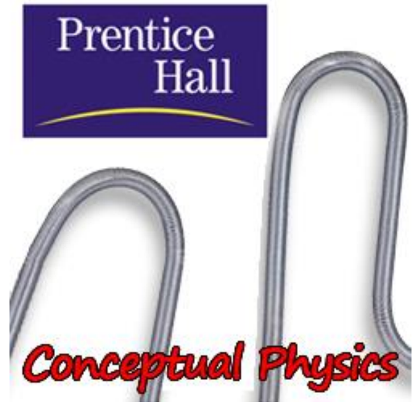


UNIT IV Sound & Light

PX-0400

BACKGROUND:

Your Sound and Light Unit contains a collection of Arbor Scientific's discovery-based teaching tools designed to supplement the concepts in Prentice Hall's *Conceptual Physics Textbook* and *Lab Manual*. The attached Teaching Guides were created specifically for use with many of your new tools and can be used along with the demonstration items to fuel your students' desire to explore.

Please visit us at www.arborsci.com for more tools and free resources for creating a hands-on learning environment in your science classroom, including videos of products in use, lesson plans, teaching strategies, and demo ideas. Sign up for our free e-newsletter Coolstuff, then check out the Archive for an online resource that's packed with lesson ideas, plans and tips!

A message from Paul Hewitt, author of Conceptual Physics:

Students learn in a variety of ways. They learn best when they DO, not just listen or read, in keeping with the adage, "I hear and I forget. I see and I remember. I do and I understand!" When we are physically active with physical equipment relevant to the concepts to be learned, we simply learn better—to nobody's surprise!

Good Energy with your activities!

Paul G. Hewitt

KIT CONTENTS:

Your Unit IV Sound and Light Kit includes one of each of the following items:

33-0130	Super Springy
33-0140	Snaky Helical Spring and Data Sheet
33-0200	Spectrum Demonstration Kit and Data Sheet
AR-7700	Standing Wave Apparatus and Data Sheet
P2-1200	Concave & Convex Lens Set and Data Sheet
P2-7040	4 - 3D Mirascope Illusion Maker
P2-7080	Periscope with Data Sheet
P2-7145	Concave/Convex Mirror Set (50mm) and Data Sheet
P2-9400	Polarizing Filters (50mm x 50mm), Pack of 20
P2-9550	Color Mixing Demo and Data Sheet
P2-9570	Reflect-View
P3-6300	Set of 30 Rainbow Glasses
P3-6500	UV Beads and Data Sheet
P2-8100	Phantom Crystals and Data Sheet
P6-7800	Primary Color Light Sticks
P7-7000	Set of 255Hz and 256Hz Tuning Forks
P7-7120	Doppler Ball and Data Sheet
P7-7200	Sound Pipe and Data Sheet
P7-7250	Singing Rods with Rosin and Data Sheet
P7-7330	Music Box Mechanism and Data Sheet
P7-7400	Boomwhacker Set and Data Sheet

Helical Spring "Snaky"

33-0140

BACKGROUND:

The snaky is a long, helical spring that can be used to demonstrate waves and other phenomena. A mechanical wave is a disturbance that moves through a medium. The snaky can demonstrate longitudinal and transverse waves. The particles move parallel to the direction of the wave in longitudinal waves. The particles move perpendicular to the direction of the wave in transverse waves. With the snaky, you can also demonstrate standing waves. Standing waves appear to be stationary because of interference. With the snaky and a rope, you can also show what happens when a wave enters a new medium. The snaky can also be used to demonstrate Hook's Law and harmonic motion, and even Hubble's constant.

In using this product, many of the national and states' science education standards are covered. Some examples are provided here. These are representative. However, check with your state to find the exact standards.

Elementary and Middle School: Vibrations in materials set up wavelike disturbances that spread away from the source. Sound and earthquake waves are examples. Waves move at different speeds in different materials. Wave behavior can be described in terms of how fast the disturbance spreads, and in terms of the distance between successive peaks of the disturbance.

High School: The student knows the effect of waves on everyday life. The student should be able to demonstrate wave interactions including interference, polarization, and reflection within various materials. Analyze the processes that power the movement of the Earth's continental and oceanic plates and identify the effects of this movement including faulting, folding, and earthquakes.

PRODUCT INFORMATION:

The snaky is a helical spring with a diameter of 2 cm and a length of 180 cm, with 7 turns/cm.

SAFETY INFORMATION:

The snaky should be handled carefully. If one or both ends are released while stretched, the spring can snap back quickly, possibly causing injury. Never let go of the spring unless it is slack.

ACTIVITIES:

Most of the activities are best done on a tile floor. It keeps the motion in two dimensions and gives a convenient reference. Also, if the spring is accidentally let loose, it is less likely to hit someone in the face.

- Longitudinal and transverse waves: You can put a piece of tape on the spring to better show how the individual parts of the spring are moving. Stretch the spring lightly across the room. For transverse waves, strike and shake the spring side to side. For longitudinal waves, gather up several coils of spring and then let go.

- The speed of a mechanical wave depends on the medium through which it travels: Stretch the spring lightly across the room. Measure the time that it takes for one pulse to make one complete trip – back and forth – down the spring. Have the students predict methods to make the wave move faster, i.e. hit the spring harder, etc. The only way to make the wave travel faster is to stretch the spring more, changing the medium. This can also be done with two springs side-by-side as a race. Have one team of students change something to try to make their wave beat the other team's wave.

- Behavior at wave boundaries: Tie a rope to one end of the spring. Make a single transverse pulse by striking the spring sideways. If the other end of the spring is held, the reflected pulse will come back on the other side of the spring (inverted). If the rope is held instead, the pulse that is reflected at the boundary of the spring and rope will come back on the same side of the spring (erect or upright). You will also get a pulse that is reflected at the end of the rope.

- Interference: Have two students at opposite ends of the stretched spring hit the spring to the side. Watch what happens at the place where the two pulses meet. Also, watch what happens to the original pulses after they pass through each other. Try having the students hit the spring on the same side and opposite sides. Also, have them hit the spring with different amounts of force in both directions.

- Standing waves: Shake the spring slowly back and forth, adjusting the speed until you get one antinode in the middle of the spring. Try to get 2, 3, 4, etc. antinodes. How many can you get? The students can touch the spring at the node with a finger without disturbing the wave, but touch it anywhere else and the motion will be dampened. Also, try this with the rope attached to the other end. You will get an antinode at that end. Show the difference between guitar strings and clarinets this way.

- Harmonic motion: Using the same setup as above, pull a light mass down a few centimeters and let go. It should bob up and down harmonically. You may have to try a few different masses and a few lengths of spring to get it to sustain motion.

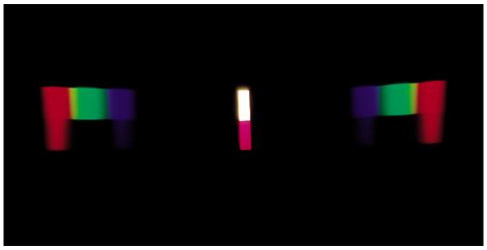
- **Hooke's Law:** Use a test tube clamp to hold the spring. Have ¼ meter or so extend below the clamp. Hang hooked masses from the spring. Show that there is a linear relationship between force applied and distance extended. (Be careful not to exceed the elastic limit.)

- **Expansion of the universe:** How can everything be moving away from us, even if we're not in the middle of the universe? How can astronomers estimate distances from speed? Take the snaky and put five or so Post-It notes or pieces of paper along the length of it. It does not matter exactly where they are. Pick one of them to be the Earth. The others are galaxies. With the snaky held lightly between two people, measure the distances between the notes. Put a table of the distances on the board or overhead. Have the two people holding the spring take a step backward. Measure the distances again. Have them take another step back. Measure the distances again. With the table that you now have, show that the galaxies that are farthest from the Earth are moving away from the Earth the fastest (moved the most distance in the time). Try it again with the Earth in a different location. It still works! The Earth does not have to be in the center.

- **Earthquakes and elastic rebound theory:** Attach the snaky to a box or other weighty object. Put the object on the floor (carpet works best). Pull the snaky slowly to the side (You can grab the snaky in the middle.) If there is enough friction between the object and the floor, the object will stick for a while, then suddenly move. Keep going. It will jump, again, but maybe not as much or more than before. This shows that as the tectonic plates slide past each other, they stick. When enough stress builds up, the plates suddenly move: an earthquake. Some earthquakes are big, some are small. You will need to find the right size, weight, and material for your box. Otherwise, it will slide too easily, or jump too much.

RELATED PRODUCTS:

The **Super Slinky** (33-0130) can be used to show many of the same principles as the Snaky. It is especially useful for showing longitudinal waves. You can also compare waves and elastic potential, etc. between the two kinds of springs.



Spectrum Demonstration Kit

33-0200

KIT CONTENTS:

Narrow slit mask
Slit/Anti-slit mask
Diffraction Grating Mount
Six color filter cards with spectrum graphs
Six 1” x 1.5” color filters
Instructions

OTHER ITEMS REQUIRED:

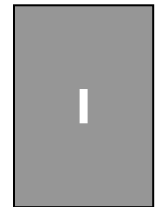
Overhead Projector
Sheets of paper, black if possible
Large sheets of white paper
Marker
Darkness

ACKNOWLEDGEMENTS:

Developed with the assistance of David Van de Baak, Calvin College, Grand Rapids, Michigan.

SETUP:

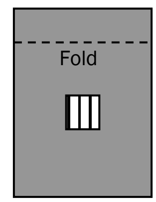
1. Place the narrow slit mask (see diagram) on the overhead projector stage. Cover the remaining lighted area with sheets of black paper, so that only a narrow slit of light is projected.



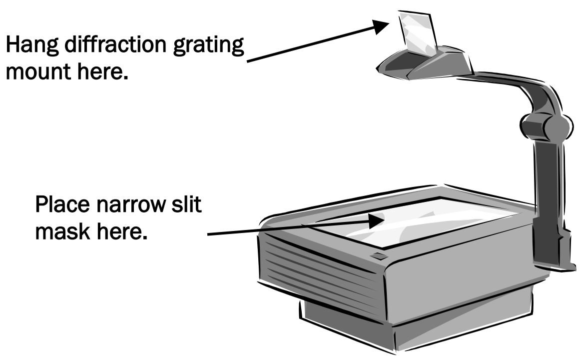
Narrow slit

2. Hold the diffraction grating mount in front of the projector lens, so that the light passes through the diffraction grating LAST before it travels to the screen. Adjust the position of the grating so that the brightest part of the light beam is centered on it and bright spectra are projected on the wall to the left and right of the slit of light.

3. Fold the diffraction grating mount so that it will hang over the projector lens in this position (see diagram below). You may need to affix the mount with tape to get it to stay in place.

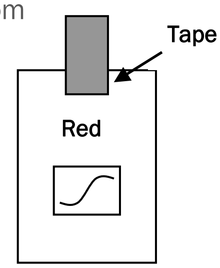


Diffraction Grating Mount



4. Check your setup with the diagram above. You should see, when the room is darkened, a vertical white strip of light with bright spectra to the left and right.

5. Prepare each color filter card by taping the appropriate color filter in the area indicated, as shown. The filter should overhang the card by at least one inch. (Note: Magenta is a bright pink color, and Cyan is a light blue-green.)



USING THE SPECTRUM GRAPHS:

Each color filter card includes a transmission graph for that color filter. It shows what percent of each wavelength is allowed to pass through the filter. Humans can see light wavelengths between about 400 and 700 nanometers. Shorter wavelengths (near 400 nm) appear as blue light, and longer (700 nm) wavelengths appear to be red. Wavelengths shorter than 400 nm and longer than 700 nm are referred to as ultraviolet and infrared, respectively.

A red filter allows mostly long wavelengths (red and infrared) to pass through, and blocks the short (blue, green, and ultraviolet) wavelengths. Examine the graph for the green filter. It allows 500-550 nm wavelengths to pass through. The blue filter allows 400-500 nm wavelengths to pass through.

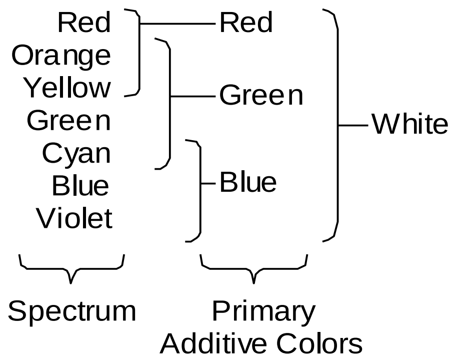
Look now at the Cyan filter. Cyan is a color that contains both blue and green. The spectrum graph confirms this, showing that wavelengths from 400-550 nm are transmitted.

Examine the graph for Magenta. Can you tell, just by looking at the other graphs, what colors combine to form Magenta? It transmits wavelengths below 500 and above 600 nm. Wavelengths below 500 nm are blue, and those above 600 nm are red. Red and blue combine to form Magenta.

You may wish to reproduce the graphs for your students, depending on their level of understanding.

DEMO #1: PRIMARY COLORS

1. Set up the projector as described in "Setup" so that a bright spectrum is projected on each side of the central white slit.
2. Explain the setup to the students: The diffraction grating separates the white light into a spectrum. (It acts something like a prism, but works in a very different way.) Each different color (wavelength) of light is deflected at a different angle so we can see all of the colors that make up white light.
3. Ask the students to identify the colors they see in the spectrum. (Don't let them merely recite the colors of the rainbow. Ask them to point out the colors they identify.) They will probably identify red, orange, yellow, green, and blue. They may recognize blue-green (cyan), but if they say that they see purple or violet, ask them to show it to you!
4. List these colors on the chalkboard.
5. Place a large sheet of white paper on the wall where one of the spectra is projected. Make sure that all of the colors are on the paper.
6. Cover half of the slit on the overhead stage with the red filter. Ask students to observe the spectrum. Where does the red light appear, compared to the red part of the spectrum? (It appears directly below the red part of the spectrum. They may also notice that, below the orange/yellow part of the spectrum, there is now some red.)
7. Mark and label on the paper the region where the red light is projected.
8. Remove the red filter, and repeat steps 6-7 with the blue filter.
9. Remove the blue filter, and repeat steps 6-7 with the green filter.
10. Remove all filters, and look at the regions covered by the three colors. Together, they should cover the entire spectrum. They should also overlap. Refer to the figure below.



11. From this, your students should be able to deduce that red, blue, and green combine to produce white light. They are called the Primary Additive Colors.

12. Summary: The primary colors of light are red, blue, and green. These three colors occupy ranges that, together, make up the entire spectrum. The color filters allow one primary color to pass through and absorb the other two.

13. Another helpful demonstration is to project three beams of light: red, blue, and green. The area where they overlap should appear white. If you have access to three slide projectors, you can do this demonstration with Arbor Scientific **color slides** (P2-9561-02).

DEMO #2: SECONDARY COLORS

1. You should do **Demo #1: Primary Colors** before proceeding.

2. Set up the projector as described in "Setup" so that a bright spectrum is projected on each side of the central white slit.

3. Remind students what they observed about Red, Blue, and Green.

4. Cover half of the slit on the overhead stage with the yellow filter. Ask students to observe the spectrum. What colors appear when yellow is split into a spectrum? (Red, orange, yellow, green.) What primary colors occupy this range of the spectrum? (Red, green.)

5. Repeat step 4 with the Cyan filter. Cyan is composed of the primary colors blue and green.

6. Repeat step 4 with the Magenta filter. Magenta is composed of the primary colors red and blue. Why doesn't this color appear in the spectrum, like yellow and cyan do? (Blue and red are at opposite ends of the spectrum and do not overlap, so magenta is not seen in the spectrum.)

7. Summary: The secondary colors (yellow, cyan, and magenta) are each composed of two primary colors. The filters allow those two colors to pass through, and absorb the other one.

DEMO #2A: COLOR SUBTRACTION

Student understanding of the secondary colors can be strengthened through the following demonstration on color subtraction.

1. Set up the projector as described in “Setup” so that a bright spectrum is projected on each side of the central white slit.

2. Cover half of the slit with the yellow filter. Which primary color is NOT passing through this filter? (Blue)

3. Cover the other half of the slit with the cyan filter. Which primary color is NOT passing through this filter? (Red)

4. Overlap the yellow and cyan filters. What color do you observe? (Green)

5. Ask students to explain this result. (Together, the filters absorb blue and red, leaving only green to pass through and be seen on the screen.)

6. Repeat steps 2-5 with yellow and magenta. (Only red passes through both.)

7. Repeat steps 2-5 with magenta and cyan. (Only blue passes through both.)

8. This process is called color subtraction because each filter subtracts one of the primary colors from light that passes through it. Yellow, cyan, and magenta are sometimes called the Primary Subtractive Colors, because each subtracts one of the Primary Additive Colors from white light.

DEMO #3: COMPLEMENTARY COLORS:

1. You should do Demo #2: Secondary Colors before proceeding.

2. Set up the projector as described in “Setup” so that a bright spectrum is projected on each side of the central white slit.

3. Remind students what they observed about the primary and secondary colors.

4. Cover half of the slit with the red filter and the other half with they cyan filter.

5. Ask students to observe the parts of the spectrum that are passed through each filter. (The two filters allow completely different parts of the spectrum to pass, without any overlap.)

6. Ask students to explain their observations, based on their knowledge of the colors. (The red filter allows only red to pass, and the cyan filter allows blue and green to pass. The two spectra do not overlap. These two colors would add together to produce white light.)

7. Ask students to predict two other pairs of complementary colors (colors that add to produce white light). Confirm their predictions by placing the filters on the slit and observing that the partial spectra do not overlap. (The other pairs are green/magenta and blue/yellow.)

DEMO #3A: "COMPLEMENTARY SPECTRUM"

1. You should do Demo #3: Complementary Colors before proceeding.

2. Set up the projector as described in "Setup" so that a bright spectrum is projected on each side of the central white slit.

3. Replace the single slit mask with the "slit-antislit" mask. You may have to remove any additional black paper that you placed on the projector stage.

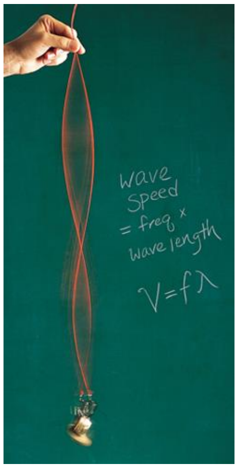
Slit-antislit Mask

4. You should observe a similar spectrum on either side of the central white slit to that observed before.

5. Ask students to look in the area directly below the spectrum. In that area, there should be another spectrum that is composed of different colors. Ask students to identify the colors they see in the new spectrum. (Cyan, magenta, yellow)

6. Ask students to relate the position of these colors to the positions of the primary colors in the normal spectrum. (The colors' complements appear directly below: cyan below red, magenta below green, yellow below blue.)

7. The special "slit-antislit" mask allows this "complementary spectrum" to form. The normal spectrum is formed when a narrow slit of white light is split into colors. The "complementary spectrum" is formed when a shadow is spread out in an area of white light. The diffraction grating separates white light into different wavelengths. The slit of light allows the wavelengths to be separated and appear individually on the screen. The "antislit" allows individual wavelengths to be subtracted from the light being projected on the screen. For example, when red light is subtracted from white, the result is cyan.



Standing Wave

AR-7700

KIT CONTENTS:

1 Vibrator Unit with string, battery holder and stopper attached
1 AA batteries

OPERATION:

To activate the motor, insert the battery into the battery holder. To deactivate, remove the battery.

EXPERIMENTS:

Demonstrating Standing Waves:

1. Activate the vibrator unit.
2. Hang the vibrator from the string. Adjust the length of string until a standing wave is obtained. To change the number of anti-nodes in the standing wave pattern, simply vary the length of the string.

Changing the Frequency:

1. To increase the frequency of the vibration, tighten the screw in the stopper. This decreases its moment of inertia and causes it to spin faster.
2. To decrease the frequency of the vibration, loosen the screw in the stopper.
3. Observe the effect these frequency changes have on the wavelength of the standing wave.
4. Determine the effect of frequency changes on wave speed using the methods described below.

Determining Wave Speed - Method 1

1. Establish a standing wave on the string.
2. Measure the distance between adjacent nodes. Multiply this distance by two to obtain the wavelength of the disturbance.
3. Use a strobe light to measure the frequency of wave.
4. Calculate wave speed from $v = f \cdot \lambda$

Determining Wave Speed - Method 2

1. Use a balance to find the mass of the vibrator unit and the mass of a string sample.
2. Calculate the weight of the vibrator in Newtons. This equals the tension in the string (T).
3. Find the linear density of the string (μ= mass/length).
4. Calculate the wave speed from $v=\sqrt{(T/\mu)}$.

RELATED PRODUCTS:

Singing Rods (Set of 2) (P7-7250). These rods are an easy way to demonstrate longitudinal waves as opposed to transverse waves.

Wave Sticks (P7-7310). With this true torsional wave, you can easily demonstrate nearly all the fundamental aspects of mechanical waves.

ACKNOWLEDGEMENT:

Thank you, Chris Chiaverina, for your help in developing this product.

Lens Set

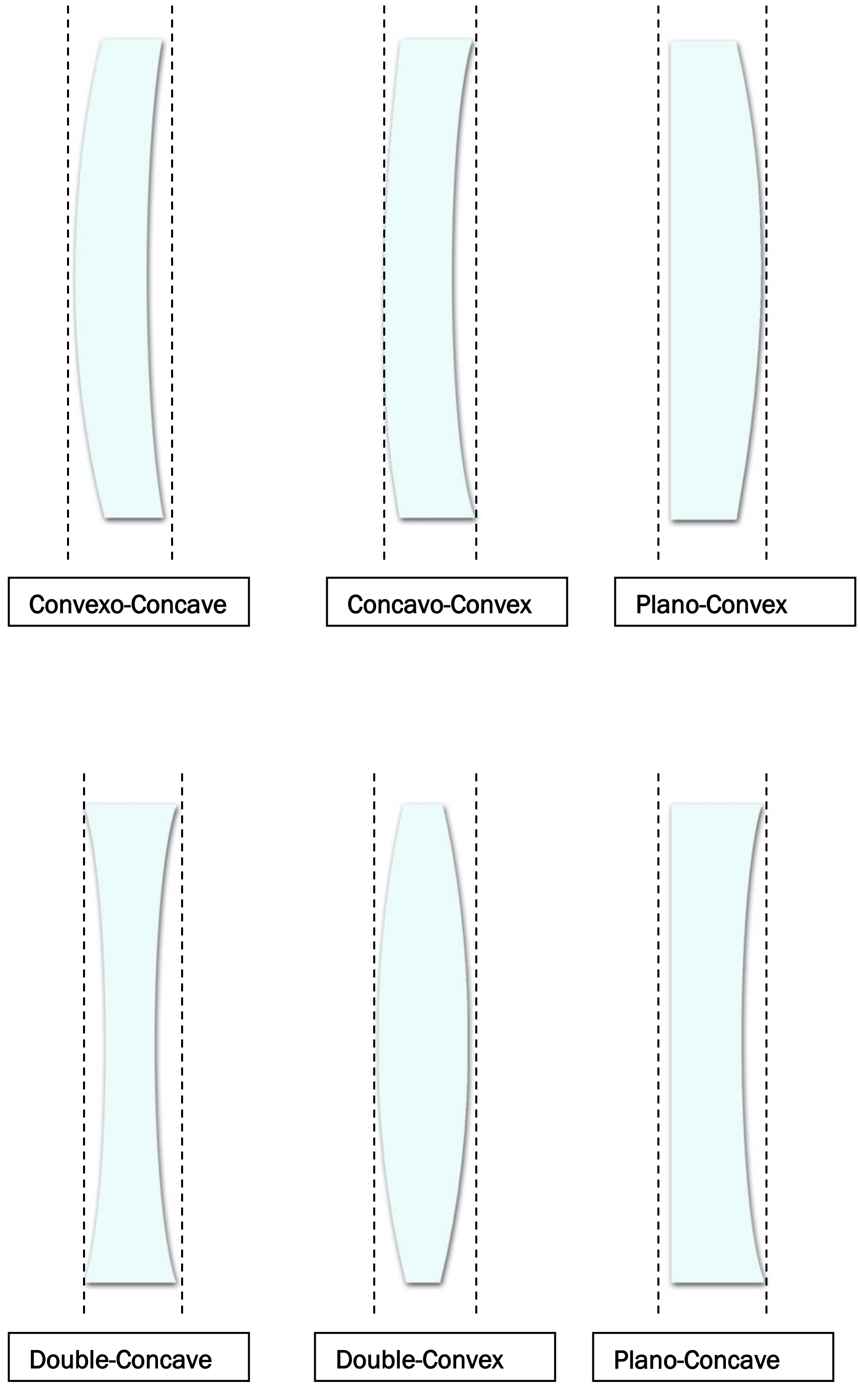
P2-1200

CONTENTS:

6 lenses in storage box.

Lens type	Focal length
Double Convex	+180mm
Plano-Convex	+180mm
Concavo-Convex	+180mm
Double Concave	-180mm
Plano-Concave	-180mm
Convexo-concave	-180mm

It is helpful to place a straight edge along each side of the lens in order to determine if it has a flat, concave, or convex curvature.


Convexo-Concave
Concavo-Convex
Plano-Convex
Double-Concave
Double-Convex
Plano-Concave

Periscope

P2-7080

ASSEMBLY:

Place the mirrored end piece firmly onto the end of the tube. The end piece should turn smoothly but not slide off of the end of the tube.

INSTRUCTIONS:

Use the Periscope with the attached lesson plan from the Light & Color Teacher's Guide (P2-9560).

ACKNOWLEDGEMENT:

Thanks to Dale Freeland for his help in developing this product and lesson.

REFLECTION—C3—HOW DOES A PERISCOPE WORK?
TEACHER'S NOTES

PREREQUISITE

This experiment is appropriate for students at any level. Students should have completed on how light reflects from a plane mirror before completing this lab.

EDUCATIONAL OBJECTIVES

- To use the Internet to find plans for a homemade periscope.
- To construct a periscope.
- To observe the operation of a periscope.
- To diagram the behavior of light in a periscope.
- Extension: To diagram the behavior of light in a modified periscope.

KEY QUESTIONS

- How does a periscope work?

CONCEPT OVERVIEW

A periscope works by reflecting light rays off of two mirrors to produce an image.

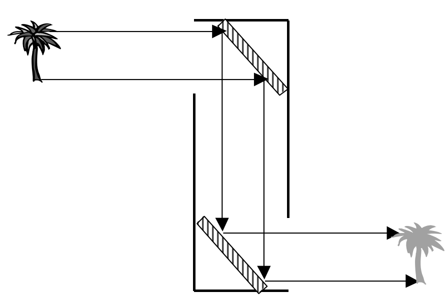


Figure 1

Notice that the image is right-side-up, with the light rays from the top of the tree going to the top of the image. Students are asked to compare this situation with one in which the top mirror is rotated so that it points behind the observer, as in Figure 1.

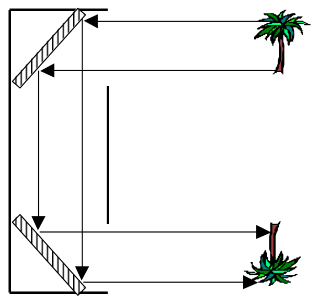


Figure 2

In this case, an inverted image is formed. For this reason, periscopes in submarines must be allowed to completely turn around. It would not work to just have the top mirror rotate.

Name: ______________________

HOW DOES A PERISCOPE WORK?

OBJECTIVE: To investigate the operation of a periscope.

MATERIALS: Periscope

PROCEDURE:

1. Draw a diagram of how light rays from an object enter and move through the periscope. Use rays to represent the top and bottom of the object.

2. Periscopes are used in submarines. When the person in the submarine wants to view things in different directions, he walks around moving the whole periscope with him. Since space is at a premium in submarines, why don't they just mechanically turn the top of the periscope, rather than use so much space inside the sub? Try it with your periscope. Rotate only the top portion so that the mirror points in different directions, and record your observations. Draw a diagram showing the operation of a periscope with the top mirror aimed behind the observer. Use this diagram to explain your observations.

Mirror Set

P2-7145

CONTENTS:

6 mirrors in storage box.

Mirror type	Focal length
Concave	10mm
Concave	20mm
Concave	50mm
Convex	10mm
Convex	20mm
Convex	50mm

Color Mixing Demo:

P2-9550

ASSEMBLY AND USE:

The Color Mixing Demo is powered with 3 AA batteries.

- Batteries: Flip the switch on the box back to 4.5V. The box comes with 3 AA batteries. Use a screwdriver to open the battery compartment and replace the batteries when necessary.

EDUCATIONAL OBJECTIVES:

- To learn the primary additive colors and how they add.
- To learn the complementary colors.

STUDENT OPERATION:

Flip the front switch up. The three primary colors may now be individually adjusted with the dials. Colors are best observed in a darkened room.

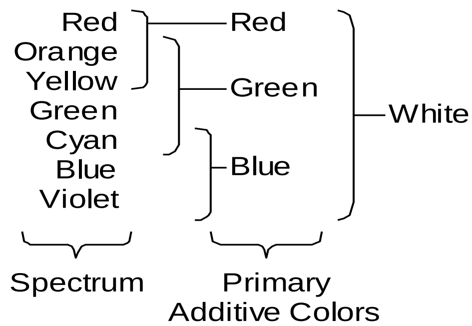
1. Color Addition – 2 colors: Turn on 2 colors at a time and observe the color that results where the 2 primary colors are cast together. Ask students to relate the results to their knowledge about paint (pigment) mixing.
2. Color Addition – 3 colors: Turn on all 3 colors and adjust the dials until the center (where all 3 colors are cast together) is white. Relate this to the reverse action – splitting white light into components with a prism.

3. **Complementary colors:** With 2 lights on, observe the center portion of the screen. Turn on the third light. Notice the combinations of two colors that, when cast together, produce white light (i.e. yellow and blue). These are known as complementary colors.

4. **Other colors:** Use the dials to adjust the lights to form other colors students know, such as orange and pink.

CONCEPT OVERVIEW:

The spectrum formed by rain and prisms show many colors, but there are specific regions of interest. The following figure shows the colors, the regions of interest, and the overlap of the regions.



This figure suggests that white light is made up of red, green, and blue light and that other colors are the result of mixing various amounts of these colors.

PRIMARY ADDITIVE COLORS:

From the previous figure, you can see that red and green overlap to form yellow or orange. Green and blue overlap to form cyan. We can write this in short hand notation simply as:

$$R + G \rightarrow Y$$

$$G + B \rightarrow C$$

Orange is also made by combining red and green, but with a higher proportion of red to green.

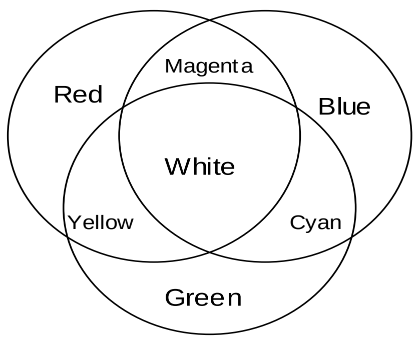
Notice that the red and blue regions of the spectrum do not overlap. The red is at one end (long wavelength) of the visible spectrum, and the blue is at the other end (short wavelength) of the visible spectrum. If we add these two colors, the result is a color that does not appear in the spectrum, magenta (hot pink).

$$R + B \rightarrow M$$

The three primary additive colors comprise the entire spectrum. If we add all three colors, the result is white.

$$R + G + B \rightarrow W$$

The combinations of the primary additive colors can be summarized with the following diagram:



COMPLEMENTARY COLORS:

Complementary colors are two light colors that add together to produce white.

Cyan is made of green and blue, so if red is added to cyan the result should be white. Cyan and red are complementary colors since they add to give white. The complementary colors are summarized below:

$G + B \rightarrow C$	$C + R = (G + B) + R \rightarrow W$	**C** and **R** are complementary.
$R + G \rightarrow Y$	$Y + B = (R + G) + B \rightarrow W$	**Y** and **B** are complementary.
$R + B \rightarrow M$	$M + G = (R + B) + G \rightarrow W$	**M** and **G** are complementary.

Notice that in the addition of light diagram above, R and C are opposite each other with W between. Each color in the figure is directly opposite its complement, with white between.

RELATED PRODUCTS:

Light Box and Optical Set (P2-9561). Conduct experiments involving refraction, reflection, color, and color mixing with one complete kit.

Color Addition Spotlights (P2-9700). A color addition demonstration for large groups.

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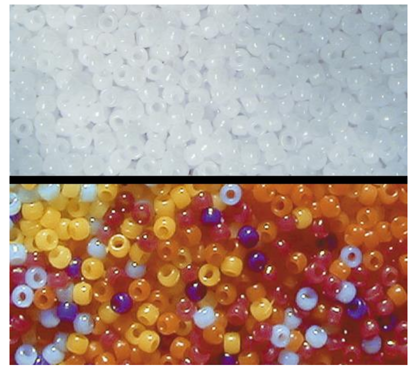


UV Beads

P3-6500

BACKGROUND:

UV Beads contain a chemical that changes color when exposed to ultraviolet light. When brought out of the UV, they will fade back to white. The beads can cycle back and forth over 50,000 times. The sun emits ultraviolet light, so exposing the beads to sunlight will cause their color to change. Students can experiment with different conditions and see which cause a color change. The ultraviolet wavelengths in sunlight cause skin to tan and burn. Students can relate the results of their experiments to the likelihood of getting sunburned in different conditions. For a more detailed explanation of how your UV beads work, see below.

EXPERIMENT IDEAS:

1. What kinds of light contain UV? Expose the beads to light from different sources, including the sun, incandescent light bulbs, fluorescent light bulbs, colored lights, and a blacklight (P2-9035).
2. Can you get sunburned on a cloudy day? Can you get sunburned in the shade?
3. How effective are different sunscreens? Coat the beads with different brands and compare the rate of color change.
4. Can UV pass through window glass? Try different types of glass, including tinted glass and car windows.
5. How much UV protection do different types of sunglasses provide?
6. How does the amount of UV from the sun compare to the UV in tanning booths?

THE CHEMISTRY OF UV-DETECTING BEADS:

UV-sensitive beads contain pigments that change color when exposed to ultra-violet light from the sun or certain other UV sources. The electromagnetic radiation needed to affect change is between 360 and 300 nm in wavelength. This includes the high-energy part of UV Type A (400-320 nm) and the low energy part of UV Type B (320-280 nm). Long fluorescent type black lights work well; incandescent black lights and UV-C lamps will not change the color of the beads.

The dye molecules consist of two large, planar, conjugated systems that are orthogonal to one another. No resonance occurs between two orthogonal parts of a molecule. When high energy UV light excites the central carbon atom, the two smaller planar conjugated parts form one large conjugated planar molecule. Initially neither of the two planar conjugated parts of the molecule is large enough to absorb visible light and the dye remains colorless. When excited with UV radiation, the resulting larger planar conjugated molecule absorbs certain wavelengths of visible light resulting in a color. The longer the conjugated chain, the longer the wavelength of light that is absorbed by the molecule. By changing the size of the two conjugated sections of the molecule, different dye colors can be produced. Heat from the surroundings provides the activation energy needed to return the planar form of the molecule back to its lower energy orthogonal colorless structure.

Although UV light is needed to excite the molecule to form the high-energy planar structure, heat from the surroundings provides the activation energy to change the molecule back to its colorless structure. If colored beads are placed in liquid nitrogen, they will not have enough activation energy to return to the colorless form.

The UV detecting beads remain one of the least expensive qualitative UV detectors available today. They cycle back and forth thousands of times.

Phantom Crystals

P6-2800

BACKGROUND ON LIGHT REFRACTION:

Light travels at slightly different speeds through different substances. As light waves pass from one transparent substance into another, the wavefronts are slowed down or speeded up and, as a result, refracted. Refraction means that the light is pointed in a new direction. The angle at which the light is redirected is called the "angle of refraction." The angle of refraction is different for each substance and is slightly different for each frequency of light. This is how a prism breaks up white light into a rainbow. The directions of the different colors (different frequencies) are changed due to refraction. Since each color is refracted at different angles, the output is a spread-out display of all the colors that made up the original light.

Refraction is also responsible for the common "broken pencil" illusion. A pencil, partly submerged in water, appears to be broken at the water's surface. The light from the pencil (the pencil's image) gets slowed down and refracted as it passes from the water to the glass. It is refracted again (in the other direction) as it passes from the glass to the water. This returns the original angle of the light, but the pencil has been shifted slightly to the side. In fact, the whole background seems "off a bit."

A ratio, called the "index of refraction," is used by physicists to describe how much refraction takes place when light travels through one substance into another. Because Phantom Crystals are made up almost entirely of water, they have almost the exact same index of refraction as water. Light will pass from the surrounding water into the crystal without being refracted. Hence, you can't see it when it is submerged in water. When the crystal is exposed to the air, it instantly becomes visible again. We can see its shape and size because air's index of refraction is very different than water's.

KIT CONTENTS:

1 vial containing 25g of Phantom Crystals

PRODUCT INFORMATION:

These carbon-based polymers were designed to be small water-absorbing crystals that may be added to potting soil to help keep plants from drying out.

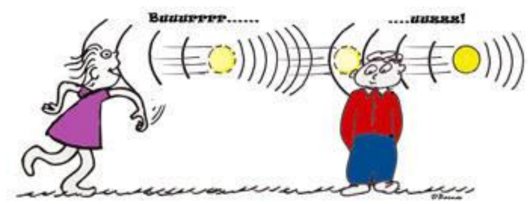
Phantom Crystals are reported to contain: Non-plantfood Products—25% Hydroxyethel Methacrylate, methacrylic acid, acrylimide copolymer, cross-linked homopolymer for absorption and desorption of water, and 35% silica to stabilize the system.

SUGGESTIONS:

1. It's a good idea to wash your hands thoroughly before handling the crystals. Oils from your skin can get absorbed onto the crystal and cloud up its surface. Also, try to handle the crystals as little as possible.
2. If bubbles form inside the crystals, try placing the jar in the refrigerator for a few hours to dissolve the excess gas. When the jar is removed and the water warms up, the dissolved gas tends to exit at the water's surface rather than back into the crystals.

ACTIVITIES:

1. Put several Phantom Crystals into a large, clean glass jar and fill it approximately ¾ full with distilled water. Place the lid on and wait a few hours.
2. When the crystals have grown to the point where they appear essentially invisible, pour four or five of them into a clean petri dish. Although they seem to appear like pieces of glass, they are actually quite rubbery.
3. Choose one of the crystals and, touching it as little as possible, attach it to a paper clip.
4. Drop the crystal and paperclip into a clear glass of shallow water. The crystal will seem to disappear.
5. Next, show your students the vial of water with what appears to be a floating or suspended paper clip inside. Let them examine it closely and postulate if it is possible that there may be something in the jar that we cannot see.
6. Lift the paper clip out of the jar and show them the crystal. Put the crystal back in the jar and show them how it disappears as it is submerged in the water.
7. Discuss why we can see the crystal when it is surrounded by air, but cannot when it is surrounded by water.
8. Have the students make predictions of how long it takes the crystals to dehydrate. Try different set-ups:
    a. crystals condensed in glass jar
    b. crystals spread out on a plate

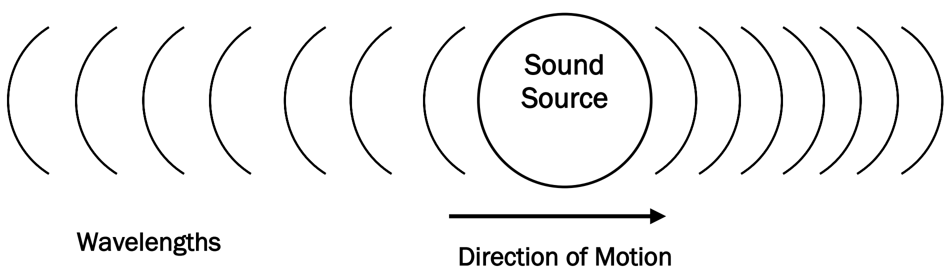


Doppler Ball

P7-7120

BACKGROUND:

The Doppler effect occurs when an observer hears a sound from a moving source. If the sound source is moving toward the observer, the perceived frequency will be higher than the actual sound frequency. If the source is moving away from the observer, the perceived frequency will be lower.



SETUP INSTRUCTIONS:

Snap the battery connection onto the 9V battery (included) to start the buzzer. Push the battery into the slit in the ball, followed by the buzzer.

EXPERIMENTS:

1. Start the buzzer and play catch. If the ball is thrown fast, students should be able to hear that the pitch is higher as the ball approaches than as it moves away.
2. Tie a string tightly around the ball. Swing it in a circle above your head. Students can hear the shift in pitch as it alternately approaches and moves away.

RELATED PRODUCTS:

Sound & Waves Advanced Demonstration Set (P7-2020)

Sound Pipe

P7-7200

INSTRUCTIONS:

Hold the Sound Pipe at one end and twirl it around. Slowly at first. Gradually increase the rate at which you twirl the tube. Notice what happens.

EXPLANATION:

What makes the Sound Pipe produce sounds? The answer is a combination of resonance and Bernoulli's principle.

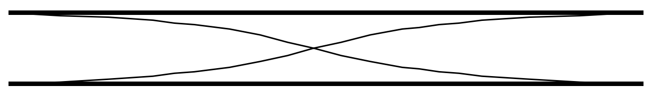
When you twirl the Sound Pipe, the outer end is moving faster than the end in your hand. Bernoulli's principle states that the faster a fluid (like air) moves across a surface the lower the pressure on the surface will be. This explains the reduced pressure at the outer opening of the tube. With higher pressure occurring at the end of the tube held in your hand, the pressure differential results in air rushing up the tube. The faster you twirl the Sound Pipe, the greater the pressure differential, increasing the speed of air moving up the tube. A revealing demonstration of this air motion can be performed by placing the stationary end of the tube over a table on which small torn-up pieces of paper have been placed. Twirling the outer end of the Sound Pipe will vacuum up the paper off the table, spraying it out the other end.

Turbulence is created when air travels through the tube. This turbulence is compounded by the ridges in the sides of the tube. These turbulences produce areas of high and low pressure which when traveling along the tube form the vibrations known as waves. Sound waves traveling out the open ends of the tube partially reflect back into the tube. (Because we can hear the sound outside the tube we know the reflection is not complete.) If the wavelength of the reflected wave matches the wavelength of the incoming wave, these waves reinforce one another, producing sound waves of greater amplitude (sound waves loud enough to hear) and that is what is called resonance.

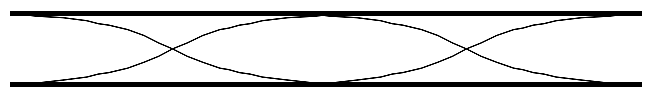
Waves of many different wavelengths are produced, but only waves whose wavelengths fit the length of the tube (or a whole number of half wavelengths) will be reinforced by the reflected waves. The lowest frequency for which the waves resonate is called the fundamental.

As the speed of the air moving up the tube increases, a different set of wavelengths is produced by the faster-moving air. Higher frequencies, related to the fundamental, will also resonate and are called overtones of the fundamental. Since the length of the tube dictates these frequencies, only these select sound waves will be heard. The diagrams below show the different wavelengths that resonate in an open-ended tube.

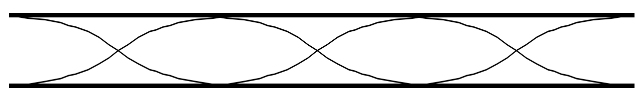
Fundamental Frequency
$L = 1/2\ \lambda$ $\lambda = 2\ L$ $f = f_1$



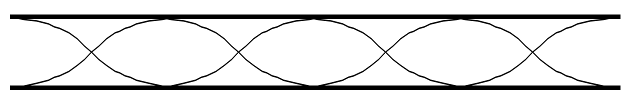
Second Harmonic
$L = \lambda$ $\lambda = L$ $f = 2f_1$

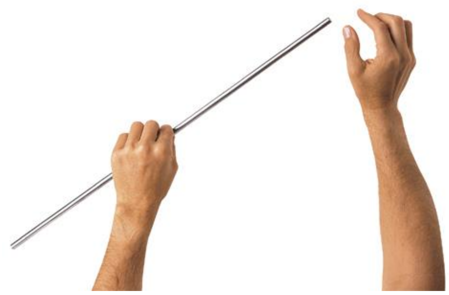


Third Harmonic
$L = 3/2\ \lambda$ $\lambda = 2/3\ L$ $f = 3f_1$



Fourth Harmonic
$L = 2\ \lambda$ $\lambda = 1/2\ L$ $f = 4f_1$





Singing Rods

P7-7250

BACKGROUND:

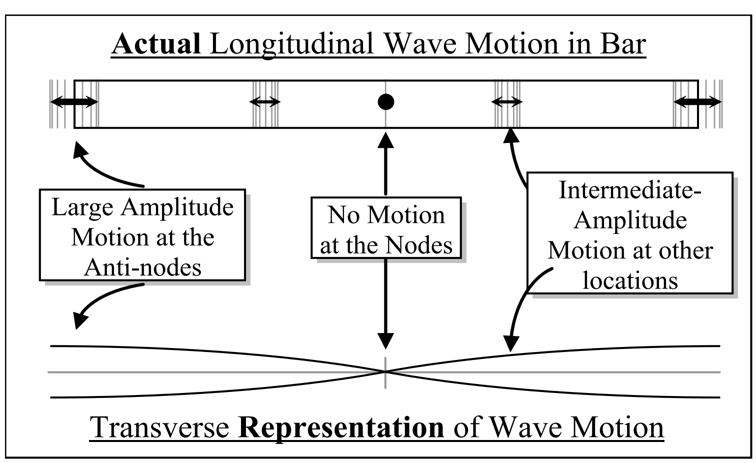
The Singing Rods “sing” because of resonance, the building up of standing longitudinal waves. These waves are created by the repeated sliding of your hand down the length of the rod, which causes vibrations within the metal. This action is helped by the addition of rosin, which causes your thumb and forefinger to stick to the rod more and vibrate as they traverse the length of the rod. The pitch of the sound can be varied by changing where one holds the Singing Rod or by changing the length of the rod itself.

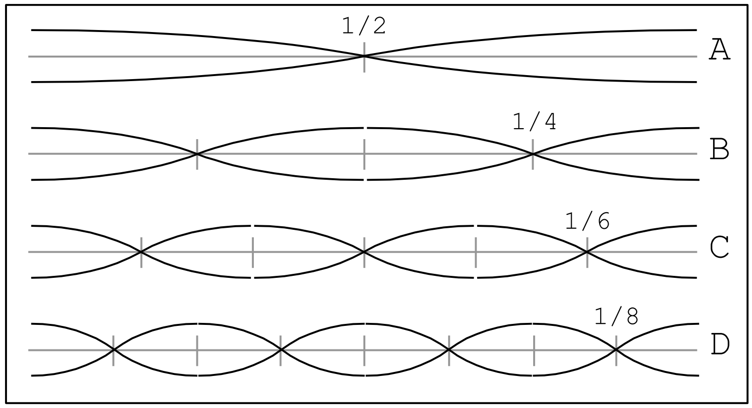
KIT CONTENTS:

1 75 cm Singing Rod
1 50 cm Singing Rod
1 bag of rosin

STANDING WAVES:

Although the waves in the singing rod are longitudinal, they are more easily represented by showing a transverse standing wave. The diagram to the right shows how the motion is represented. When an object such as the Singing Rod resonates, standing waves result.





A standing wave in the rod has nodes, or regions where the rod does not vibrate at all, and antinodes, or regions where the rod is vibrating at its maximum. A rod will always have antinodes at its ends. The lower diagram shows the four standing wave patterns that will occur in the singing rods. Each pattern has antinodes at the ends of the rod and equally spaced nodes in between.

When you cause the rod to vibrate longitudinally, you can force it to vibrate in one of these wave patterns by holding the rod at the place you don't want it to vibrate. The damping from your fingers will cause a node to occur there.

INSTRUCTIONS:

Each Singing Rod is marked in its center. The longer of the two is also marked near either end at a fourth of the length of the rod. The trick to making the Singing Rods sing is in how the rod is held and in the generous use of rosin. Begin by holding the center of one rod firmly between the thumb and forefinger of one hand (using the edges of your fingers to minimize the area of contact). Place some rosin on your other thumb and forefinger and pinch the rod while pulling your fingers towards its end. Each successive stroke on the rod will add to the amplitude of the vibrations within the rod until you can begin to hear them. By continuing this action the sound will become louder and louder. With a little practice you will be able to generate a sound that will certainly get your students' attention as well as cause teachers in classrooms down the hall to wonder what mischief you're up to.

If you do not want your hand to get as dirty, try putting rosin on a heavy cloth and rubbing the cloth on the rod. As you use your Singing Rods more, and as more rosin coats the surface, it will be easier to generate a sound.

ACTIVITIES:

A basic lesson that can be seen immediately is causing the longer of the two Singing Rods to "sing" by holding the marked center point of the rod and noting its pitch (wave pattern A). Then take the same rod and hold it by one of the marks near the end. When the rod begins to sing, a noticeable change in pitch can be heard (wave pattern B). This will reinforce the idea of the inverse relationship between frequency and wavelength. Examine the diagrams above and notice that the wavelength of wave pattern B is half that of wave pattern A. That means that the frequency is doubled. You may be able to notice that the higher tone is exactly one octave above the lower.

Note: The tone you hear is not the only wave occurring in the rod. When you force a node in the center of the rod, higher resonant frequencies with nodes in the center also exist. The longest wave is the loudest, though, and that is the one you hear. Ex: When you produce wave pattern A, wave pattern C also exists, although you cannot hear it.

Next, while the rod is "singing" in wave pattern B, grasp it at the mark near the opposite end. Since the mark represents the other node in that wave pattern, grasping it there will not stop the vibration. Touching the rod anywhere else will stop the sound.

Other wave patterns can be produced in the rod (wave patterns C, D, and beyond), but their pitches are too high for most people to hear. For that reason, only the nodes for the longest two waves have been marked on the longer rod. The shorter rod has only been marked in the center, but some people can hear wave pattern B (with a very high pitch) in it also. Estimate or measure 1/4 of the rod length and try to force a node there.

Measure the frequency produced by each rod. Use that, along with the wavelength (determined from the diagrams above) to find the speed of sound in aluminum. Compare that to the speed of sound in air.

Use a sound level meter to measure the loudness of the sound produced down the length of the bar. Show how the sound intensity increases at the antinodes and decreases at the nodes.

Demonstrate the Doppler Effect by tying a string around the rod at its middle node. Make the rod sing and swing the rod as a pendulum. You will hear the sound change pitch as it approaches and recedes. You can also spin the rod on its string. Since the sound is mostly coming from the ends of the rod, as the rod spins you hear a combination of the approaching and receding ends, resulting in a beat frequency.

You can also produce transverse waves in the singing rod. Hold the rod at the middle node and strike it with a mallet on the side near the end of the rod. You will hear a lower pitch that dies away. The higher pitch of the longitudinal waves persists longer. The production of transverse waves in the singing rods is more complex. They do not follow the same pattern as the longitudinal waves.

RELATED PRODUCTS:

If you run out of rosin, re-supply with **Extra Rosin** (P7-7250-01).

Our **Super Slinky** (33-0130) and **Snaky** (33-0140) can further enhance your demonstration of the behavior of longitudinal and transverse waves.

Wave Sticks (P7-7310) are a hands-on approach to learning about torsional and transverse waves which is intriguing and visually exciting.

Boomwhackers (P7-7400) can be used to demonstrate resonance and standing waves in open and closed tubes

BIBLIOGRAPHY:

Thanks to Mark Fischer, Assistant Professor at College of Mount St. Joseph, for making the diagrams and for activity suggestions.

Music Box Mechanism

P7-7330

BEFORE USE:

1. Unscrew the two small screws on top of the plastic box.
2. Use the screwdriver to pop the metal mechanism out of the plastic box.
3. Attach the handle to the winding mechanism.
4. Discard the plastic box, lid, and screws.

DEMONSTRATIONS:

1. Hold the mechanism in your hand (or, better yet, hang it from a string) and wind it. Ask students to listen and describe the loudness of the sound.
2. Amplify the sound with one of the methods listed below.
3. Ask students to predict which amplification method will produce the loudest sound.

WHAT'S GOING ON?

Sound travels as a longitudinal wave through the air (or another medium). Sound waves originate with a vibrating object. The vibrating object must be rigid enough to maintain the frequency of vibrations. A large object can transmit more energy than a small object. Certain materials (like drumheads) transmit sound energy better than other materials. The presence of a resonance chamber (like a paper cone or guitar body) can also help to further amplify the sound.

TO AMPLIFY THE SOUND, HOLD THE MUSIC BOX MECHANISM AGAINST:

Chalkboard
Desk
Window
Piece of paper
Piece of paper rolled into a cone
Piece of coverstock rolled into a cone
Drum
Guitar body
Piano cabinet
Student’s temple
Student’s elbow, as they press an index finger against the bone near their ear

RELATED PRODUCTS:

Thunder Drum (P7-3100). Vibrations in a spring are amplified by a drumhead and resonance chamber to produce an incredible thundering sound.

Sympathetic Tuning Fork Set (P7-6000). Includes two tuning forks with resonance chambers. Great for demonstrating sympathetic resonance and beats.

Sound & Waves Discovery Pack (P7-2030): A collection of items to demonstrate a range of concepts related to waves and sound.

Boomwhackers

P7-7400

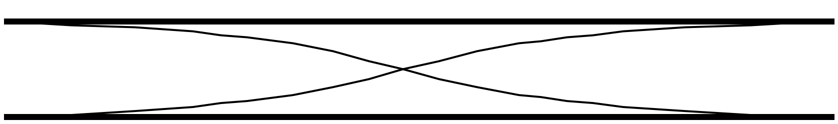
BACKGROUND:

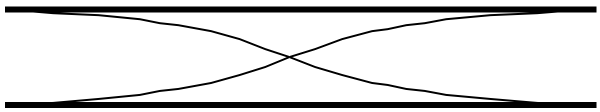
Boomwhackers create distinct tones when whacked against a surface. The tone is determined by the length of the tube. The tubes are cut to the correct lengths to form the eight notes in a C major diatonic scale (C-D-E-F-G-A-B-C).

The tubes create tones in much the same way as other tube-shaped instruments. They filter a particular tone from noise that is introduced into the tube. A clarinet is played by vibrating a reed at one end. The reed does not vibrate at any particular frequency, but produces a range of frequencies (a buzzing noise). The shape of the clarinet and which holes are covered determine which frequency is amplified. Boomwhackers work in much the same way. Whacking the tube produces a noisy sound that contains many frequencies. The tube, because of its length, resonates and amplifies one of the frequencies. Notice, in the figures below, that the resonant wavelength is one that has antinodes at both ends of the tube.

EXPERIMENTS:

1. **Pitch/Wavelength:** Whack two different tubes. Which tube produces the lower tone? How do the lengths of the tubes compare? Longer tubes produce lower tones because they amplify a longer wavelength (lower frequency).

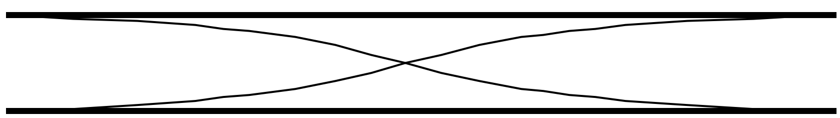


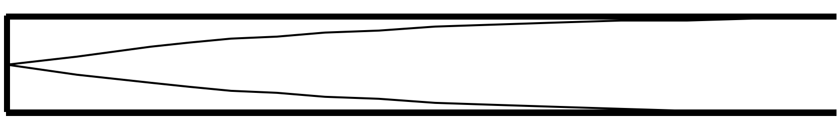


2. Resonance: Hum loudly over the end of a tube near and at its natural frequency. The tube will vibrate when you reach its natural frequency, in addition to amplifying the sound.

3. Resonance 2: Strike a 256 Hz tuning fork and hold it just inside the end of the longest C tube. The tube will resonate and amplify the 256-Hz tone. Strike the tuning fork again and hold just inside the SHORTEST C tube. The short tube also resonates, because the tuning fork's vibration includes another frequency, 512 Hz. This overtone is much quieter than the fundamental tone, so it is usually not noticed.

4. Open/Closed Pipe Resonance: Whack one tube and notice the tone it produces. Cap one end with one of the black caps and whack the tube again. How does the new tone differ from that produced by the open tube? The capped (closed) pipe produces a tone that is exactly one octave lower than the uncapped (open) pipe. The cap forces a node to be at the end of the tube, and the lowest resonant wavelength is twice as long as the wavelength of the uncapped tube. An octave is produced by doubling the frequency (or halving the wavelength) of a sound.





5. Noise Filtering: Take the Boomwhackers to a noisy environment, such as a crowded hallway or cafeteria. Put a tube to your ear and listen to the sounds. The tube filters and amplifies the same tone that it produces when it is whacked. If you hold the tube tightly against your head, it becomes a closed tube and will amplify the note an octave lower.

6. End Correction: Ideal open pipes amplify a sound whose wavelength matches the length of the pipe. The frequencies of each note are listed below. Calculate the wavelength of each note (wavelength = speed of sound in air / frequency) and compare them to the tube lengths. (For open pipes, the length of the tube is HALF of the wavelength of the fundamental tone. See the diagrams above.) The tubes are a bit shorter than the calculated wavelengths. This is because the vibrating air in the tube does not disperse immediately at the end of the tube. This causes the tube to effectively be slightly longer when it is played.

C 256 Hz	F 341.3 Hz	B 480 Hz
D 288 Hz	G 384 Hz	C 512 Hz
E 320 Hz	A 426.7 Hz	

Thanks to Bob Williamson, Walt Krell, and Clarence Bennett for their experiment ideas.