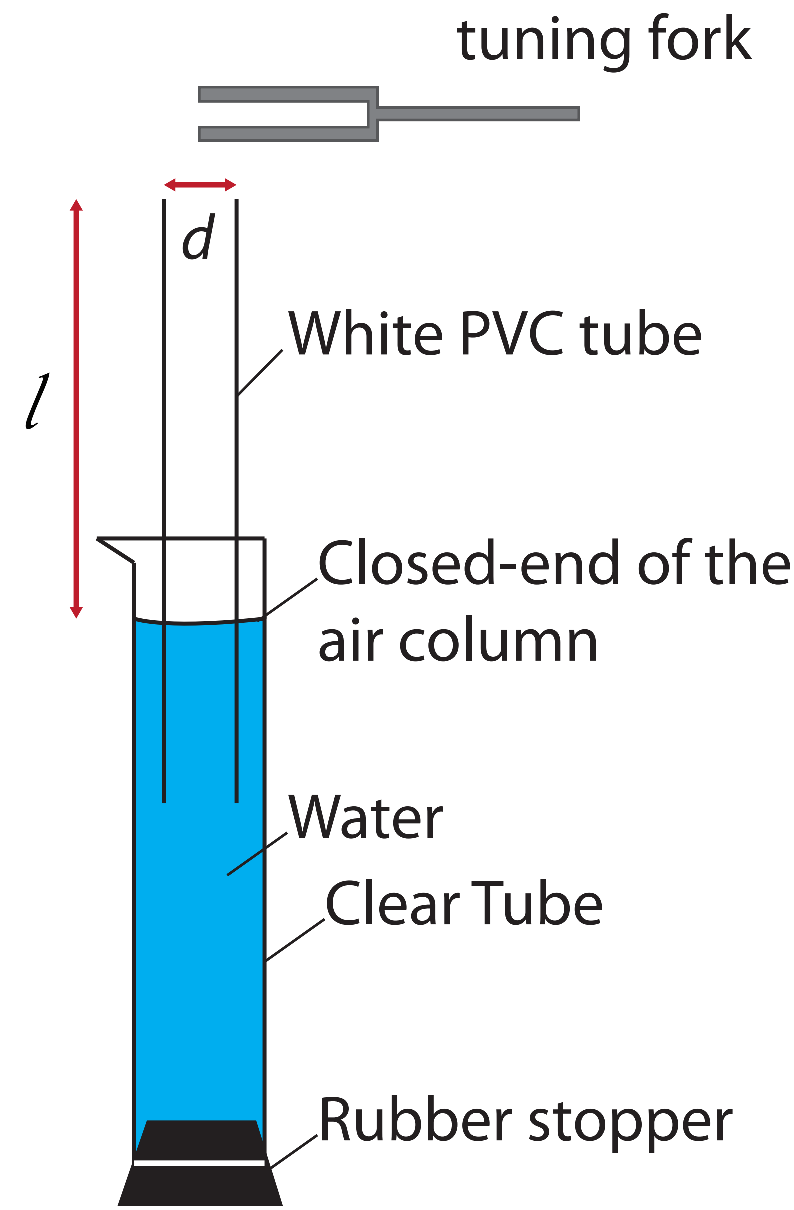


Fig. 6 Resonance in closed and open pipes (λ = wavelength)

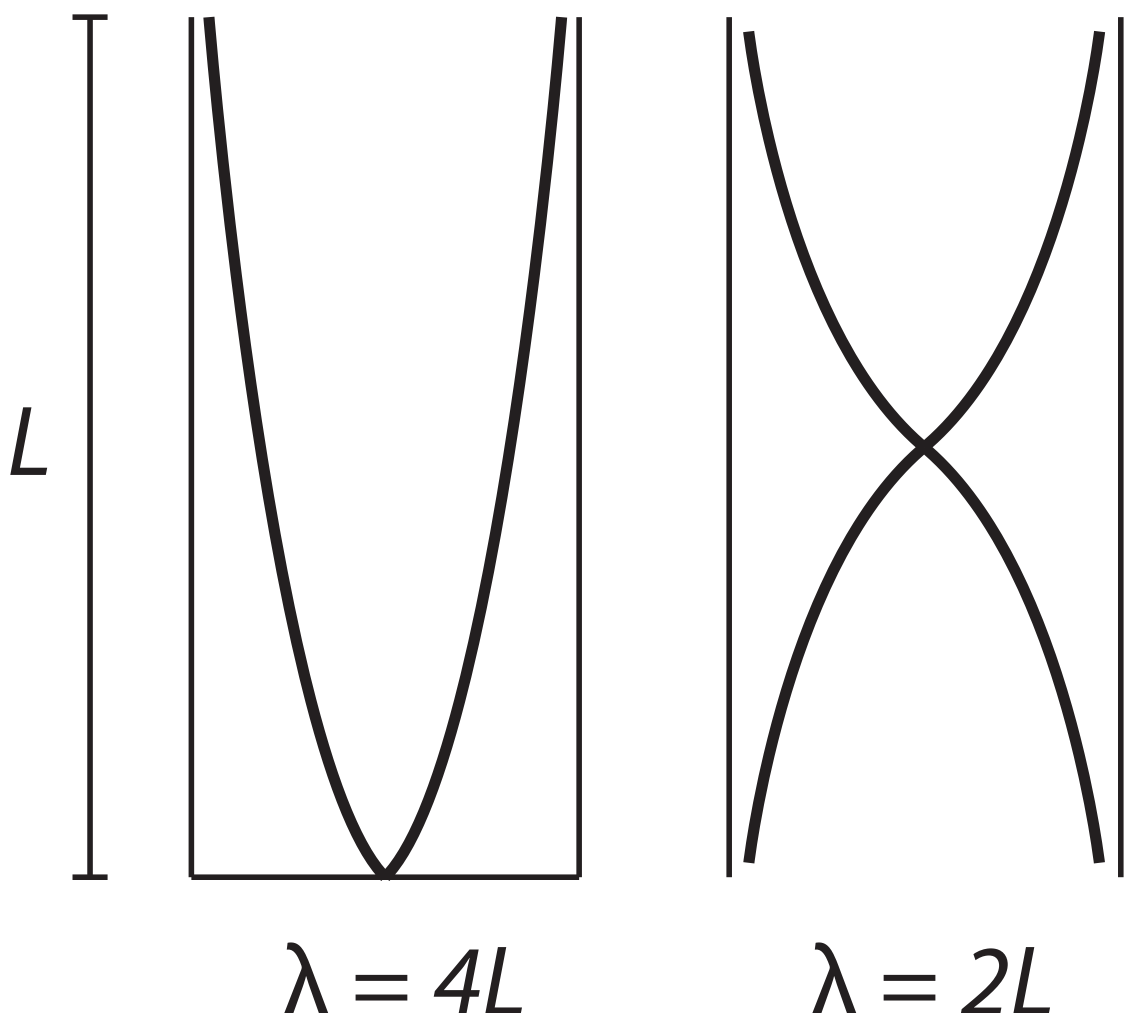


Fig. 7 Transverse wave

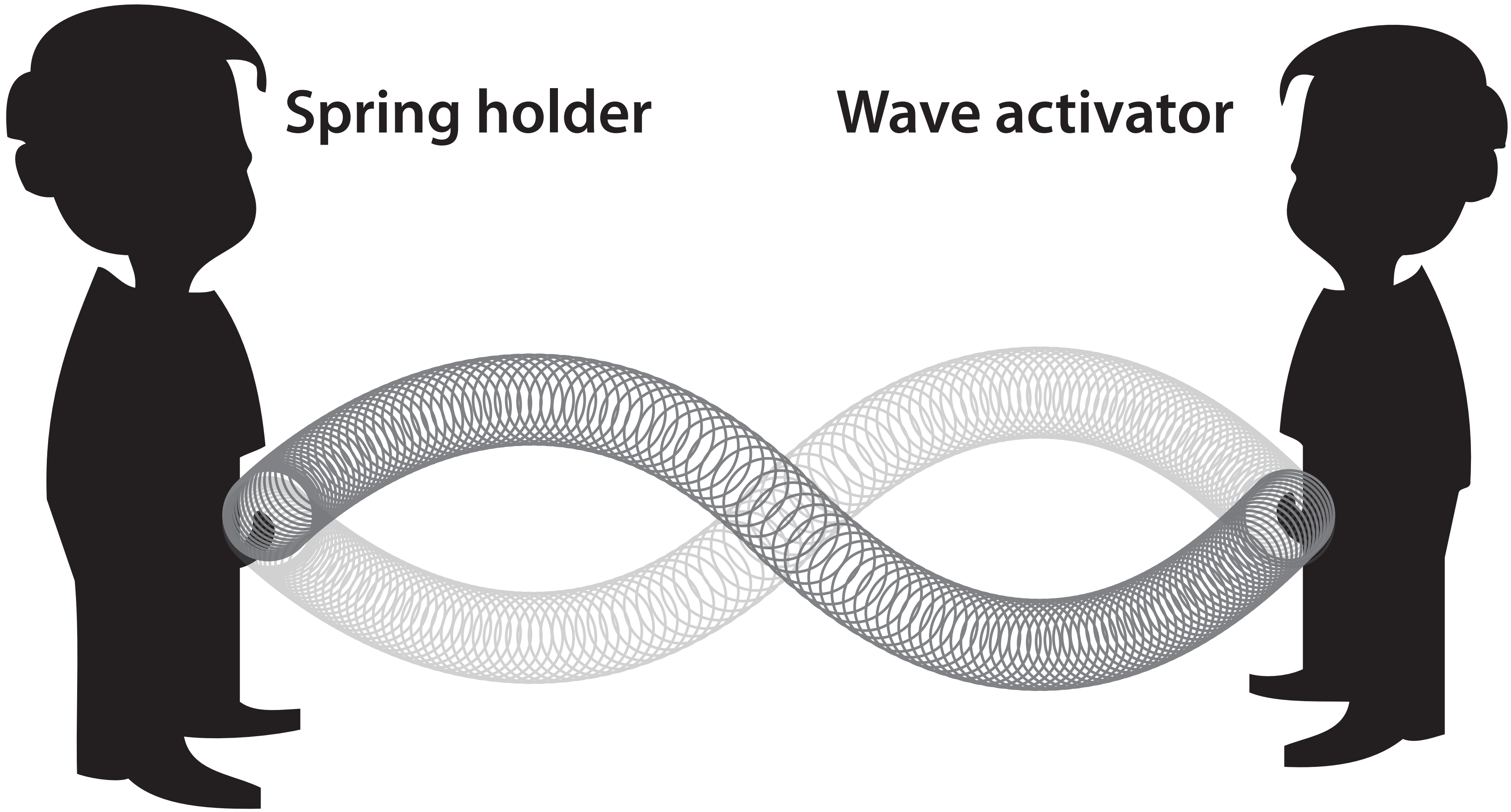


Fig. 8 Longitudinal waves

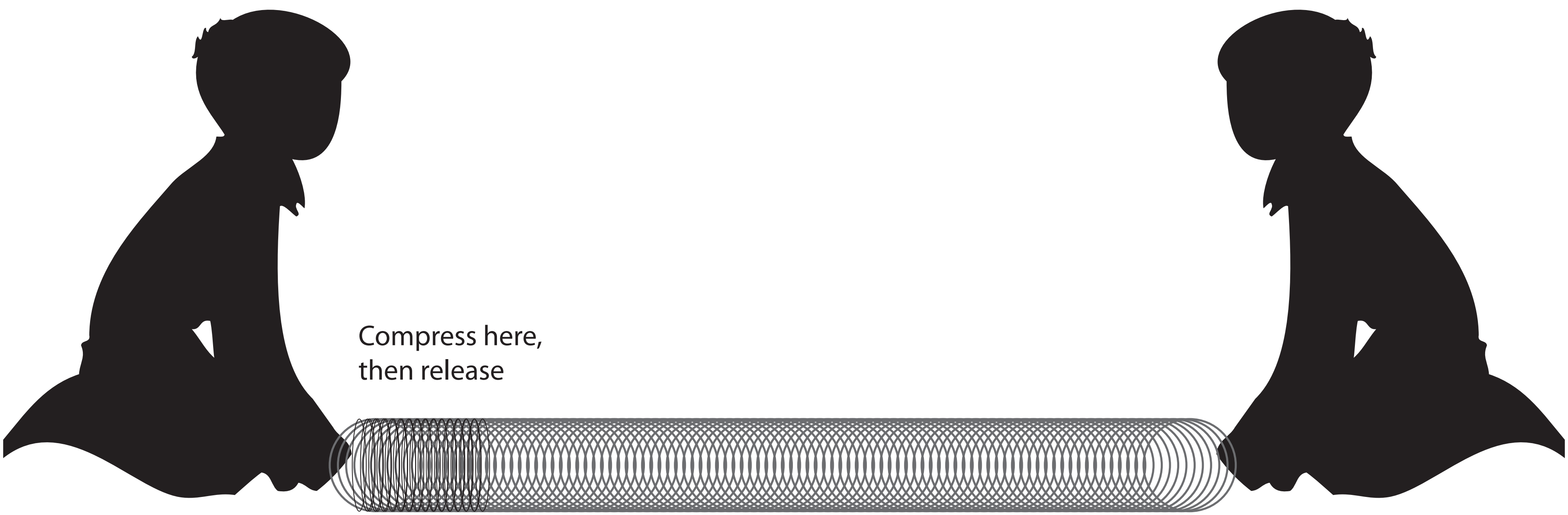


Fig. 9 Fundamental or First Harmonic

A = Antinode   N = Node

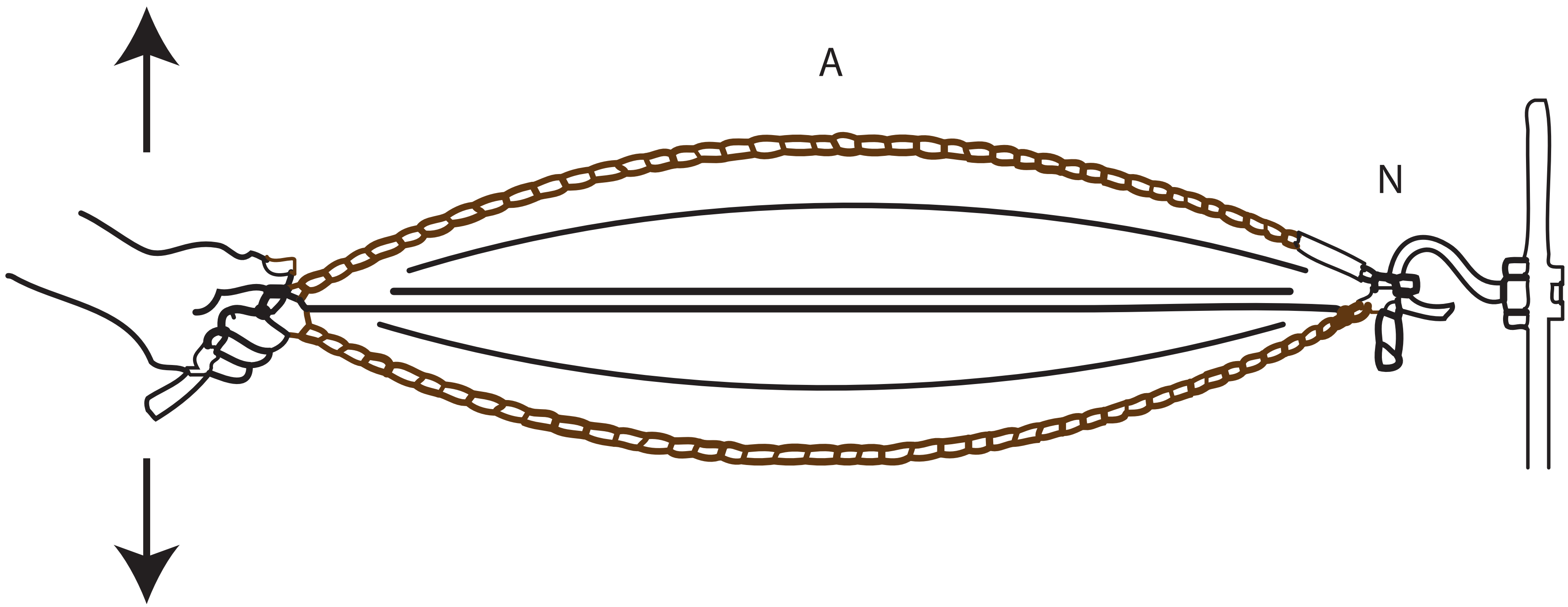


Fig. 10 First Overtone or Second Harmonic

A = Antinode   N = Node

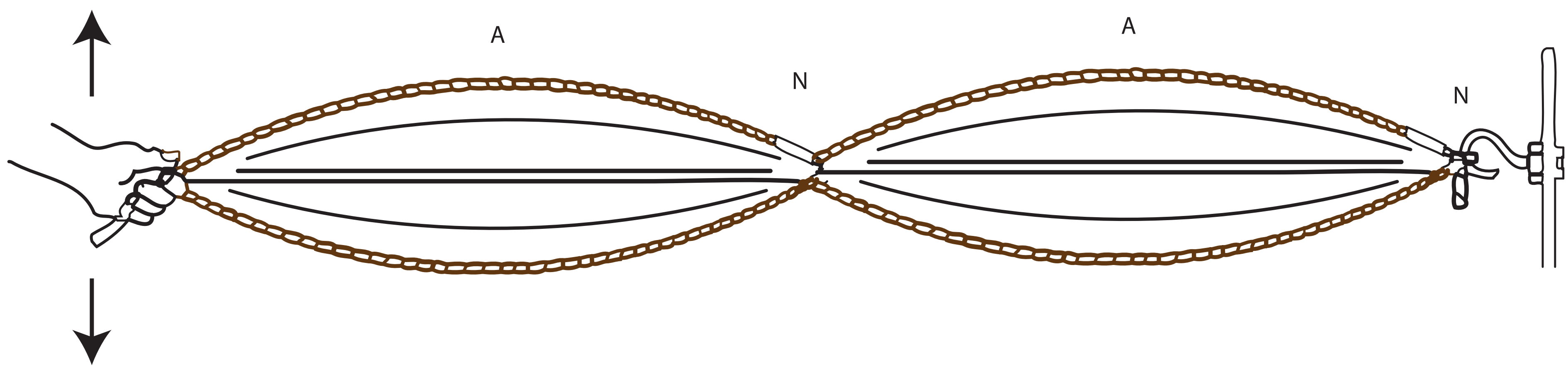


Fig. 11 Second Overtone or Third Harmonic

A = Antinode   N = Node

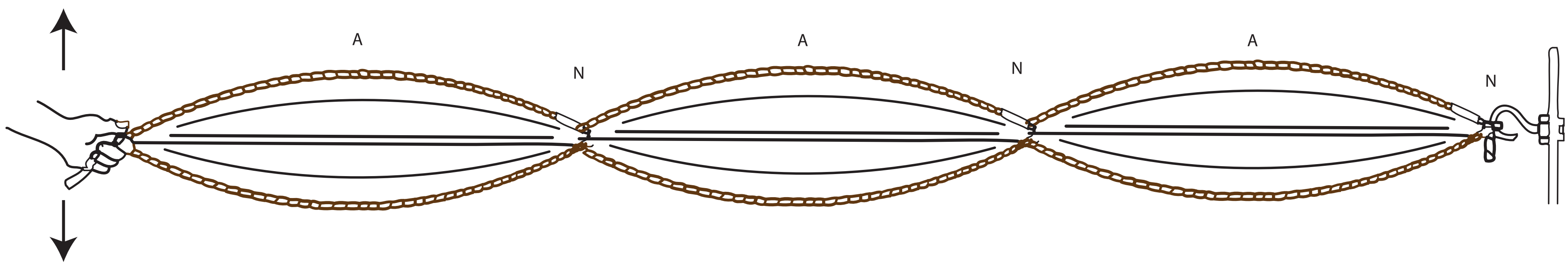
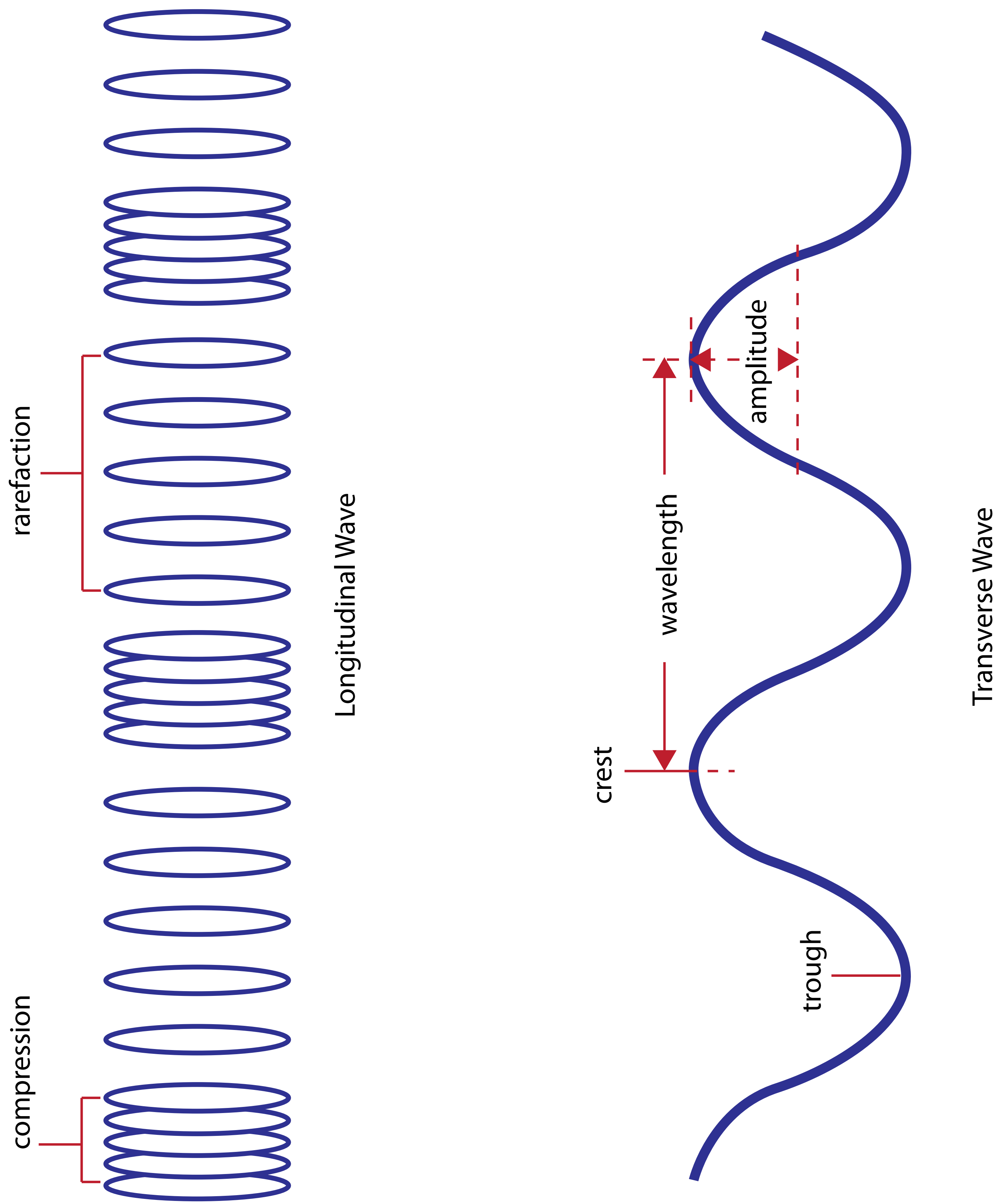


Fig. 12 Longitudinal and Transverse waves



Worksheets

Worksheet 1 Measuring the Speed of Sound Using Resonance

Tuning Fork Frequency (Hz)	d (meters)	Wavelength 4 *l* (meters)	Velocity (meters/sec)	Temperature °C	Accepted Value for Velocity (meters/sec)

v = wavelength · frequency = 4 (*l* + .3d) · frequency

where:

l = length (meters) of the closed tube (Fig. 5) when resonance occurs
d = inside diameter (meters) of the clear plastic tube
frequency = 256 Hz, or the number inscribed on the tuning fork

Worksheet 2 Determining the Speed of a Wave in a Spring

1. In a transverse wave does the spring vibrate perpendicular to or in the same direction as the wave travels?

For a longitudinal wave?

2. When the small transverse wave traveled down the spring and reached Person Two, what happened?

3. Did the reflected transverse wave return on the same side of the spring or did it invert? For example, if the pulse traveled down the spring on the top, did the return pulse travel on the top or bottom?

4. Describe what happened when the longitudinal wave pulse reached Person Two's hands.

Worksheet 2 (cont.)

Data for the Speed of a Wave in a Spring

[1]Harmonic (1st, 2nd, or) 3rd	Wavelength (m)	Time for 10 cycles (sec.)	Period, T (sec.)	[2]Frequency, F (Hz)	Speed of the wave (m/sec.)

[1] See Fig. 9, 10 and 11.

[2] Frequency is the reciprocal of T, or 1/T where T is in seconds.

1. In a transverse wave does the spring vibrate perpendicular to or in the same direction as the wave travels?

Perpindicular to

For a longitudinal wave?

In the same direction as the wave travels

2. When the small transverse wave traveled down the spring and reached Person Two, what happened?

It reflected off the hands of the Spring Holder

3. Did the reflected transverse wave return on the same side of the spring or did it invert? For example, if the pulse traveled down the spring on the top, did the return pulse travel on the top or bottom?

It inverted

4. Describe what happened when the longitudinal wave pulse reached Person Two's hands.

It also reflected

Aeronautics
Research
Mission
Directorate

Museum in a BOX Series

airspace

EP-2010-12-494-HQ