The Society of Physics Students
Presents…

World Year of PHYSICS 2005

The 2005
Student Outreach Catalyst Kit

The **2005 S.O.C.K. (SPS Outreach Catalyst Kit)**

Brought to you by: SPS Interns Morgan Halfhill, Rebecca Keith, Heather Lunn and Matt Shanks

The 2005 SOCK

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Dear SOCK Recipient,

Congratulations! Here is your [2005/2006] SPS Outreach Catalyst Kit (SOCK). **As the name implies, the SOCK is meant to be an outreach catalyst—a spark to get you started**. You will probably need to supplement the materials here to use them in a lesson. To get you started, we've included sample lessons for a range of ages and situations and ideas of how to use the materials. It's up to you to decide what age students you want to work with, if you'll work in groups or with individuals, and how you'll scale the SOCK to fit your own situation.

There are two basic topics included, which have proven themselves to be versatile and popular in past outreach efforts:

1) ***The Martian Surface,*** dropping experiments that follow-up on previous experiments with cylinders

2) Lessons in light including ***Invisible Mirrors,*** with ***The Rainbow Room*** and ***Measuring the Speed of Light with Marshmallows***

The first lesson, "The Martian Surface," is an extension of the 2003 cylinder drop experiment. We're changing shapes from cylinders to cones/hexagons so that we can continue our national experiment on the dropping of objects. After seeing the data you sent back (email sps@aip.org for more info.), we added an extension where you can characterize the surface you're dropping on. This is paired with a lesson on bouncing that demonstrates why the materials of the surface and the object being dropped make such a huge difference.

The second lesson, "Invisible Mirrors," focuses on the phenomenon of total internal reflection. There is an entirely new lesson on fiber optics that can be paired with the rainbow glasses, led lights, and led pens that have been perennial favorites in past SOCKs. This section also includes a final lesson, "Marshmallows, Microwaves and Measuring the Speed of Light", celebrates the World Year of Physics through investigating Einstein's work with the speed of light. In this experiment, students can find the speed of light using marshmallows and a microwave!

These lessons are only a starting point. Use the materials to come up with your own ideas, and then tell us what you did! We hope you'll find numerous uses for your SOCK within your chapter and beyond into your community. Your input is necessary to keep improving the SOCKs and changing them to better meet your needs, so please fill out a SOCK feedback form before the end of the year.

Thank you for taking part in this year's SOCK project. Have fun exploring the lessons and send any questions or comments to sps@aip.org. Happy outreaching, and good luck!

Sincerely,

Rebecca Keith and Morgan Halfhill
2005 AIP/SPS Outreach Interns

Matthew Shanks and Heather Lunn
2004 AIP/SPS Outreach Interns

Product	**Quantity**	**Vendor**
Red Keychain LED	3	Gee Sales
Blue Keychain LED	3	Gee Sales
White Keychain LED	3	Gee Sales
Red Laser	1	The Laser Guy
Multi-LED SPS pen	2	SPS
Dolphin Fiber Optic Wand	1	Gee Sales
Star Fiber Optic Wand	1	Gee Sales
Fiber Optic Cable	8 strands	Fiber Optic Products
Grape Jello Packet	1	Local Grocer
Diffraction Glasses	20	SPS
SPS Mini-Flashlight	2	SPS
Happy/Unhappy Balls	1 pair	NADA Scientific
Golf ball, ping-pong ball, marble	1 each	Target
Solid Wooden Cones	12 total; 3 of 4 different heights	American Wood Working Co.
Wooden Sphere	1 each	American Wood Working Co.

History of the SOCK

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). We hope that the lesson ideas and demonstration materials will help stimulate an interest in physics through SPS chapters starting outreach programs with students from kindergarten through college. 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* kept all the popular light elements, and brought in the first experimental component with a nation-wide cylinder dropping experiment.

The latest incarnation of the 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. This SOCK, titled *The World Year of Physics 2005*, is a celebration of the World Year of Physics. It expands upon the experiments started in 2003, adds a new twist to the ever-popular light elements, and includes a special lesson to commemorate Einstein's discoveries in 1905 with an experiment to measure the speed of light.

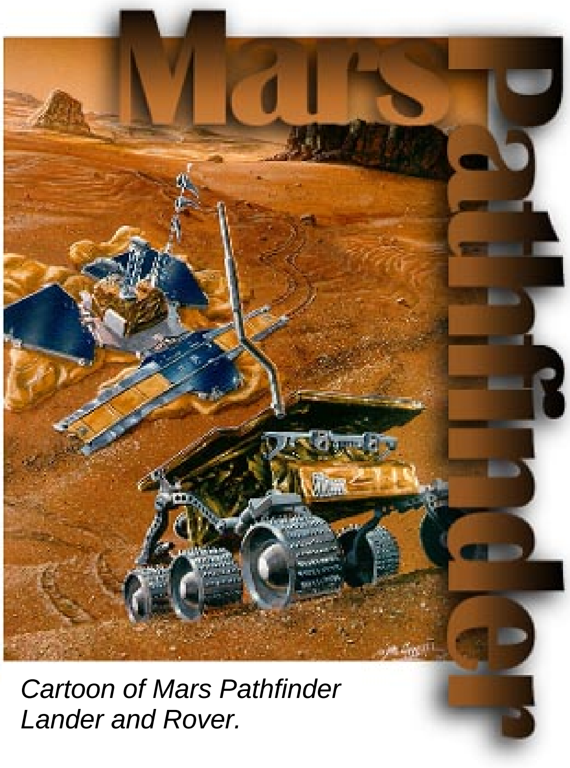
The SOCK project is supported by the Society of Physics Students, its associated honors society Sigma Pi Sigma, and the Research Science and Engineering Center's (MRSEC) GK 12 outreach program at the University of Maryland. SPS is the professional society for physics students and their mentors. It operates within the American Institute of Physics (AIP), an umbrella organization for ten other professional societies.

Unit I: Martian Surface
Refining an Experiment for All Ages

This extension of last year's cylinder dropping experiment marks a step forward in the understanding of data gathered from a nationwide experiment undertaken last year. If you want to jump into the experiments then just flip ahead to page 4. Through the first sections in this unit you will be taken through the original motivation for this nationwide experiment and then through a brief motivation of this extension.

Revisiting Mars

In the year 1997 the Mars Pathfinder entered the martian atmosphere 125 km. (80 mi.) above the surface and slowed from a whopping 7.5 km/s (16780 mph) to a mere 400 m/s (900 mph) as it whizzed past air molecules and drew closer to the red planet's surface. The pyramid shaped Pathfinder Lander bounced a few times and came to rest at a random orientation. Motors then had to turn the craft upright. (Note: for a complete description of the Pathfinder Lander visit http://mars.jpl.nasa.gov/MPF/mpf/edl/edl1.html.) The random nature of the landing of different shapes is a little explored area of physics that has potential to be very useful. The cylinder dropping experiment sought to examine the nature of a cylinder's landing with a varying center of mass to determine if a generalization could be made about the nature of a randomly oriented cylinder's landing.

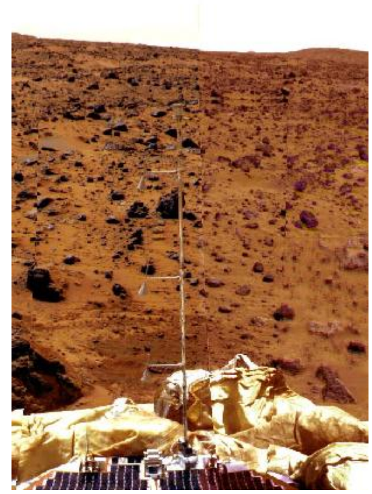


Cartoon of Mars Pathfinder Lander and Rover.

Surface properties

After plotting and observing data received from SPS chapters across the country it became clear that we needed to do further experiments with shapes other than cylinders. We also needed to have a better characterization of the landing surfaces in terms of the coefficient of restitution. In response to this an extension of the experiment was proposed that would use cones rather than cylinders to help eliminate issues observed with cylinders rolling into external objects. It was also proposed that an investigation into the significance of surface elasticity would aid in determining the effect of bounce on observed results.

Nuts and Bolts: In the Classroom



Materials:

- 12 wooden cones of 4 different heights (3 cones per height)
- 1 wooden sphere 2 inch diameter

Lesson:

1.) Engage the students with discussion of recent NASA projects such as the Saturn mission and Cassini then mention the Mars Pathfinder Lander.

2.) Explain that the Pathfinder landed on the wrong side and had to put itself right side up. Discuss that there is a national experiment going on to figure out how to fix this landing problem and that they get to be a part of it.

3.) Next begin discussion of important topics of the experiment. For example some things that could be discussed are:

- Scientific Method (ex. Have students break into groups and go through the scientific method about how a physical aspect will affect landing.)
- Area (ex. Students can use paper and something to write with to trace out the area of the rounded side and flat side of the cone and then use scissors to cut them out to compare the areas. Have the students explain any relevance this comparison has to the way the cones land.)
- Ratios (ex. Break the students into groups and give each group a cone and have them measure the height and diameter and determine the ratio of height over diameter. Have the students explain any relevance this number may have to the way things land)
- Center of Mass (ex. Using different cones, explain how the center of mass moves. Illustrate how if the center of mass moves outside of the base, the object tips. Ask how the location of the center of mass affects the landing of an object.)
- Materials (ex. Show the students a picture of Mar's terrain and have them describe it; write down adjectives on the board. Show the students a picture of a field and have them describe the surface; write down adjectives in another column. Ask students how the different surfaces will affect the way a spacecraft lands.)

The black happy/sad balls may be useful in this discussion.

4.) Relate these subjects to dropping objects and have students hypothesize how different the different topics can affect how an object lands.

Experiment:

1.) Break the students into groups, preferably four.
2.) Create a space (6'x6' works well) by moving the desks to the side of the room.
3.) Give each student a page detailing the experiment and have the class read the coefficient of restitution section. (If the students are younger, it might be best to review the material and explain it to them rather than having them read, or just skip that section and performing the calculation yourself.)
4.) Once everyone has finished reading, take the wooden ball and explain that using it you are going to measure the coefficient of restitution of the surface you are dropping on.
5.) Distribute a set of cones to each group and have them spread out.
6.) Call up the first group to determine the coefficient of restitution.
7.) While the first group is determining the coefficient of restitution have the other 3 groups begin reading the section titled Cone Dropping and then start the experiment.
8.) Once the first group is finished getting values for the coefficient of restitution, rotate and have the second group determine the coefficient of restitution and continue this rotation until all groups have determined the coefficient of restitution.

Analysis:

1.) Depending on educational level, data can be analyzed in a table or a graph.
2.) Tables and graphs may compare cones by area, ratio, center of mass or any other way that was chosen to characterize the cones. It can be useful to compare the data to the hypotheses proposed earlier during the lesson time.

Letter to NASA:

A good way to wrap up the lesson is to have students write a letter to NASA recommending a design for their next surface lander and then justifying that design based on what was discussed in the lesson and observed in the experiment.

Some sample lesson suggestions follow.

Bouncing Lessons Complete Outline

Introduction:

Many sports require a ball to play; furthermore many have rules about the way you can bounce a ball, how many times, or any other number of restrictions on bounce which affect the way the game is played.

Schedule:

1.) Introductory Questions:
  1.) Why is it important to regulate the bounciness of balls?
  2.) What factors could change the bounciness of a ball?
  3.) What type of ball do you think bounces the highest?

2.) Exercise 1:
  Warm-Up Exercise (Basketball Referee, attached document): need a few basketballs, preferably with at least one of them under-inflated.

3.) Follow Up:
  1.) Discuss answers to Introductory Questions.
  2.) Did anything surprising happen in the Warm Up?

4.) Quantifying Bounce:
  1.) Begin with a discussion of basketball and tennis:
    a.) "Would you rather play on concrete or in a gym? Why?"
    b.) "Would you want a racquet to be strung tightly or loosely? Why?"
    c.) "Does where you hit the ball on the racquet matter in tennis?"
    d.) Do you think that people measure bounciness? If so how?
    e.) What problems could happen if we just used bounce height?
    f.) Is there some way to eliminate the problems of just using bounce height?
  2.) Discuss the method to measure coefficient of restitution:
    a.) Definition: ratio of velocity right before and right after collision
    b.) Work through kinematics equations, if so inclined
  3.) Go and measure:
    a.) Give groups materials including selection of balls (Sock includes marble, wooden sphere, happy ball, sad ball, ping-pong ball and golf ball, also can use tennis ball, basketball, racquetball, etc.)
    b.) Do Measuring Bounciness experiment(another attached document to learn about the Coefficient of Restitution
    c.) Present questions again; some bounciness rules for some sports are appended to the Measuring Bounciness document; review rules for some sports and comment.

6.) Follow Up:
  1.) Compare your values with the other group.
  2.) Is there anything surprising?
  3.) Why do you think the values are different?

Basketball Referee

Introduction:
According to the rules established by the NCAA a basketball, after being dropped from a height of 6 feet, can bounce:

1.) No less than 49 inches on its least resilient spot, and
2.) No more than 54 inches on its most resilient spot.

Your job, as referee, is to determine which balls can legally be used in the game.

Instructions:
1.) Observe the ball and note anything in the physical appearance that might affect the legality of the ball and write that in the column labeled “Irregularities”.
2.) Watch the ball drop and record the height, which it bounced back to as best you can in the column labeled “Bounce Height”.
3.) From your observation record if the ball is legal for play according to NCAA rules in the column labeled “Legality”

Trial Number	Bounce Height	Irregularities	Legality?
1			
2			
3			

Table:

Measuring Bounciness

Introduction:

There is a way that scientists represent bounciness numerically called the "Coefficient of Restitution." This number can be determined experimentally by taking several easy measurements. Your goal is to determine the coefficient of restitution of several different balls. The 'happy/sad balls' (pair of black rubbery looking balls, one that bounces well and the other that barely bounces) are especially good to use here.

Instructions:

1.) Write down each type of ball you have in the row labeled "Type of Ball" in the table.
2.) Make a prediction! Based on your experiences with these balls try to predict how you think the experiment will come out by ranking the balls from bounciest (1) to least bouncy (4).
3.) Decide from what height you should drop the balls. A good height is between 1.20 and 1.50 meters. Record this in the blank labeled "Drop Height"
4.) Drop a ball from the drop height and record what height it bounced back to in the corresponding box in the row labeled "Bounce Height." It is better to average several trials for each ball to get a more reliable number and to test if the experiment is repeatable.
5.) After averaging the bounce heights for a given ball, then compute the bounce height ratio for that ball, and the Coefficient of Restitution and record these values in the table. Repeat for the other balls. See next page for theory ideas

Drop Height:_________________

Type of Ball				
Predicted bounciness rank				
Bounce height Trial 1 Trial 2 Trial 3 Average				
R = Bounce Height Ratio (= drop height divided by bounce height)				
Coefficient of Restitution (= $\sqrt{R}$)				

Some notes: The Bounce Height Ratio, R, is most closely related to the energy transfer of the collision, whereas the coefficient of restitution is more closely related to the speed or momentum transfer. These quantities depend upon the dropping surface as well, which might be another interesting experiment to pursue. See next page for some detail about the theoretical ideas. Here are some questions to consider; use the next page to answer them. 1) Which did you determine to be bounciest? 2) Which is the least bouncy? 3) Are there any patterns that you notice, say, hard versus soft, heavy versus light? 4) How did your predictions work out? 5) Which of the boxes above should have quantities with units or dimensions in it? 6) Which boxes ask for unitless or dimensionless quantities?

Some Questions about Measuring Bounciness

1) Which did you determine to be bounciest?

2) Which is the least bouncy? Are there any that are so close that your experiment could not reliably determine which was bouncier?

3) Are there any patterns that you notice, say, hard versus soft, heavy versus light? Comment.

4) How did your predictions work out? Comment.

5) Which of the boxes above should have quantities with units or dimensions in it?

6) Which boxes ask for unitless or dimensionless quantities?

Some details about the theory:

For a collision of a ball with a floor, the Coefficient of Restitution can be defined as the ratio of the speed of the ball just before hitting the floor to the speed just after it leaves the floor. These speeds are not easy to measure directly, but we can use Conservation of Energy to help us relate them to the height of the ball at various times. Here we go:

The initial energy of the ball is all potential energy, $PE_i = mgh_i$, where m is the mass of the ball (to get the energy in Joules, this mass must be in kilograms), g is the gravitational constant on the earth's surface (9.8 m/s/s) and h_i is the initial height (in meters, if you want to have the energy in Joules) from which the ball is released. When the ball is released this is gradually converted to kinetic energy, $(1/2)mv^2$, where v is the speed of the ball at any point while it falls. If we ignore any effects due to wind resistance, then we expect that the speed of the ball just before the ball hits the ground (let's call this v_{before}) can be computed by Conservation of Energy:

$$\text{Initial Energy} = \text{Energy just before hitting ground}$$
$$mgh_i = (1/2)mv_{before}^2$$

or when solving the above equation for v_{before} we get

$$v_{before} = \sqrt{2gh_i}$$

After the ball hits the ground the ball bounces up with a slower speed (less kinetic energy) and sometimes it is said that the ball 'loses' energy; the energy is not really lost, it has been converted to other forms such as sound energy, vibrational energy of the ball and floor, etc. In any case, the bounciness of the ball can be measured by the speed of the ball as it leaves the floor, which we will call v_{after}. The kinetic energy as the ball is leaving the floor can then be expressed as $(1/2)mv_{after}^2$. By using conservation of energy once again, this time setting the energy of the ball just after it leaves the floor equal to the energy of the ball when it reaches it maximum height after the bounce, we can get an expression for v_{after} in terms of the height, h_1 after the bounce:

$$\text{Energy just after ball leaves floor} = \text{energy at maximum height after bounce}$$
$$(1/2)mv_{after}^2 = mg\,h_1$$

or

$$v_{after} = \sqrt{2gh_1}\,.$$

So, if we define R, the bounce height ratio, to be the ratio of the heights before the bounce and after the bounce

$$R = h_i/h_1\,,$$

then we see that the square root of R is also equal to the ratio of the speeds of the ball just before and after the bounce:

$$v_{before}/v_{after} = \sqrt{2gh_1}\,/\sqrt{2gh_i} = \sqrt{h_i/h_1} = \sqrt{R}\,,$$

Thus we can say that R is the ratio of energies before and after the collision, while the square root of R is the speed ratio.

The Coefficient of Restitution (CoR) can depend on both the ball that you use and upon the surface that you use.

Some rules about bounciness in sports

Tennis
Each ball shall have a bound of more than 53 inches (134.62 cm) and less than 58 inches (147.32 cm) when dropped 100 inches (254.00 cm) upon a flat, rigid surface e.g. concrete.

Baseball
The coefficient of restitution (COR) of a baseball cannot exceed .555.

Basketball
A ball shall be inflated to an air pressure such that when it is dropped to the playing surface from a height of 6', measured to the bottom of the ball, it shall rebound to a height, measured to the top of the ball, of not less than 49 inches when it strikes on its least resilient spot, not more than 54 inches when it strikes on its most resilient spot.

Racquetball

The standard racquetball shall be 2 1/4 inches in diameter; weigh approximately 1.4 ounces; have a hardness of 55-60 inches durometer; and bounce 68-72 inches from a 100-inch drop at a temperature of 70-74 degrees Fahrenheit.

Temperature Dependency

Purpose:
The purpose of this lesson is to demonstrate the changes in objects and materials due to exposure to extreme cold and the subsequent freezing and material property changes the object undergoes. This lesson is designed around the use of liquid nitrogen because it is so cool (insert rim shot here). OK, so it doesn't really fit with the others but we like it a lot, so it got in.

Suggested Materials:

Demo:

- Balloons
- Nail
- Board
- Milk
- Sugar
- Racquetball
- Bananas
- Vanilla
- Half and Half or Heavy Cream

Safety/Preparation:

- Bucket/Large Coffee Can
- Wooden Mixing Spoon
- Liquid Nitrogen
- Large Mixing Bowl or Pot
- Gloves and Tongs

Procedure:
Obviously there are quite a few things you can do with such a wide variety of objects at your disposal.

Balloons:

- Balloons
- Liquid Nitrogen
- Bucket/Large Coffee Can
- Gloves and Tongs

Kids tend to enjoy the activity where you put a balloon in liquid nitrogen and it shrinks and then they can play with it and watch it return to normal size.

Racquetball:

- Racquetball
- Liquid Nitrogen
- Bucket/Large Coffee Can
- Gloves and Tongs

The racquetball can be used to demonstrate how the chemical bonds become more rigid when an object is cooled. A good way to demonstrate this is to throw it against a wall while it is at room temperature, then freeze the ball and repeat. If you have cooled the ball enough it should shatter when the ball hits the wall.

Nail, Board, Bananas:

- Nail
- Bananas
- Liquid Nitrogen
- Board
- Bucket/Large Coffee Can
- Gloves and Tongs

Another fun demonstration is to have a child hammer in a nail with a banana. You can have the child first try to hammer a nail into a board with a room temperature banana. After observing the somewhat messy effects, freeze a second banana. Give the kid a glove to hold the frozen banana and let them go to town. Again, if you froze the banana long enough everything should go well.

Vanilla, Milk, Sugar, Half and Half (Heavy Cream):

- Vanilla
- Milk
- Sugar
- Half and Half or Heavy Cream
- Large Mixing Bowl or Pot
- Wooden Mixing Spoon
- Liquid Nitrogen
- Gloves and Tongs

This is what the kids really love, liquid nitrogen ice cream. Capping off a lesson with this really makes them love you.

Liquid Nitrogen Ice Cream Recipe (Vanilla Ice Cream):
(Source: http://www.polsci.wvu.edu/Henry/Icecream/Icecream.html)
Makes ~ ¾ Gallon Ice Cream

1 Quart Milk
2 Quarts Half and Half or Heavy Cream
6 Tbsp Vanilla
¾ Cup Sugar

Mix all of the ingredients in you Large Mixing Bowl until the sugar has dissolved into the milk and half and half. Pour in liquid nitrogen while stirring until the ice cream reaches the consistency you desire. Serve immediately.

Caution:
Be sure to wear proper safety attire whenever handling and using liquid nitrogen. Also make sure the kids stay back and let all of the fog boil off cold objects before touching them with their bare hands.

Final Notes:
These are just a few demonstrations with liquid nitrogen that can be instructive in a classroom setting; the web is full of lots more.

Sample Worksheet to be Handed out After the Demos

Liquid Nitrogen Worksheet

Name_________________

1.) Had you ever heard about or seen liquid nitrogen before today? If so, when?

2.) What happened when the balloon was put into the liquid nitrogen? Why?

3.) What happened to the way the racquetball bounced after it was put in the liquid nitrogen?

4.) Did the banana hammer better before or after it was frozen? Why?

What was your favorite part of the lesson and why?

Cone Drop Experiment

Name(s) ______________________ ____________________ ___________________

Preparing for the Cone Experiment

→ *Predict* ←

Imagine you drop 30 of the cones labeled C1 from a height of ½ meter, how do you predict they will land? (Write your predictions in the space provided)

Predict how many will end up like this

______ +

Predict how many will end up like this

______

TOTAL

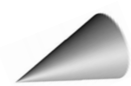
= 30

Imagine you drop 10 of the cones labeled C4 from a height of ½ meter, how do you predict they will land? (Write your predictions in the space provided)

Predict how many will end up like this

______ +

Predict how many will end up like this



______

TOTAL

= 30

Why do you predict the cones will fall this way?

____

____

Describing the bounce surface

What surface are you dropping your cones on (describe)? ______________________________

____

Find the wooden sphere in your SOCK and drop it onto the surface; as it bounces back up the first time measure how high it bounces. This will help us determine the coefficient of restitution for this wood on the surface you are using.

Initial drop height for wooden sphere _____

Rebound height 1 _____ Rebound height 2 _____ Rebound height 3 _____

Average Rebound Height _____________

Sphere Bounce Height Ratio (Initial Drop Height divided by the Average Rebound Height) ________

(See 'Measuring Bounciness', another SOCK exercise for more details about Coefficients of Restitution.)

Dropping the C1 Cones---Now it is time to conduct the experiment! Gather the three cones labeled C1 in your hands and drop them all at once from height of about ½ meter. Record (in the table) the number that land on the base, the number that land on the side, and the number you are uncertain about*. Sphere Bounce Height Ratio from previous page is ____

Drop Number For C1 cones	Number that land like this: 	Number that land like this: 	Number you are uncertain about*	Total
1				**3**
2				**3**
3				**3**
4				**3**
5				**3**
6				**3**
7				**3**
8				**3**
9				**3**
10				**3**
TOTALS--Add the numbers in each column				**30**

Dropping the C2 Cones---Now gather the three cones labeled C2 in your hands and drop them all at once from height of about ½ meter. Record how many land on the base, the number that land on the side, and the number you are uncertain about*.

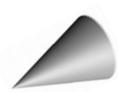
Drop Number for C2 cones	Number that land like this: 	Number that land like this: 	Number you are uncertain about*	Total
1				**3**
2				**3**
3				**3**
4				**3**
5				**3**
6				**3**
7				**3**
8				**3**
9				**3**
10				**3**
TOTALS--Add the numbers in each column				**30**

*Sometimes you may have trouble deciding to which category they belong; for example, if they end up leaning on each other, or if one wobbles a lot and then falls over because it hits something. It is up to you to decide in these cases, or to assert that you are uncertain---after all, ***you are the scientist doing the experiment here…*** just try to be consistent and write a note about your uncertainties.

Dropping the C3 Cones----- **Now it is time to conduct the experiment! Gather the three cones labeled C1 in your hands and drop them all at once from height of about ½ meter. Record (in the table) the number that land on the base, the number that land on the side, and the number you are uncertain about*. Sphere Bounce Height Ratio from earlier page is ____**

Drop Number For C3 cones	Number that land like this: 	Number that land like this: 	Number you are uncertain about*	Total
1				**3**
2				**3**
3				**3**
4				**3**
5				**3**
6				**3**
7				**3**
8				**3**
9				**3**
10				**3**
TOTALS				**30**

Dropping the C4 Cones-----**Now it is time to conduct the experiment! Gather the three cones labeled C4 in your hands and drop them all at once from height of about ½ meter. Record (in the table) the number that land on the base, the number that land on the side, and the number you are uncertain about*.**

Drop Number for C4 cones	Number that land like this: 	Number that land like this: 	Number you are uncertain about*	Total
1				**3**
2				**3**
3				**3**
4				**3**
5				**3**
6				**3**
7				**3**
8				**3**
9				**3**
10				**3**
TOTALS				**30**

*Sometimes you may have trouble deciding to which category they belong; for example, if they end up leaning on each other, or if one wobbles a lot and then falls over because it hits something. It is up to you to decide in these cases, or to assert that you are uncertain---after all, ***you are the scientist doing the experiment here…*** just try to be consistent and write a note about your uncertainties.

Results

For C1 cones I had _______ base landings and ________side landings out of 30 total drops.

For C2 cones I had _______ base landings and ________side landings out of 30 total drops.

For C3 cones I had _______ base landings and ________side landings out of 30 total drops.

For C4 cones I had _______ base landings and ________side landings out of 30 total drops.

Do the results of your experiment match your prediction? Explain.

____

____

____

____

Were there any surprising results from your experiment? Explain.

____

____

____

____

Other questions to consider: Does the surface you are dropping the cones on matter? Does the material of the cones matter? Does the drop height matter, do you think? Does it matter if you drop them one at a time or three at a time or thirty at a time?... What do you think?

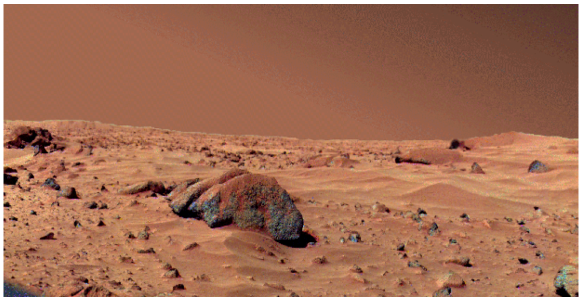
____

____

____

____

Curious to know more?
Take these pages home…



In 1997, the Mars Pathfinder bounced across the surface of Mars and landed on its side. Engineers and scientists at NASA anticipated this might happen so they installed motors in the spacecraft that would turn it upright. The same type of bulbous pyramid protected the Spirit and Opportunity rovers when they landed in 2004, but they landed upright on their own. In this experiment we will learn more about how things land. Then we can predict how spacecraft will land and how to give the best chance of landing upright.

Cone Drop Experiment: Real Science in a public setting

The idea is to learn about the relationship (if there is one) between the shape of an object and which side is up when it lands. In 1993, noted physicist and cosmologist Sir Hermann Bondi addressed how cylinders land when they fall ("The Dropping of a Cylinder," *European Journal of Physics*, Volume 14, pages 136-140), and you may have been part of an experiment involving cylinders last year, but very little has been written about cones. There have been few controlled experiments to explore this relationship until today, so this is new science!

Analysis and study of the data from today's experiment might result in a better understanding of the principle factors that determine how an object will land. These results could lead to predicting the landing orientation of space vehicles like the Mars Pathfinder and the Spirit and Opportunity Rovers which bounced across the surface of the planet before coming to a rest. The Pathfinder was roughly in the shape of a pyramid that came to rest on its side and required special mechanical features to turn it upright while the two rovers of the same shape landed upright. Better understanding of the probabilities of landing might result in better designs for spacecraft.

What if the cone hits something besides the floor?
It is the experimenter's choice whether data should be collected if the cone hits something besides the floor. It is important to say in your notes what happened and whether you counted it or not. Since we want the cones to start out every which way, having the con hit something else before the floor might actually help!

Why don't I get the same answer every time I drop a cone? Don't science experiments have to be repeatable?
By taking lots and lots of data, we should be able to see a pattern for which sides land face up most and least often. This means that although we don't get the same answer every time, if we were to come back and do the experiment again we should see the same pattern. This is called having the same statistical behavior or following a trend, and scientists use it to learn about complicated interactions.

Mars Pathfinder just before dropping

Related websites of interest:

http://mars.jpl.nasa.gov/MPF/default.html
http://eis.jpl.nasa.gov/~skientz/little_rock/
http://eis.jpl.nasa.gov/~skientz/little_rock/update.html
http://mars.jpl.nasa.gov/MPF/mpf/realtime/edlstatus.html
http://marsrovers.jpl.nasa.gov/home/index.html

Spirit Opportunity rover on the Martian surface

Summary of SPS Cylinder Drop Data from 2003-04

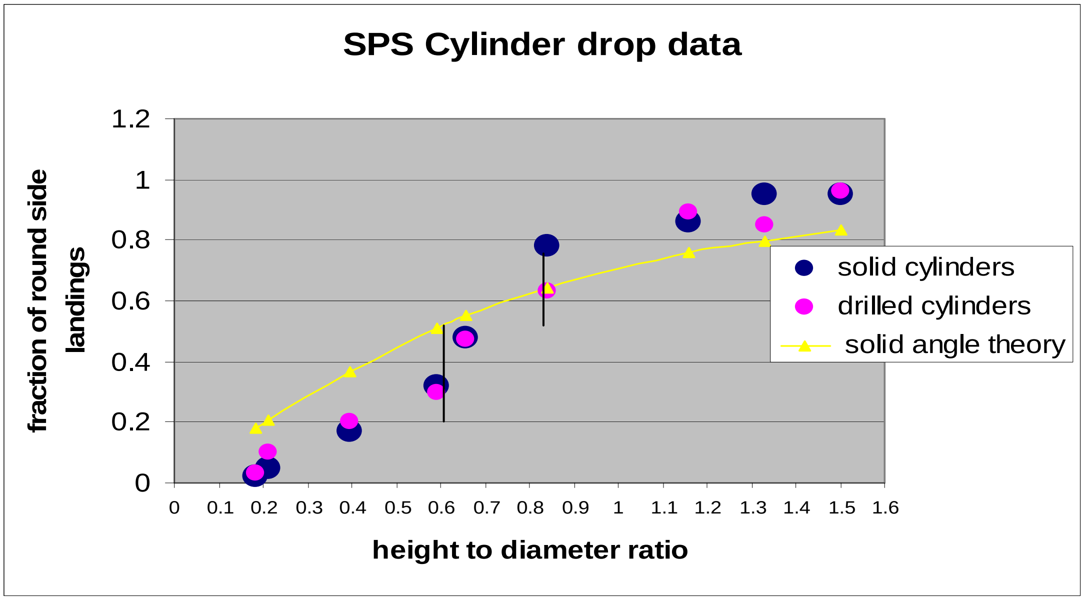
This is a summary of all the data collected from participating SOCK chapters that returned data to the SPS office: Christian Brothers University (TN), Rollins College (FL), University of Louisville (KY), Carthage College (WI), Embry-Riddle Aeronautical University (FL), Lafayette College (PA), University of North Carolina at Asheville, Massachusetts College of Liberal Arts.

The experiments involved solid wooden cylinders and cylinders with holes drilled in them. The idea was to learn a little about how the aspect ratio and the center-of-mass affected the side upon which the cylinder landed. While some interesting lessons were learned (see below), it was also apparent that a better way of describing the landing surface was needed. In future experiments we plan to do this, and work with other shapes (cones, hexagons, etc.) as well.

The solid circles below show the fraction of round side landings for the cylinders with increasing cylinder length. Dark blue solid circles indicate solid uniform cylinders, and the smaller pink solid circles indicate the cylinders with the holes drilled halfway through along the axis, like a thick-walled drinking glass. The trend is as expected, longer cylinders being much more likely to have round side landings. We found no statistical difference between the solid cylinders and the cylinders with holes in this data.

The number of drops varies dramatically from point to point, with many points corresponding to an average of more than 1000 drops (the data points at abscissa 0.65, for example), and one with as few as 20 drops. The largest vertical standard deviation is about 10% in each direction (on the small round drilled cylinder data points with abscissa of 0.6 and point .85 as shown), but most error bars are much smaller than 5%, about the size of the dots themselves. There is a question about the extent to which type of surface matters, but the impreciseness with which we had the experimenters identify the surfaces has resulted in no conclusions thus far; this summary reports on the average results only.

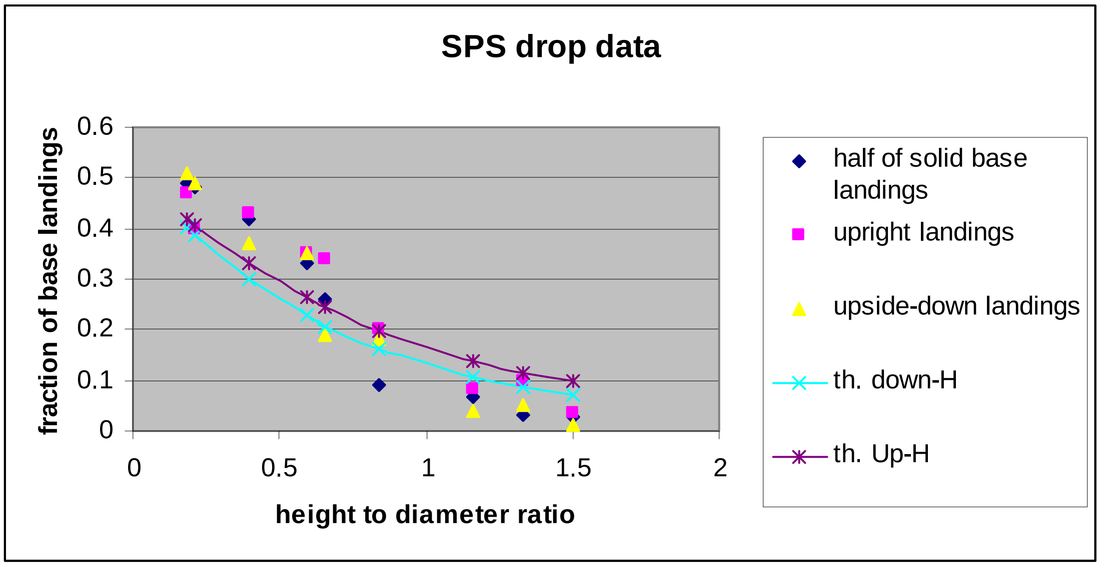
The yellow curve represents elementary theoretical estimates of the fraction of round side landings for a uniform cylinder. In this theory, the fraction of the solid angle occupied by the rounded cylindrical surface as measured from the center of mass of the cylinder is computed and plotted. One can see that this theoretical estimate has the right trend but it overestimates the rolling landings for coin shaped cylinders and underestimates the rolling landings for stick-shaped cylinders.



The data points below represent the fraction of landings on a given circular face of a cylinder. The dark diamonds represent the fraction of solid cylinders that landed on a base, divided by two for easy comparison to the drilled cylinders. The pink squares represent the fraction of drilled cylinders that landed 'upright' (that is, sitting like a typical glass on a table), while the yellow triangles represent the fraction of drilled cylinders that landed 'upside down'.

One expects that upright landings would be the most likely since the center of mass is lowest in this orientation. Generally speaking, the data tend in this direction with upright landings more prevalent than upside down landings, with uniform cylinders producing a standing cylinder on a given face with probability between the two. This trend held true in the cases with the most data; when the data was limited this expected order sometimes did not hold.

The solid angle theory (the curves—brown gives upright prediction and light blue gives upside-down prediction) is also deficient in that it appears not to predict enough spread between upright and upside-down landings---that is, the separation between the curves is generally less than the corresponding separation between the data points, especially where there is lots of data (such as the points with abscissa 0.65, for example, which has statistical error bars of about 2%)



Gary White and the SPS undergraduate interns---Matt Shanks (2004), Heather Lunn (2005), Morgan Halfhill (2005), Rebecca Keith (2005), Mika McKinnon (2005), American Institute of Physics, July 2005

Unit II: “Invisible Mirrors??”

By Heather Lunn with help from references below, SPS 2004 Intern

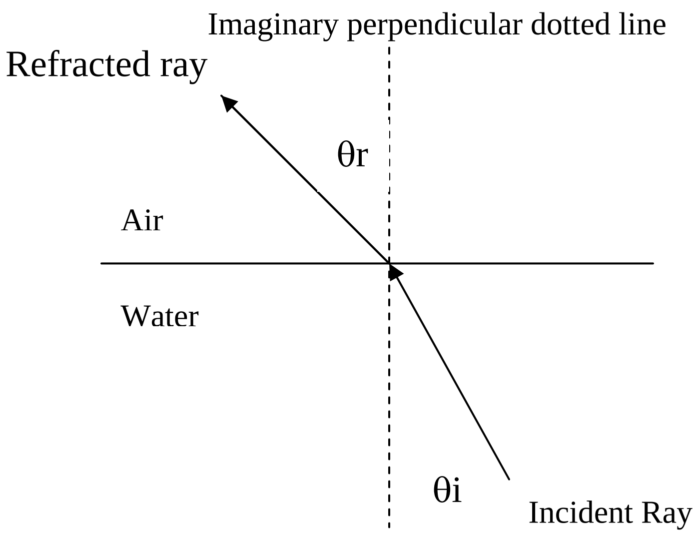
Refraction

Light speeds change as they travel through different mediums. The speed of the light wave depends on the optical density of the material. One indicator of optical density is the index of refraction of the material. Index of refraction values (n) are numerical index values, which are expressed relative to the speed of light in a vacuum. The index of refraction value of a material is a number that indicates the number of times slower that a light wave would be in that material than it is in a vacuum (n = 1.0000). This is very similar to when you have a car traveling and it suddenly hits the mud. It slows down just like the light in a different medium other than a vacuum. Since light travels about 1.5 times faster in vacuum than in regular glass, the index of refraction for regular glass is 1.5. For water, the index of refraction is 1.33, and for air at room temperature it is 1.0003, very nearly the same as in vacuum.

Refraction Experiment and Snell’s Law

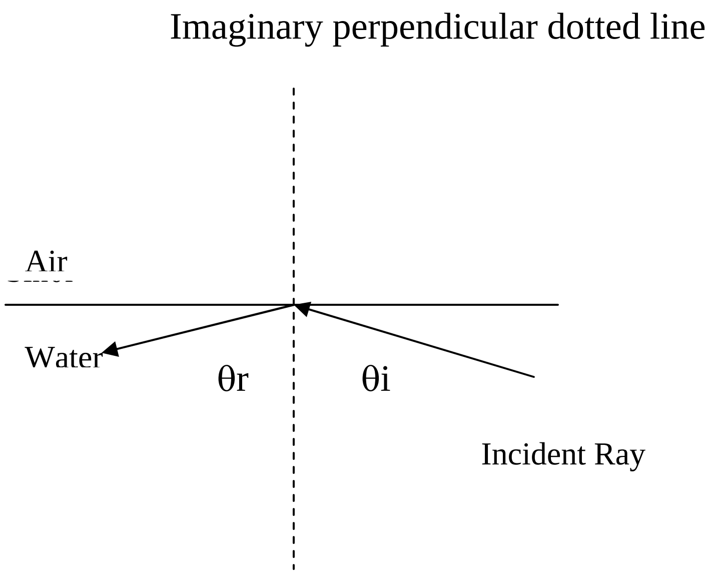
Refraction is the bending of a light path as it passes across the boundary separating two media. If you take a clear cup and fill it with water and stick a pencil in it, it looks like it is bent at the point at which it enters the water. This is an example of refraction. The light from the bottom part of the pencil has to come thru the water (and the cup wall, but this is a minor complication), then through the air to your eye, while the light reflected from the top part of the pencil only travels through the air to get to your eye. It is this difference that makes the pencil look bent; the image of the bottom part appears at a different angle than the top part due to the fact that the light paths bend as they come out of the water.

If a ray of light (like a thin beam from a red laser pointer) comes from below up through some water and into the air as shown, then the refracted ray comes out closer to the horizon as shown:



Critical Angle and Total Internal Reflection (TIR)

As the angle of the incident ray is increased, eventually an angle is reached where the incident ray comes out parallel to the boundary surface, the critical angle. Ray that impinge upon the surface at larger angles θi are simply reflected from the surface back into the water below as shown:



This just happens to work out to be about 48.6 degrees for light traveling from a water medium to an air medium.

So, for any angle larger than 48.6 degrees, Total Internal Reflection (TIR) will occur. TIR is the phenomenon in which all of the incident light (the light coming in) is reflected off the boundary, and it is only possible when light is attempting to exit a denser medium into a less dense medium. TIR gives the false idea of having invisible mirrors within the medium because of the reflecting properties.

A Simple TIR Experiment—Mirrors in Water??

A simple experiment to perform demonstrating TIR is the two-liter waterspout experiment. All you need is a clean two-liter soda bottle with the wrapper removed, a laser light, and a pan to catch excess water. Drill a pea-sized hole in the side of the bottle and put a small plug in it. Fill the bottle with water and set it on the side of the table so when unplugged, the water will have plenty of room to drain. Remove the plug and aim the laser through the hole from the opposite side of the bottle so it exits the hole into the falling stream of water. The laser light will become trapped with in the water due to total internal reflection. It is in the more dense medium (water) heading toward the less dense medium (air) and it is at angles of incidence greater than the critical angle, so it never leaves the water, but rather follows the parabolic stream. Again, are we dealing with the idea of mirrors in the water helping the light follow the stream? No, we are facing the phenomenon of total internal reflection.

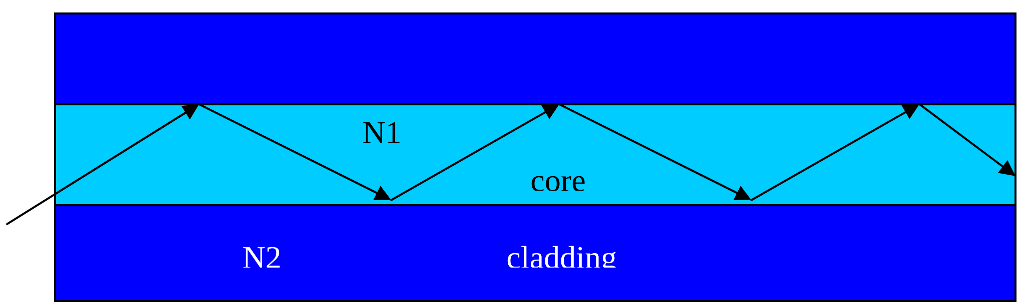
Fiber Optic Experiment

What is fiber optics?
They are thin strands of glass or plastic that carry information.
Ask the students what will happen if you shine the laser though the fiber optic cable. Have them write down their theories. Have them try the red laser and the blue light emitting diode (LED) through the cable and explain the concept of total internal reflection.

Fiber Optics
Total internal reflection is the principle on which the transmission of light inside the fiber optic cable occurs. Light traveling inside the center of the fiber strikes the outside surface at an angle of incidence greater than the critical angle, so that all the light is reflected without loss. Nearly all of the light entering one end can emerge many kilometers away on the other end. Total internal reflection will only occur when light is in the more dense medium approaching the less dense medium, i.e. glass to air, but not vice-versa, and the angle of incidence is greater than the so called critical angle.

The cable has been designed so that any ray of light meeting the outer surface of the glass fiber is totally internally reflected back into the fiber because the glass has a much higher index of refraction than does the air that surrounds the fiber optic cable on the outside. The critical angle traveling from glass to air is about 42 degrees, which is small. Any angle of incidence greater than this will produce total internal reflection, and as the fiber is very narrow, this angle is always achieved.

Every fiber also has an outer microscopic layer called cladding that is usually made of a separate glass layer of a much lower index of refraction. So, if the light does escape from the core glass fiber, total internal reflection occurs between the glass fiber and the cladding. Because of total internal reflection, the light can never change directions, therefore continuing on in the same direction it began in.



Total internal Reflection

White light is made of the full spectrum of colors. To further reiterate this point, have the students put on the diffraction grating glasses to see a rainbow of colors. Each color has a different wavelength, different frequency and therefore travels at a different speed.

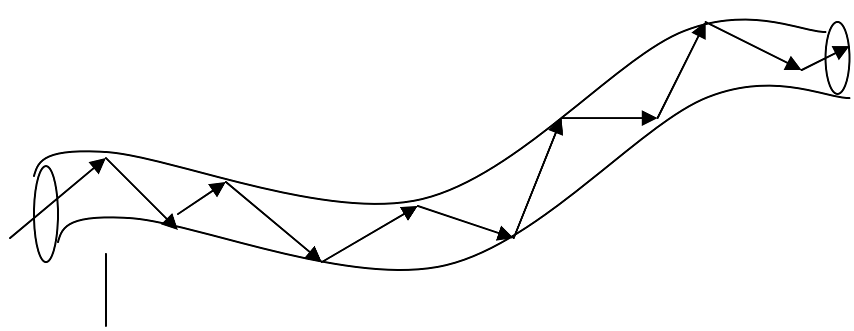
The light that is used in commercial fiber optics is laser light. Laser light won't disperse or radiate away because all of the rays travel at the same frequency. If white light was used, the different color components of the white light would travel at different speeds, and signals would become distorted since its pieces would arrive at different times.

It is possible to send the entire 32 volumes of the Encyclopedia Britannica through a fiber optic cable across the Southern Hemisphere in less than one second!

Fiber optic cables are very versatile in that they can be bent and curved in any which way and information will still pass to the end as long as they are not bent at a sharp (90 degree) angle, which would place a permanent kink in the cable. The cables can face extreme conditions without distorting signals and can be run under the ocean.

Have the students bend the fiber optic cable and even tie it into a loose knot. Ask the students to write down their theories of what will happen when they shine the laser through the cable now. Will the light be able to make it through? Of course it will, even if it is in a complete circle! The concept of total internal reflection will still occur even though the cable is bent. Does that happen with the garden hose in your yard? No, not likely, because it was not designed and built to work with the properties of total internal reflection. If you bend the cable very sharply you will be able to see that some of the light leaks out at the acute part of the bend.

Fiber optics also give a false impression of possessing invisible mirrors, but they do not include mirrors; they are made to have TIR properties.



Total Internal Reflection

Fiber optics hold a very important place in technology. Copper wires previously used for telephone lines and for the Internet are being replaced by fiber optic cables. Fiber optics can bend more, send information much faster, are more resilient to harsh weather conditions, and have no risk of electric shock when they are being worked on. Fiber optics are also used in microsurgeries. Doctors only have to make a very small cut to look inside the body. Then they use special fiber optic cables to actually do the surgery. One has a light at the end, one with a microscope, and one with a scalpel. These take inches out of the size of the cut needed to do say knee surgery, which pleases many people every year.

Fiber optics also have been used in the light-up Christmas trees and in the wands at dinner theaters like the ones provided in the SOCK.

So we are not dealing with invisible mirrors after all, just dealing with the special properties of TIR with water-air boundaries and glass- or plastic-air boundaries. It was sure cool to think about the concepts of invisible mirrors, wasn't it??

A Total Internal Reflection Experiment with gelatin

First:

Explain the dangers of lasers, and that they shouldn't point the laser directly at another person or look directly into the laser!!!

Jell-O Experiment

Prepare a pan of Jell-O using the Jigglers recipe. You need the Jell-O to be firm enough for the students to play with. (Use 4 packets with 2 ½ cups of hot water). You can put wax paper down first in the pan (9 by 12 is a good size) so it is easier to get the Jell-O out. Next, cut the Jell-O into strips of 1 inch by 3 inches with a sharp knife. Don't use a serrated knife, as you want smooth edges on the Jell-O to maximize the experiment results.

Break students up into groups of two. Then, ask students what will happen if you shine a laser through Jell-O, and have them write down their guesses. Now, have each of the students pick up a piece of Jell-O. Have them experiment with different angles on the Jell-O, testing their theories. Also, for a neat refraction experiment, have the students shine the laser at the very corner of the Jell-O to see the laser split in multiple directions. Make sure they try bending the Jell-O also.

Students should shine the laser in one end and see the laser bounce back and forth off the walls of the Jell-O to exit the other end. The laser could be totally internally reflected and this is often used to show how fiber optics work.

Sources

The Physics Classroom—Lesson 1: Refraction at a Boundary
www.physicsclassroom.com/Class/refrn/u1411d.html
The Physics Classroom—Lesson 2: The Mathematics of Refraction
www.phyusicsclassroom.com/Class/refrn/U14L2a.html
The Physics Classroom—Lesson 3: Total Internal Reflection
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Jiskha Homework Help—Fiber Optics by Emily McPherson
www.jiskha.com/science/physics/fiber_optics.html
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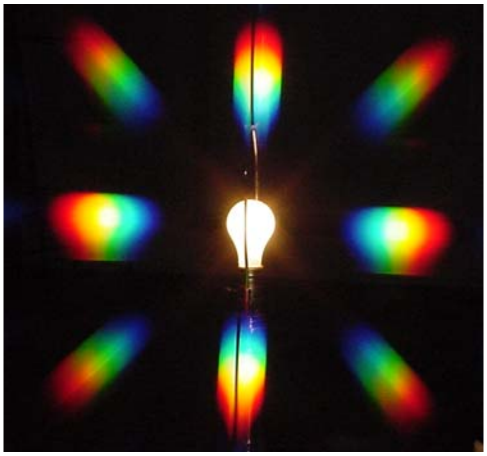
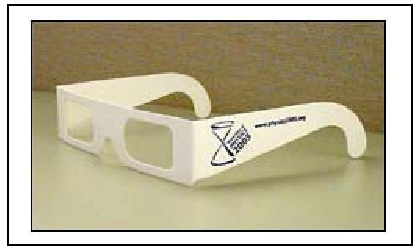
http://olli.informatik.uni-oldenburg.de/sirohi/guidance.html
GCSE Physics Waves-Light-Total Internal Reflection-Critical Angle
www.gcsescience.com/pwav23.htm
How Stuff Works—How Fiber Optics Work—Physics of Total Internal Reflection
http://electronics.howstuffworks.com/fiber-optic6.htm
Total Internal Reflection
www.gunn.palo-alto.ca.us/~cbakken/p1A/optics/obookshelf/total.html
What Are Optical Fibers Made Of? By Susana B. Grassino
www.psrc.usm.edu/macrog/fiberopt/of.htm
Applications of Total Internal Reflection
http://regentsprep.org/Regents/physics/phys04/captotint/default.htm
Fiber Optics
http://hyperphysics.phy-astr.gsu.edu/hbase/optmod/fibopt.html

SPS Intern Heather Lunn with Gary White, American Institute of Physics, October 2005

THE RAINBOW ROOM

Some information about ‘Spectral glasses’ also called ‘Rainbow glasses’





Use SPS Rainbow Glasses to see things in a new light. Any white light source is revealed in its full rainbow splendor; the smaller and brighter the source, the more dramatic the rainbows. Paperboard frames house diffraction gratings with striations in both horizontal and vertical directions; spacing between striations is roughly 4.5 microns, meaning that there are about 2200 lines per cm or 5500 lines per inch. See things like you’ve never seen them before---fireworks, holiday lights, flames, etc.

Table of information about visible light (labeled ‘Optical’ in the table) and other kinds of electromagnetic radiation

	Wavelength (m)	Frequency (Hz)	Energy (J)
Radio	> 1×10^{-1}	< 3×10^{9}	< 2×10^{-24}
Microwave	1×10^{-3} - 1×10^{-1}	3×10^{9} - 3×10^{11}	2×10^{-24}- 2×10^{-22}
Infrared	7×10^{-7} - 1×10^{-3}	3×10^{11} - 4×10^{14}	2×10^{-22} - 3×10^{-19}
Optical	4×10^{-7} - 7×10^{-7}	4×10^{14} - 7.5×10^{14}	3×10^{-19} - 5×10^{-19}
UV	1×10^{-8} - 4×10^{-7}	7.5×10^{14} - 3×10^{16}	5×10^{-19} - 2×10^{-17}
X-ray	1×10^{-11} - 1×10^{-8}	3×10^{16} - 3×10^{19}	2×10^{-17} - 2×10^{-14}
Gamma-ray	< 1×10^{-11}	> 3×10^{19}	> 2×10^{-14}

Not all light sources give off the same colors of light. The rainbow glass separate out the colors according to their wavelengths: Pure red light has a wavelength of about .0000025 inches or 6.5×10^{-7} meters and bluish light has shorter wavelengths, around .0000016 inches or 4.0×10^{-7} meters. You may be able to see a second or third square pattern of rainbows further from the center; this can be thought of as ‘echoes’ of the first square pattern.

The next pages give some examples of how you might introduce students to the science of light and spectroscopy.
Gary White, Society of Physics Students, October 2005

Rainbows of Light---Put on your rainbow glasses and look at any source of light in the SOCK. Can you see the rainbows off to the side and at the top and bottom? Which color in the rainbow is closest to the source of the light as you look through the glasses, red or blue? Do all the rainbows you see have the same order of colors? Are there colors present in some rainbows but not in others?

Here are some more science ideas that you might want to try out by using your rainbow glasses. Which one would you think most interesting to explore?

1. What happens if you put on two pairs of glasses?

2. What if you looked at the element in your toaster oven while it was on?

3. What if you use the glasses underwater?

4. What would you see if you look at the moon (don't try the sun!)?

5. What if you looked at some fireworks (this is very cool!)?

6. What kind of rainbows would you see if you look at headlights or streetlamps?

7. Can you make the rainbows from two different lights mix up?

A casual way to introduce the science of light

Have a seat, put on the rainbow glasses, and look at all the rainbows. Which one is most interesting to you? Can you identify which light source is responsible for each rainbow?

Write down something you notice about the rainbows in the room.

How are the various rainbows different from each other?...

How are they similar to each other?

Some information about various light sources:

A. Low Density Gas Source

An example of this is a neon light or mercury vapor street lights. Notice that there separated lines of color, and that not all of the colors of the rainbow are present. This is called a discrete spectrum. Usually discrete spectra are produced by low density gasses.

B. Solids, Liquids, Dense Gas Source

Notice the smeared rainbow. A full, smeared rainbow is also called a continuous spectrum. Solids, liquids and dense gases produce continuous spectra. Regular light bulbs, which have a very hot wire in them, and the sun are good examples of this type of source.

C. LEDs

Some special materials produce a spectrum that is a smear of colors but not the full rainbow. LEDs (light emitting diodes) are found in digital clock radios, the light next to the on-button for your computer and new traffic lights. In new traffic lights each color is made up of an array of little lights. These little lights are LEDs. These sources do not get hot and do not use as much energy as regular light bulbs.

D. Lasers

Lasers usually only produce one color of light (a very narrow band of wavelengths), an extremely discrete spectrum. Lasers have a very tight beam of light unlike the wide spread out beams of flashlights; they also produce coherent light (all waves ‘in-phase’ with each other), whereas flashlights produce waves with random phases.

E. Fluorescent Bulbs

Fluorescent bulbs have a low density gas (mercury) on the inside that produces a discrete spectrum like those labeled A above, but it also has a thin layer of solid material painted on the inside of the bulb that produces a continuous spectrum, as well. To see the subtleties of these features look at a fluorescent bulb though a very thin slit, if possible…

Marshmallows, Microwaves and Measuring the Speed of Light

Introduction

In order to determine the speed of light, we will use a microwave and the equation $c = f*\lambda$, where λ, lambda, is the wavelength of the microwaves, and f, is the frequency. The frequency of the microwave should be located on the microwave. If it is not, most microwaves operate at 2450MHz.

In a microwave, the electromagnetic waves are emitted from a magnetron, (see http://hyperphysics.phy-astr.gsu.edu/hbase/waves/magnetron.html , for example). These waves travel back and forth in between the walls of the microwave. Because these waves have the same frequency and are traveling in two different directions, the superposition of the waves creates a standing wave. When the microwaves constructively interfere, the locations of the largest amplitude, the antinodes, are the hottest spots in the microwave. This is where we will find the greatest amount of cooking takes place.

Procedures

- Remove the rotating table inside the microwave. You will need something to elevate the tray of marshmallows; a pizza or cereal box works well. Cheese slices work well, maybe even better, if marshmallows are not available.
- Line up the marshmallows into a grid, you can use a square baking pan or a shallow cardboard box.
- Place the tray of marshmallows on top of the box used for elevation inside the microwave. You do not want to have space in between the marshmallows (or the cheese slices but don't overlap them either), so they should be as even and close together as possible.
- Start the microwave; it should take about 20 seconds or more, depending on the microwave, for the marshmallows to start melting. You will notice that certain sections of the marshmallows will start to melt and expand, while others remain the same.
- Once the marshmallows have cooked enough, to a point in which you will be able to identify the hotspots when you take them out of the microwave, stop the microwave and remove the marshmallows.
- Measure the distance between two hotspots. This is half of a wavelength because it is the distance between two antinodes.
- In order to calculate the speed of light you will need to use the formula $c = f*\lambda$.The frequency should be on the microwave, if not use 2450 MHz.
- Multiply the distance you measured by 2 to determine the wavelength of the microwave and using the given frequency to calculate the speed of light. Your answer should be within a factor of two or so of 3×10^8 m/s…There are lots of possible reasons why the answer won't be exactly the accepted speed of light: the anti-nodes aren't well-defined visually and their just our best guess in 2 dimensions when the wave really has a 3-dimensional form, the speed of light in marshmallows is slower than the speed of light in air (which means the wavelength of microwaves in marshmallows is shorter than it is in air)…

Check this out:http://www.colorado.edu/physics/2000/microwaves/mwintro.html

The speed of electromagnetic waves is constant at 299, 792, 458 m/s ≈ 3 x 10^8 m/s. If we know the wavelength and the frequency, we can calculate the speed of the wave. There is a wide range of names for the various types of electromagnetic waves: visible light, x-rays, gamma rays, radio waves, microwaves etc. All of these waves travel at the same speed but have different wavelengths.

Understanding Frequency

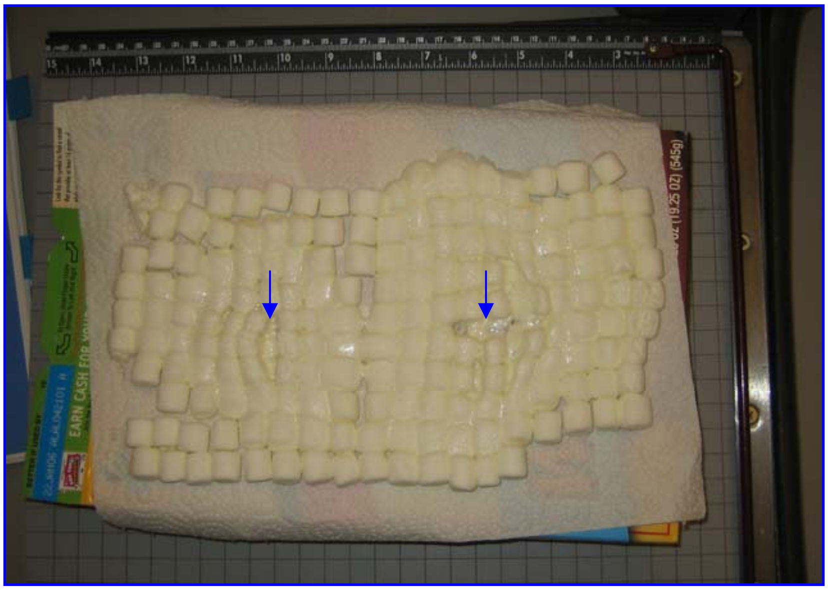
Two waves decide to have a race to see how far they can travel in 10 seconds. These two waves have very different wavelengths; one has a very long wavelength, the other a short wavelength. In this race, both of the waves have to travel at the same speed, the speed of light. In one second they travel a distance of 3 x 10^8 meters. Draw one wavelength of each of the waves and a finish line on a chalkboard or poster board to help the students visualize the race. Two people can demonstrate the race. Have them draw the waves traveling across the board and reach the finish line at the same time. Identify one wavelength of each of the waves and ask the students how many wavelengths did it take for each wave to reach the finish line. Explain to them that that is what frequency is, how many wavelengths it takes to travel per timer interval. The shorter wavelengths have a larger amount of waves per second and thus a larger frequency than the long wavelengths.

This can be paralleled to a tall person and a short person having a speed walking race. If they are going at the same speed they should reach the finish line at the same time, but the number of steps that the short person has to take is greater than the number of steps the tall person takes. The frequency is the number of steps the person has to take per time interval.

Understanding $c = f*\lambda$

If a car travels 100 miles in 2 hours how fast was the car going? We know how far the car went and we know how long the car traveled so we can figure out how fast the car was going. How fast you are going is how far you went divided by how long it took.
In the case of the microwave we know how far the waves traveled, measured by the distance between two hotspots and the frequency. Taking the reciprocal of the frequency will give us the length of time. Then you can solve for c, the speed.

You may want to practice this experiment before using it at an outreach event; if possible, with the microwave you are planning to use. If you find that there are no distinct hotspots, try increasing the elevation of the marshmallows. The results you get for this experiment may not be very accurate considering we are taking 2-dimensional measurements of 3-dimensional waves. When we did this experiment we obtained results that were off by small degrees of magnitude. You can also do this experiment using cheese, chocolate or any food that melts to see if you get better results. See a picture of our results on the following page:



Example of speed of light experiment. The blue arrows indicate the two burned spots.

Sources

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