SOCIETY OF PHYSICS STUDENTS SOCK

Science Outreach Catalyst Kit

2009-10
Rolling with LaserFest

LASERFEST
CELEBRATING 50 YEARS OF LASER INNOVATION
WWW.LASERFEST.ORG

The 2010 SPS SOCK

Dear SOCK Recipient,

Congratulations on taking this step toward building a successful outreach program – receiving the SPS Science Outreach Catalyst Kit. 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 event.

To get you started we have enclosed materials for three lessons. These items and lessons are a starting point. We encourage you to try out the activities in the kit, and then come up with your own additions and modifications. We just ask that you turn in your report and complete a SOCK Survey after your event so that we can make the next SOCK even better.

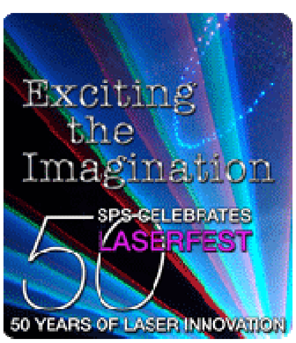
SPS National and the 2009 & 2010 Summer SPS SOCK interns thank you for taking part in this project. Have fun exploring and modifying the lessons to suit your outreach programs. If you have any questions or comments please feel free to contact us at sps@aip.org.

Good luck on all of your outreach events!

Sincerely,

2010 Interns
Jasdeep Maggo, East Carolina University
Patrick Haddox, University of IL at Urbana-Champaign

2009 Interns
Mary Elizabeth Mills, The College of Wooster
Scott Stacy, Texas Christian University
Erika Watkins, Chicago State University



LaserFest

In January, 2010, we set off on a yearlong celebration – the 50th anniversary of the invention of the laser. The Society of Physics Students (SPS) has joined in this effort by selecting as its 2010 theme *Exciting the Imagination*. This theme was chosen by the 2009 SPS National Council for its holistic, yet simple message: That while the laser is unarguably the tangible product of human minds, it was the imagination (and dedication) of its creators that brought it into being. SPS is proud to lend its voice to those who celebrate our past and look forward to our future.

Kit Contents

On a Roll
9 Pairs of rolling objects:

- Small metal cylinder & sharpie
- Large metal cylinder & rubber ball
- Ping pong ball & golf ball
- Golf ball & tennis ball
- Ping pong ball & small rubber ball
- Small pvc pipe filled & empty
- Large pvc pipe & wooden cylinder
- Cans of cream of chicken soup & chicken broth
- Water bottle & bottle of gravel

Celebrating Lasers

- Green & red laser pointers
- White, red, green, and blue LEDs
- Fiber optic cable
- Rainbow glasses
- Binder clips (4)
- Spectra Sound kit with batteries
- Amplified speaker with 9V battery
- Comb
- Clay

Building a Galileoscope

- Galileoscope kit (2)
- Tripod (1)
- Galileoscope Activity Guide

Posters

- "Making Waves – Discover Science" poster series, courtesy of the Optical Society of America and The Acoustical Society of America
- "Gravitational Waves" poster, courtesy of the American Physical Society and the Laser Interferometer Gravitational-Wave Observatory (LIGO)
- "Why Physics" poster, courtesy of the American Association of Physics Teachers, the American Physical Society, and ComPADRE (the physics and astronomy digital library)
- "Nobel Prize 2009 in Physics" poster, printing and distribution made possible by Volvo

The Story 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.

2001 *Rainbow Suite e*xplored different properties of rainbows. Created by Mark Lentz.

2002 *Dimensions in Physics* explored geometry in a variety of settings. Created by Lauren Glas and Jason Tabeling.

2003 *Spanning Space* brought in the first experimental component with a nation-wide cylinder dropping experiment. Created by Stacey Sude and Ashley Smith.

2005 *The World Year of Physics 2005* celebrated Einstein's accomplishments and included an experiment to measure the speed of light. Created by Heather Lunn and Matthew Shanks (2004) and Morgan Halfhill and Rebecca Keith (2005).

2006 *Absolute Zero* centered on the effects of temperature and it coincided with the *Absolute Zero and the Conquest of Cold* campaign. Created by by Katherine Zaunbrecher and Jackie Michalek.

2007 *Motion and Collisions* had many experiments, including the ever popular Diet Coke and Mentos reactions. Created by Justin Reeder and Ryan Field.

2008 *Makin' Waves* included a giant slinky and lessons on polarization, sound, and reflection/refraction. Created by Mary Mills and Jenna Smith.

2010 *Rolling with LaserFest* includes activities related to rolling objects and optics. In celebration of the 50^{th} anniversary of the laser, the kit includes a new lesson on the difference between LEDs and lasers. Another popular item is the Galileoscope, a kit for building a refracting telescope modeled after Galileo's first telescope. Created by Mary Mills, Scott Stacy and Erica Watkins (2009), Jasdeep Maggo and Patrick Haddox (2010).

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.

What's so special about the laser?

A guide for taking LaserFest into the classroom.

SPS

Developed by 2010 SPS SOCK interns
Patrick Haddox & Jasdeep Maggo.
www.spsnational.org

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Activity 1: Exploring laser light

Students view various light sources, with and without diffraction glasses, to see the different rainbows (visible spectra) they create. By looking at reflected light from laser pointers, students explore how laser light is different from other kinds of light.

Objectives

- Learn to identify the colors that make up a particular light source using diffraction glasses
- Recognize that all light sources produce rainbows with colors in a specific order
- Determine the difference between "regular" light and laser light
- Introduce the concept of the wavelike behavior of light (see appendix)
- Introduce the phenomenon of the interference of light waves

Materials Included

- Laser pointer
- White, red, and blue LEDs (Light-Emitting Diodes)
- Three binder clips
- Rainbow diffraction glasses

Materials Needed

- Tape
- Large piece of cardboard (approximately 1x2 feet or so)

Advanced Preparation

- Bend the cardboard into a tri-fold, as shown in the picture.
- Remove the chains from the white, red, and blue LEDs and attach a binder clip to each as shown below.
- Tape the LEDs vertically (in a stoplight arrangement) to the cardboard, as shown. This will be referred to as the "light board" for the rest of this activity.

In the Classroom:

WARNING

Lasers can cause serious damage to one's eyesight. **Do not look directly into any laser beam and do not shine one at any student's eyes or onto shiny reflective surfaces.** Do not allow children to use a laser pointer unless supervised by a responsible adult. In particular, the laser pointers used in these activities are less than 5 mW and are class IIIA---dangerous, but safe if used properly.

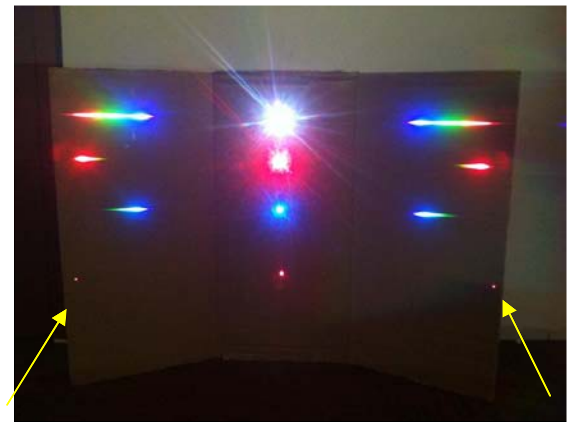
1. Have each student put on a pair of rainbow glasses (make sure to have yours on too!). Many blurry rainbows are likely to be visible from the myriad light sources around the room. Dim or turn off the room lights and shut the blinds on the windows if possible.

2. Place the light board at the front of the room and turn on the white LED. Ask the students what they see through the glasses. The LED's white light should now be flanked by rainbow "fringes" on either side. Clarify that white light contains all of the colors of the visible spectrum (or Newton's famous 7 colors known by ROY G BIV). Note that in India the acronym is memorized as VIBGYOR!

3. Ask for predictions of what will happen when a red LED is turned on, and then turn on the red LED. Notice it contains red, orange, and yellow light and that they appear directly under the corresponding colors in the white LED fringes.

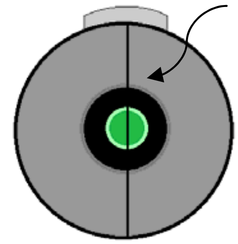
4. Repeat with the blue LED and notice the (mostly) blue, green, and violet colors.

5. Now ask for predictions of what will appear when one shines a red laser just below the other three lights. Upon doing so, show that the laser's rainbow is only one color and appears as a single dot (as indicated by the arrows in the photo; the dot is very dim in the photo), as opposed to a "smear" of colors from the LEDs. **Note: Do not shine the laser at the students, stand behind them and shine it onto the cardboard so they can see the diffuse reflection off of the light board.**



6. Shine the laser pointer directly on top of the other LEDs central spots to show that it appears in the red part of the spectrum on each. **Conclusion: lasers produce a single color of light.**

Activity 2: Measuring a hair's width with lasers



Put a single hair in the path of the laser beam and students can view the diffraction pattern produced by the hair. This activity allows for comparative measurements of hairs' widths; if one desires to estimate the numerical value for the width of the hairs from the fringe spacing, see the Appendix.

Objectives

- Show that small objects, like a strand of hair, can cause light to diffract around it and this makes a distinctive "fringe" pattern.
- Help students recognize that the spacing between the fringes reveals the comparative size of the object in the path of the beam
- Show that lasers can be used for practical things, like measuring the size of small objects.
- Introduce the concept of the wavelike behavior of light (see appendix)
- Introduce the phenomenon of the interference of light waves

Materials Included

- Red laser pointer (the activity also works well with a green laser, which is used in the images)

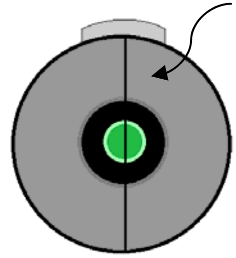
Material Needed

- Tape
- Clay
- A strand of hair from a volunteer or leader

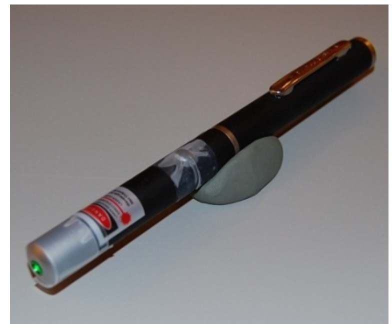
Warning:

Lasers can cause serious damage to one's eyesight. **Do not look directly into any laser beam and do not shine one at any student's eyes or onto shiny reflective surfaces.** Do not allow children to use a laser pointer unless supervised by a responsible adult. In particular, laser pointers used in these activities are less than 5 mW and are class IIIA---dangerous, but safe if used properly.

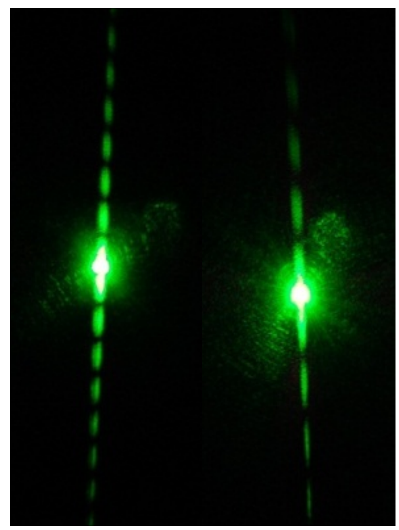
In the Classroom:



1. Obtain a piece of hair at least 1-inch long and place it across the center of the hole at the end of the green laser **while the laser is turned off** (see the drawing looking down the barrel of the laser shown at right). Then tape it down on the sides of the laser to hold it in place. When done, the hair should be secured at the end of the laser through the center of the beam.



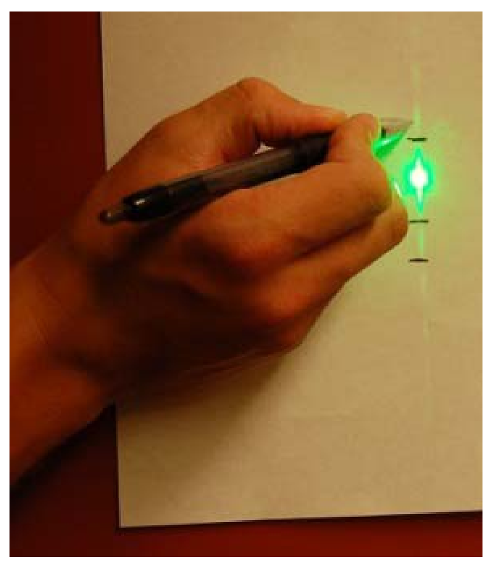
2. Tape the button on the laser down and use some clay to secure the laser in place such that when the laser light is viewed on a distant wall, it has a vertical or horizontal diffraction “fringe” pattern. Dim the lights, if possible. Vertical patterns from two different hairs are shown to the right.



3. Tape a piece of white paper to a somewhat dark wall such that the laser setup can be aimed at its center.

4. Aim the laser at the paper to reveal the diffraction pattern on the paper. Take note of the color of the hair and the spacing between the fringes. The purpose of this exercise is to show how the laser can be used to measure small things, but depending on the class’s level of understanding of light and waves, you may want to remark upon what is causing the pattern. In particular, note that when the hair is horizontally oriented, the fringe pattern is vertical, and vice versa.

5. Mark the centers of the first few dark spots on the paper.



6. Repeat steps 4 and 5 with several different color hairs to demonstrate the relationship between hair color and hair thickness. Dark hairs are generally thicker, and therefore they will have a finer diffraction pattern. ***You may want to skip drawing on the paper and just use two lasers simultaneously to compare two different hairs if you happen to have another laser with the <u>same wavelength</u>.***

7. Note that often lasers are used in this manner for quality control in measuring the thickness of wires as they are manufactured.

Going Farther, Making an Actual Measurement of a Hair:

1. Measure the distance from the hair to the paper on which the “fringes” appear and record this distance as D.

2. Without moving the laser or the paper, mark the center of the central bright spot on the paper. Now, mark the center of the first 4 dark spots on the upper side of the pattern. Note: using both sides could be boring and redundant, but will give a better measurement.

3. Remove the paper from the wall. Using a ruler, measure the distance from the center to the first dark spot, and record this as y_1. Measure the distance from the center of the first dark spot to the center of the second dark spot, and record this as y_2. Repeat for the remaining dark spots.

4. Average the values for y and calculate the diameter using the formula in the appendix.

Activity 3: Transmitting sound with a laser

Rewire the red laser pointer so that it can send a music signal across the room to be detected by a solar cell, which in turn can drive a speaker to hear the music.

Objectives

- Demonstrate that a laser light signal can carry the information needed to produce music
- Introduce some basic elements of electronics: batteries, solar cells, circuits.
- Show that lasers can be used for practical things like communication through a fun example.

Materials included

- Red laser pointer
- Spectra Sound kit
- Amplified Speaker
- Fiber optic cable
- Comb

Material Needed

- Clay
- Tape
- Music player (like an MP3 player)

Advance preparation

- Follow the directions provided in the Spectra Sound kit to set it up. Note: Pay special attention to steps 3-6 instead of relying on the circuit diagram alone.
- Plug the solar cell into the speaker and tape it to a side of the speaker with the "blue" side of the cell facing out.
- Use the clay to properly align the laser to hit the solar cell.
- The setup should look like the pictures on the next page. Note: this kit was soldered together instead of using the B connectors provided.

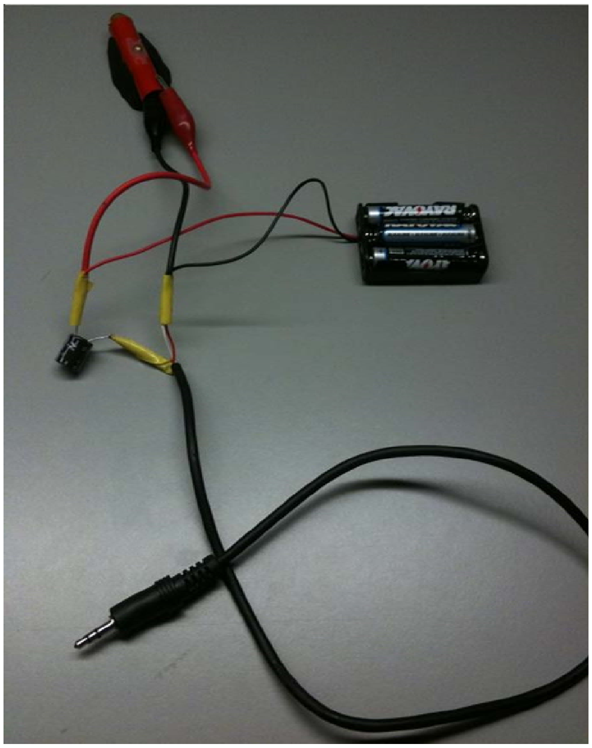
Prefacing Remarks

Another use for lasers is transferring the sound signal from a music player to speakers. This may be done with a little simple, but clever, wiring. The concept is to have a solar cell pick up the small changes in intensity from the laser when it's modified by a music signal, and have them amplified with a speaker. When the laser is incident on the solar cell, a constant voltage is produced and no sound is heard (other than the sound produced when the laser initially hits the cell). However, when the laser is wired in parallel with a capacitor and a music player as shown in the Spectra Sound kit, the intensity of the laser varies slightly according to the signal sent out by the music player. This same signal is then picked up by the solar cell and amplified by the speaker for surprisingly good results.

Blocking and unblocking the laser results in large voltage changes through the speaker which create a somewhat loud sound every time the laser hits the cell. Doing this fast enough (by using the comb provided) can result in different pitches and effects. The laser may also be reflected off of mirrors or other surfaces to reach the solar cell without disturbing the signal. It may even be sent through the piece of fiber optic cable provided to arrive at the solar cell. In this situation, the light undergoes total internal reflection through the cable until it reaches the other end and comes out.

In the photo at left below, we show the speaker with a solar cell input (taped to front of speaker at lower right of photo).

In the photo at right below we show a red laser pointer (at the top of the photo), wired with a capacitor, batteries, and a jack to be plugged into your favorite music source. The idea is to shine the laser pointer on the solar cell so that you can hear the sound from your player emitted from the speaker across the room—music carried by the light fantastic!



Warning:

Lasers can cause serious damage to one's eyesight. **Do not look directly into any laser beam and do not shine one at any student's eyes or onto shiny reflective surfaces.** Do not allow children to use a laser pointer unless supervised by a responsible adult. In particular, the laser pointers used in these activities are less than 5 mW and are class IIIA---dangerous, but safe if used properly.

In the Classroom:

- Comment on how lasers are used in everyday life: fiber optics, transmitting signals for internet and cable, etc.

- With the speaker turned on and the Spectra Sound kit set up, play some class appropriate music and talk about what is happening. Or, you may want to leave the source of the music a mystery and ask a volunteer to sit in a cleverly placed chair, so that when the student sits down he/she will block the laser beam and cause the music to stop**. Note: Do not have the student sit such that the laser could hit his/her face**. Ask the student to stand up and the music plays again (repeat if necessary). See if anyone can guess what is happening.

- Block the laser with your hand to show that the music turns off and angle your hand so that everyone can see the spot from the laser. Chalk dust or dry ice vapors are also good for revealing the path of the laser beam.

- Move the comb through the laser to create different sound effects, and encourage students to try it themselves. Moving the entire comb back and forth very fast through the laser makes some pretty cool sounds.

- Put the speaker behind or above the laser and use the fiber optic cable to bend the light back to the solar cell, so that the music starts again. Relate this to data transfer used in everyday life.

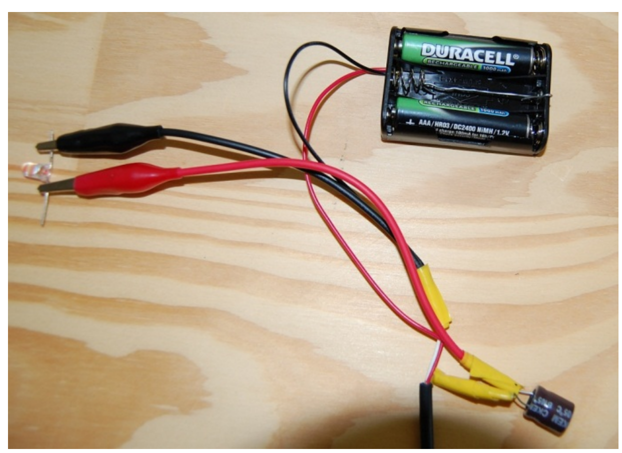
Extra Demonstrations with Spectra Sound:

1. Let students predict what will happen when you…
    - Place a bottle of water between the laser and the solar cell?
    - Reflect the laser off a piece of white paper and onto the solar cell?
    - Put a piece of hair in front of the laser and shine the diffraction pattern on the solar cell?

    In all cases the music should still play just fine. This is because the solar cell only picks up the changes in intensity of the light, and is not affected by different patterns and interference. This may be shown with the next step.

1. Take the LED out of a keychain light and remove the batteries from the Spectra Sound kit. Attach the black alligator clip to the short lead of the LED and the red alligator clip to the longer lead. Since the LED only uses 3V, short one pair of battery terminals with a wire or piece of solder. O**nly use 2 AAA batteries** (2 x 1.5V = 3V).

    Use the new setup as you did with the laser and note that it still works (when within range). Move the LED very close to the solar cell and then back it away. The advantage of a laser is that you can transmit the signal from close range or much farther away without disturbing the signal.

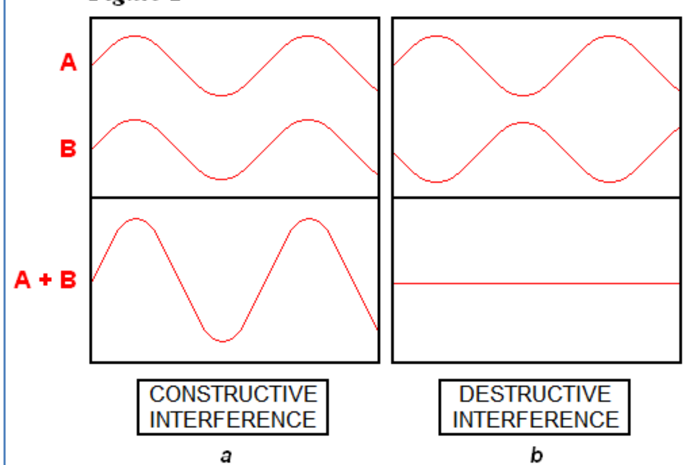


Appendix: Introduction to light as a wave

As you might know, light acts as a wave in many settings. Certain waves, such as the light waves produced by lasers, are considered **coherent**. Generally speaking, this means that all of the light waves in a laser beam have nearly the same wavelength, are approximately in phase with each other, and have nearly the same direction of propagation (though there are exceptions).* The light produced by a light bulb or the Sun is not coherent, as it is made up of light waves that contain several different wavelengths (thus, they exhibit rainbows), that are not in phase, and that are not limited to a small set of directions. For example, the light from the white LED (Light-Emitting Diode) provided to you in this kit contains all the wavelengths (colors) of the visible spectrum. As a side note, you might be interested to know that the word "laser" is an acronym: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

Two light waves that are coherent may interfere with each other either constructively or destructively when they overlap. Constructive interference occurs when the two waves are in phase with one another, producing a wave with larger amplitude than either individual wave (shown in Figure 1a). Destructive interference occurs when the two are out of phase and a wave with smaller (or even zero) amplitude is produced (Figure 1b).

Figure 1

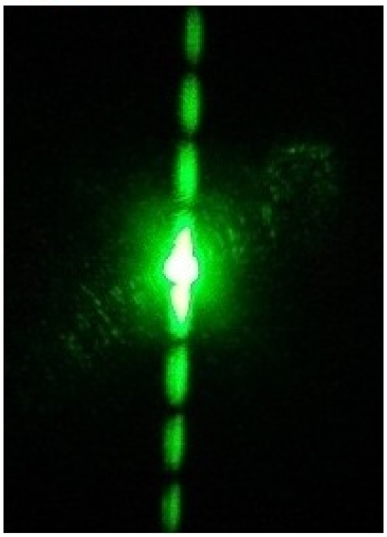


http://www.vectorsite.net/tpecp_11.html

An interference pattern is created when a coherent light source, such as a laser, is incident on a narrow slit of width *d* (narrow, but still many times larger than the light's wavelength).

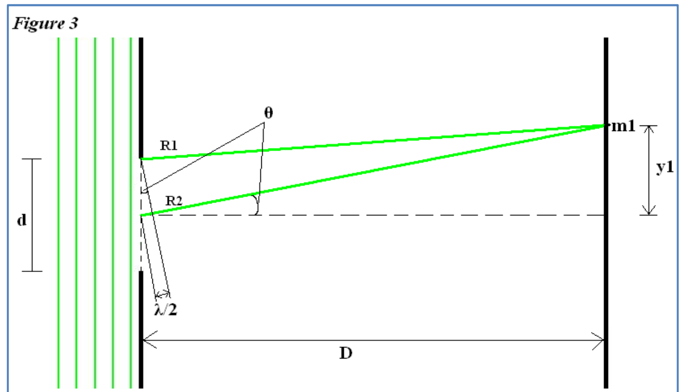
This pattern can be observed by placing a screen at a set distance *D* behind the slit. A horizontally-oriented slit with a laser beam incident will produce a central bright dot on the screen along with vertically-oriented, alternating bright and dark spots above and below it, shown in Figure 2. These bright spots are known as fringes.

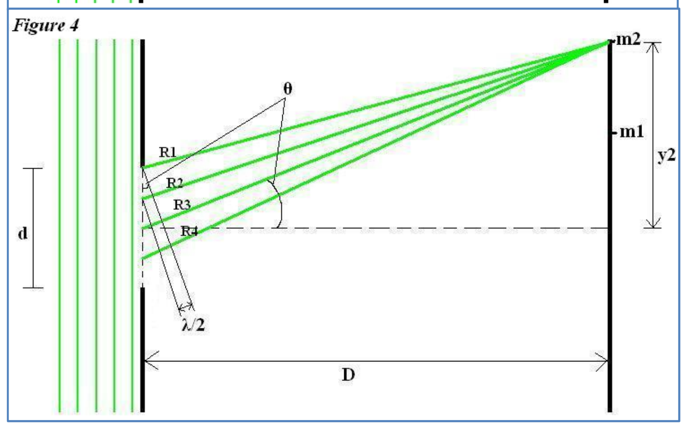
Figure 2



*For a contrasting experts' view about what lasers are, check out the talk by Warren S. Warren of Duke University at the 2010 Summer Meeting of the American Association of Physics Teachers. Start at the 5:30 mark, www.ustream.tv/recorded/8382372.

At the dark spots, or minima, destructive interference is occurring. This means that at a dark spot, each ray (R) shown in Figure 3 must be canceled out by another that is 180° out of phase. For this to happen, the second ray's path to the screen must be an odd integral number of *half wavelengths* longer (or shorter) than the first ray's path. So when the origins of two rays are separated by $d/2$ and with the assumption $D >> d$, the path of ray R_2 is one half wavelength longer than the path of ray R_1 and this results in a minimum at point $\mathbf{m_1}$. So the condition is as follows:





$$\frac{d}{2}sin\theta = \frac{\lambda}{2} \text{ or } dsin\theta = \lambda \qquad (1)$$

where λ is the wavelength.

Similarly, in Figure 4 when the rays are separated by $d/4$, the path of ray R_2 is one half wavelength longer than the path of ray R_1 and results in a minimum at $\mathbf{m_2}$. So, the condition is:

$$\frac{d}{4}sin\theta = \frac{\lambda}{2} \text{ or } dsin\theta = 2\lambda \qquad (2)$$

Note that this differs from Eq. 1 by just a coefficient of 2. Had there been 6 rays drawn, the coefficient that would correspond to the 3rd minimum would have been 3, and so on. Now let the path length of a ray be L. Since $D >> y$ for this experiment, $L \approx D$ and therefore $\sin\theta \approx y / D$. So, generalizing the previous 2 equations, the distance from the central bright spot to the next minimum is given by:

$$y_m = \frac{\lambda D}{d} m \qquad (3)$$

where m corresponds to the fringe number (1st: m=1, 2nd: m=2, etc.). Since all the minima will be equidistant from one another, one may just use m=1 and average the distances between the adjacent minima.

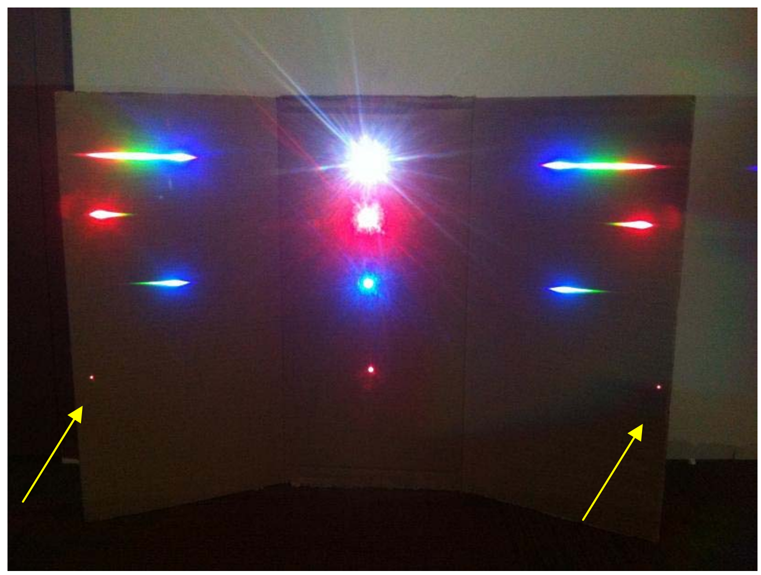
Interestingly, using the "negative" of this experiment (a narrow barrier instead of a slit) produces similar results, at least in the region away from the bright central spot. This is known as *Babinet's Principle* and may be referenced in a number of popular textbooks. A human hair works very well for this barrier. The diameter of the hair would correspond with the distance d. As stated earlier, one would then find the diameter of a hair by averaging the distances between adjacent minima on the interference pattern displayed on the screen. This averaged number would correspond to $\boldsymbol{y_1}$. Now the diameter of the hair may be calculated by rearranging Eq. 3 (with m=1) as:

$$d = \frac{\lambda D}{y_1} \qquad (4)$$

The wavelength of the green laser pointer is about 532x10^{-9} meters, while the red laser has $\lambda \sim$ 660x10^{-9} meters. It can be seen from Eq. 3 that a hair with a smaller diameter will produce more widely separated fringes. Likewise, thicker hair will produce more closely spaced fringes. It turns out that hair color generally corresponds with hair thickness, with lighter hairs being thin and darker hairs being thick. Qualitatively, this can clearly be observed from the activity when different colors of hair are used.

The diffraction glasses used in this activity create a similar interference pattern. The diffraction in this case, however, is due to multiple slits instead just a single slit. In fact, these glasses have hundreds of tiny, closely-spaced, vertical scratches that act as slits (500 lines per millimeter). Thus when shining a laser through the glasses onto a far screen, one sees bright fringes oriented horizontally that are spaced much further apart than in the single-slit case (see the two tiny dots indicated by the arrows at the bottom of the figure below). Other higher order interference fringes from the laser are not seen because they are outside the boundary of the photo (and likely too small and dim, anyway).

The picture at right was snapped with one lens of the rainbow glasses covering the camera lens, so the image duplicates what is seen when looking at the light sources through the rainbow glasses. The image shows four light sources arranged vertically down the center of the picture, along with the interference patterns produced on either side of each of the four light sources. At the top center is the central spot from a white LED, beneath that is the central spot of a red LED, then the central spot from a blue LED, and at the bottom is a dim dot of light from a laser pointer someone is shining on the screen.



When white light (with many different wavelengths) is incident on the rainbow glasses, as in the top center of the photo, the result is a similar set of bright spots or interference fringes. Since each wavelength of light is diffracted at different angles, when viewed through the glasses each color of light produces its own fringe, with the blue fringe appearing somewhat closer to the central spot than green or red, which accounts for the rainbow effect. Note that the red LED produces a smear of red and orange-ish colors, and the blue LED a smear of blue and greenish colors, while the red laser dot produces essentially a single dot of red color. Note also that the colored fringes from each source are aligned vertically on each side of the central spots—red with red, blue with blue, etc. The red laser pointer is thus seen to be different from the red LED in that its spectrum only includes a small window of red light (single-frequency), while the red LED is seen in the photo to have a much broader spread of red and orange-ish colors.

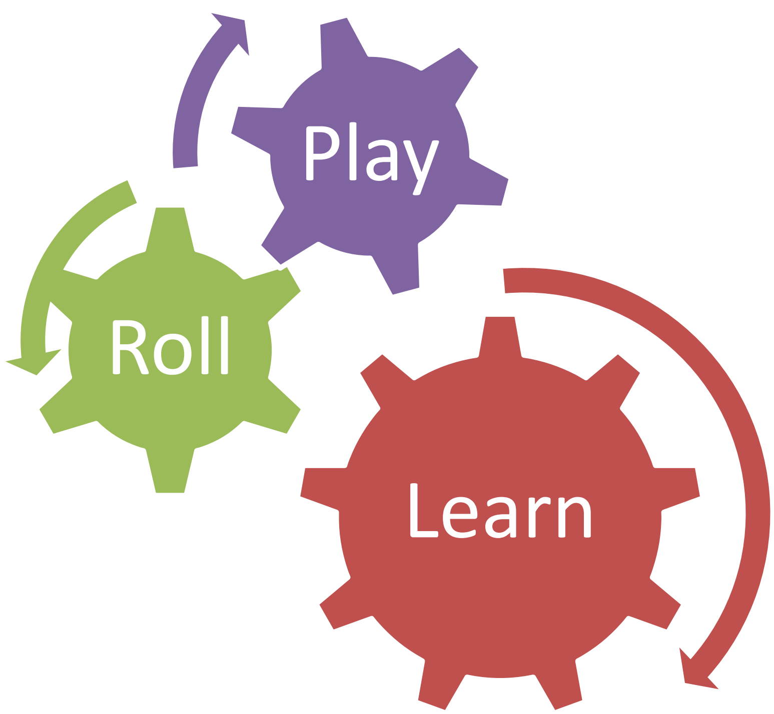
SPS on a Roll

Which will roll down a hill faster…

A can of Dr. Pepper or a bowling ball?

A marble or a bike tire?

A can of chicken broth or cream of chicken soup?



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Speedsters and Crawlers

Students roll pairs of items down a ramp and categorize objects as "speedsters" or "crawlers". Then they explore the similarities between the objects in the two categories to see what factors affect how fast an object rolls.

Estimated time: 20-30 minutes

Objectives:

- Engaging students in physics through a fun activity.
- Helping students see the connections between an object's properties and how fast it rolls.
- Exploring student predictions about factors that affect the speed of a rolling object.

Materials Included:

- Nine pairs of rolling objects
    - Type 1 (solids only):
        - Small metal cylinder & sharpie
        - Large metal cylinder & rubber ball
        - Ping pong ball & golf ball
        - Golf ball & tennis ball
        - Ping pong ball & small rubber ball
        - Small pvc pipe filled & empty
        - Large pvc pipe & wooden cylinder
    - Type 2 (involves liquid):
        - Cans of cream of chicken soup & chicken broth
        - Water bottle & bottle of gravel

Materials Needed:

- A ramp (we used a long board propped up on one end)
- A small board at least the width of the ramp (called "release board" in the rest of the lesson)
- Water

Advance Preparation:

- Set up the ramp and draw a starting and finishing line, as shown in the picture.
- On a large poster board, make a table with two columns: *Speedsters* and *Crawlers*.
- Fill one of the small PVC pipes with play-doh and the empty water bottle with water.
- Make copies of the handout if you decide to distribute them.

In the Classroom:

Note: We suggest designating a "roller" and a "catcher" for each of the pairs, and rotating through these positions until everyone in the group has had a chance.

Rolling Technique
Place the release board directly on top of the starting line as shown in the picture. Rest the two rolling objects against the back of the board. To release the objects, in one fluid motion move the board forward (toward the finish line) and up. If you pull the board directly up, smaller objects will have an advantage.

1. Select a student and have him/her choose a **type 1** pair of objects.

2. Let the student feel the objects, and then ask the student to predict which of the objects is a "speedster" and which is a "crawler."

3. Have the students vote on their predictions.

4. Roll the objects and discuss the results with the group.
    Which object was the crawler? The speedster?
    Why do think this one was the speedster?

5. Record the results in the Speedster/Crawler table.

6. Repeat steps 1-5 until you have rolled all of the type 1 pairs.

7. When the type 1 items have all been rolled, discuss the similarities among the speedsters and the crawlers, and, if necessary, lead students to notice that the speedsters are all solid and the crawlers are all hollow.
    Is the heavier/lighter/smaller/larger object always the speedster?

8. Next, repeat steps 1-5 with the type 2 pairs, first with the two bottles and then with the broth/soup pair. These should initiate new predictions and discussions, as we are now introducing liquids into the activity. Point out that as the liquid-filled bottle is rolling the bubble stays at the top. This indicates that the water is not rotating with the bottle, which is a clue as to why it is a speedster.

9. (optional) As a finale, we like to bring out a bowling ball and 2-liter bottle of pop (or soda…). Students invariably predict that the bowling ball will win, despite step 8.

10. Wrap up the discussion by summarizing the main points (see below), and encouraging students to further explore the science of rolling at home using the handouts provided (page 8).

Key Observations and Results:

- Hollow objects roll slower than solid objects.
- Objects filled with liquids roll even faster than solid objects.
- Objects with thin liquids roll faster than objects with thick liquids.

Important Notes for SPS Members:

- Review the science behind rolling (page 5) and decide the level of explanation appropriate for your participants. We have used this activity with students as young as 5 years old and with adults—all are engaged. For example, you might discuss conservation of energy using terms like potential, rotational, and kinetic energy with high school students, but not even bring up the term "conservation of energy" with 5 year olds.

- Make sure that you focus the activity on the science, as students may get distracted with the activity itself. The activity should be presented as a **fun method of learning science and not as a competition regarding whose object will "win" the race.** We have seen that the science gets overlooked if the students identify too strongly with the "winning" objects. The science is better conveyed and recalled, in our view, when both categories are seen as meritorious.

- **Practice the activity before going in front of a live audience!**

- A possible handout for students is provided on page 8. A copy is also provided in the pocket of this folder for easy copying.

The Science behind Rolling Objects

Mechanical energy is the energy associated with the motion or position of an object. It is the sum of potential and kinetic energy. If a rigid object (say a tennis ball or a skate board) with total mass M is allowed to roll along a horizontal straight line then there will be no change in the potential energy, since the center of mass remains at the same height from the ground. On the other hand, if the object is allowed to roll along an incline, the potential energy of the object changes as it rolls because the center-of-mass height is changing. In this activity we will be considering an object rolling along an incline.

As the object rolls, the potential energy changes with the height. The potential energy of the object, relative to a reference height h_0=0, is given by

$$U = Mgh, \tag{1}$$

where U is the potential energy of the object, M is the total mass of the object, g is the acceleration due to gravity and h is the height of the object.

As the object rolls down the incline, its height gradually goes to zero. As the height decreases, the potential energy changes into kinetic energy. Basically, $\Delta K = -\Delta U$ (ignoring friction). The kinetic energy is the sum of the translational (K_t) and rotational energy (K_r) and can be written:

$$K_T = K_t + K_r$$

$$K_T = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2, \tag{2}$$

where v is the translational speed of the center of mass of the object, I is the moment of inertia of the rotating part (the entire tennis ball, for example, or in the case of the skateboard, only the wheels) and ω is the angular velocity of the rotating part of the object. This equation involves both the linear and the angular velocity so it is helpful to express the equation in terms of either v or ω. If we have rolling without slipping then the relation between the two is given by:

$$v = \omega\, R, \tag{3}$$

where R is the radius of the rotating part (from the axis of rotation). After using Eq. (3) we can find the total kinetic energy in terms of linear velocity. Also, by the law of conservation of energy, if the object is released from a height h and rolls to a height zero, the amount of potential energy lost, and the amount of kinetic energy gained, is the full Mgh. If the object was initially at rest, then the initial kinetic energy was zero and final kinetic energy is also Mgh.

$$Mgh = \frac{1}{2}Mv^2 + \frac{1}{2}I\left(\frac{v^2}{R^2}\right) \tag{4}$$

Often, we can write

$$I = \alpha m R^2$$

where α is a constant which varies according to the geometry of the object being rolled, and m is only that part of the total mass that is actually rotating (α is ~ 2/3 for a tennis ball since it can be modeled as a spherical shell; solid cylinders have α = ½). Substituting for I in Eq. (4) and solving for v will enable us to get the velocity of the rolling objects. The final equation is given as follows:

$$v = \sqrt{\frac{2gh}{1+\alpha m/M}} \qquad (5)$$

The above model predicts the surprising result that the final speed v at the bottom of the incline is not determined by either the radius or total mass, but rather, on the amount and distribution of mass that is actually rotating—on m/M and α, but not R and M, in other words.

We will be using this concept in the activity to help students understand different factors that affect the speed of rolling objects. With pre-college students we cannot use the technical language of the concept, so we will help them learn by using simple words.

The message that we are trying to communicate is that the solid objects roll faster (the speedsters) than the hollow objects (the crawlers). A second part of the lesson shows that if the object is filled with a "slippery" liquid, or otherwise has parts that don't rotate as it rolls down the incline, as in a skateboard or tricycle, then that object will roll faster in comparison to rigid solids, because the former have a smaller fraction of their relative mass in rotation and the latter have more of their kinetic energy in rotation rather than translation, thus resulting in slower center-of-mass speed.

The following table shows the objects being rolled with their respective explanations for winning and losing. We do not advocate explaining all this and then showing the results, but rather, the idea is to engage the students in rolling races and identifying the *Speedsters* (objects that roll down the incline faster) and the *Crawlers*. After several races, the students should be able to characterize the traits that best predict to which category a new object belongs.

	Crawler	Speedster
	Type 1	
Pair 1	Small metal pipe	Sharpie marker
Pair 2	Large metal pipe	Rubber ball
Pair 3	Ping pong ball	Golf ball
Pair 4	Tennis ball	Golf ball
Pair 5	Ping pong ball	Small rubber ball
Pair 6	Small PVC pipe	Filled small PVC pipe
Pair 7	Large PVC pipe	Wooden cylinders
	Type 2	
Pair 8	Bottle filled with gravel	Bottled filled with water
Pair 9	Can of cream of chicken soup	Can of chicken broth

-"Hollow" objects are slower because a higher fraction of their mass is far from the center of rotation.
-"Solid" objects roll faster because more of their mass is close to the center of rotation.

-Objects with "thin liquids" inside are fast because a smaller fraction of their energy is rotational, since the liquid does not rotate initially (note the air bubble stays at the top during the rolling). That is, m/M is smaller.

Note: The model doesn't include subtleties like the roughness of the incline which can affect the results in some cases.

For More Information

Online Rolling Resources:

Society of Physics Students, rolling information data collection www.spsnational.org/programs/rolling/

Connexions http://cnx.org/content/m14391/latest/

PBS Kids- Their rendition of a rolling experiment
http://pbskids.org/curiousgeorge/parentsteachers/activities/pc_ramp_n_roll.html

University of California in Los Angeles
http://www.physics.ucla.edu/demoweb/demomanual/mechanics/rotional_inertia/rolling_objects.html

Year of Science 2009 http://www.yearofscience2009.org/themes_physics_technology/general/physics-experiment.html

Rolling References from the Physics Literature

Elsner, Kaye M., "Dispense With Misconceptions About Inertia: Have A Race!", The Physics Teacher (TPT), Vol. 30, # 2, Feb. 1992, p. 108.

Iona, Mario, "Friction When Rolling", TPT, Vol. 19, # 3, Mar. 1981, p. 154.

Kagan, David, "The Shaken-Soda Syndrome", TPT, Vol. 39, May 2001, p. 290.

Lanni, Robert P., "Grandma Brown vs. Chicken Soup", TPT, Vol. 16, # 8, Nov. 1978, p. 553.

March, Robert H., "Who Will Win the Race?", TPT, Vol. 26, # 5, p. 297, May 1988.

Melvin, Cruse, "Downhill Races", TPT, Vol. 40, # 4, p. 222, (April 2002), and "Correction" TPT, Vol. 40, # 6, p. 325, Sept. 2002.

Micklavzina, Stanley J., "It's in the Can: A Study of Moment of Inertia and Viscosity of Fluids", Physics Education, Vol. 39, # 1, Jan. 2004, p. 38.

Niculescu, Adam, "A Rolling Sphere Experiment", TPT, Vol. 44, # 3, March 2006, p. 157.

Shafer, Robert, "Downhill Races Revisited", TPT, Vol. 42, # 6, Sept. 2004, p. 324.

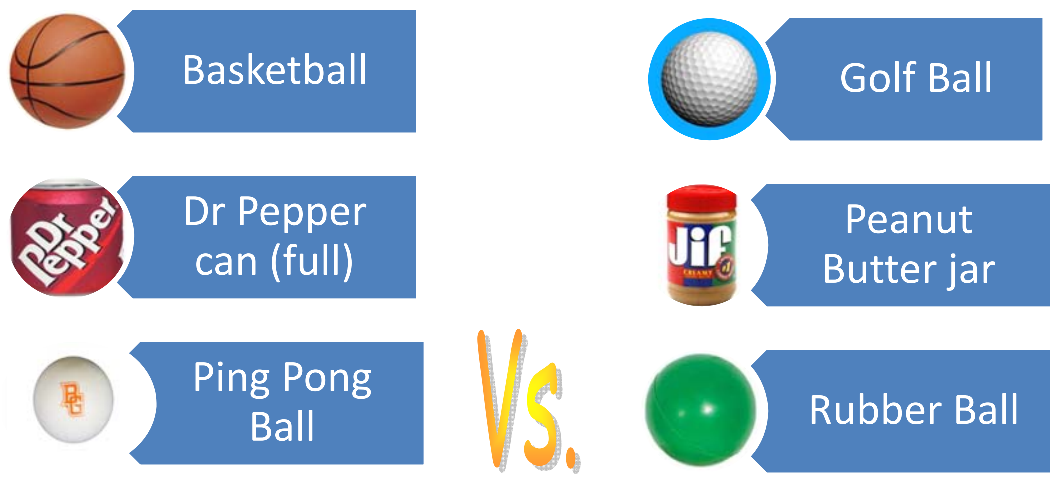
Solbes, Jordi and Francisco Tarin, "Which Reaches the Bottom First?", TPT, Vol. 46, # 9, Dec. 2008, p. 550.

Taylor, Andrew and Mary Fehrs, “The Dynamics of an Eccentrically loaded hoop”, American Journal of Physics (AJP), May 2010 -- Volume 78, Issue 5, pp. 496-498

Theron, W. F. D., "The Rolling Motion of an Eccentrically Loaded Wheel", AJP, Vol. 68, # 9, p. 812, Sept. 2000.
"And the Winner Is...", Mad About Physics, Christopher P. Jargodzki and Franklin Potter, p. 95, 231.

Are you ready to roll?

Challenge your friends and family to see if they know as much about rolling as you do. Here are few suggestions for things that you can use:



Which are the crawlers and which are the speedsters?

Do the experiment, be a scientist, and see how things roll!

Then, add your information to the Society of Physics Students' rolling database...

www.spsnational.org/programs/rolling

Investigating Telescopes

The Galileoscope™ is a high-quality, low-cost telescope kit developed for the International Year of Astronomy 2009 by a team of leading astronomers, optical engineers, and science educators. No matter where you live, with this 50-mm (2-inch) diameter, 25- to 50-power achromatic refractor, you can see the celestial wonders that Galileo Galilei first glimpsed 400 years ago and that still delight stargazers today. These include lunar craters and mountains, four moons circling Jupiter, the phases of Venus, Saturn's rings, and countless stars invisible to the unaided eye.

Two Galileoscopes are included in this SOCK, one for your SPS chapter and one to leave with the participants in your outreach activity. A tripod and star charts are also enclosed to make viewing objects easier.

The official *Galileoscope Optics Activity Guide* is provided in the SOCK. The guide includes a number of activities related to optics appropriate for students. Please note that not all of the materials needed for these activities are included in the SOCK, but they are available in most physics departments.

Finally, please note that the instructions enclosed in the Galileoscope package are difficult to follow, so you may want to refer to the detailed instructions available on the Galileoscope website, https://www.galileoscope.org/gs/content/downloads.

Planning an Outreach Event

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.

Suggested Procedure for Planning Outreach Events

- Determine what topic(s) you would like to cover with the students, and the amount of time you and your chapter are willing to invest.

- Identify an audience
    a. Talk to your chapter advisor, physics faculty, and education faculty to see if there is an existing outreach program you can join.
    b. Contact the science teachers in your local school district to let them know you are interested in putting on science events for their students.
    c. Contact local youth organizations such as the Boy and Girl Scouts of America, 4H, and YMCA to see if they have any interest.

- Schedule an event and get all the details—contact person, phone number, parking restrictions, setting, number of students, grade level, available equipment, time constraints, and any other special considerations.

- Create an outline for your time, include time for volunteers to introduce themselves and talk about their physics interest.

- Test the experiment and demonstrations.

- Verify the logistics the day before your event and pack. Make sure everything is ready to go, including replacement parts (like extra batteries).

- Do a post evaluation of your outreach event to discuss how things went and what you can do better next time.

- Complete the SOCK survey!

SPS's primary goal with the SOCK program is to encourage others to explore the universe around them. 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 may 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 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 (NAP) 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