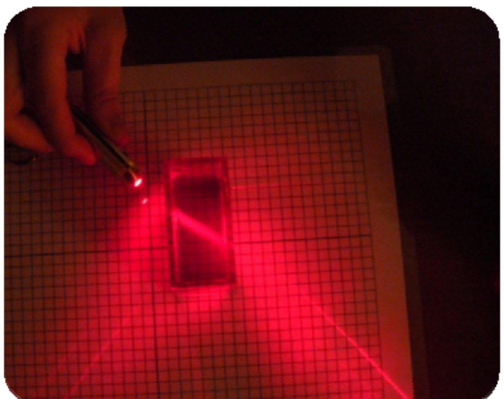
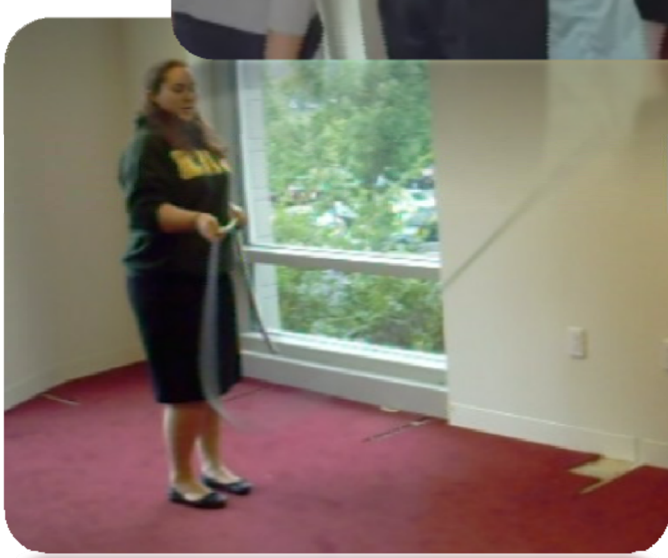
Makin' Waves

The 2008 Student Outreach Catalyst Kit (SOCK)





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Dear SOCK Recipient,

Congratulations on taking a first step in building a successful outreach program—taking interest in the SPS Outreach Catalyst Kit (SOCK). The next step involves sitting down with your chapter and going through this kit to see how the enclosed materials can help you with your outreach events.

We have enclosed materials on three separate topics. For each topic we suggest two lessons– one designed for high school students and one for elementary school students (placement of middle school students varies depending on the difficulty of the topic and activity). An electronic copy of this manual is included on the CD provided, and can also be found on the SPS website and on The Nucleus if you want to physically change any of the lessons or the worksheets. The CD also includes pictures and videos to help explain the lessons so that you can see exactly what we had in mind when we were planning the lessons.

Other documents included in this manual:

- a step-by-step guide to planning an outreach event
- National Science Education Standards
- supply and vendor lists that give recommendations for purchasing additional items and replacement parts
- construction details for the parts of the kit that were handmade
- a list of demonstrations that come from the lessons
- a SOCK survey

Please note that these items and lessons are only a starting point. You can use the materials as described in the lessons and/or come up with your own creative ideas and improvisations. We welcome your feedback (it helps us keep improving the SOCKs to better meet your needs), so please fill out a SOCK Survey and return it to us before the end of the school year.

SPS National and the 2008 Summer SPS SOCK interns thank you for taking part in this year's project. Have fun exploring and modifying the lessons to suit your outreach programs. If you have any questions or comments please feel free to contact us.

Good luck on all of your outreach events!

Sincerely,

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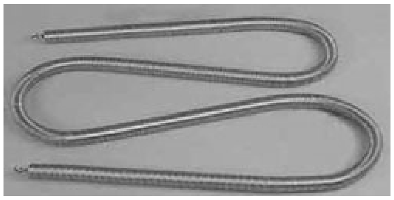
1 long spring



1 diatonic set of Boomwhackers®

1 pair of Polarized sunglasses

1 semicircular refraction box

1 laser pointer

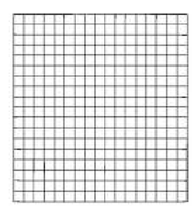
1 rectangular refraction box

1 cut and many uncut straws

1 box of Jell-O®

1 12'' x 12'' piece of polarized film

1 sheet of laminated graph paper



25 pairs of Rainbow Glasses

2 Tension Rods

If any of these items are missing from your SOCK, please contact the SPS National Office at sps@aip.org or (301) 209-3007.

History of the SOCK

www.spsnational.org/programs/socks

The SPS Outreach Catalyst Kit (SOCK) began in 2001 as part of an outreach effort by the National Office of the Society of Physics Students (SPS). This kit was designed for SPS chapters starting outreach programs to students from kindergarten through college, to help them stimulate interest in physics at any age level. For younger students there are qualitative lessons to introduce critical thinking and brainstorming skills. More advanced students can be challenged with quantitative aspects of the lessons, reinforcing critical thinking skills and learning to apply mathematics to real situations. The demonstrations are hands-on to encourage active participation, and the lessons can be adjusted to fit any situation.

The first SOCK was created by SPS intern Mark Lentz in 2001. The SOCK was titled *Rainbow Suite* and sought to teach different properties of rainbows. This started the legacy of light demonstrations that have been present in every subsequent SOCK. The 2002 SOCK was put together by SPS interns Lauren Glas and Jason Tabeling. *Dimensions in Physics* explored geometry in a variety of settings. The 2003 SOCK was constructed by SPS interns Stacey Sude and Ashley Smith. *Spanning Space* included all the popular light elements, and brought in the first experimental component with a nation-wide cylinder dropping experiment.

The 2005 SOCK was a joint effort of the 2004 SPS interns Heather Lunn and Matthew Shanks and the 2005 SPS interns Morgan Halfhill and Rebecca Keith. Entitled *The World Year of Physics 2005*, it was a celebration of the World Year of Physics. It added a new twist to the ever-popular light elements and included a special lesson to commemorate Einstein's discoveries in 1905 with an experiment to measure the speed of light.

The 2006 SOCK was constructed by Katherine Zaunbrecher and Jackie Michalek. Its theme centered on the effects of temperature and it coincided with the *Absolute Zero and the Conquest of Cold* campaign. The 2007 SOCK, planned by Justin Reeder and Ryan Field, was on motion and collisions and had a variety of lessons and demonstrations in this area, including experiments with the ever popular Diet Coke and Mentos reactions.

The 2008 SOCK was designed by Mary Mills and Jenna Smith. It is all about waves and includes one of the most popular items used to illustrate waves – a giant Slinky®. Using three different topics, polarization, sound, and reflection/refraction the kit provides a range of possible lessons and activities for chapters to choose from. It also has a myriad of demos to use at SPS events, in outreach, or just for fun.

The SOCK project is supported by the Society of Physics Students and its associated honor society, Sigma Pi Sigma. SPS is the professional society for physics students and their mentors. It operates within the American Institute of Physics (AIP), an umbrella organization for ten other professional societies.

Makin' Waves with

FUTURE FACES OF PHYSICS

In keeping with its commitment to help physics students transform themselves into contributing members of the professional community, the SPS National Council adopted "Future Faces of Physics" as the theme for the 2007-2008 academic year. With this theme, the council aimed to raise visibility and focus on issues of diversity in physics.

The representation of women in physics is dramatically lower than in other scientific disciplines, and the representation of minorities remains very low when compared to the general population distribution. Students from the nation's poorest families have a much lower rate of college attendance and graduation, and first generation college attendees rarely earn degrees in any field of science.*

As you think about your science outreach plans for this year, please consider the theme of this SOCK, *making waves*. When you bring science activities like the SOCK into your local community, you have an opportunity to share your knowledge, enthusiasm, and love for science with people that may not have ever had a personal or positive association with science. And so we challenge you—the SOCK recipient—to think strategically about your outreach plans for this year and to consider how you might encourage diversity in the future faces of physics.

Join us in encouraging diversity in the future faces of physics!

- Make an effort to include students from groups that are underrepresented in physics in your outreach activities.
- Check out *Touch the Universe* by Noreen Grice from your library and find out what it's like to see the universe with your fingers.
- Host a *Future Faces of Physics* session at your zone or chapter meeting (email Kendra Rand at krand@aip.org for more information on the free *Future Faces of Physics* kit).
- Hold a joint event with a minority group on campus.
- Organize a panel discussion on diversity issues in science.
- Evaluate how well your SPS group reflects the larger student population distribution at your school.
- Re-decorate your physics lounge with a focus on creating a welcoming atmosphere for all students.
- Invite scientists from underrepresented groups to give talks at SPS meetings.

*For detailed information on the demographics of the physics community, visit the Statistical Research Center of the American Institute of Physics, www.aip.org/statistics.

Beginning Your Outreach Program

There are many different levels and types of science outreach that can be done in your community and school. Outreach activities might include performing science shows and demonstrations for local schools, performing workshops and demonstrations for campus clubs and organizations, homework tutoring, and high school mentoring programs.

After establishing a willingness within your chapter to do outreach, there are a few steps you should take before you actually perform an outreach event. We have provided a basic outline to guide you through the process of setting up your first outreach event.

Suggested Procedure for Your Outreach Events

- Determine the amount of time you and your chapter are willing to commit to these events and their preparation.
- Determine what topic(s) you would like to cover with the students.
- Talk to your chapter advisor as well as your physics and education department faculty to see if there are already existing outreach programs offered through your campus or in your local community that you can join.
- Contact the math, science, and technology teachers in your local school districts to let them know you are interested in putting on science events for their students.
- Contact local youth organizations such as the Boy and Girl Scouts of America, 4H, and YMCA to see if they have any interest.
- When scheduling an event, make sure to get all the specifics including: a contact person, number of students, grade level, available equipment, time constraints, and any other special considerations.
- Make sure you have enough volunteers and transportation for everyone to and from the event.
- Test the experiment and/or demonstrations and research the topic of your lesson(s) before your event.
- Verify that the logistics are ready the day before your event. Make sure everything is set out and ready to go so you don't forget anything vital.
- Do a post evaluation of your outreach event to discuss how things went and what you can do better next time.

SPS's primary goal with the SOCK program is to encourage others to explore the universe around them. This kit provides chapters with ideas for physics projects and demonstrations that they can do and share with the local community through outreach programs. It is through this method that we hope to present scientific inquiry as a fun activity that everyone can enjoy.

As the name suggests, the SOCK is meant to serve as a catalyst, prodding your chapter to plan an outreach activity with local schools and community members. You will likely need to supplement the materials in this SOCK in order to engage students effectively. Therefore we have provided contact information for all the vendors we used to compile this kit. Have fun and enjoy your outreach programs!

National Science Education Standards

One important topic to take into account when visiting a classroom is how your lessons fit in with the what the students are supposed to be learning, as given by national, state, and local curriculum standards. While each state defines its own standards, most are based on the National Science Education Standards (NSES), published in 1996 by the National Academy of Science. These standards cover K-12 and describe what students should understand and be able to do in science at each level. The NSES are available on the National Academies Press (NAS) website, http://www.nap.edu/catalog/4962.html#toc.

Below we highlight some of the standards that the lessons and demonstrations in the SOCK address. There are two Content Standards addressed – Scientific Inquiry (Content Standard A) and Physical Science (Content Standard B). Detailed descriptions for each topic can be found on the NAS website.

Scientific Inquiry

Content Standard A:

As a result of the activities in grades K-12, all students should develop an understanding of:

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

Physical Science

Content Standard B:

As a result of the activities in grades K-4, all students should develop an understanding of:

- Properties of objects and materials
- Position and motion of objects
- Light, heat, electricity, and magnetism

As a result of the activities in grades 5-8, all students should develop an understanding of:

- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

As a result of the activities in grades 9-12, all students should develop an understanding of:

- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

Chapter Cheat Sheet: Polarization

What is polarization? Polarization is the property a transverse wave that describes the directions in which the wave is oscillating. A *linearly polarized wave* is a wave that oscillates in a single plane perpendicular to the direction of propagation. An *unpolarized* wave is one that has components of oscillation in different planes perpendicular to the direction of travel. For light, the oscillation direction refers to the oscillation of the electric field.

In the "Advance Preparation" section of the polarization lessons, the horizontal transverse wave and vertical transverse wave are both examples of linearly polarized waves.

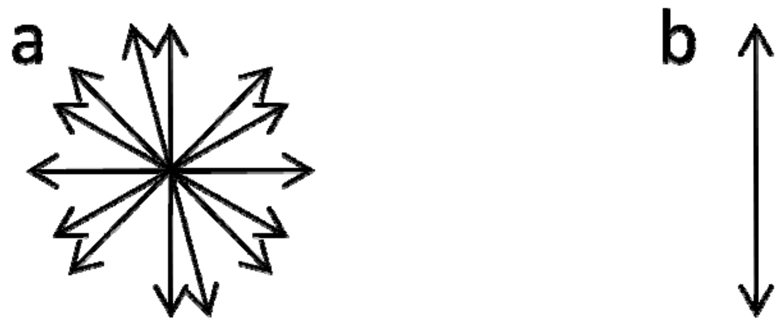


Figure 1: Unpolarized light (a) and polarized light (b), viewed from the direction of propagation

What do the polarizers do? The polarizers block one component of the oscillation, allowing roughly half the unpolarized light though. Just like any vector in a plane can be broken down into perpendicular components, so can an oscillation. If a polarizer blocks out the horizontal component of oscillation in a beam of unpolarized light, only the vertical components of the light will get through, resulting in a beam of vertically polarized light, as in Figure 1(b).

How do the polarizers work? Each polarizer is a stretched piece of plastic. The stretching aligns the plastic molecules in long parallel chains. These chains absorb the component of the light in that direction; for example, horizontal chains will absorb the horizontal component, leaving vertically polarized light. The polarization axis of the polarizer is perpendicular to the direction of the chains in the polarizer.

What happens with two polarizers? If you look at a light source through two polarizers with their polarization axes parallel, you won't notice a difference in intensity as compared to one polarizer. However, if you arrange the polarizers so their axes are perpendicular, no light will get through. If you let the polarizers absorb two perpendicular components of the light, there is no light left to transmit. The transmitted intensity through two polarizers at an angle of θ is: $I=I_0 \cos^2 \theta$ where I_0 is the original intensity and θ is the angle between the two polarization axes.

What happens with three polarizers? Imagine unpolarized light going through three filters. The first filter has a polarization axis at 0°, the second at 45°, and the third at 90°. Light enters the first polarizer and is horizontally polarized. The second polarizer then linearly polarizes the light at 45°, since the horizontal light has a component parallel to the second polarization axes. The third polarizer linearly polarizes the light at 90°, since the 45° light has a component parallel to the third polarization axis. Instead of blocking all the light, inserting the 45° polarizer between the two perpendicular ones allows some of the light to be transmitted.

Lesson 1: Polarization (Elementary School level)

In this activity, students will explore polarization of light and mechanical waves. They will begin by exploring light polarizing sheets. In the second part, a mechanical models will help them visualize the changes to the light wave as it goes through polarizers.

Note: This lesson is best executed with at least three teachers (chapter members): two to hold the spring and one to point out and direct students with the pipes.

Objectives

- Students will be able to explain what a polarizer does.
- Students will relate a mechanical model of waves to experiences with light and polarizers.

Materials

- Polarized Sunglasses
- Polarizing sheets
- Long spring
- 6 PVC pipes (or curtain rods, broom sticks, mop handles, etc.)

Advance Preparation

Estimated time: as long as it takes to make yourselves confident

1. **Wave practice**

   The two teachers who will be controlling the mechanical wave should practice using the spring beforehand. It's easiest if one person controls the waves (input) and the other person holds their end still (output). There are number of things you can demonstrate on the spring:

   a. Vertical transverse standing waves: One person moves their end of the spring up–and-down continuously. The right frequency will resonate with the length of the spring and a standing wave will emerge. The standing wave is identifiable by sight and the resonance is identifiable by touch: a non-resonant wave will feel like it's fighting the input. It's possible to create standing waves with one to five anti-nodes.

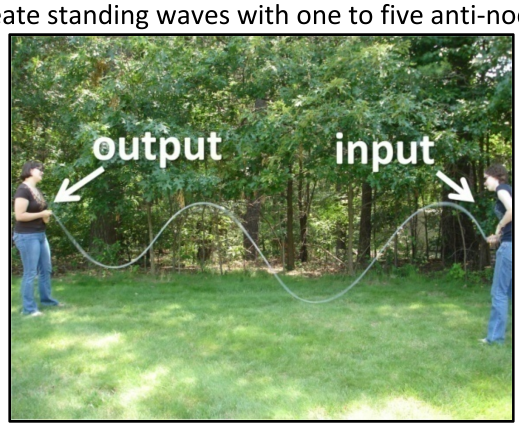


Figure 1: A vertical transverse wave with 4 anti-nodes.

   b. Horizontal transverse standing waves: The same as the vertical transverse wave, but with side-to-side motion instead of up-and-down.

   c. Circular wave: This can also be set up as a standing wave, but instead of moving the spring back and forth, move it in a circle, like the end of a jump rope. Again, it's possible to create standing waves with one to five anti-nodes.

For an example of a circular wave, see video *Circular_Wave* on the included CD.

Conducting the Activity
Estimated time: 45 minutes

1. **Teacher explanation with sunglasses**
   Goal: Students will understand what a polarizer does and be able to identify one use outside of the classroom.

   Begin by holding up a pair of polarized sunglasses. Explain that this is what you're going to talk about today. Make sure you keep it simple; they will think it's cool that they're going to learn about sunglasses.

   Suggested questions: Has anyone heard of polarized sunglasses? Does anyone have any? Why are polarized sunglasses so special? What makes them polarized?

2. **Student exploration with one polarizer**
   Goal: Students will discover that rotating a polarizer changes the amount of light let through from certain (polarized) light sources.

   Hand out polarizers to the students. Ideally, each student should have one polarizer, but this may not be feasible in all situations and the lesson will also work if there is one polarizer for every two students. Direct them to look at different sources of light through their polarizers. Some interesting sources: reflected light (such as a glare off the floor), cell phone screens, camera screens, digital displays, sunlight, and florescent lights. Encourage the students to share their observations with you and other students.

   Suggested questions: What do the polarizers do? What happens when you rotate them?

   For examples of this exploration, see *Glare* and *Polarized_Phone* on the included CD.

3. **Student exploration with two polarizers**
   Goal: Students will be able to describe and predict how the amount of light let through the two polarizers changes with their orientation; when the polarizers are perpendicular to each other, no light is let through.

   Ask students to find a partner and look at light sources through two polarizers, one placed directly on top of the other, and discuss any observations they have. Many students will discover how the amount of light changes with their relative orientation, but you may need to nudge some students.

   Suggested questions: What do you expect to see when you look through two polarizers? Do you see a difference when you look through two polarizers? Is it always different (or the same)? Can you hypothesize a rule for when light gets through and when it doesn't?

Figure 2: L: polarizers are parallel and light gets through. R: one is rotated 90°, blocking the light.

For an example of two polarizers at work, see video *Two_Polarizers* on the included CD.

4. **Group discussion of polarizers**
Ask students to share any observations or conclusions they have made with the class. Do they have any idea why a second polarizer sometimes blocks light and sometimes doesn't? Encourage them to keep these things in mind as we move to talking about other kinds of waves.

5. **Demonstration of spring as mechanical wave**
To get the kids up and moving, create a "stadium" wave by having them raise their arms when you walk in front of them (like at a baseball game). They can also create a "sound" wave by standing in a line with their hands on the shoulders of the person in front of them. Start the wave from the back, by gently pushing on the shoulders of the last person in line. This should create a ripple effect on down the line, like dominoes. Please be gentle!

For examples of these demonstrations, see *Stadium_Wave* and *Sound_Wave* on the CD.

From there move on to talking about the spring. Spread it out across the room, with one teacher holding each end. Identify the input and output ends to the students. Demonstrate how the spring can be used to create mechanical waves: horizontal, vertical, and circular.

Optional: Depending on the level and needs of the students, this part can also be used as a quick review of waves: amplitude, frequency, wavelength, node, anti-node, standing wave, transverse wave, longitudinal wave.

6. **Demonstration with one set of pipes**
Goal: Students will be able to predict the resultant mechanical wave through one set of pipes.

Ask for two volunteers to hold a set of PVC pipes. Direct the students to hold the pipes vertically, one on either side of the spring. There should be just enough space in between the pipes for the spring to move up and down. Make sure the spacing is even from the floor to the top of the pipes; many times students won't be careful about the bottoms of the pipes. Have the students place the pipes vertically and start a random wave. The resultant wave should be a vertical transverse wave. Make sure there isn't a node of your circular wave where the pipes are; if there is, the demonstration won't work.

Repeat the demonstration with a vertical wave (to show that the pipes don't affect it) and a horizontal wave (to show that the pipes completely block the wave). Let students suggest other combinations of waves and pipe arrangements until the majority of the group can predict the resultant wave.

Suggested questions: What do you think the output wave will look like if we send a random/horizontal/vertical wave through a horizontal/vertical/tilted set of pipes? What does it look like? What other arrangements should we try? How can I block a vertical/horizontal wave?

7. **Demonstration with two sets of pipes**
Goal: Students will be able to predict what the wave looks like after one and two sets of pipes.

Ask the students what they think will happen if you use two sets of pipes instead of one. Ask for two more volunteers to hold pipes. Let the other students decide where the pipes should be, how they should be arranged, and what kind of wave should be input. Before trying each wave, students should hypothesize what the wave will look like after the first set and then after the second set. Challenge them to create a combination of sets that will completely block a circular

wave. (Any combination with the sets of pipes perpendicular will block the wave, but the most likely combination is one set vertical and one set horizontal.)
Suggested questions: What do you think the wave will look like after the first set of pipes if we input a circular/horizontal/vertical wave? After the second set of pipes? What does it look like? How can I block a circular wave from reaching the output? Are there any other arrangements you would like to try?

Two see this set-up, see video *Two_Sets* on the included CD.

Final Discussion
Estimated time: 10 minutes

Goal: Students will be able to describe what a polarizer does as well as connect the model and polarizers.

Begin a group discussion, letting student's responses lead you to the next question:
- Where can you find a polarizer at home?
- What does a polarizer do?
- Was there a pattern to how the polarizers blocked the light?
- Was there a pattern to how the pipes affected the waves on the spring?
- Are there any similarities between the light/polarizers and the spring/pipes?
- Can you make a hypothesis about the light/polarizers and the springs/pipes?
- What does the spring represent? The pipes?

Notes:

Figure 3: The proper way to hold the spring.

- To make the polarizers, plastic is stretched, forcing the molecules to arrange themselves in long lines, along the direction of pull. This creates a grid of molecules. It's important to note that *the pipes in our model do not represent the lines of molecules, but the polarizer as a whole*. Light does not slip through the spaces between these lines like the spring slips through the space between the pipes. A polarizer with molecules stretched in horizontal lines will actually absorb and reflect the horizontal part of the light and only let through vertically polarized light.
- It is very likely that students will relate the polarizers to Polaroid film. Edwin Land was the first person to realize that by stretching plastic you could create cheap polarizing material. He created a corporation to sell this new material. After a few years of business, he changed the name of his company to Polaroid. One of his later discoveries was the instant camera, which is now called a Polaroid camera.
- Please hold on tightly to the spring with both hands!

Additional Resources
- Colorado University has a nice online lesson about polarization, complete with some really good Java applets. http://www.colorado.edu/physics/2000/polarization/index.html
- Wikipedia page on Edwin Land, Polaroid founder and discoverer. http://en.wikipedia.org/wiki/Edwin_Land
- Wikipedia page on polarizers. http://en.wikipedia.org/wiki/Polarizer
- Wikipedia page on Polaroid. http://en.wikipedia.org/wiki/Polaroid

Lesson 1: Polarization (MS/HS level)

In this activity, students will explore the polarization of light and mechanical waves. They will begin by exploring how polarizers affect light and how different arrangements of polarizers produce different results. In the second part, a mechanical model of polarization will help them understand the changes to the light beam as it goes through polarizers.

Note: This lesson is best executed with at least three teachers (chapter members): two to hold the spring and one to point out and direct students with the pipes.

Objectives

- Students will be able to explain what a polarizer does.
- Students will be able to relate mechanical waves to experiences with light and polarizers.
- Students will conclude that light acts like a wave.

Materials

- Polarizing sheets
- Long spring
- 6 PVC pipes (or curtain rods, broom sticks, mop handles, etc.)

Advance Preparation

Estimated time: as long as it takes to make yourselves confident

1. **Wave practice**
   The two teachers who will be controlling the mechanical wave should practice using the spring beforehand. It's easiest if one person controls the waves (input) and the other person holds their end still (output). There are number of things you can demonstrate on the spring:

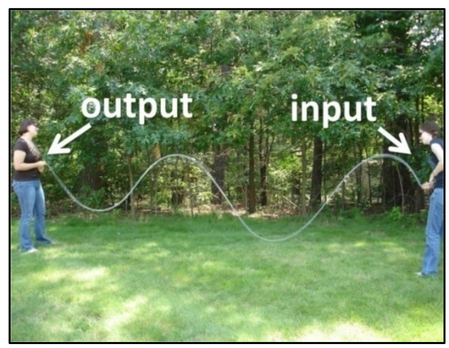


Figure 1: A vertical transverse wave with 4 anti-nodes.

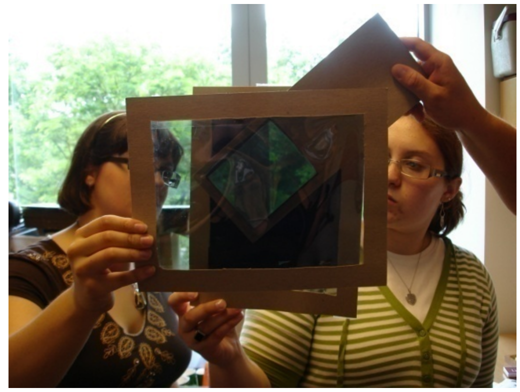
   a. Vertical transverse standing wave: One person moves their end of the spring up–and-down continuously. The right frequency will resonate with the length of the spring and a standing wave will emerge. The standing wave is identifiable by sight and the resonance is identifiable by touch: a non-resonant wave will feel like it's fighting the input. It's possible to create standing waves with one to five anti-nodes.

   b. Horizontal transverse wave: The same as the vertical transverse wave, but with side-to-side motion instead of up-and-down.

   c. Circular wave: This can also be set up as a standing wave, but instead of moving the spring back and forth, move it in a circle, like the end of a jump rope. Again, it's possible to create standing waves with one to five anti-nodes.

For an example of a circular wave, see video *Circular_Wave* on the included CD.

Conducting the Activity
Estimated time: 30-45 minutes



1. **Student exploration with one polarizer**
   Goal: Students will discover that rotating a polarizer changes the amount of light let through from certain (polarized) light sources.

   Hand out polarizers to the students. Ideally, each student should have one polarizer, but this may not be feasible in all situations and the lesson will also work if there is one polarizer for every two students. Direct them to look at different sources of light through their polarizers. Some interesting sources: reflected light (like glare off of the floor), cell phone screens, camera screens, digital displays, sunlight, and florescent lights. Encourage the students to share their observations with the class.

   Suggested questions: What do the polarizers do? What happens if you rotate a polarizer?

   For examples of this exploration, see *Glare* and *Polarized Phone* on the included CD.

2. **Student exploration with two polarizers**
   Goal: Students will be able to describe and predict how the amount of light let through the two polarizers changes with their orientation; when the polarizers are perpendicular to each other, no light is let through.

   Ask students to form groups and look at light sources through two polarizers, one placed directly on top of the other, and discuss any observations. Many students will discover how the amount of light changes with relative orientation by themselves, but you may need to nudge some students.

   Suggested questions: What do you expect to see when you look through two polarizers? Do you see a difference when you look through two polarizers? Is it always different (or the same)? Can you hypothesize a rule for when light gets through and when it doesn't?

Figure 2: On the left, the polarizers are parallel and light gets through. On the right, one is rotated 90°, blocking the light.

   For an example of two polarizers at work, see video *Two_Polarizers* on the included CD.

3. **Student exploration with three polarizers**
   Goal: Students will discover that a third polarizer inserted (at approximately 45 degrees) between two perpendicular polarizers will let light through.

Encourage students to try adding a third polarizer into their arrangement, in such a way as will let light through the system even when the original two polarizers are kept perpendicular. Students may require more nudging for this exploration, as the arrangement is rather particular. Students may be completely mystified as to how this happens. That's okay; the following model is designed to help them understand.

Figure 3: The third polarizer lets light through!

Suggested questions: What do you expect to see when you look through three polarizers? What do you see when you look through three polarizers? Earlier, you could change what you saw through two polarizers; is there a way you can change what you see with three?

For an example of three polarizers at work, see video *Three_Polarizers* on the included CD.

4. **Group discussion of polarizers**
   Ask students to share observations or conclusions they have made with the class. Do they have any idea why a third polarizer actually lets light through? Encourage them to keep their observations in mind as we move to talking about mechanical waves.

Note: The goal of this lesson is to have the students connect the light and polarizers with the model of the spring and PVC pipes. To that end, we recommend that you not use the words light or polarizers when introducing the following mechanical model. Simply talk about it as a mechanical wave demonstration with a spring and pipes.

5. **Demonstration of spring as mechanical wave**
   Spread the long spring out with one teacher holding each end. Identify the input and output ends for the students. Demonstrate how the spring can be used to create mechanical waves: horizontal, vertical, and circular.
   Optional: Depending on the level and needs of the students, this part can also be used as a quick review of waves: amplitude, frequency, wavelength, node, anti-node, standing wave, transverse wave, longitudinal wave.

6. **Demonstration with one set of pipes**
   Goal: Students will be able to predict the resultant mechanical wave through one set of pipes.

   Ask for two volunteers to hold a set of PVC pipes. Direct the students to hold the pipes vertically, one on either side of the spring. There should be just enough space in between the pipes for the spring to move up and down. Make sure the spacing is even from the floor to the top of the pipes; many times students won't be careful about the bottoms of the pipes.

   Direct the students holding the pipes to keep the pipes in place at the bottom, but pull the tops apart, to form a V. Start a circular wave with the spring and direct students to slowly close the tops of the pipes, going back to the vertical position. After the pipes are vertical, the resultant wave should be a vertical transverse standing wave. Make sure there isn't a node of your circular wave where the pipes are; if there is, the demonstration won't work.
   Note: This V-formation with the pipes allows students to see the wave change. It's effective once, but is probably more trouble than it's worth after that. We recommend using it for this first wave, and then just letting students set up the pipes normally.

   Repeat the demonstration with a vertical wave (to show that the pipes don't affect it) and a horizontal wave (to show that the pipes completely block the wave).

Let students suggest other combinations of waves and pipe arrangements until the majority of the group can predict the resultant wave.

Suggested questions: What do you think the output wave will look like if we send a circular/horizontal/vertical wave through a horizontal/vertical/tilted set of pipes? What does it look like? What other arrangements should we try? How can I block a vertical wave? How can I block a horizontal wave?

To see this set-up, see video *One_Set* on the included CD.

7. **Demonstration with two sets of pipes**
   Goal: Students will be able to predict the wave after one and two sets of pipes.

   Ask the students what they think will happen if you use two sets of pipes instead of one. Ask for two more volunteers to hold pipes. Let the other students decide where the pipes should be, how they should be arranged, and what kind of wave should be input. Before trying each wave, students should hypothesize what the wave will look like after the first set and then after the second set. Challenge them to create a combination of sets that will completely block a circular wave. (Any combination with the sets of pipes perpendicular will block the wave, but the most likely combination is one set vertical and one set horizontal.)

   Suggested questions: What will the wave look like after the first set of pipes if we input a circular/horizontal/vertical wave? After the second set of pipes? What does it look like? How can I block a circular wave from reaching the output? What other arrangements should we try?

   Two see this set-up, see video *Two_Sets* on the included CD.

8. **Demonstration with three sets of pipes**
   Goal: Students will be able to predict the mechanical wave after one, two, and three sets of pipes and will be able to arrange the pipes to model the earlier example with the polarizers.

   When the two sets of pipes are set up perpendicularly, the wave doesn't get through. Give the students a challenge: Can they add another set of pipes to this arrangement so that the wave *does* reach the output? Try any suggestions they have. Before each wave, students should hypothesize about what the wave will look like after the first, second, and third sets of poles. The arrangement that lets the most wave through is adding the third set between the other two at a 45 degree angle. If students are still having trouble predicting the mechanical wave through the sets of pipes, let them choose different arrangements and try again.

   Suggested questions: What do you think the wave will look like after the first set of pipes if we input a circular/horizontal/vertical wave? After the second set of pipes? After the third? What does it look like? Are there any other arrangements you would like to try?

   For an example of this, see video *Three_Sets* on the included CD.

Final Discussion
Estimated time: 10 minutes

Goal: Students will be able to conclude from the model and polarizers that light acts like a wave.

Begin a group discussion, letting student's responses lead you to the next question:

- What are your observations about the demonstration with the spring and the pipes?
- Does this remind you of anything else we've talked about today?
- When some concepts are hard to grasp, we use a model to better understand. What does the spring in our model represent? What do the pipes represent?
- What conclusions can you draw about light and polarizers from this model?

You can relate this lesson to student's daily lives by mentioning polarized sunglasses. Polarized sunglasses reduce glare by reducing horizontally polarized light. When light reflects off surfaces (like car hoods and water), it becomes polarized parallel to the surface. You can test this by looking at that reflected light through a polarizing sheet

Notes:

- To make the polarizers, plastic is stretched, forcing the molecules to arrange themselves in long lines along the direction of pull. This creates a grid of molecules. It's important to note that *the pipes in our model do not represent the lines of molecules, but the polarizer as a whole*. Light does not slip through the spaces between these lines like the spring slips through the space between the pipes. A polarizer with molecules stretched in horizontal lines will actually absorb and reflect the horizontal part of the light and only let through vertically polarized light.
- It is very likely that students will relate the polarizers to Polaroid film. Edwin Land was the first person to realize that by stretching plastic you could create cheap polarizing material. He created a corporation to sell this new material. After a few years of business, he changed the name of his company to Polaroid. One of his later discoveries was the instant camera, which is now called a Polaroid camera.
- Please hold on tightly to the spring! Use two hands and don't just use the loop at the end of the spring.

Figure 4: The proper way to hold the spring.

Additional Resources

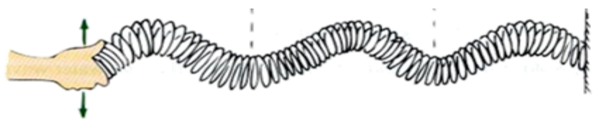
- Colorado University has a nice online lesson about polarization, complete with some really good Java applets. http://www.colorado.edu/physics/2000/polarization/index.html
- Wikipedia page on Edwin Land, Polaroid founder and discoverer. http://en.wikipedia.org/wiki/Edwin_Land
- Wikipedia page on polarizers. http://en.wikipedia.org/wiki/Polarizer
- Wikipedia page on Polaroid. http://en.wikipedia.org/wiki/Polaroid

Chapter Cheat Sheet: Sound Waves

What is a sound wave?

Longitudinal waves (also called compression waves) are waves in which the motion of the medium (slinky coils, air molecules, etc.) is in the same direction as the motion of the wave, like shown below.

In contrast, *transverse waves* are those in which the slinky coils oscillate perpendicularly to the direction of travel, like in the wave shown below whose coils are oscillating up-and-down while the wave is traveling side-to-side. Waves on the surface of a lake are transverse, but gases like air cannot support transverse waves.



A sound wave is a longitudinal wave characterized by density or pressure oscillations.

Open pipes and resonant standing waves:

A spring (and a pipe) will naturally vibrate at certain frequencies that are integer multiples of one another, called resonant frequencies. When they vibrate at these frequencies, standing waves are created in the material. It's easy to see and feel when a moving spring is at a resonant frequency—the amplitude is high, standing wave can be clearly seen, and the people holding the ends are no longer fighting the spring.

Hitting (i.e. vibrating) a pipe creates a pressure wave within the column of air inside. For open-ended pipes like the Boomwhackers®, there is a pressure node at each end of the pipe where the pressure is equal to atmospheric pressure.

When the pressure wave reaches the node at an open end of a pipe, it is reflected, producing a wave traveling in the opposite direction. When the two waves are resonance frequencies of the pipe, their combination creates a standing wave whose period depends on the length of the pipe by $f = v/2L$, where *f* is the frequency of the wave, *v* is the wave speed and *L* is the length of the pipe. So, since the speed of a sound wave is a constant (about 330m/s), as the length of the pipe increases, the frequency of the note decreases—i.e. longer pipes produce lower sounds.

Because the air pressure in a standing wave doesn't instantly equalize with atmospheric pressure at an open end, there is a correction to this approximation. L is better approximated by $l + 0.6d$, where *l* is the length of the pipe and *d* is its diameter.

When *f* is the lowest resonant frequency of the pipe, the standing wave produced is the first harmonic of the system and $\lambda=2L$, where λ is the wavelength of the wave. Substituting $2L$ for λ in the equation for frequency gives $f = v/\lambda$ or $v = f\lambda$.

Lesson 2: Sound Waves (Elementary School level)

This activity teaches students about sound waves and guides them to determine that longer pipes produce lower notes. The students begin by reviewing what they know about waves and, in particular, sound waves. They also learn the difference between longitudinal waves and transverse waves with the help of a Slinky®-like spring. Through the use of Boomwhackers®, they discover that pipes produce notes, and longer tubes produce lower notes. The students then make musical instruments out of straws, which they can use to reinforce what they learned about pipes.

Objectives

- Students will learn about sound waves are and how they are different from "stadium" waves.
- Students will discover that longer pipes produce lower sounds.

Materials

- Boomwhackers®
- Slinky®-like spring
- Skinny straws, pre-cut (see *Construction Instructions*)
- Straws that fit snugly over the skinny straws
- Scissors
- Worksheet (optional)

Advance Preparation

Estimated time: 1 hour

1. **Straw preparation**
    a. Cut as many straws as needed, according to the directions in the *Construction Instructions* section.
2. **Straw practice**
    We recommend all instructors be able to play the straw before the lesson!
    a. How to play your straw: Put the "cut end" of the straw in your mouth with the flaps on the top and bottom. Put your lips a few centimeters below the end of the "V" and squeeze lightly but not enough to close the straw. When you blow into the straw, it should produce a duck-like squawking noise.

For more on how to play the straw, see the videos *Playing_Straw1*and *Playing_Straw2* on the included CD

3. **Spring practice**
    The two teachers who will be controlling the mechanical wave should practice using the spring beforehand. It's easiest if one person controls the waves (input) and the other person holds their end still (output). There are number of things you can demonstrate on the spring:

    a. Vertical transverse standing waves: One person moves their end of the spring up–and-down continuously. The right frequency will resonate with the length of the spring and a standing wave will emerge. The standing wave is identifiable by sight and the resonance is identifiable by touch: a non-resonant wave will feel like it's fighting the input. It's possible to create standing waves with one to five anti-nodes.

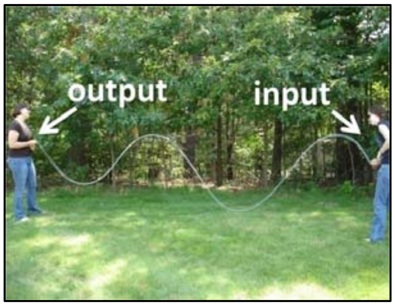


Figure 1: A vertical transverse wave with 4 anti-nodes.

b. Horizontal transverse standing waves: The same as the vertical transverse wave, but with side-to-side motion instead of up-and-down.

c. Circular wave: This can also be set up as a standing wave, but instead of moving the spring back and forth, move it in a circle, like the end of a jump rope. Again, it's possible to create standing waves with one to five anti-nodes.

For an example of a circular wave, see video *Circular_Wave* on the included CD.

Conducting the Activity
Estimated time: 60 minutes

1. **Discussion of sound waves**
   Goal: Students will learn (or review) sound waves

   Begin with a discussion about waves. Find out what students know about waves so that you know what level of terminology and understanding they are working with. We suggest using terms such as *up-and-down* instead of *transverse* and *back-and-forth* instead of *longitudinal*.

   Let the students know that this lesson is on sound waves and tell them that a sound wave is a vibration–the air around the object making noise is moving back and forth really fast and it we "hear" these vibrations as sound. A great review of how we hear sound can be found at: http://www.howstuffworks.com/hearing.htm.

   To further understand sound waves, have the students model an up-and-down "stadium" wave and then a back-and-forth "sound" wave. To create a "stadium" wave, have them raise their arms when you walk in front of them, like at a baseball game. Then have the students create a back-and-forth wave by standing in a line with their hands on the shoulders of the person in front of them. Start with the student in the back and have them gently push the person in front of them to create a ripple effect that will carry on down the line. Stress the need to be gentle and careful!

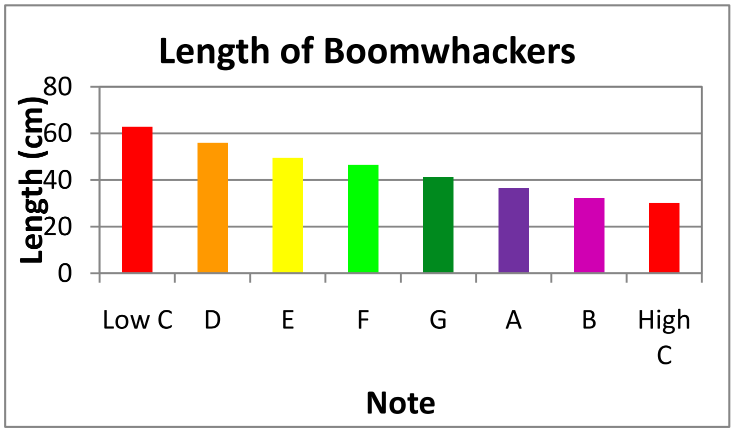
   Suggested questions: What is a wave? What kinds of waves exist? Where can you find waves?

For examples of the stadium and sound wave demonstrations, see the videos *Stadium Wave* and *Sound Wave* on the included CD.

2. **Student exploration with Boomwhackers®**
   Goal: Students will conclude that longer pipes produce a lower note.

   Ask for 8 volunteers, give each of them a Boomwhacker®, and have them line up from the highest note to the lowest note, based on what they hear when they hit each tube on a table or the floor. (Make sure they don't hit the Boomwhackers® on their heads, or anyone elses!) Then ask the class if they notice a relationship between the physical tubes and the notes they produce.

   Have volunteers measure the length of each Boomwhacker® and graph the note versus the length. If you have more than one set of Boomwhackers®, you can have the students do this in groups instead of as an entire class. You can use the worksheet provided to do this or it can be put up on the chalkboard by volunteers.



Suggested questions: What do you observe about the Boomwhackers®? How many notes do they play? Do you recognize the notes? What do you think determines the pitch of the note?

3. **Discussion of waves with the spring**
   Goal: Students will better understand the difference between "stadium" and sound waves as well as the fact that longer correlates to lower and slower and shorter correlates to higher and faster.

   Use the spring to
   a) Show the difference between up-and-down waves and back-and-forth waves.
   b) Make a standing wave with only one node.
   c) Make a standing wave with multiple nodes – this wave has a higher pitch than (b).

   Suggested questions: What are the differences between the waves?

4. **Making musical instruments**
   Goal: Students will have fun while reinforcing the idea that longer correlates to lower and shorter correlates to higher.

   Alert! Before passing out the pre-cut straws, set down some ground rules. For example,
   - When a teacher raises his or her hand, students must take the straws out of their mouths and hold the straws down by their sides.
   - Don't use the straws as spit ball shooters.

   Next, explain how to play the straws. Pass out only the pre-cut skinny straws and let the kids play them. Some people may need a bit of help getting it right, so all of the teachers should have one as an example. This is a time for kids to have some fun, so mingle and play around with them.

   After about 5 minutes, or once everyone seems to have the hang of it, ask for observations. Then tell students that you have another straw and see if anyone can guess what you're going to do with it. Slide it over the end of the first straw. As you play, slide the second straw up-and-down like a trombone slide or penny whistle. Pass the larger straws out to the kids and let them play again.

Final Discussion
Estimated time: 10 minutes

Goal: Students will recap what a sound wave is as well as the idea that longer pipes produce lower notes.

Begin a group discussion using the following questions as a model:

- How did adding the second straw change the sound you were able to play? Why?
- What happened when you slid the second straw up and down while playing?
- Does a longer straw produce a lower or higher note than a shorter straw? Why?
- What is a sound wave?
- What is the difference between a sound wave and a "stadium" wave?
- Do your observations about the straw instrument agree with your observations about the Boomwhackers®?

Notes:

- If you're really ambitious and have more than one set of Boomwhackers®, you can talk to students about the length of the next lowest C (125cm – double the length of the C above it). See if there are any musicians in the room and see if they know the word "octave". Ask for observations about the length of the octave C's. See if students can predict the length of the next octave's C. You can test different hypotheses by taping Boomwhackers® together and listening to the sound.
- Please hold tightly on to the spring! If you don't use two hands then your end may fly out of your hand!

Figure 2: The proper way to hold the spring.

Additional Resources

- How Stuff Works has a great website to learn about how you hear sound. http://www.howstuffworks.com/hearing.htm
- Wikipedia page on sound. http://en.wikipedia.org/wiki/Sound
- HyperPhysics website from Georgia State University has a clickable chart that has just about everything you could ever want to know about sound and hearing. http://hyperphysics.phy-astr.gsu.edu/hbase/sound/soucon.html
- The Non-Destructive Testing Resource Center's website has an interactive guide to sound. http://www.ndt-ed.org/EducationResources/HighSchool/Sound/introsound.htm
- High speed film, by a professor from the University of Salford, illustrating how sound is made by vibrations, acceleration noise, shock waves and sonic booms. http://www.youtube.com/watch?v=26qvYE-w8Eo
- Prof. Trevor Cox, from the University of Salford, uses high speed filming to explain how wind instruments work, with the aid of a whoopee cushion. http://www.acoustics.salford.ac.uk/schools/whoopee.htm?v=PVGk85rHjfE
- Whacky Music, Inc.'s website: The creators of Boomwhackers®. http://www.boomwhackers.com
- LoPresto, Michael. "A Resonance Tube Experiment Using 'Boomwhackers'." *The Science Teacher*. January 2005: 50-52.
- "The Physics of Open Pipe Wind Chimes" contains a fairly good "Background for Teachers" of the resonance of open pipes. It also has many other good ideas for applications, demonstrations and lessons of open pipe resonance. http://epic.physics.missouri.edu/PDF%20files/Physics_of_Wind_Chimes-KimB.pdf

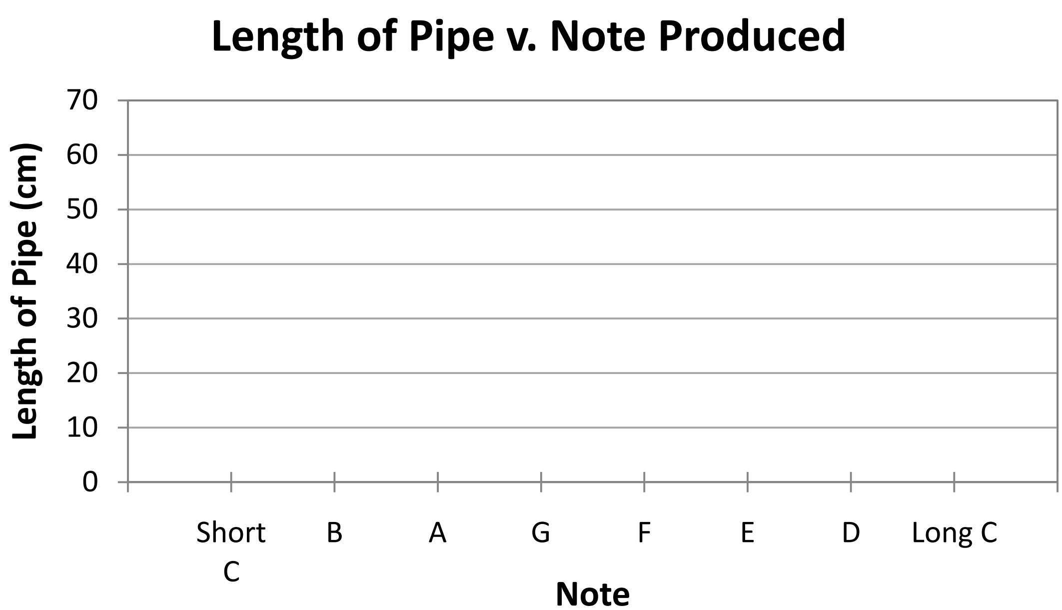
Name: ______________________ Date:_______________________

BOOMWHACKERS!!!

1. Write the lengths of the Boomwhackers in the table below:

Note	Length (cm)
Long C	
D	
E	
F	
G	
A	
B	
Short C	

2. Graph your data on the chart below:



3. When whacked a longer pipe produces a _________________ sound.

When whacked a shorter pipe produces a _________________ sound.

Lesson 2: Boomwhackers® (MS/HS level)

This lesson explores the science of sound with the colorful Boomwhacker® toys and a spring. Students will begin by analyzing wavelength and frequency data for the C major scale. Using a mechanical model, they will then confirm that v=fλ and gain an understanding of standing and resonant waves. In the final part of the lesson, students will apply those concepts to the Boomwhackers® and confirm that the length of each pipe is approximately half the wavelength of the note it plays.

Objectives

- Students will be able to quantify the relationship between frequency, wavelength, and velocity.
- Students will be able to quantify the relationship between the length of an open pipe and the wavelength of the lowest resonance.
- Students will gain an understanding of standing and resonant waves.

Materials

- Set of Boomwhackers®
- Slinky®-like spring
- Worksheet
- Calculators
- Meter sticks or other length measuring devices

Advance Preparation

1. **Spring practice**
   The two teachers who will be controlling the mechanical wave should practice using the spring beforehand. It's easiest if one person controls the waves (input) and the other person holds their end still (output). There are number of things you can demonstrate on the spring:

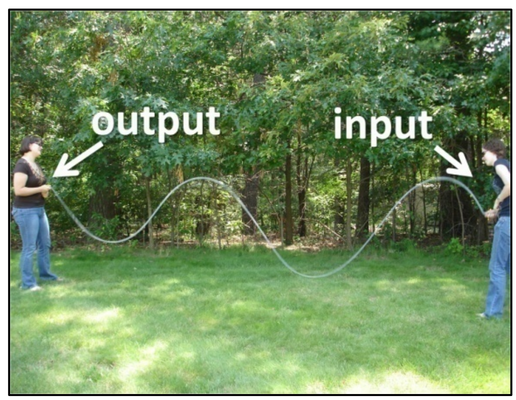


Figure 1: A vertical transverse standing wave with 4 anti-nodes.

   a. Vertical transverse standing waves: One person moves their end of the spring up–and-down continuously. The right frequency will resonate with the length of the spring and a standing wave will emerge. The standing wave is identifiable by sight and the resonance is identifiable by touch: a non-resonant wave will feel like it's fighting the input. It's possible to create standing waves with one to five anti-nodes.

   b. Horizontal transverse standing waves: The same as the vertical transverse wave, but with side-to-side motion instead of up-and-down.

   c. Circular wave: This can also be set up as a standing wave, but instead of moving the spring back and forth, move it in a circle, like the end of a jump rope. Again, it's possible to create standing waves with one to five anti-nodes.

For an example of a circular wave, see video *Circular_Wave* on the included CD.

Conducting the activity
Estimated time: 60-90 minutes

1. **Student exploration with Boomwhackers®**
   Goal: Students will conclude that when vibrated, longer pipes produce lower notes.

   Hand out a set of Boomwhackers® to the class. Let them play with the Boomwhackers® for a minute or two. Solicit their observations about the Boomwhackers®.

   Suggested questions: Look at these like a scientist… how do they work? What are some of your observations about the Boomwhackers®? How many notes do they play? Do you recognize the notes? What do you think determines the pitch of the note?

2. **Student analysis of data**
   Goal: Students will conclude that frequency multiplied by wavelength produces a constant with units of m/s.

   Do a vocabulary review (or introduction) of frequency and wavelength. Be certain to establish that the frequency of the note gives it its pitch. Give students wavelength and frequency data for the C major scale (see worksheet).

   Tell the students that before computers made data analysis easier, scientists would search for relationships between variables by making lists of possible relationships and looking for patterns. Ask them to use this method to determine the relationship between f and λ by looking at the values of f, λ^2, $f\lambda$, and f/λ for each note. Once they realize that $f\lambda$ is a constant, begin a discussion on what that constant might represent. Ask them to figure out what the units are for that constant.

   Suggested questions: What is frequency? What is wavelength? What are some ways we can find a possible relationship between the frequency and wavelength? What do you observe about the values we calculated? What are the units of each calculated value? What conclusions can you draw from these values? What might that constant represent?

3. **Analogy to mechanical waves**
   Goal: Students will conclude that the constant $f\lambda$ is the velocity of the wave.

   Warning: For many reasons, this data is not so great in practice. We've put this part after the Boomwhackers® data set so you don't have to rely on this data to establish the relationship between wavelength and frequency.

   Tell the students that wavelength and frequency are wave properties, and that the next activity is to see if the same relationship holds true for mechanical waves. If you have just one spring, set up standing waves of different frequencies and measure the frequency and wavelength of waves on the spring as a group. If you have enough springs, let the students set up the waves and collect the data in groups. Direct students to measure the frequency and wavelength of waves on the spring to confirm that the product of the two remains constant no matter how many humps (anti-nodes) are on the spring.

For examples of this, see the videos *Measuring_Wavelength* and *Measuring_Frequency*.

Let students guess what the constant represents; nudge them until someone suggests that it is the velocity of the wave on the spring. Allow them to test this idea by measuring the velocity of a pulse on the spring. At this point, if they measure node to node, the velocity of the pulse should be twice as much as their calculated velocity. If this happens, you can bring up that measuring node to node is only measuring half the wavelength.

For an example of this, see the video *Pulse_Velocity* on the included CD.

After students have established that the constant they found earlier is the velocity of the wave on the spring, be sure to relate this idea back to the constant velocity of the Boomwhackers®, the velocity of sound in air.

Suggested questions: Does the constant relationship we found between frequency and wavelength hold true for mechanical waves? How does the calculated velocity compare to the velocity of the pulse? What would the equivalent Boomwhackers® velocity represent?

4. **Discussion of standing waves on the spring**
Goal: Students will be able to draw the lowest resonant frequency standing wave and conclude that the length of the spring is half the wavelength at this frequency.

Set up a non-standing wave (a wave without any nodes or anti-nodes) and ask students how this wave is different than the waves they were measuring.

Set-up a standing wave at the lowest resonant frequency and ask students to draw the wave (sample drawing below). Discuss the wavelength of the wave and establish that at the lowest resonant frequency, exactly half a wavelength fits on the spring.

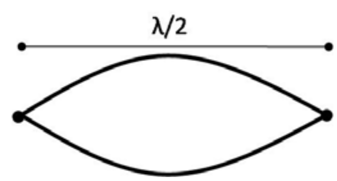


Figure 2: A standing wave on a spring at the lowest resonant frequency, where the length of the spring is half the wavelength.

Suggested questions: How can you tell when a standing wave is set up? Can you set up a wave at the lowest resonant frequency? What does it look like? How many humps (anti-nodes)? What is the highest resonant frequency you think we can reach on the spring? What is the wavelength of this wave?

5. **Discussion of resonant waves in the Boomwhackers®**
Goal: Students will connect the lesson of standing waves to their experiences with Boomwhackers® and predict that the lengths of the pipes are half the wavelength of the note.

Direct the conversation back to the Boomwhackers®. The students have already seen that the relationship between wavelength and frequency is the same for the spring and Boomwhackers®. Nudge them to draw the conclusion that a resonant wave is set up in the Boomwhackers®. One way to do that is to sing a scale into one of the Boomwhackers®. The sound will be amplified greatly when you hit the note of the Boomwhacker® itself.

Earlier, it was established that the pipe length had some effect on the note produced by a

Boomwhacker®. Direct the students to make this more specific, by asking questions about which resonant wave is set up and reminding them of the spring model and the relationship between wavelength and the length of the spring.

Suggested questions: Can you draw any more conclusions about the Boomwhackers® after our spring modeling? Why does a Boomwhacker® play just one note? What kind of resonant wave is set up? How does the length of the pipe affect the note it plays? Is there a relationship between the length of the pipe and the wavelength?

6. **Student experiment with Boomwhackers®**
   Goal: Students will determine how the length of a pipe is related to the wavelength of the note.

   Have the students measure the lengths of the pipes and compare them to the wavelength of the notes. They should measure a value fairly close to ½ of the wavelength, although it won't be exact (explanation in next section).

Final Discussion
Estimated time: 10-15 minutes

Goal: Students will conclude that the length of the pipe is roughly half the wavelength of the note and that it is very close after accounting for end effects.

Begin a group discussion, allowing students answers to lead you to the next question:
- How do your results compare to what you expected?
- Is your data as accurate as you expected it to be?
- Why do you think the numbers don't match up exactly?

The values they measure will be a little short of the half-wavelength. This is due to end effects. The resonating column of air doesn't stop cleanly at the end of the tubes; it extends a little beyond the ends of the tubes. For this reason, the Boomwhackers® act as though they were slightly longer than they actually are.

Optional: The previous explanation should be appropriate for middle-schoolers, but high schoolers might want more of a challenge. The correction formula for the length is: $L=l+0.6d$ where d is the diameter of the tube, l is the measured length of the tube, and L is the length of the resonating air tube. High school students can measure the diameter of the tubes and account for the end effects. Accounting for end effects, the correlation between tube length and wavelength should be very strong.

Note	Measured length (cm)	Corrected length (cm)	Wavelength (m)
Middle C	62.9	65.57	131.14
D	55.9	58.57	117.14
E	49.5	52.17	104.34
F	46.5	49.17	98.34
G	41.1	43.77	87.54
A	36.4	39.07	78.14
B	32.1	34.77	69.54
C	30.2	32.87	65.74

Table 1: A comparison of the measured and corrected lengths with the wavelengths of the Boomwhackers®.

More questions:

- What length pipe should play the C below middle C? How might you test your hypotheses? (With two sets of Boomwhackers®, you can actually tape two middle C tubes together to make the C below middle C.)
- Would a Boomwhacker® play a higher or lower note underwater? Why? (The speed of sound is greater underwater—the wavelength would stay the same because it depends on the tube length, which means the frequency would have to increase, creating a higher pitch.)
- The people that sell Boomwhackers® also sell end caps for the pipes that they call "Octavators." What do you think these end caps do? (The caps drop the frequency down an octave. They turn an open pipe into a pipe with one closed and one open end.)

Notes:

- One fun thing to do for this lesson is to have the instructors practice a song on the Boomwhackers® to play for the students. We've included some samples of sheet music that you can use, or you can find your own.
- We'd love to see what creative ways your group comes up with to use Boomwhackers®! Make a video of your group playing songs, improvising, or doing battle with the Boomwhackers® and post it on YouTube. Then, post a message on The Nucleus (www.the-nucleus.org) on the SOCK/Outreach board so we know that your video is up.

Additional Resources:

- How Stuff Works has a great website to learn about how we hear sound. http://www.howstuffworks.com/hearing.htm
- Wikipedia page on sound. http://en.wikipedia.org/wiki/Sound
- The HyperPhysics website from Georgia State University has a clickable chart that has just about everything you could ever want to know about sound and hearing. http://hyperphysics.phy-astr.gsu.edu/hbase/sound/soucon.html
- The Non-Destructive Testing Resource Center's website has an interactive guide to sound. http://www.ndt-ed.org/EducationResources/HighSchool/Sound/introsound.htm
- A high speed film, by a professor from the University of Salford, illustrating how sound is made by vibrations, acceleration noise, shock waves and sonic booms. http://www.youtube.com/watch?v=26qvYE-w8Eo
- Prof. Trevor Cox, from the University of Salford, uses high speed filming to explain how wind instruments work, with the aid of a whoopee cushion. http://www.acoustics.salford.ac.uk/schools/whoopee.htm?v=PVGk85rHjfE
- Whacky Music, Inc.'s website on Boomwhackers®. http://www.boomwhackers.com
- LoPresto, Michael. "A Resonance Tube Experiment Using 'Boomwhackers'." *The Science Teacher*. January 2005: 50-52.
- "The Physics of Open Wind Chimes" contains a fairly good "Background for Teachers" of the resonance of open pipes. It also has many other good ideas for applications, demonstrations and lessons of open pipe resonance. http://web.missouri.edu/~umcaswwwepic/PDF%20files/Physics_of_Wind_Chimes-KimB.pdf
- Russ Harkay from Keene State College wrote a slew of lessons for an AAPT Workshop. It has a Boomwhacker® lesson similar to ours on page 57, which contains the end effects correction formula. http://www.sciartmedia.com/PPhysics/docs/Excerpts.pdf

Name: _______________________ Date: ________________

BOOMWHACKERS!

1. Before computers made data analysis easier, scientists would look for relationships between variables by making tables of possible relationships and looking for patterns. Search for those patterns yourself.

Note	f, Frequency (Hz)	λ, Wavelength (m)
Middle C	261.63	1.32
D	293.67	1.17
E	329.63	1.05
F	349.23	0.988
G	392.00	0.880
A	440.00	0.784
B	493.88	0.699
C	523.25	0.659

For example, it might be that $f = \lambda^2$. Try a few values and see if a pattern emerges.

Note	f	λ^2
Middle C		
D		
E		
F		
G		
A		
B		
C		

Or they would look for constant relationships between variables. Try a few values.

Note	$f\lambda$
Middle C	
D	
E	
F	
G	
A	
B	
C	

Note	f/λ
Middle C	
D	
E	
F	
G	
A	
B	
C	

2. What is the relationship between frequency and wavelength?

3. What are the units of $f\lambda$? Speculate on the meaning of this.

4. Draw a picture of the standing wave on the spring at the lowest resonant frequency.

5. What is the relationship between the wavelength of the note and the length of the Boomwhacker?

Chapter Cheat Sheet: Reflection and Refraction

Reflection

What is reflection? Reflection is the change in direction of a wavefront at an interface between two media that causes the wavefront to return to the medium from which it originated. *Diffuse reflection* occurs when the surface is rough and the light is reflected in many directions. *Specular reflection* occurs when the surface is smooth (the surface irregularities are smaller than the wavelength of the incident light) and the light is reflected in only one direction.

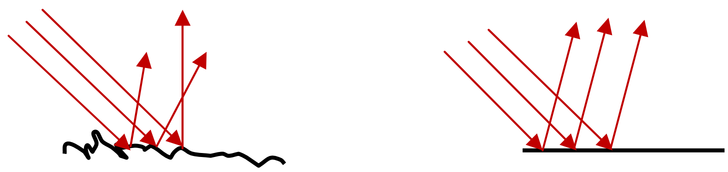


Figure 1: diffuse reflection (left) and specular reflection (right)

The Law of Reflection: The direction of the specular reflected light is given by the law of reflection. It states: *The angle of incidence* θ_i *is equal to the angle of reflection* θ_r. The angles are measured with respect to the normal. This was first determined by Hero of Alexandria in the 2nd century B.C. Then in 1000 A.D., Alhazen, an Arab scholar realized that the incident ray, the normal to the plane, and the reflected ray all lie in the same plane. We call this the plane of incidence.

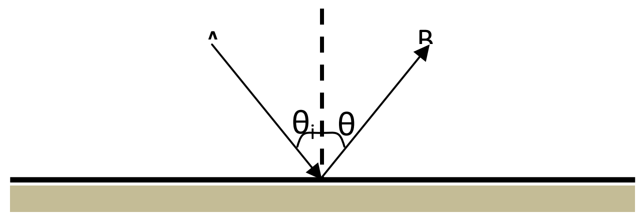


Figure 2: The law of reflection states that the angle of incidence θ_i is equal to the angle of reflection θ_r.

Huygens' Principle: Huygen's principle can be used to help connect reflection to wave phenomena, which is neat since most students learn reflection as purely geometric or ray optics. Huygen's principle is useful in predicting the propagation of wavefronts. The principle states: *Each point on a wavefront acts as a source of secondary wavelets. At a later time, the envelope of the leading edges of the wavelets forms the new wavefront.* Using geometry, Huygens used his principle to obtain the law of reflection.

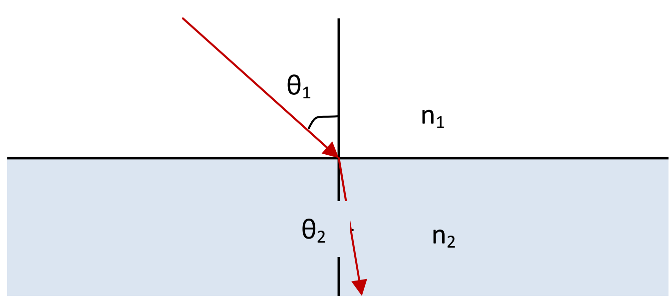
Refraction

What is refraction? Refraction is the bending of light at the boundary between two media due to the change in direction of a wave because of a change in its speed. The *index of refraction, n,* of a medium is defined as the ratio of the speed of a light in a vacuum *c* to the speed *v* in a medium. $n = c/v$

Snell's Law: This describes how the angle of incidence θ_1 and the angle of refraction θ_2 are related.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

When the light enters a medium with a higher index of refraction ($n_2>n_1$ and $\theta_2<\theta_1$), the ray bends toward the normal.



Lesson 3: Reflection and Refraction (ES/MS level)

In this activity, students will explore reflection and refraction as wave phenomena. Most of the time reflection and refraction are introduced with a strictly ray view of light, but they can also be explained by a wave view of light. Students begin by exploring reflection with a laser and a reflective surface. Next, they explore refraction in multiple kinds of Jell-O®, or with different concentrations of a water and creamer mixture.

Objectives

- Students will be able explain that the angle of incidence is equal to the angle of reflection.
- Students will understand that different objects bend light differently.
- Students will understand reflection and refraction as wave phenomena.

Materials

- Laminated graph paper
- Worksheets
- Laser pointer
- Small, clear plastic boxes
- Small pieces of paper
- Jell-O® (or water and liquid coffee creamer)
- Protractors (optional)

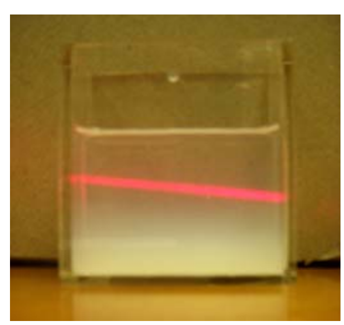
Advance Preparation

Estimated time: 5 minutes - 4 hours

1. **Making the Jell-O®**
    a. If you're going to use Jell-O®, be sure to prepare samples ahead of time using the "Jigglers" recipe on the box. You can use the refraction boxes as molds and leave the Jell-O® in the mold, or take it out—either way works. If you leave the Jell-O® in the mold, make sure to bring a mirror or other reflective surface for the reflection part of the lesson–you don't want to spoil the refraction surprise! You can also make your own pan of Jell-O and cut it into squares, making sure the edges are smooth.
    Notes: *If you do the experiment with the Jell-O® in the mold, please keep in mind that the plastic casing will change the index of refraction (ours went from 1.36 to 1.74) but that the overall effect will be the same.*

2. **Making the water and creamer mixture**
    a. You can use a water and creamer mixture instead of Jell-O®. Practice this mixture ahead of time so you know about how much creamer to add. We recommend you use liquid coffee creamer, not powder creamer. Begin with the amount of water you'll need and add creamer drop-by-drop until you can see the laser passing through the mixture, as shown in the picture.

3. **The index of refraction of Jell-O®**
    a. Different colors, flavors, and concentrations of Jell-O® have different indices of refraction (n). You should measure the n of the Jell-O® you are using before doing the lesson, so you know what the students' values should look like. One resource we found gave the n of red Jell-O® as 1.33.



Conducting the Activity
Estimated time: 45-60 minutes

1. **Introduction of light as waves**
   Goal: Students will recognize that light can be thought of as a series of wavefronts and that a laser is a very focused stream of wavefronts.

   Start by talking about the waves created by tossing a stone into a pond—the water ripples out in all directions from the place where the stone landed. Similarly, when you turn on a lamp, the light travels out in all directions away from the light bulb. From there discuss a flashlight—a flashlight has a light bulb in it, but the light is focused in a certain direction. Finally, introduce a laser as a narrower version of a flashlight.

   Suggested questions: What happens when you drop a pebble in a pond? What does the water do? In what direction does light come out of a light bulb? If you drew the light, what would it look like? In what direction does light come out of a flashlight? What about a laser?

2. **Student discussion of laser light**
   Goal: Students will conclude that light travels in a straight line and that its direction can be changed by reflection and refraction.

   Talk to the students about laser light. Solicit from them the idea that light travels in a straight line. Then, discuss ways that to change the direction of light, or bend it.

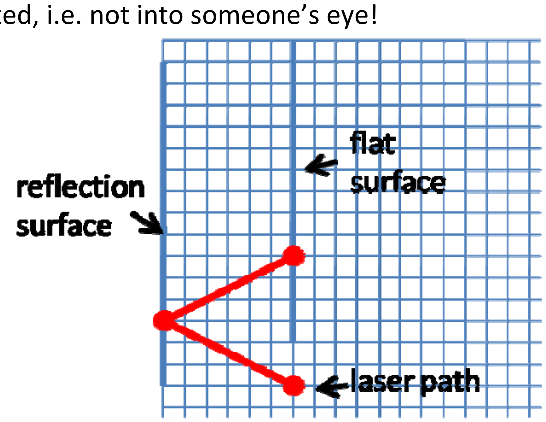
   Suggested questions: Where do you expect the laser to shine if I point it this way and turn it on? Why is this? In what direction does the light travel? What are some ways I can change the way it travels? How can I bend the light? If I point the laser in this direction, but want the laser light to end up behind me, what can I do? What if I just want to bend it just a little?

3. **Student exploration/experiment with reflection**
   Goal: Students will gain an intuitive understanding of reflection

   Because of the importance of laser safety, we suggest you do this lesson in supervised groups with an SPS member using the laser. If you think your students can handle lasers and it has been approved by the teacher or leader, then split the students up into groups and give them each a laser pointer. However, stress the importance of laser safety for the entire lesson.

   Give groups of students an empty rectangular reflection/refraction box or another reflective surface. If you shine the laser at an empty box, most of the light will be transmitted through the walls, but some of it will be reflected. Let students explore for a few minutes, but sure they are careful about where the beam is being reflected and transmitted, i.e. not into someone's eye!

   This experiment should help students see how light reflects:
   a. Hand out the laminated graph paper.
   b. Set up the reflective surface along the line on one side of your graph paper. (You can use the empty boxes as reflective surfaces if you line the flat side with a piece of paper to keep the light from transmitting into the box.)



c. Setup the laser so the beam starts at an intersection and points at the reflective surface. ***Note:*** *You will change the direction of the beam during the experiment, but it should always start from this intersection.*
d. Place a flat, opaque surface parallel to the reflective surface **but in line with the intersection from which the laser shines**. This will allow you to see where the laser goes after it reflects off the surface.
e. Draw the setup your graph paper.

After setting up the experiment, use the laser to test different angles of incidence and see how the light is reflected. The procedure is outlined below:

f. Shine the laser at the reflective surface.
g. Record on your paper where the beam hits the reflective and opaque surfaces.
h. Using these points, draw the path of light from the laser to the reflective surface to the opaque surface.
i. Repeat steps f-h for at least three different angles of incidence.

Suggested questions: What do you notice about how light is reflected? How does the reflection change as your angle of incidence changes?

4. Group discussion about reflection
Goal: Students will conclude that the angle of incidence equals the angle of reflection.

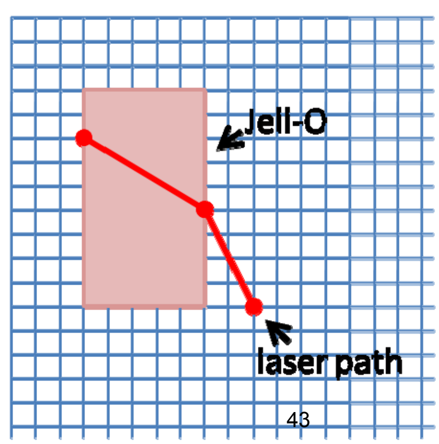
Engage the students in a discussion about their observations and results. Students should conclude that light reflects at the same angle from the normal as it hits, no matter the angle. You might have them use protractors to measure the angles so they know that the angle of incidence equals the angle of reflection.

Suggested questions: What did you notice about the way the laser light was reflected? How did the path of the light change when you changed the angle of the laser? Can you think of a rule to describe how the light was reflected?

5. Student exploration with refraction
Goal: Students will gain an intuitive understanding of refraction.

Now that we've discussed a way to turn light completely around, we're going to explore how to bend light. The following exploration and experiment follow roughly the same procedure as the reflection exploration and experiment. Instead of handing out the empty boxes, fill the boxes with a water and creamer solution or hand out Jell-O® squares. Let the students play with the lasers and Jell-O® for a few minutes, then solicit their observations about what happens to the laser light in the Jell-O®. Students should observe that the Jell-O® bends the light away from the path it would have taken if the Jell-O® hadn't been there.

Suggested questions: What did you observe when you saw the laser beam travel through the Jell-O®/creamer and water mixture? Is this why you expected? Why or why not?



6. Student experiment with refraction
Goal: Students will understand that different materials bend light differently.

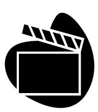
There are two different ways you can do this depending on the time you have for preparation and the number of students. For this part of the lesson you will require different kinds of Jell-O®. You can set up different stations and have students walk around the room and investigate each one, or you can give each group different kinds of Jell-O®. We suggest making them in the semicircular refraction boxes, as they make good molds. The Jell-O® can be kept in the boxes for the experiment or taken out and used separately.

No matter what setup you choose, have each student investigate 3-5 different types of Jell-O®. On their worksheets, have students draw the path of the laser as it goes through different kinds of Jell-O®. They can use a protractor to be more precise. Have students compare their results.

7. **Demonstration of refraction**
   Goal: Students will understand that light refracts because light travels at different speeds in different mediums.

   For this, you need space for four students to walk abreast in the room. Designate a line in this area to represent the boundary between the air and the Jell-O® (or creamer mixture).
   - Have four students line up in a row and hook arms. These students will be one wave front coming from our laser. When each person crosses over the line from air to Jell-O®, he or she should start walking a slower. Remind the students that they have to keep a straight line at all times.
   - Ask the line of students to walk from the "air" side of the line to the "Jell-O®" side of the line at an angle. As each individual student crosses the boundary and begins to walk slower, the line of students will change direction toward the normal. This provides a great visual illustration of refraction.

   Suggested questions: What do you think will happen to our "laser wave front" as it crosses the boundary? What did happen to it? Why? Did this happen in the Jell-O®? Why?



To see this activity in action, see video *Refraction_Demonstration* on the included CD.

Final Discussion
Estimated time: 5 minutes
Goal: Students will synthesize the information they learned in the lesson.

Begin a group discussion to review what students learned in the lesson, letting student's responses lead you to the next question:
- What have you learned about light today?
- How can you make light change directions?
- What did you learn about reflection?
- What did you learn about refraction?

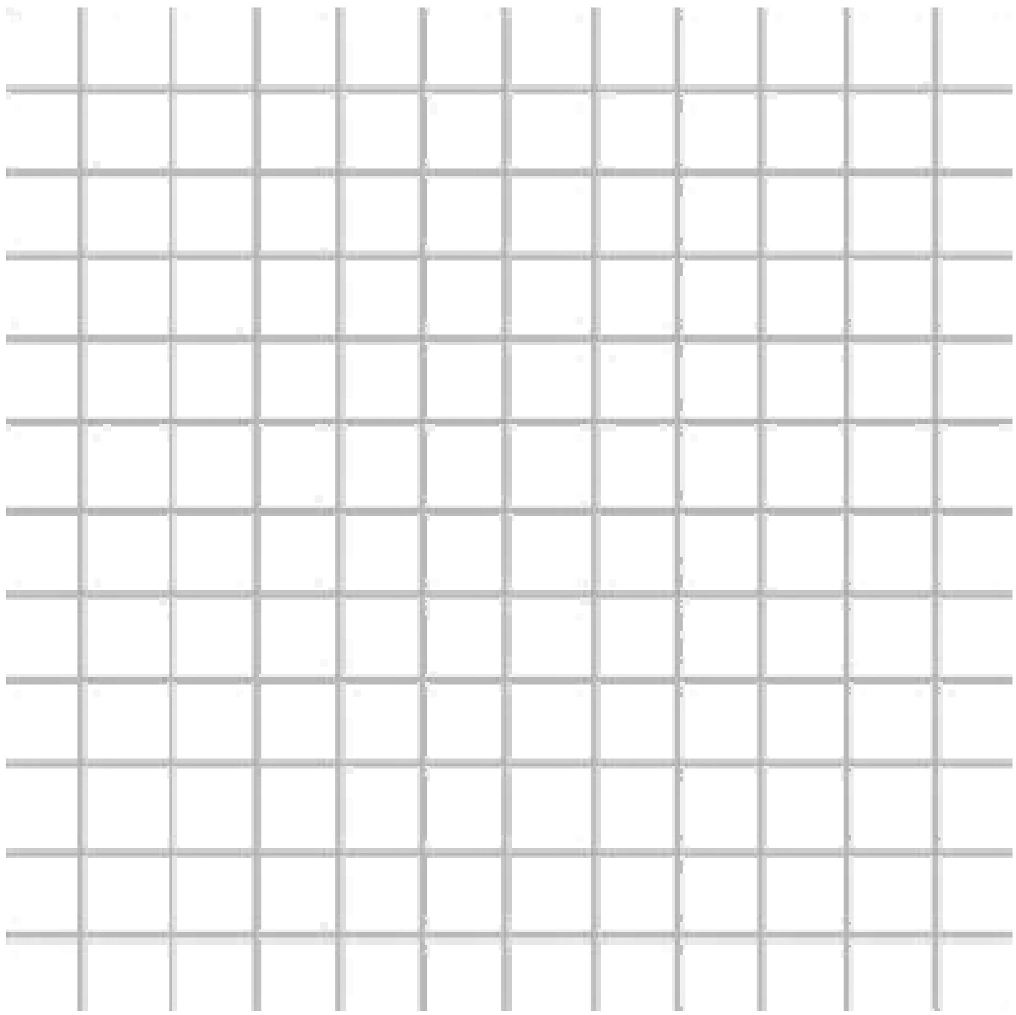
Additional Resources
- Java simulation of wave reflection and refraction: www.phy.ntnu.edu.tw/ntnujava/index.php?topic=16
- HyperPhysics guide to plane wave reflection: http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/reflec2.html#c1
- Physics Classroom tutorial on reflection, refraction, and diffraction: www.glenbrook.k12.il.us/GBSSCI/PHYS/Class/waves/u10l3b.html
- YouTube video exhibiting reflection with water waves: www.youtube.com/watch?v=8LrrWvfyqLo

Reflection and Refraction

Name: ______________________ Date: _______________

Reflection

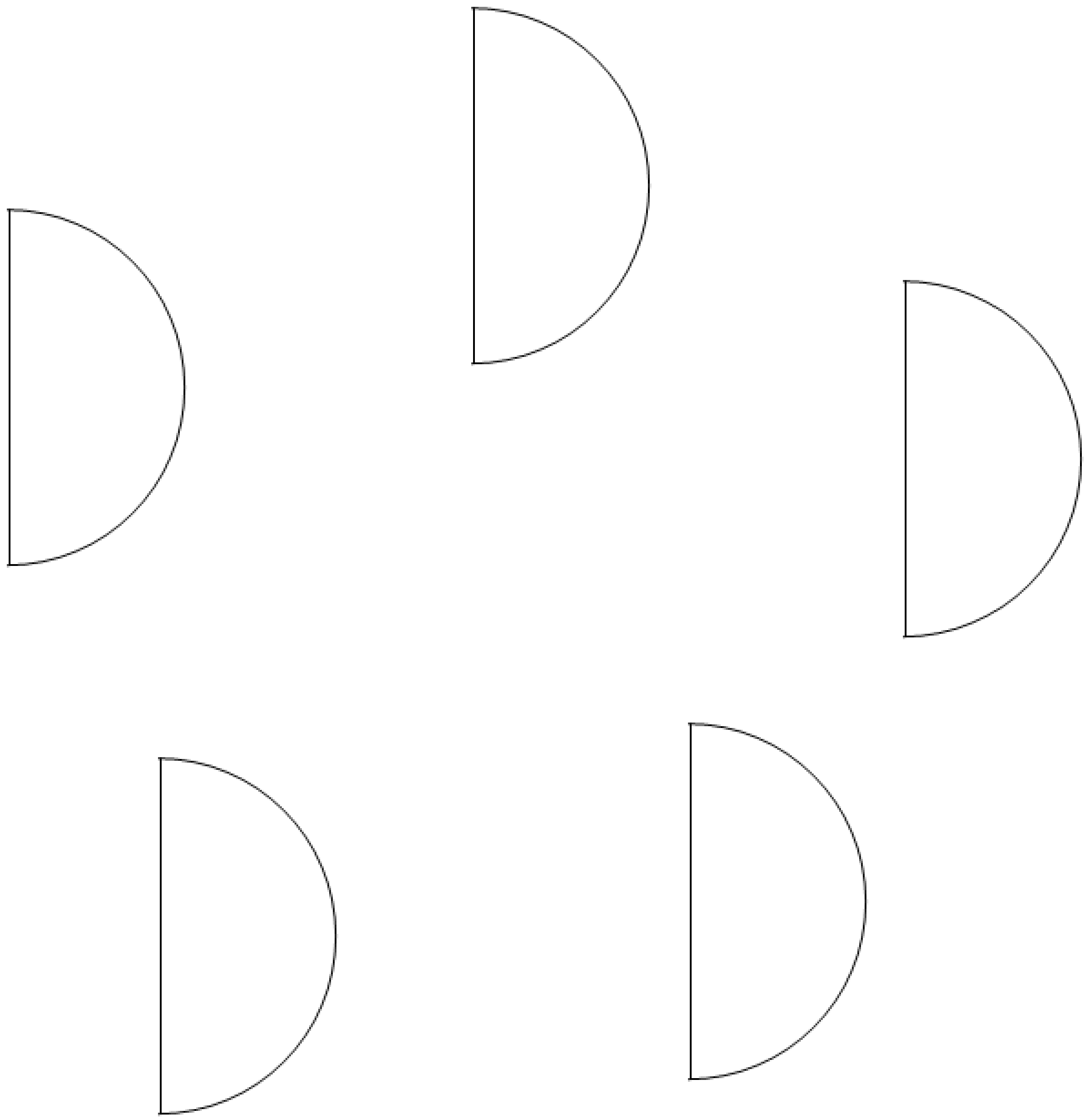
1. On the graph below, sketch how the light reflects off of the surface.



2. What do you notice about the angle between the beam of light that hits the box and the beam that is reflected?

Refraction

3. Using the semicircles below, draw the paths of the light through the different kinds of Jello (or mixtures).



4. Which one bent the light the most? Why?

Lesson 3: Reflection and Refraction (HS level)

In this activity, students will explore reflection and refraction as wave phenomena. Most of the time reflection and refraction are introduced with a strictly ray view of light, but they can also be explained by a wave view of light. Students begin by exploring reflection with a laser and a reflective surface. Next, they explore refraction with Jell-O® or a water and liquid creamer mixture. Students will use Snell's law to calculate the index of refraction of Jell-O®.

Note: *This lesson requires a background of trigonometric functions, namely the sine function. If your group is not familiar with these, we recommend you use the Elementary School level lesson.*

Objectives

- Students will be able to qualitatively explain reflection and refraction.
- Students will be able to use Snell's Law to calculate the index of refraction of a medium.
- Students will understand reflection and refraction as wave phenomena.

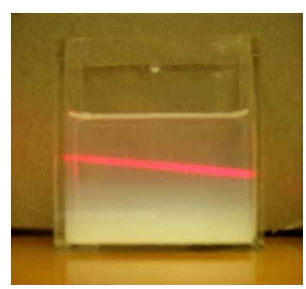
Materials

- Laminated graph paper
- Worksheet and 2 pieces of graph paper/group
- Laser pointer
- Refraction boxes
- Small pieces of paper
- Jell-O® (or water and liquid coffee creamer mixture)
- Protractors
- Scientific calculators
- Light bulb and flashlight (optional, to facilitate discussion)

Advance Preparation

Estimated time: 5 minutes - 4 hours

1. **Making the Jell-O®**
    a. If you're going to use Jell-O® in your activity, be sure to prepare samples ahead of time using the "Jigglers" recipe on the box. You can use the refraction boxes as molds and leave the Jell-O® in the mold, or take it out—either way works. If you leave the Jell-O® in the mold, make sure to bring a mirror or other reflective surface for the reflection part of the lesson–you don't want to spoil the refraction surprise! You can also make your own pan of Jell-O and cut it into squares, but make sure the edges are smooth.
    Notes: *If you do the experiment with the Jell-O® in the mold, please keep in mind that the plastic casing will change the index of refraction (ours went from 1.36 to 1.74) but that the overall effect will be the same.*



2. **Making the water and creamer mixture**
    a. You can use a water and creamer mixture instead of Jell-O®. You should practice this mixture ahead of time so you know about how much creamer to add. We recommend you use liquid coffee creamer, not powder creamer. Begin with the amount of water you'll need and add creamer drop-by-drop until you can see the laser passing through the mixture, as shown in the picture.

3. **The index of refraction of Jell-O®**
    a. Different colors, flavors, and concentrations of Jell-O® have different indices of refraction (*n*). You should measure the *n* of the Jell-O® you are using before doing the lesson, so you know what the students' values should look like. One resource we found gave the *n* of red Jell-O® as 1.33.

Conducting the Activity
Estimated time: 45-60 minutes

1. **Introduction of light as waves**
   Goal: Students will recognize that light can be thought of as a series of wave fronts and that a laser is just a very small stream of wave fronts.

   A solid understanding of waves is necessary for this lesson. Begin by engaging the students in a discussion of the wavefronts that you can see when you drop a pebble into a still pool. When students are clear that waves radiate from the point where the pebble hit the water, begin talking about light from a light bulb. Discuss how you can think of a light bulb as radiating light waves all around, like the pebble. Then discuss flashlights, and how the wave fronts are still there, but they are more focused in one direction. Next move to lasers and make sure the students understand that lasers can be thought of as a very focused stream of wavefronts. Mention that although it's easy to think of lasers as a ray of light, we're going to think of them as a series of wave fronts during the lesson.

   Suggested questions: What happens when you drop a pebble in a pond? What does the water look like? In what direction does light radiate from a normal light bulb? What do the wavefronts look like? In what direction does light radiate from a flashlight? What do the wavefronts look like? What about a laser? Can we describe laser light as a series of wavefronts? What would that look like?

2. **Student discussion of laser light**
   Goal: Students will conclude that light travels in a straight line and that its direction can be changed by reflection and refraction.

   Talk to the students about laser light. Solicit from them the idea that light travels in a straight line. Then, discuss ways that we can change the direction of light, or bend it. Let the students come up with reflection and refraction (refraction may be a little harder to elicit, depending on the level of the students). This will set up the rest of the lesson.

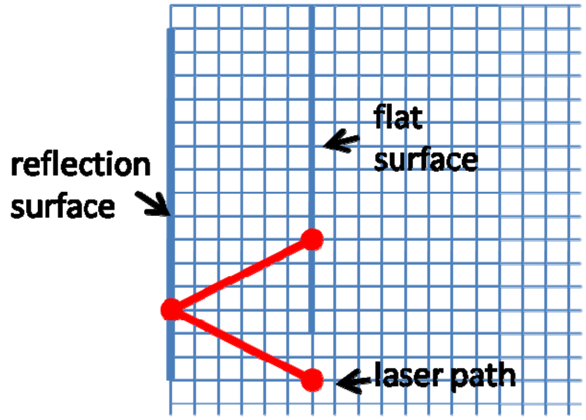
   Suggested questions: Where do you expect the laser to shine if I point it this way and turn it on? Why is this? In what direction does the light travel? What are some ways I can change the way it travels? How can I bend the light? If I point it in front of me, but want the laser light to end up behind me, what can I do? What if I just want to bend it a little?

3. **Student exploration/experiment with reflection**
   Goal: Students will gain an intuitive understanding of reflection.

   Give an empty refraction box (or another reflective surface, like a mirror) and laser to pairs of students. If you shine a laser at an empty box, most of the light will be transmitted through the walls, but some of it will be reflected. Let students explore this and solicit their observations about how the light is reflected.

The following experiment should help students quantify how light reflects:

a. Hand out the laminated graph paper.
b. Set up the reflective surface along the line on one side of your graph paper. (You can use the empty boxes as reflective surfaces if you line the flat side with a piece of paper to keep the light from transmitting into the box.)
c. Setup the laser so the laser beam starts at an intersection and points at the reflective surface. ***Note:*** *You will change the direction of the laser beam during the experiment, but the beam should always start from this intersection.*
d. Place a flat, opaque surface parallel to the reflective surface **but in line with the intersection from which the laser shines**. This will allow you to see where the laser goes after it reflects off the surface.
e. Draw the setup your graph paper.



After setting up the experiment, use the laser to test different angles of incidence and see how the light is reflected. The procedure is outlined below:

f. Shine the laser at the reflective surface and record on your drawing where the laser hits the surface.
g. Look at the flat surface in line with the tip of the laser and record where the laser beam was reflected.
h. Using these points, draw the path of light from the laser to the reflective surface to the opaque surface.
i. Repeat steps f-h for at least three different angles of incidence.

Suggested questions: What do you notice about how light is reflected? How does the reflection change as your angle of incidence changes?

4. Group discussion about reflection

Goal: Students will conclude that the angle of incidence equals the angle of reflection.

Engage the students in a discussion about their observations and results. Students should conclude that light reflects at the same angle from the normal as it hits, no matter the angle. You might have them use protractors to measure the angles. This is a good time to introduce vocabulary such as angle of incidence and angle of reflection, both of which are measured from the normal, an imaginary line perpendicular to the surface.

Reinforce the idea that a laser can be thought of as a stream of wavefronts, so the wavefronts themselves are reflecting. If you have the ability, you can show a video about wave reflection (see “Additional Resources” below).

Suggested questions: What did you notice about the way the laser light was reflected? How did the path of the light change when you changed the angle of the laser? Can you think of a rule to describe how the light was reflected?

5. Student exploration with refraction

Goal: Students will gain an intuitive understanding of refraction.

Now that we've discussed a way to turn light completely around, we're going to explore how to bend light. The following exploration and experiment follow roughly the same procedure as the reflection exploration and experiment. Instead of handing out the empty boxes, fill the boxes with a water and creamer solution or hand out Jell-O® squares. Let the students play with the lasers and Jell-O® for a few minutes, then solicit their observations about what happens to the laser light in the Jell-O®. Students should observe that the Jell-O® bends the light away from the path it would have taken if the Jell-O® hadn't been there.

Suggested questions: What did you observe when you shined the laser through the Jell-O® (or water and creamer mixture)? Where did you expect the light to go? Where did it go? Did it always bend the same way? What about when you changed the angle of incidence?

6. **Refraction experiment introduction**
   Goal: Students will be introduced to Snell's Law.

   If the students haven't already put forth the information themselves, introduce a name for this bending of light waves: refraction. Just like we talked about an angle of incidence and an angle of reflection, we can also talk about an angle of incidence and an angle of *refraction*. Just like the angles we talked about earlier, both of these are measured from the normal.

   Talk with the class about the relationship between these two angles, incidence and refraction. See if they have any ideas what the relationship is. If no one mentions it, ask if they've ever heard of Snell's Law. If someone has, they can explain it to the class.

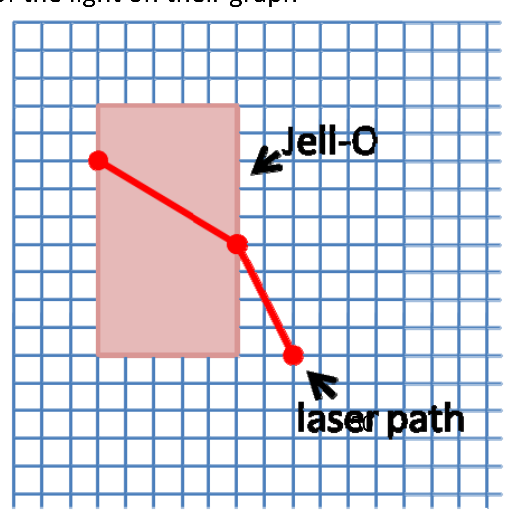
   Snell's Law is a mathematical relationship between the angle of incidence and the angle of refraction, given by , where the 1 subscripts refer to the medium the light is traveling in and the 2 subscripts refer to the medium the light will cross the boundary of and travel into. The number *n* is a property of a medium that tells us about how light travels through the medium. Everything that light travels through has an *n*, including air, water, and Jell-O®. The *n* for air is 1. In the next experiment, students will calculate the *n* of Jell-O®.

   Suggested questions: Do you think the relationship between the angle of incidence and angle of *refraction* is the same as the relationship between the angle of incidence and the angle of *reflection*? What do you think the relationship between angle of incidence and the angle of refraction is? Have you ever heard of Snell's Law?

7. **Student experiment with refraction**
   Goal: Students will use Snell's Law to calculate the index of refraction of Jell-O®.

   Just like the reflection experiment, students will sketch the path of the light on their graph paper.

   a. Set up the refracting medium (box with the creamer water solution or the Jell-O® square) in the middle of the laminated graph paper.
   b. Mark the location of the refracting medium on your graph paper.
   c. Set up the laser so the laser beam begins at a line intersection and is pointing at the refractive medium.
   d. Shine the laser at the refractive medium.



e. Mark where the laser beam hits the refractive medium on your own graph paper.
f. Mark where the laser beam leaves the refractive medium on your own graph paper.
g. Using these points, draw the path of the light from the laser to and through the refractive medium.
h. Use a protractor to measure the angle of incidence and the angle of refraction, making sure to measure them from the normal.
i. Record your angles in the table on your worksheet.
j. Repeat the procedure for 3-5 different angles.
k. Calculate the *n* for each set of angles and then average your results.

After they've found a value for *n* (we found a refractive index of 1.36 for Cherry Jell-O®), encourage them to compare their answers with other groups.

Suggested questions: What kind of values are you getting for the angles? What kind of values are you getting for *n*? Do these results seem logical? Why or why not?

8. **Group discussion/demonstration of refraction**
Goal: Students will understand that light refracts because the light changes speed in the second medium.

At this time, you can introduce the name for the *n* they just calculated: the index of refraction. It gives us an idea of how light will refract in a new medium. We actually have another way to calculate the index of refraction, which is $n = \frac{c}{v}$, where *c* is the speed of light in a vacuum and *v* is the velocity of light in the medium. Look at the values for *n* that they calculated and ask them to figure out what that must mean for *v* if *c* is always constant. Let them realize for themselves that since *n* is greater than 1, *v* must be less than the speed of light. This means the light actually travels slower in the Jell-O® than in the air. Let them ponder this for a little while, and then do the following demonstration.

For this, you need space for four students to walk abreast in the room. Designate a line in this area to represent the boundary between the air and the Jell-O® (or creamer mixture).

- Have four students line up in a row and hook arms. These students will be one wave front coming from our laser (Remind the students that at the beginning of the lesson we talked about a laser being a series of very small, focused wave fronts). They can all move individually, but what one does will affect all of them. When each person crosses over the line from air to Jell-O®, he or she should start walking a little bit slower. Remind the students that they have to keep a straight line at all times.
- Ask the line of students to walk from the "air" side of the line to the "Jell-O®" side of the line at an angle. As each individual student crosses the boundary and begins to walk slower, the line of students will change direction toward the normal. This provides a great visual illustration of refraction.

To see this activity in action, see video *Refraction_Demonstration* on the included CD.

Suggested questions: What do you think index of refraction means? Based on your values for *n*, what can you say about the velocity of the light wave in the Jell-O® (or water and creamer mixture)? Was your value for *n* greater than or less than 1? What does this mean for *v*, compared to *c*? What do you think will happen to our “laser wavefront” as it crosses the boundary? What did happen to it? Why?

Final Discussion
Estimated time: 5 minutes

Goal: Students will synthesize the information they learned in the lesson.

Begin a group discussion to review what students learned in the lesson, letting student’s responses lead you to the next question:

- What have you learned about light today?
- What did you learn about reflection?
- What did you learn about refraction?
- At the beginning of the lesson, we talked about the idea that you can think of light as a wave, specifically as a series of wavefronts. When does it make sense to use this description of light? What are the limitations? How else can we think about light?

Additional Resources

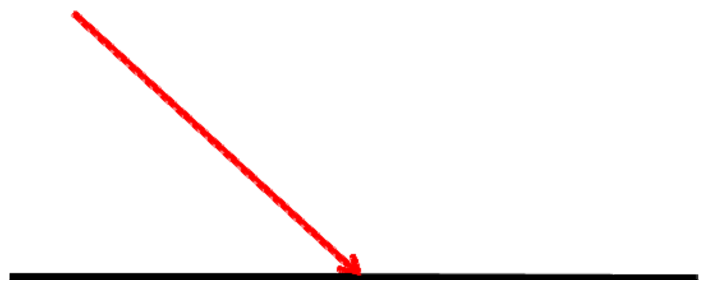
- Wikipedia page on Snell’s Law: http://en.wikipedia.org/wiki/Snell's_law
- Java simulation of wave reflection and refraction: http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=16
- HyperPhysics guide to plane wave reflection: http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/reflec2.html#c1
- Physics Classroom tutorial on reflection, refraction, and diffraction: http://www.glenbrook.k12.il.us/GBSSCI/PHYS/Class/waves/u10l3b.html
- A YouTube video exhibiting reflection with water waves: http://www.youtube.com/watch?v=8LrrWvfyqLo

Reflection and Refraction

Name: _______________________ Date: ________________

1. On a sheet of graph sheet, draw your reflective surface and mark where your laser beam begins. As you go through the experiment, draw the path of the light as it leaves the laser and reflects off the surface.

2. Draw the path of the reflected light and label the angles of incidence and reflection in the drawing below.



3. On a sheet of graph paper, draw your refraction medium. As you test different angles, draw the path of the laser on your graph paper. Measure the angles of incidence and refraction and record them in the table below.

Angle of Incidence	**Angle of Refraction**	**Calculated *n***
	Average calculated *n*:	

Rainbow Glasses

Every year the SOCK has included Rainbow Glasses and this year is no different! There are plenty of wonderful things that can be done using these glasses, which show the spectral components of any visible light source. The lenses in these glasses are diffraction gratings, with a line spacing of 4.5 microns in the horizon and vertical directions.

Theory tells us that for a given wavelength, maxima will occur according to $d \sin \theta = m\lambda$, where θ is the diffraction angle, *d* is the distance between slits, *m* is the order, and λ is the wavelength of incident light. Qualitatively, this means that the Rainbow Glasses bend longer wavelengths of light (ie. red light) at a greater angle than shorter wavelengths. This is illustrated in Figure 1, where you can see that the red maxima are father away from the light source than the blue. Note that this is opposite from a prism, which separates light into its component colors by dispersion. Red light passing through a prism will be bent less than blue light, as shown in Figure 2.

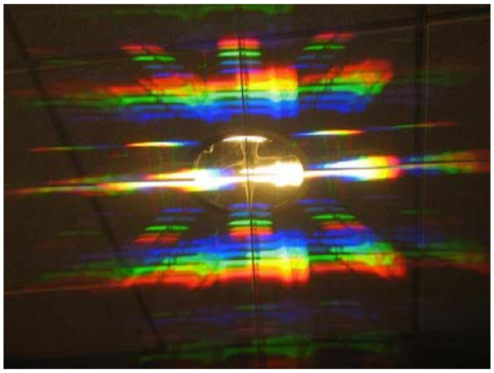


Figure 1: A light source as seen through Rainbow Glasses

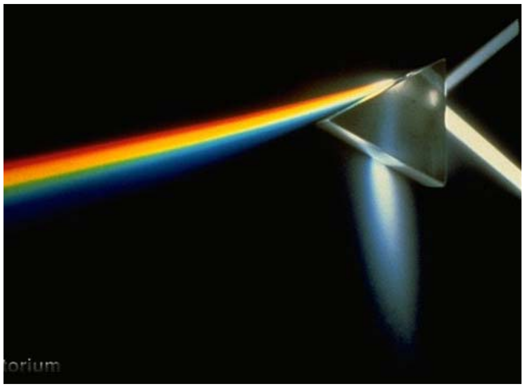


Figure 2: Light travelling through a prism. Image from The Exploratorium www.exploratoruim.edu

Outreach Activity

A favorite SPS activity is to have people put on the glasses and investigate the differences between different light sources, such as neon, mercury, LEDs, lasers (don't look directly into any light source!), and fluorescent bulbs. How are the rainbows different from one another? What does this mean? How could knowing the spectrum of an unknown light source help you identify the source?

The glasses are great for watching fireworks and looking at holiday lights too!

Related Demonstrations

We know that you don't always have the time, or the need, for a full lesson. Therefore, we have provided suggestions related to our lesson topics for short demos that you can do with students, within your own chapter, or wherever you need them. We suggest that you also look through the lessons when planning for the demos, because the lessons include related pictures and links to movies that will help clarify some of the setup and instructions.

Polarization

Make three large polarizers. Hold up one polarizer and have people predict what will happen to the light coming through it when you rotate the polarizer. Try this with light coming from a cell phone or reflecting off the floor. Then ask students to predict what will happen if you put another polarizer in front of the first one and rotate it. If you have older students, try three polarizers.

If you're doing this activity as a class with only one set-up, make sure you have a light source behind the polarizers—otherwise with a large group it may be difficult for everyone to see what's going on.

If you still have time, you can use the spring to demonstrate polarization. See the polarization lesson for instructions on this activity.

Sound

Play songs with the Boomwhackers®, while illustrating how the different pipes make different sounds. Not only will it be a lot of fun for you, but the kids will think that it is cool as well! Then let the kids play with the Boomwhackers® and explore the different sounds.

Similarly, you can give each of the students a musical straw and let them play for a few minutes. Then ask them to make observations about the sounds they produce.

Refraction & Reflection

-For a small scale demonstration, you can show refraction using a laser beam and a refracting medium. Fill the rectangular box partially full with a mixture of coffee creamer and water. Start by shining the laser across the empty top part of the box, perpendicular to the side of the container. Students should be able to see spots of light where the laser goes through the container.

Then, keeping the laser at the same angle, move it down so that it shines through the creamer mixture. The laser point will "jump" to a different spot because the creamer mixture refracts the beam.

-Total Internal Reflection is a key concept in fiber optic technology. Light entering a fiber optic cable at one end will reflect off the sides of the cable and come out the other end with very minimal loses. Light is completely reflected by an interface as long as the angle at which it is incident is greater than the critical angle of the interface, which depends on the refractive indices of the materials.

You can illustrate this concept with Jell-O®. Shine a laser pointer through a block of Jell-O®, perpendicular to the surface. Then, change the angle of the incoming laser beam. As you pass the critical angle, the laser beam will be completely reflected within the Jell-O®.

Lenses

You can also use Jell-O to show how light travels through lenses. First, cut a piece of Jell-O into a semicircle to act as the lens. Shine the laser beam into the Jell-O, perpendicular to the flat side of the semicircle, and then change the incident beam to illustrate the properties of lenses.

Construction Instructions

I. Polarizers

The polarizers in your kit were handmade with supplies easily available or included in the SOCK.

Supplies:

- Polarizing film (enough film is included to make 9 polarizers of this size)
- Cardboard
- X-Acto knife or other sharp hobby knife—Please be very careful!
- Tape

It is a good idea to have multiple people working on this because it can take up to an hour to make all of these the first time. We recommend using the following assembly line.

Have one person:

- Cut the film into 3”x4” sections (paper cutters work well).
- Measure out a 2.5’’ x 3.5’’ rectangle on a piece of cardboard, and then use the X-Acto knife to cut out the rectangle, leaving a “window” for the film.
- Trace the rectangular opening onto the remaining pieces of cardboard, and remove the middle sections.
- Tape the film on to the cardboard so that it covers the opening.

Alert! Be sure that all of the polarizers are oriented in the same direction and indicate that direction on the cardboard frames. In other words, people need to know when two polarizers are aligned. (This is why the enclosed set has anti-symmetric cardboard frames.)

II. Straws

The straw instruments in your kit were also made by hand.

Supplies:

- Two straws – one that fits snugly into the other.
- Sharp scissors

1. Cut a “V”, about 0.25” long in the end of a skinny straw. Make sure the “V” comes to a point, otherwise it won’t vibrate properly. Make sure the cut is even and smooth. You don’t want the kids to cut themselves!

The reed end of the instrument is the end that students will put in their mouths. The bigger straw then slides over the other end of the skinny straw, so that you can adjust the total length of the instrument by moving it up and down

III. Boomwhackers®

Since Boomwhackers® are expensive and it is a good idea to have more than one set, we have included instructions on how you can make your own. We have not actually attempted this, but it was suggested to us at the 2008 American Association of Physics Teachers Summer Meeting. We found these instructions online, http://alornecassidyes.ocdsb.ca/smith/teacher/boomwhackers.pdf.

Supplies

- 9 golf club tubes –Black, white, or clear plastic tubes about 34" long with a diameter of about 1.25". You can get them at Walmart for about $0.65 each.
- 8 different colors of tape, or another way to color the tubes.
- A tool to cut the tubes, such as a radial arm saw, sharp scissors, an electric knife, or a hack saw.

1. Cut the golf tubes slowly and carefully to the lengths given below. The end needs to be very straight and even.

   -Two G's can be cut from one tube (with little waste)
   -D and high C can be cut from one tube (exactly)
   -E and A can be cut from the same tube (exactly)
   -F and B can be cut from the same tube
   -Low C takes one tube and the other part is waste.

Note	Length (cm)	Color
C	62.9	Red
D	55.9	Orange
E	49.5	Yellow
F	46.5	Light Green
G	41.1	Dark Green
A	36.4	Purple
B	32.1	Fuchsia
C	30.2	Red

2. Wrap wide colored tape on the ends—a different color for each note. Write the name of the note on the tape in permanent marker.

Alert! It is important to use these exact colors given for your tubes if you plan to use them with the Boomwhackers® that came in the SOCK and the sheet music provided in the User's Manual.

IV. Graph Paper

The graph paper in the SOCK was printed free from http://incompetech.com/graphpaper/plain/ and laminated. If you are placing the Jell-O® directly on the paper, it must be laminated if you want to move or reuse the paper.

V. PVC Pipes

The tension rods used in the polarization lessons need to be supplemented with other poles. We suggest using PVC pipe, which isn't very expensive. The poles need to be about 5 feet long and can be purchase from any home improvement or hardware store.

Vendor List

This list is meant to be a starting point for people that want to expand or create their own SOCK. This is not an exhaustive list and SPS does not endorse any of the vendors.

Item	Source	Estimated Price
6 foot spring	Arbor Scientific http://www.arborsci.com/ "Snaky Helical Spring" Item #33-0140	$14.00
Polarized film	Alight http://polarization.com/ linear polarizer film	$15.00/foot (you can only buy it quantities of 2 feet or more)
Boomwhackers® (C Major diatonic set)	Musical Instrument Haven http://www.musicalinstrumenthaven.com	$18.74/set
Polarized sunglasses	Various	$10.00
Rectangular refraction box	Physlink.com http://physlink.com Item #11023	$4.95
Semicircular refraction box	Home Science Tools http://www.hometrainingtools.com Item #OP-REFRAC3	$2.75
Laser pointer	The Laser Guy http://thelaserguy.store.yahoo.net	$8.50
Tension rod	Polsteins Home and Beyond http://homeandbeyond.com	$3.10/rod
Straws	Local grocery store	About $200/pack of 100
Graph paper	http://incompetech.com/graphpaper/plain/	free
Jell-O®	Local grocery store	$0.99
Rainbow Glasses	SPS National http://www.spsnational.org/about/merchandise.htm	$30.00/pack of 20

Makin' Waves

The SPS Outreach Catalyst Kit Survey, 2008-09

Please return completed form to SPS, One Physics Ellipse, College Park, MD 20740, sps@aip.org

Academic Institution:

Contact person and email address:

1. Please provide a brief description of the outreach activities held by your chapter this academic year. What topics were covered in these activities? About how many people participated in each activity?

2. Has your club performed outreach events in the past?
    - Yes
    - No

3. What age group does your chapter typically target when doing outreach events?
    - K-12
    - K-5
    - 6-8
    - 9-12
    - Collegiate
    - General Community
    - Other:

4. Please indicate the items that you used from the 2008 SOCK for an outreach or chapter activity.
    - Boomwhackers®
    - Jello-O®
    - Graph Paper
    - Laser Pointer
    - Musical Straws
    - Polarized Film
    - Polarized Sunglasses
    - Refraction Boxes
    - Resource CD
    - Spring
    - Tension Rods

5. Did you use any of the lesson plans in the User's Manual? If "yes", which ones in particular and how were they employed? If "no", were the lessons plans helpful in providing a guide to putting together an outreach activity?

6. Please indicate the sections in the User Manual that you considered most useful.

- Planning an Outreach Activity
- Science Education Standards
- Related Demonstrations
- Instructional Videos
- Polarization Lesson
- Sound Lesson
- Reflection/Refraction Lesson
- Cheat Sheets
- Worksheets
- Construction Details
- Vendor List

Comments:

7. Did you open the SOCK at SPS chapter meeting?
   - Yes
   - No

   If yes, how many people were present? Was your SPS adviser present?

   If yes, what was your SPS chapter's first reaction to the SOCK? Tell us what you did…For example did you try any of the demonstrations or play with any of the materials? What did people say?

8. What are topics or lessons would you like to see included in a future SOCK?

Additional Comments or Suggestions:

Thank you for taking an interest in public outreach programs and for taking the time to complete this survey. Your input is an invaluable measure of the effective use of this outreach kit and your opinions and suggestions are greatly appreciated.
Sincerely,
Mary Mills & Jenna Smith, 2008 SPS Outreach Catalyst Kit Developers