Bell Labs Science Grant Program: Commitment to High School Science Education

Inquiry-Based Physics Projects in Optics and Acoustics: An Effort to Understand Experimentally Everyday Life Phenomena and Activities

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Lucent Technologies
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Bell Labs Science Grant Program
Sample Project Booklet

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Introduction

Science is perhaps unique as a subject in the curriculum of schools all over the world. This uniqueness results from the variety of materials and experiments necessary for its effective teaching. If it is to be learned effectively science must be experienced. "It must be learned and not learned about."

Believing that science and scientific method of problem solving should play a significant role in science education, especially physics education, Lucent Technologies through their Science Grant Program, Commitment to High School Science Education, offers this book in the hope that it will assist students in their efforts to understand everyday life phenomena related to optics and acoustics. It is also being offered with the hope that science educators can use it as a resource book for experiments in optics and acoustics. The underlying philosophy is that science is most effectively taught when students follow an inquiry-based experimental procedure that investigates questions related to their everyday life experience and activities.

The book includes instructions for making most of the apparatuses, used in the following experiments from relatively inexpensive material. However, the main criterion for the selection of the particular topics introduced in this book, was to include experiments that interest students and challenge them at the same time.

We believe that we have provided a broad and balanced range of ideas, skills and contexts through which students can construct scientific knowledge. However, no claim that this book is complete is made. But it is hoped that these pages will serve as a stimulus to both students and teachers to define their own science problems and then find the answers to their own questions through inquiry-based experimental procedure.

Foreword

This handbook is designed to assist in the creation of science projects for The Bell Labs Science Grant Program. Projects may be derived from this handbook, but we welcome and encourage projects in Computer Science, Information Science, Physics, Electrical Engineering, Mechanical Engineering and other sciences. All African American, Hispanic, and Native American high school science students in New Jersey and New York City are encouraged to participate in this grant program. Students may apply for up to $1,000 under this program toward the completion of a science project. Each participant and project funded under The Bell Labs Science Grant Program will be assigned a staff scientist or engineer from Bell Labs and other research and development organizations as a mentor. There is no limit to the number of applications and grants per school.

For additional information on the Bell Labs Science Grant Program please visit our website: *www.bell-labs.com/fellowships/sgp/* This website will provide you with the complete introductory package, guidelines, application forms and specific dates related to The Bell Labs Science Grant Program. We look forward to your participation.

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Make Your Own Camera

Photos are indisputably a major part of our life. People everywhere in the world treasure them because of their personal meaning or use them in order to support their ideas, projects, stories, etc. However, have you ever wondered how moments or things related to our lives can be captured on a piece of paper? Do you know what a camera is? Do you know what film is? Why do we use film? How many times did you wonder how a camera works? Follow us through the process of creating your own camera and find out for yourself the answers to these questions or the ones that were troubling you so far!

Degree of Difficulty

Experiment: Easy

Conceptual: Easy

Objectives

Completion of the activities should enable you to:

- construct your own Pinhole Camera
- explain the reasons for each decision you make regarding the construction of the camera (i.e. the size of the hole)
- explain how a "clear" image can be formed
- compare the image with the real object (i.e. size)

Materials: Shoebox, black paint or black paper, scissors, greaseproof paper (with grids if possible), stiff cardboard, pins, scotch-tape, meter stick, small convex lens (its size must be about 1cm. and its focal length can be anything).

Procedure

Constructing the camera

1. Cut one of the small sides out of the shoebox, but not the lid.
2. Paint the inside of the box and the lid black, or attach black paper along all sides of the box and the lid.
3. Take the small side of the box (the one that you did not cut out) and make a pinhole somewhere in the center.
4. Hinge the lid on the shoebox with scotch-tape. Have in mind that the lid will be opened several times in this experiment. Thus, it must easily open and close without destroying the other parts of the camera (cut the corners so you can easily raise the lid).
5. Place a piece of greaseproof paper (with 1cm. grids) on a stiff cardboard or wooden frame so it can fit inside the box. The dimensions of the frame must be slightly less than the width and the height of the box. The frame must be put inside the box and it must be removable. If you have problems fixing the screen in parallel position with the small side of the shoebox, use some dark clay to fasten the two lower corners of the screen on the box. Another

way of fixing the screen and keeping it removable at the same time is to stick it on a small ruler (the ruler's length must not be more than half of your shoebox's length—otherwise it will bother your face when trying to see through it). Can you think of another way of fixing the screen but at the same time being able to remove it without opening the lid? Include a description and an explanation of your idea in your final report.

6. The final setup must be: eye - greaseproof paper - pinhole - object.

Activities

1. Point the camera at something bright and look at the picture. Draw the object and the picture/image.
    - How does the image relate to the object? Is it larger or smaller? Is it upside down or right side up?
2. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a *systematic research method* you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested that you change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).
    - How does the relationship change as we change the distance between the camera and the object? Measure the image sizes (how many grids does the image area cover?), as the distance between the camera and the object increases or decreases and plot these on a graph.
    - Does the brightness of the picture change, as the distance between the camera and the object increases or decreases?
3. Try making 2 more holes close to the first pinhole. Do you see any changes regarding the picture/image that is being formed on the screen (all 3 holes must be opened)? Try making 1 of the 2 additional holes bigger and the other smaller than the initial hole. By covering 2 of the holes each time, explain how the size of the uncovered pinhole affects what you see on thescreen.
4. Move to a darkened room, where transparencies of various letters are projected on a big screen. Project one of the transparencies and before using your pinhole camera predict what you will see on the screen of your camera (draw a sketch of your prediction). Does your prediction agree with what you actually see on your camera's screen? (This activity must be done in school, with help from your science teacher)

5. Look only in your pinhole camera and try to determine the word your teacher projects on the wall.
6. Make a hole 1cm. in diameter and place a convex lens in front of it. Find a screen position for a clear image. Can you find more than one point where you can get a clear image? **Follow Steps 1 though 5 once more.** How do your results compare with the pinhole camera you have at first? Explain.
7. Visit the following website *(http://www.exploratorium.edu/light_walk/camera_todo.html)*. The site will give you specific information on how to construct a different version of a pinhole camera. The advantage of this camera is that you can take pictures with it (special film must be purchased). Why can your shoebox camera not be used for taking pictures? In order to answer this question you will have to investigate what the films are made of (try both your school library and the internet).
8. Design and perform experiments to answer the following questions regarding the camera you constructed in the previous activity. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion.
   - How does the time you leave your camera's hole open affect the quality of your pictures?
   - Does the brightness of the light surrounding the object you are taking the picture of affect the quality of your pictures? (For this experiment, it is suggested to take the picture of the same object at different times of the day, i.e. early in the morning, at noon, in the afternoon, at night. Your source of light will be the sun, a light with a dimmer switch, or a 3-way bulb)

Final Project/Report

- Your have been asked to write the manual for the pinhole camera you have constructed in activity 7 by a major camera manufacturer. You have the freedom to make your own selections concerning the content of the manual. Do not forget to summarize all the experiments and the activities you have performed in this project. In addition, the manual must be descriptive and understandable by people that have never used a pinhole camera before. Therefore,it is strongly suggested that sections about how to build the pinhole camera, how to use the camera, and how/why the camera works be included within your manual. Use of diagrams or pictures is strongly suggested. A camera manual would be a good point to start your research from. Have fun!

Reference

Smith, G. and Holloway, G. (1985). *40 Science Activities*. London: Macmillan Education

Make Your Own Animated Movie

Have you ever wondered how an animated movie is created? How do pictures become alive in front of our eyes? Follow us through the process of creating your own animated movie by using a very simple device (stroboscope) that you will built yourself, and find out the answers to these questions or the ones that were troubling you so far!

Degree of Difficulty

EXPERIMENT: Easy

CONCEPTUAL: Moderate

Objectives

Completion of the activities should enable you to:

- construct your own stroboscope
- understand the principles underlying the stroboscope
- be able to produce sets of pictures (flip-book figures) showing physical phenomena or physics laws
- be able to explain the practical applications of a stroboscope

Materials: Scissors, stiff cardboard, pins, scotch-tape, meter stick, a wooden handle (a piece of wood - 1.5cm. x 2cm. x 25cm.), mirror, bolt, 2 washers, two nuts, one lock nut, permanent marker, drill.

Procedure

Constructing the stroboscope

1. Take the stiff cardboard and cut a disk with a diameter of 36cm.
2. Mark off about twelve equal spaces along the periphery of the disk.
3. Cut a slit about 2x3cm. (starting from the periphery - 3cm. along the radius) for each one of the marked points of Step 2.
4. Make a single hole at the center of the disk, equal to the diameter of the bolt that is available (you will use the bolt to attach the disk to the wooden handle).
5. Draw a set of flip book pictures, one under every slit (about 1cm. underneath the slit), with their head facing right.
6. Take the wooden handle (1.5cm. x 2cm. x 25cm.) and drill a hole, equal to the diameter of the bolt that is available, at one of its ends.
7. Attach the center of the disk (after you make the slits and draw the flip-book pictures) to the wooden handle (the disk will be parallel to the handle). First, insert the bolt into the wooden handle hole and fasten it with a

nut. Second, pass the bolt that is already on the handle through the center hole of the disk. Third, fasten the disk with a second nut and lock the second nut with the use of a third nut ("lock nut").

8. Put your device (stroboscope) between one of your eyes and a mirror (the mirror does not have to be of particular size, but must be big enough for you to see clearly the flip-book pictures in it) with the revolving figures facing the mirror.
9. With one hand hold the wooden handle, and, with the other one, spin the disk. Look through the slits of the stroboscope at the pictures in the mirror, as the disk is rotating.

Activities

1. Look through the slits of the stroboscope at the pictures in the mirror as the disk is rotating. Change both the rates and the direction of rotation. What do you observe?
2. How does this phenomenon relate to slow motion photography or speeded up photography? (Physics books and internet would be helpful)
3. Draw a new set of flip-book pictures, one under every slit (about 1cm. underneath the slit), with the head now facing left instead of right. Do you observe any differences? How about if you draw the top towards the edge?
4. Use your stroboscope to observe a spinning wheel of a bicycle.
    - What do you observe when you rotate your stroboscope in the same direction as the spinning wheel?
    - What do you observe when you rotate your stroboscope in the opposite direction as the spinning wheel?
    - What physical value relates to the rotation rate of your stroboscope?
5. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested to change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).

- Can you make the spinning wheel of a bicycle seem to stop turning? Can you make it seem to turn in the opposite direction it rotates (backwards)?
- How does the angular velocity of the spinning wheel relate to the angular velocity of your stroboscope in each of these two cases? We use the term *angular velocity* to refer to the rate with which the rotating body (i.e. wheel) is rotating. If you have more questions regarding this physical value, ask your science teacher to help you.
- Is it possible to make the wheel seem to spin faster than it actually is?

6. Follow Steps 1 to 4, and 8 to create a new stroboscobe. However, instead of drawing flip-book pictures on the disk, divide one of its surfaces in three equal areas/pieces (it will look like a pie graph). Paint the first piece cyan, the second magenta, and the third yellow. Put your stroboscope between one of your eyes and a mirror. Look through one of the slits at one of the colored pieces.
   - Try to rotate the two wheels with the same angular velocity (at this point you will probably need someone to rotate the two wheels for you). What do you see? Are you able to see all colors? If no, how can you see the rest of the colors? Explain your reasoning and report any mathematical calculations you might make.
   - What if the disk is divided in more than 3 equal pieces? Will it take the same time as before to see a second colored area? Explain your reasoning and report any mathematical calculations you might make.
   - What do you see when the angular frequency of your stroboscope is much less than the angular velocity of the colored spinning wheel? Explain your reasoning. Change the colors of your colored wheel. Do you observe any differences? Explain.
7. Create a second spinning wheel for your stroboscope, where you present a physical phenomenon. For example, show how a feather and a stone will move relative to each other, when you drop them from a certain height. First, assume that the air resistance is negligible and then show how the two items will move with the presence of air resistance. You are encouraged to create more flip-book pictures for your own ideas.
8. Create another spinning wheel for your stroboscope, where you use more than one color to color parts of the item you are sketching. For this part you have to be systematic. For example, start with one stationary item painted with one color, then use two colors (one every other picture), then use three colors (one every two pictures), etc. Make sure that each time you are adding a color you make the corresponding observation by rotating your stroboscope. It is suggested to create a two-column table where you report the colors you used for your picture and your observation.

9. Design a set of flip-book pictures where you present a stationary wheel spinning.

Final Project/Report

- You have been asked to write a manual for the stroboscope by a major company. You have the freedom to make your own selections concerning the content of the manual. Do not forget to summarize all the experiments and the activities you have performed in this project. Keep in mind the manual must be descriptive and understandable by people that have never used a stroboscope before. Therefore, it is strongly suggest that sections about how to build the stroboscope, how to use the stroboscope, and how/why the stroboscope works are included within your manual. Use of diagrams or pictures is strongly suggested. At the end of your manual give examples of possible applications of the stroboscope in our everyday life.

Reference

Smith, G. and Holloway, G. (1985). *40 Science Activities*. London: Macmillan Education

Invisible Animals

Did you know that colorless animals can become invisible in water? Do you want to know how they do it? Follow this experiment and see not only the magic surrounding these animals, but also learn how to make items become invisible yourself!

Degree of Difficulty

EXPERIMENT: Easy

CONCEPTUAL: Moderate

Objectives

Completion of the activities should enable you to:

- understand Snell's law
- explain the phenomenon of how colorless animals can "disappear" in water.
- simulate the phenomenon by using a test tube made of glass and different solutions, such as, corn syrup, sugar solution, etc.

Materials: Clear corn syrup, water, graph paper, a semi-cylindrical petri dish, protractor, ruler, laser pen or light box, calculator, polar graph paper.

Part A: Procedure

Snell's Law

1. Place the protractor on the graph paper and mark a point around its semi-circular side at 15º, 30º, 45º, 60º, 75º, 90º, 105º, 120º, 135º, 150º, and 165º. Make sure that you mark a line at the center of the protractor (midpoint of line at 0º).
2. Connect each point marked on the circumference of the protractor with the point at its center. The line at 900 is called "the normal."
3. After you draw the lines, remove the protractor and place the dish on the paper. Make sure that the center of the flat side of the petri dish and the already marked point of the protractor's center match.
4. Fill the petri dish with water.
5. Place the laser pen or light box about two inches away from the petri dish and aim a beam of light from the laser pen at the curved side of the dish. Examine what happens when the beam strikes the dish at different angles. Starting from the normal try to match the beam coming out from the laser pen with the already marked lines on the graph paper. Sketch various arrangements of the dish and beam, both before it passes through the dish (*incident beam*) and after it a passes through (*refracted beam*). In some cases you will not see a refracted beam, but a reflected beam. This phe-

nomenon is called *total internal reflection* and the angle between the reflected beam and the normal is called *angle of reflection*.

6. Place the petri dish of water on a sheet of polar graph paper. The center of the flat side of the dish must be positioned at the center of the paper. Arrange the light beam and dish as you did in Step 5. Concentrate on the angle of incidence (angle between the normal and the incidence beam) and the angle of refraction (angle between the normal and the refracted beam). Note that when the beam of incidence matches with the normal, the angle of incidence is 0º. Use angles of incidence ranging from 0º to 90º in increments of 5º. Measure the angle of refraction for each case with the protractor and use your calculator to get the sine of an angle. Record your data in the following table:

Angle of Incidence	Angle of Refraction	Sine of Angle of Incidence	Sine of Angle of Refraction

7. Make a graph of Sine of Angle of Incidence versus Sine of Angle of Refraction. Should your graph pass through the origin? Determine the slope of the graph and write an equation that relates the slope, Angle of Incidence, and Angle of Refraction.
   - Repeat Steps 6 and 7, by changing the content of the petri dish. Use material such as glass (for this one you will need a petri dish of solid glass), alcohol, corn syrup, vegetable oil, corn oil, salt water (try different concentrations), sugar and water (try different concentrations), and soda and air. Try it with different things in the tank and dish (water in tank, air in dish; air in tank, water in dish; etc.) for all fluids.You could try material of your own preference, as well. Record your data in the following table:

Solution	Slope of the graph

8. Get a relatively big tank (i.e. ripple tank), which allows you to repeat Steps 6 to 8, and put some water in it. Make sure that you use a waterproof laser pen before you put it in the tank. The level of water must not surpass the petri shell's height. Once, again repeat Steps 6 to 8 and record your data in an identical table as the one presented at Step 8.

9. Compare the two tables and explain any differences.

Activities

1. At Step 3 of the procedure we mention that “after you draw the lines, remove the protractor and place the dish on the paper. Make sure that the center of the flat side of the petri dish and the already marked point of the protractor’s center match.” Would this also work with a circular petri dish, if the center of the dish is placed on the mark?
2. Design and perform experiments to answer the following questions:
   - Is the angle of reflection the same for all the substances you tested? Could this experiment be used as a method for identifying substances or materials? Explain.
   - Can a total internal reflection occur when a light beam in water is incident on air?
   - Does total internal reflection occur for a specific angle or for a range of angles? Give the angle or the range of angles for each substance you tested at Step 8.
3. The slope of the graph of Sine of Angle of Incidence versus Sine of Angle of Refraction from Step 8 is called the index of refraction of water with respect to air. The relationship between the Sine of Angle of Incidence versus Sine of Angle of Refraction is called the law of refraction or Snell’s Law:

   index of refraction of inside stuff x Angle of Refraction =
   index of refraction of outside stuff x Angle of Incidence

   Given Snell’s Law and that the i**ndex of refraction of air** is equal to 1, interpret the slopes of the graphs you obtained at Step 9.

Part B: Procedure

“Invisibility”

1. Place the petri dish on a sheet of polar graph paper. The center of the flat side of the dish must be positioned at the center of the paper and the line at 90^o must be perpendicular to it.
2. Set the laser pen so that the angle of incidence is 45^o. In this part of the experiment the angle of incidence will be kept constant. Therefore, it is a good idea to fasten the laser pen at 45^o with some masking tape.
3. Fill the semi-cylindrical plastic dish with clear corn syrup and pass the laser light through it. Measure the angle of refraction. Repeat the same process for different solutions by diluting corn syrup with water. The solutions should have different concentrations (90% of corn syrup to 10% of water, 80% of corn syrup to 20% of water, 70% of corn syrup to 30% of

water ..10% of corn syrup to 90% of water, and 100% water). Record your data in the following table:

Solution	Angle of Incidence _i	Angle of Refraction _r	Sine of Angle of Incidence	Sine of Angle of Refraction	Refractive index *n*

4. Describe how does the refractive index of corn syrup change as water is added.
5. Repeat Steps 1 to 4 for other solutions (i.e. salt and water, and sugar and water), including different types of oils (corn oil, vegetable oil, olive oil). Do not mix water with oil. Why will mixing water with oil not work? However, if you want to dissolve them use ethanol.
6. Describe which of the substances give you the same visual result as the corn syrup.

Activities

1. Take two glass test tubes. Fill two thirds of the first one with corn syrup and the other with water. Place both in a small beaker half filled with corn syrup. Explain what you observe by using concepts from the experiments you conducted in Part A and B.
2. Notice that the corn syrup test tube seems to disappear, while the test tube of water is clearly visible. Select two other substances that you used at Step 5 of Part B to make one of the test tubes disappear.
2. Design and perform experiments to answer the following questions:
   - Could the substance that is in the test tube that seems to disappear be different from the substance that is in the beaker?
   - Could the test tubes be of different material than glass?
3. Explain how do you think colorless animals can “disappear” in water?

Final Project/Report

- Write a report summarizing all the experiments and the activities of Parts A and B. In addition,do some research on animals that can “disappear” in water. Does their method of becoming “invisible” agree with the prediction you made in Activity 4 of Part B?

Reference

Sheppard, K. (2000) Index of Refraction. *Scientific American,* Teacher’s kit, p. 6

Are There Artificial Colors in Your Food?

Do you want to know whether your food contains artificial color? Do you want to know if that color is not harmful to your health? Follow this experiment and see how a dye or dyes contributing to the color of a substance can be identified spectrophotometrically. Spectrophotometry involves the photometric (the measurement of the interaction of radiant energy with matter) comparison between parts of the spectra (ultraviolet and visible). The experiment is separated in two parts. The first part aims to familiarize you with the operation of the Spectrometer. The second part describes a simple method you can follow in order to identify dye(s) that might be in your favorite candy!

Degree of Difficulty

EXPERIMENT: Moderate

CONCEPTUAL: Moderate to Difficult

Objectives

Completion of the activities should enable you to:

- understand the function of the spectrometer 20D.
- set the spectrometer to a specific wavelength.
- extract the dye(s) from a substance and identify it using a spectrophotometer.

Part A Materials: Spectrophotometer 20D, 2 cuvettes, Chalk, Water, Kimwipes. Educational Absorption Spectra Kit is available from: Milton Roy Company, 820 Linden Avenue, Rochester, NY 14625, Phone: 800-654-9955 (Catalog # 333135, List Price: $62.00)

Part B Materials: Candies, cuvettes, spectrophotometer, test tubes, distilled water.

Part A: Procedure

The Digital Spectrometer 20D

1. Turn on the Spectrometer (turn the left front knob clockwise).
2. Turn the large knob (wavelength control knob) on the top slowly. What do you observe on the display? What does the number represent?
3. Adjust the wavelength to 450nm (nm corresponds to *nanometers*, which is a wavelength's unit of measurement - 1 nanometer = 1 x 10^{-9} meters). Place a cuvette with white chalk (or a white piece of plastic/rubber) into the *sample compartment* (if you have difficulty finding it, ask your teacher or use the manual). Look into the sample compartment and describe what you see. What do you observe as you increase the wavelength? How about when you decrease the wavelength?
4. Without removing the chalk, slowly turn the front right knob (Transmittance control knob) both towards right and towards left. What do you observe?
5. Adjust the wavelength to the lowest possible setting without removing the

chalk in your cuvette. Increase the wavelength until you see light appearing on the chalk. This is the *lowest visible wavelength*. What light's wavelength is immediately beneath the lowest visible wavelength?

6. Remove the chalk cuvette and close the lid on the sample compartment. Turn the left front knob (zero control knob) until the data value is 0.0. (The minus sign may flash on and off this is normal.)
7. Fill a cuvette with deionized water to within 2cm of the top (the water is called a *blank* because it does not have anything dissolved in it). Make sure that the bottom of the cuvette is clean. Why is it important to keep the cuvette clean? (The manufacturer suggests handling cuvettes by touching them near the top by the mark. This mark should line up with the raised ridge on the front of the sample compartment.) Insert the blank (cuvette with deionized water) into the *sample compartment*. Make sure that the lid is closed.
8. Adjust the transmittance control until the right number reads 100.00. Press the mode button once. The spectrophotometer should now be set on absorbance and the data should read 0.00. Remove your cuvette from the spectrophotometer and set the mode to transmittance. Set the wavelength to 450nm. Insert a blank and set transmittance to 100.0%. Adjust the wavelength to 550nm. What has happened to the percent transmittance? (According to the manufacturer, Milton Roy, because the instrument is not equally sensitive to all wavelengths, it must be adjusted *every time you change wavelengths*. The transmittance control should be adjusted so that the instrument reads 100.00 transmittance or 0.00 absorbance when a blank is placed in the sample holder).

Note: *The structure and procedure of introducing the Spectophotometer 20D was based upon the description that was provided by the manufacturer's manual (Harris, 1993).*

Activities

1. Repeat Steps 1 to 5. Looking at the chalk, determine the range of wavelengths for each color of light and record your data in the following table:

Color of Light	Wavelength-Lowest Value	Wavelength-Highest Value
Red		
Orange		
Yellow		
Green		
Blue		
Indigo		
Violet		

Using your data, describe the relationship between color and wavelength. Have you seen colors appear in this order before?

2. In addition to the markings, is there anything that has to be done more carefully on a cuvette than on test tubes? Explain.
3. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested to change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).
   - Do different solutions absorb light of different colors or wavelengths?
   - Does the wavelength of light that a solution absorbs best depend on the color of the solution?
   - Does the amount of light absorbed depend on concentration?
   - What would be an approximation for the wavelength of the infrared or ultraviolet light? Is it possible to approximate wavelengths smaller than the wavelength of the ultraviolet light or bigger than the wavelength of the infrared light?
   - What is the wavelength of maximum absorbance of a colored solution? (Help: Start with 350nm. Set to 0% transmittance, place the blank into the *sample compartment* and set to zero absorbance. Remove the blank and place the colored solution into the unit. Record the absorbance in a table. Repeat the same process in increments of 25nm. Locate the 50nm region in which the absorbance is highest and repeat the process in increments of 10nm. By plotting absorbance versus wavelength, it will be easier for you to find the maximum absorbance—it's the point where your graph peaks. If you do not have a graphing program, such as Cricket Graph, use Microsoft Excel.)

Part B: Procedure

As you have seen in the previous part of this experiment, each particular color/dye has a known wavelength where the absorbance of light is at a maximum. By scanning the entire visible spectrum one can determine the wavelength of maximum absorbance for a particular dye. After determining the wavelength of maximum absorbance, the identification of a dye can easily be done by referring to a list of approved dyes and their wavelengths of maximum absorbance.

Identifying food dye(s)

1. Prepare a solution of the food dye. To make a solution of the candy (M&Ms or Skittles are suggested), place it in a test tube with distilled water, shake gently, and then filter quickly.
2. Turn on the spectrophotometer. The manufacturer suggests allowing 15 minutes before use for warming up. With nothing in the sample compartment, set the transmittance to 0%.
3. Place 3-4ml of water (if you are using a different solvent, use that one as blank) into a cuvette to serve as a blank.
4. Insert the blank into the spectrophotometer and set the wavelength to 350nm. Set the absorbance to zero.
5. Replace the blank with the cuvette containing the sample and record the absorbance.
6. Repeat Steps 4 and 5, changing the wavelength to 375nm. Continue recording absorbances for increments of 25nm until you reach 700nm. The following table is suggested to be used for recording your data:

Data Table: Identification of Food Dyes

Wavelength (nm)	Absorbance
350	
375	
400	
425	
...	
...	
...	
675	
700	

7. Use a reference table (Merck Index), which provides the names of the dyes and the wavelengths of maximum absorbances to identify the dyes you were testing at Step 6. Record your data in the following table:

Dye#	Wavelength of maximum absorbance	Name of the dye

For a reference table use the list that is provided by Marmion (1991). The list will provide you with the name of the dye, the solvent system that was used, and the maximum wavelength.

Activities

1. Repeat Steps 1 to 7 for food coloring (add one drop of food coloring to 100ml of distilled water). Use as many colors as possible.
2. Explain why it was necessary to scan the blank solution at Step 5? If we skip this step how would our experiment be affected?
3. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions.
   - Would this method we are using for identifying dye(s) in food be effective in separating two dyes that are very similar in color?
   - Try two food colors at once. Do you get two peaks that can be used to identify both?
   - Does a mixture of different dyes, that corresponds to an already existing dye you have available, have the same wavelength of maximum absorbance with the available dye that matches its color?

Final Project/Report

- You have been asked by the Consumer's Union to investigate 20 different brands of candies and report whether they fulfill the federal standards by reporting the dye(s) they are using. You have the freedom to make your own candy selections. Do not forget to summarize all the experiments and the activities you have performed in this project. Have in mind the report must be descriptive and understandable by people that have never done this experiment. Use of tables, diagrams or pictures is strongly suggested. At the end of your report give examples of other possible applications, of this method of identifying dye(s) in food, in our everyday life.

References

Harris, E. and Anderson, M. (1993). *Spectrometry Made Simple*. Milton Roy

Marmion, D. M. (1991). *Handbook of U.S. Colorants - Foods, Drugs, Cosmetics and Medical Devices*. Wiley and Sons.

Save Yourself From a Sunburn: A Scientific Way to Determine the Most Effective Suntan Lotion

Do you want to know whether the suntan lotion you are using to protect you from sunburn is the most effective in blocking the radiation that causes them? Do you want to know if you are using the right protection factor? Follow this experiment and see how an effective sunscreen (one that completely blocks the radiation in the vicinity of the wavelength that causes sunburn) can be identified spectrophotometrically. Despite the fact that the term might sound complex, for the purpose of this experiment the process you will follow is very simple. Spectrophotometry involves the photometric (the measurement of the interaction of radiant energy with matter) comparison between parts of the spectra (ultraviolet and visible). The experiment is separated in two parts. The first part aims to familiarize you with the operation of the Spectrometer. The second part describes a simple method you can follow in order to identify the suntan lotion that will best protect you from getting sunburned.

Degree of Difficulty

EXPERIMENT: Moderate

CONCEPTUAL: Moderate to Difficult

Objectives

Completion of the activities should enable you to:

- understand the function of the Spectrometer 20D.
- set the spectrometer to a specific wavelength.
- determine the most effective lotion through spectrophotometric analysis.

Materials for Part A: Spectrophotometer 20D, 2 cuvettes, Chalk, Water, Kimwipes. The Educational Absorption Spectra Kit is available from: Milton Roy Company, 820 Linden Avenue, Rochester, NY 14625, Phone: 800-654-9955 (Catalog # 333135, List Price: $62.00)

Materials for Part B: “PABA free” suntan lotions (they can be dissolved with *n*-propanol), cuvettes, spectrophotometer, *n*-propanol, waterproof and not waterproof lotions, deionized water.

Part A: Procedure

The Digital Spectrometer 20D

1. Turn on the Spectrometer (turn the left front knob clockwise).
2. Turn the large knob (wavelength control knob) on the top slowly. What do you observe on the display? What does the number represent?
3. Adjust the wavelength to 450nm (nm corresponds to *nanometers*, which is

a wavelength's unit of measurement - 1 nanometer = 1 x 10^{-9} meters). Place a cuvette with white chalk (or a white piece of plastic/rubber) into the *sample compartment* (if you have difficulty finding it, ask your teacher or use the manual). Look into the sample compartment and describe what you see. What do you observe as you increase the wavelength? How about when you decrease the wavelength?

4. Without removing the chalk, slowly turn the front right knob (transmittance control knob) towards the right and towards the left. What do you observe?
5. Adjust the wavelength to the lowest possible setting without removing the chalk in your cuvette. Increase the wavelength until you see light appearing on the chalk. This is the *lowest visible wavelength*. What light's wavelength is immediately beneath the lowest visible wavelength?
6. Remove the chalk cuvette and close the lid on the sample compartment. Turn the left front knob (zero control knob) until the data value is 0.0. (The minus sign may flash on and off; this is normal.)
7. Fill a cuvette with deionized water to within 2cm of the top (this water is called a *blank* because it does not have anything dissolved in it). Make sure that the bottom of the cuvette is clean. Why is it important to keep the cuvette clean? (The manufacturer suggests handling cuvettes by touching them near the top by the mark. This mark should line up with the raised ridge on the front of the sample compartment). Insert the blank (cuvette with deionized water) into the *sample compartment*. Make sure that the lid is closed.
8. Adjust the transmittance control until the right number reads 100.00. Press the mode button once. The Spectrophotometer should now be set on absorbance and the data should read 0.00. Remove your cuvette from the Spectrophotometer and set the mode to transmittance. Set the wavelength to 450nm. Insert a blank and set transmittance to 100.0%. Adjust the wavelength to 550nm. What has happened to the percent transmittance? (According to the manufacturer, because the instrument is not equally sensitive to all wavelengths, it must be adjusted *everytime you change wavelengths*. The transmittance control should be adjusted so that the instrument reads 100.00 transmittance or 0.00 absorbance when a blank is placed in the sample holder).

Note: *The structure and procedure of introducing the Spectophotometer 20D was based upon the description that was provided by the manufacturer's manual (Harris, 1993).*

Activities

1. Repeat Steps 1 to 5. Looking at the chalk, determine the range of wavelengths for each color of light and record your data in the following table:

Color of Light	Wavelength-Lowest Value	Wavelength-Highest Value
Red		
Orange		
Yellow		
Green		
Blue		
Indigo		
Violet		

Using your data, describe the relationship between color and wavelength. Have you seen colors appear in this order before?

2. In addition to the markings, is there anything that has to be done more carefully on a cuvette than on test tubes? Explain.
3. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested to change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).
    - Do different solutions absorb light of different colors or wavelengths?
    - Does the wavelength of light that a solution absorbs best depend on the color of the solution?
    - Does the amount of light absorbed depend on concentration?
    - What would be an approximation for the wavelength of the infrared or ultraviolet light? Is it possible to approximate wavelengths smaller than the wavelength of the ultraviolet light or bigger than the wavelength of the infrared light?
    - What is the wavelength of maximum absorbance of a colored solution? (Help: Start with 350 nm. Set to 0% transmittance, place the blank into the *sample compartment* and set to zero absorbance. Remove the blank and place the colored solution into the unit. Record the absorbance in a table. Repeat the same process in increments of

25nm. Locate the 50nm region in which the absorbance is highest and repeat the process in increments of 10nm. By plotting absorbance versus wavelength, it will be easier for you to find the maximum absorbance—it's the point where your graph peaks. If you do not have a graphing program, such as Cricket Graph, use Microsoft Excel.)

Part B: Procedure

Sunburn is caused most severely within the range of 285-315nm. An effective sunscreen would be one that completely blocks the radiation of these wavelengths(Harris, 1993). In order to be effective, active ingredients of the suntan lotion must exhibit an intense absorption maximum centered around 300nm while transmitting the longer wavelength tanning radiation (It could also block the tanning wavelengths. There's no requirement that you end up tanned).

Your experience with the Spectrophotometer from Part A, can be used to find the absorbance of suntan lotions at various wavelengths. Despite the fact that absorption below 320nm can not be obtained by using Spectrophotometer 20D, general trends in absorption can be observed graphically and decisions can be made about the lotions' effectiveness (Harris, 1993).

Determining effective sunscreen

1. Prepare a solution of the suntan lotion. To make the solution, *n*-propanol must be used as a solvent. Pour some suntan lotion in a test tube with *n*-propanol and shake gently (Precision isn't important, but it shouldn't be too dilute for the 20D to detect it, or so concentrated that there's no transmission). After the solution is ready pour 5ml in a cuvette.
2. Turn on the Spectrophotometer. The manufacturer suggests allowing 15 minutes before use for warming up. Using *n*-propanol as a blank, set the wavelength to 420nm and zero the instrument.
3. Replace the blank with the cuvette containing the sample and record the absorbance.
4. Continue to take readings at 10nm intervals to the lowest wavelength your spectrophotometer is giving you. Remember to zero the instrument using the blank at every wavelength. Record your data in the following table:

Wavelength (nm)	Absorbance
420	
410	
400	
...	

5. Use the data collected in Step 4 and graph absorbance versus wavelength.

Activities

1. "Despite the fact that absorption below 320nm cannot be obtained by using Spectrophotometer 20D, general trends in absorption can be observed graphically and decisions can be made about the lotions' effectiveness." Explain why this is a good assumption; i.e., why it's not likely that the sunscreen you buy isn't a notch filter that blocks only the burning wavelengths?
2. Repeat Steps 1 to 5 for different brands of suntan lotion. Use as many as possible.
3. Why did we use *n*-propanol for blank and not water?
4. Repeat Steps 1 to 5 for different brands of non-waterproof suntan lotions. What solvent shall we use in this case?
5. Explain why it was necessary to scan the blank solution at Step 2? If we skip this step how would our experiment be affected?
6. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions.
    - Do the suntan lotions of a particular brand, but of different protection factor, have the same sunscreen effectiveness? Check various brands (at least five).
    - Do suntan lotions of different brands, but of the same protection factor, have the same sunscreen effectiveness? Compare all possible combinations (i.e. compare all the brands you have with protection factor 10 and then compare all the brands you have with protection factor 20, 30, etc.)

Final Project/Report

You have been asked by the Consumer's Union to compare 5-10 different brands of suntan lotions and report which of them are the most effective for each particular protection factor and at the most affordable price. You have the freedom to make your own suntan lotion selections. Remember to summarize all the experiments and the activities you have performed in this project. Have in mind the report must be descriptive and understandable by people that have never done this experiment. Use of tables, diagrams or pictures is strongly suggested. The first part of your project report must summarize how suntan lotions are made, which are the active ingredients of the suntan lotion that exhibit an intense absorption maximum centered around 300nm, how do we obtain different protection factors, and why do we need different protection factors.

References

Harris, E. and Anderson, M. (1993). *Spectrometry Made Simple*. Milton Roy

Measuring the Diameter of a Hair with a Laser

Have you ever wondered what the width of your hair is? Do you want to know how to obtain a very good estimation of its diameter? Follow this experiment and see how to measure the diameter of a hair and wire using a He-Ne laser. The experiment is separated in two parts. The first part aims to familiarize you with the operation of the laser and to measure the wavelength that the laser is emitting. The second part describes a simple method you can follow in order to measure the diameter of a hair and wire. It is suggested that you study diffraction before performing this experiment, even though it is not necessary for the procedure of the experiment, in order to have a better conceptual understanding of the phenomenon.

Degree of Difficulty

EXPERIMENT: Moderate to Difficult

CONCEPTUAL: Difficult

Objectives

Completion of the activities should enable you to:

- measure the wavelength of light from a He-Ne laser.
- measure the wavelength of light from a He-Ne laser and measure the diameter of a hair and wire using a He-Ne laser, steel rule, and meter stick.

Materials: He-Ne laser, hair, steel ruler (instead of diffraction grating), white screen, meter stick, computer, Microsoft Excel (or any other software with graphing capabilities).

Part A: Procedure

The wavelength of light from a He-Ne laser

When lights from two different sources cross they can interfere with each other to produce an alternating pattern of *bright and dark* regions. If the wave peaks are *in phase* there will be *constructive interference* and the *intensity* will be a maximum (bright region on the screen), while if they are exactly out of phase the intensity will be zero (dark region on the screen). The interference can be generated in a number of ways. Every point on a *wave front* could be considered as the source of a new wave spreading out in all directions at the *velocity* of the wave, with the new wave front being the envelope of all the *wavelets* (Rutgers University Laboratory Manual, 2000). If a smooth wave front is interrupted in some way, the missing wavelets will lead to a new wave front exhibiting a diffraction pattern. A diffraction pattern is easily seen using a *diffraction grating*, a series of regularly spaced scratches or absorbing lines, which serve to remove parts of the wave front in a *periodic fashion* (Rutgers University Laboratory Manual, 2000). The *maxima* in the diffracted spectrum are given by

$$d\,[\sin(\theta_m) - \sin(\theta_i)] = m\lambda$$

where d is the spacing between grating lines, λ is the wavelength of the light, θ_m is the diffracted order, θ_i is the angle of incidence, and θ_m is the angle of diffraction of the m^{th} order maximum, measured from the normal. This formula will be used in the first part of our experiment for determining the laser light's wavelength. Thus, in terms of our data collection we have to measure θ_m, θ_i, λ, and m (d is a constant).

1. Set up the laser approximately 1m away from the screen.
2. Take the steel ruler (it must have gratings of mm) and place it between the laser and the screen. The ruler must be at the same height and nearly parallel to the light (θ_m and θ_i are measured relative to a line perpendicular to the ruler, which means they will be near 90º).
3. By trial and error change screen's position until you find a place where the diffracted spectrum is clear enough to be studied.
4. After setting up the laser at the appropriate location make the necessary measurements, needed to determine the wavelength, of θ_m, θ_i, d and m (use several maxima and average the values to get the final wavelength):
   - θ_m and θ_i will not be calculated directly. Instead you will measure D (distance from grading lines to screen, this measurement is taken only once because the distance from grading lines to screen does not change) and X (distance from the level of the steel ruler and the m^{th} maxima/bright spot), with a meter stick and then use the trigonometric identity

     $$\theta_m = (\pi//2 - \tan^{-1}(X_m/D) \qquad (1)$$

   - The number of maxima m was counted directly from the screen (try to get a big number of maxima. Why?).
   - Record your data in the following table:

Ruler-screen distance (D)	**Grating width (d)**	**Angle of incidence (θ_i)**	**Sin(θ_i)**	
m	**X_m**	**Tan(θ_m)**	**θ_m**	**Sin(θ_m)**

5. For getting a value for λ use the formula

$$\sin(\theta_m) = m\lambda/d + \sin(\theta_i) \qquad (2)$$

Graph $\sin(\theta_m)$ versus **m** by using Excel. The graph should be a straight line, and from the slope (**slope** = - λ/d) you can calculate λ. Since only the slope of the line is of interest for determining λ, the constant factor $\sin(\theta_i)$ of the formula can be ignored.

Activities

1. Briefly summarize the phenomenon you observed in this experiment. Emphasize the reasons why a particular pattern of bright and dark spots appears on the screen.
2. Why can the constant factor $\sin(\theta_i)$ of formula **(2)** be ignored, when graphing $\sin(\theta_m)$ versus **m**?
3. How will the graph change if the grating width **d** is increased? How will the graph change if the grating width **d** is decreased? Is there a limit in terms of how big or how small **d** can get, if we want the bright and dark pattern on the screen to be repeated? Explain.
4. Why do we use several maxima and graph the values to get the final wavelength? Explain.

Part B: Procedure

A single slit will also give a diffraction pattern, with the *minima (dark spots)* in intensity given by

$$B \sin(\theta_n) = n \lambda \qquad (3)$$

where ***B*** is the slit width (in our case it will be the width of the hair), ***n*** the diffraction order, and θ_n the diffraction angle to the ***n****th* minimum. The same pattern is formed by an opaque strip of width ***B***. This formula will be used in the second part of our experiment for determining the width of a hair. (Halliday, Resnick, & Walker, 1997)

Determining the width of a hair

1. Position one of your hairs in front of the laser (you can fix it on the laser or use a stand). When fastened make sure that the hair is straight.
2. By trial and error put the screen at a place where the diffracted spectrum is clear enough to be studied.
3. After setting up the laser at the appropriate location make the necessary measurements, needed to determine the wavelength, of θ_n, **B** and ***n*** (use several minima and average the values to get the final wavelength):
   - θ_n will not be calculated directly. Instead you will measure D (distance from the hair to screen, this measurement is taken only once

because the distance from the hair to screen does not change) and **X** (distance from the central maxima to the ***n***th minima), with a meter stick and then use the trigonometric identity

$$\theta_n = \tan^{-1}(X_n/D) \qquad (4)$$

- The number of minima (**n**) was counted directly from the screen (try to get a big number of minima). Why?
- Record your data in the following table:

Hair-screen distance (D)	Hairwidth (B)			
n	X_n	**Tan(θ_n)**	θ_n	**Sin(θ_n)**

4. For getting a value for λ use the formula

$$\sin(\theta_n) = n\lambda/B \qquad (3)$$

Graph **sin(θ_n)** versus **n** by using Excel. The graph will give you a straight line, and from the slope (**slope** = λ/ **B**) you can calculate λ.

Activities

1. Repeat the same experiment with wires of different diameters. Why do you get the screen pattern you observed in the hair experiment only with opaque strips (thin wires)?
2. Briefly summarize the phenomenon you observed in this experiment. Emphasize the reasons why a particular pattern of bright and dark spots appears on the screen.
3. How will the graph change if the hair width **B** is increased? How will the graph change if the hair width **B** is decreased? Is there a limit in terms of how big or small **B** can get, if we want the bright and dark pattern on the screen to be repeated? Explain.

4. Why do we use several minima and graph the values to get the final wavelength?
5. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define: (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested to change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).
    - How does the pattern on the screen change as the diameter of the wire changes (use thin wires)? Explain.
    - What will happen if I put two hairs next to each other (vary the distance between the two hairs)? Explain.
    - What will happen if I put three hairs next to each other (vary the distance between the two hairs)? Explain.
    - How does the distance between the minima change? Explain.
    - Is the number of minima finite? Explain.
6. When a small source of white light illuminates a compact disc (CD), colored "lanes" are observed. Explain the phenomenon. (Hint: Use concepts from both parts of the experiment and search for applications of *Diffraction Gratings*).

Final Project/Report

Write a report summarizing all the experiments and the activities of Parts A and B, and include information on the applications of diffraction in science (i.e. "cleaning" of a satellite picture).

References

Halliday, D., Resnick, R., and Walker, J. (1997). *Fundamentals of Physics*, NY: John Willey & Sons, Inc.

Rutgers University Laboratory Manual (2000). *Computer Experimentation.* New Brunswick: Rutgers University, The State University of New Jersey

Make Your Own Guitar

Have you ever wondered why a guitar produces sound? Do you want to know how to make one yourself and discover how sound is produced by plucking its strings? Follow this experiment and see how to make a playable guitar.

Degree of Difficulty

EXPERIMENT: Moderate

CONCEPTUAL: Moderate to Difficult

Objectives

Completion of the activities should enable you to:

- construct your own guitar
- understand the relationships among the length, tightness, and diameter of a string and the note produced when it is plucked.
- identify the note produced when the string is plucked
- predict the effect of changes of the length, tightness, and diameter of a string and apply that knowledge to making a playable guitar.

Materials: A guitar, a piece of wood (60x50x2.5cm), guitar strings, 20 weights (0.5kg-10kg, increments of 0.5kg), three 4cm lengths of 1cm wooden dowel per string used, hammer, nails, computer, sound sensor (universal lab interface is needed), "Interactive Physics" software or "Macmotion" software.

Procedure

Constructing the guitar

1. Put the 60x50x2.5cm piece of wood on a table.
2. Hammer one nail into the wood every other 5cm, along one of the smaller sides (8 nails in total). The nail must be about 1cm away from the periphery of the smaller side. Tie a small loop at the end of the string (any string) and loop it over a nail. Tie a weight (1kg) to the other end of the string and let it hang over the edge of the table (align the smaller side that is free of nails with one of the table's edges).
3. Put two dowels under the string about 40cm apart.
4. Connect the universal lab interface to the computer and the sound sensor to the interface (use the manual or ask your teacher to help you at this stage). Start the computer and open the Interactive Physics Software. Select the real time data collection program and set it to graph frequency vs. time (this program collects data and graphs them at the same time) for the first 10 seconds.
5. Place the sound sensor a couple of centimeters away from the center of the string Pluck the string and see the graph that appears on the screen. What does the graph look like? Why does it look like that? What is the frequency of the produced note?

6. Repeat Step 5 as you move the dowels to different positions. Use the same string, the same weight, and vary the length. Start with the dowels being 5cm apart and use increments of 5cm. Record your data in the following table:

Length of the string (distance between the two dowels)	Frequency

Graph frequency versus length (use Microsoft Excel). What does the graph look like? How does the length of the string relate to the frequency? What happens to the note (i.e. loud, soft, high, low, etc.)?

Activities

1. Repeat Steps 1 to 6, but use strings of different diameters this time. Use the same length, the same weight, and vary the diameter of the string (use as many strings of different diameter as you have). Compare the resulting graphs of Step 6 among each other. Explain your observations. Does the frequency depend upon the diameter of the string? What happens to the note (i.e. loud, soft, high, low, etc.)?
2. Repeat Steps 1 to 6, but use different weights. Use the same string, the same length, and vary the weight (from 0.5kg to 10kg. Use increments of 0.5kg). Compare the resulting graphs of Step 6. Explain your observations. Does the frequency depend upon the tightness of the string? What happens to the note (i.e. loud, soft, high, low, etc.)?
3. Describe what happens when a string is plucked. Connect this to how sound is produced and how that sound reaches your ear. In addition, explain how our ears work.
4. How does the volume of the sound change when you place your guitar above an empty box?
5. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested to change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).

- How does the strength of plucking a string relate to the sound's volume?
- How does the strength of plucking a string relate to the frequency of the sound?
- Where do you have to press, along a string, so that you get each note of the scale (doh, ray, me, fah, soh, la, te, doh)? (Hint: Use a real guitar and the Interactive Physics Program, as you did at Step 5. Save a graph of each note the real guitar produces and then try to match each note with your one string guitar.)
- Does the whole string vibrate or just the part between the dowels?
- Suggest how to tune your instrument by using the software you used in this experiment.
- Is it possible to get each note of the scale (doh, ray, me, fah, soh, la, te, doh), with the weights that we have available? The length and diameter must be kept constant.
- Is it possible to get each note of the scale (doh, ray, me, fah, soh, la, te, doh), with the different string diameters that we have available? The length and weight must be kept constant.
- Is it possible to get each note of the scale (doh, ray, me, fah, soh, la, te, doh) by varying only the length of the string?
- What will be the most effective combination of the three variables (length, diameter, tightness) for getting notes of the same frequency as the one-string guitar you made by just varying the length of the string, if we want to have the smallest guitar (in length) possible?

6. How do you think you play higher frequencies on a guitar? Explain.
7. How do you think you tune a string on a guitar? Explain.
8. Explain the importance of the guitar box?

Final Project/Report

- Your have been asked to construct and write a manual for an eight string guitar (one string for each note) by a major guitar manufacturer (use the eight nail piece of wood. It is up to you to decide which of the three variables—length, diameter, tightness—will be varied in order to achieve the eight string guitar). You have the freedom to make your own selections concerning the content of the manual. Remember to summarize all the experiments and the activities you have performed in this project. In addition, the manual must be descriptive and understandable by people that have never used a guitar before. Therefore, it is strongly suggested that sections about how to build the guitar, how to use the guitar, and how/why the guitar works be included within your manual. Use of diagrams or pictures is strongly suggested.

Reference

Smith, G. and Holloway, G. (1985). *40 Science Activities*. London: Macmillan Education

Make Your Own Bottle Organ

Hollow pipes have long been used for making musical sounds. Organ pipes, flutes, and whistles produce sound in the same way. Do you want to know how they work? Follow this experiment and by examining the behavior of air in a bottle that has one of its ends closed off, create your own musical instrument.

Degree of Difficulty

EXPERIMENT: Moderate

CONCEPTUAL: Moderate to Difficult

Objectives

Completion of the activities should enable you to:

- construct your own bottle organ.
- understand the relationships between the length of empty space in a bottle and the note produced.
- identify the note produced.
- predict the effect of changes of the length of the container's empty space, the substance of the container, and shape of the container, and apply that knowledge to making an organ.

Materials: A flute, 8 plastic or glass bottles, at least one bottle (or bottle shaped container) made of different material than glass or plastic (i.e. glass or plastic, stainless steel, aluminum, etc.), at least five identical bottles but of different shapes, permanent marker, water, alcohol, cotton, pipettes (longer than the height of the bottles you are using), liquids of different densities (oil, salt water, corn syrup, etc.), computer, sound sensor (universal lab interface is needed), "Interactive Physics" software or "Macmotion" software.

Procedure

Constructing the bottle organ

If you blow air across the open end of a bottle, the disturbance due to the moving air at that end propagates along the bottle to the far end. Since one of the bottle's ends is closed, the air is not free to move any further in that direction and the closed end becomes a *node* (point of zero amplitude). However, the sound that is produced by your blowing has to do with the fact that an anti-node (point of maximum amplitude) is being formed at the open end of the bottle.

1. Take an empty bottle (plastic or glass) and fill half of it with water.
2. Put some alcohol on a piece of cotton or cloth and clean the bottle top (this is for killing any germs that are on the bottle; do not exchange bottles with other people, if you do so, make sure that you clean it with alcohol before putting it in your mouth).

3. After you make sure that the bottle is clean, press the bottle top to your chin just below your lower lip and blow steadily. If the bottle does not "sing," add water (as much as is needed to raise the level of the water by a couple of millimeters) and blow again. If you still do not get a note, repeat the same process (of adding water) until you finally hear a sound.
4. After your bottle "sing" for the first time, keep adding water (as much as is needed to raise the level of the water by 4-5mm) and testing it until you get a second note. Repeat the same process and get as many notes as possible.
5. Connect both the universal lab interface to the computer and the sound sensor to the interface (use the manual or ask your teacher to help you at this stage). Start the computer and open the Interactive Physics Software. Select the real-time data collection program and set it to graph frequency versus time (this program collects data and graphs them at the same time) for the first 10 seconds.
6. Take an empty bottle and repeat Steps 2 and 3. Use the sound sensor to graph frequency versus time for each note (since there is not only one point where the bottle "sings," take the note with the highest amplitude at that particular water level. For this reason you will need to add or remove small quantities of water with a long pipette until you get the note). Place the sound sensor a couple of centimeters away from the top of the bottle and save the graph that appears on the screen for each note. What does the graph look like? Why does it look like that? What is the frequency of the produced note? In addition, use the permanent marker to mark the level of the water on the bottle for each note. Repeat the same process and get as many notes as possible. Record your data in the following table:

Length of empty space	Frequency

Graph frequency versus length (use Microsoft Excel). What does the graph look like? How does the length of the string relate to the frequency? What happens to the note (i.e. loud, soft, high, low, etc.)?

Activities

1. Repeat Steps 1 to 6, but use bottles of different material this time. Use the same height, same shape, same liquid (water), and vary the material that the bottle is made of (use as many bottles of different material as you have). Compare the resulting graphs of Step 6 to each other. Explain your observa-

tions. Does the frequency depend upon the material the bottle is made of? Can you explain why it does or does not depend on the material the bottle is made of? What happens to the note (i.e. loud, soft, high, low, etc.)?

2. Repeat Steps 1 to 6, but use different shapes. Use the same height, same material, same liquid (water), and vary the shape of the bottle (use as many bottles of different shapes as you have). Compare the resulting graphs of Step 6 to each other. Explain your observations. Does the frequency depend upon the shape of the bottle? Can you explain why it does or does not depend on the shape of the bottle? What happens to the note (i.e. loud, soft, high, low, etc.)?
3. Repeat Steps 1 to 6, but use different liquids. Use the same height, same material, same shape, and vary the liquid in the bottle (use as many liquids of different densities as you have). Compare the resulting graphs of Step 6 to each other. Explain your observations. Does the frequency depend upon the liquid in the bottle? Can you explain why it does or does not depend on the liquid in the bottle? What happens to the note (i.e. loud, soft, high, low, etc.)?
4. Describe what happens when air is blown across the top of the bottle. Connect this to how sound is produced and how that sound reaches our ears. In addition, explain how our ears work?
5. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested that you change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).
    - How does the strength of blowing across the top of the bottle relate to the volume of the sound?
    - How does the strength of blowing across the top of the bottle relate to the frequency of the note?
    - Choose eight bottles, all the same. Make them 'sing' a scale (doh, ray, me, fah, soh, la, te, doh) by putting a different amount of water in each. (Hint: Remember that you have marked the level of the water on a bottle for each note at Step 6.) For precision you can use a flute and the Interactive Physics Program, as you did at Step 5.

Save the graph/data of each note the flute produces and then try to match each note with your one bottle organ.

- Is it possible to get each note of the scale (doh, ray, me, fah, soh, la, te, doh) starting with a bottle that has already been half filled?
- What is the minimum amount of liquid that can be included in the bottle and still remain possible to get each note of the scale (doh, ray, me, fah, soh, la, te, doh)? Try to use as many liquids of different densities as possible.

6. How do you think you play higher frequencies on a pipe organ? Explain.
7. How do you think you play lower frequencies on a pipe organ? Explain.

Final Project/Report

You have been asked to construct and write the manual for an eight bottle organ (one bottle for each note) by a major music instrument manufacturer. (Use the eight bottle organ you already have. It is up to you to decide which of the three variables—length, shape, substance in the container—will be varied in order to achieve the eight bottle organ). You have the freedom to make your own selections concerning the contents of the manual. Do not forget to summarize all the experiments and the activities you have performed in this project. In addition, the manual must be descriptive and understandable by people that have never used a bottle organ before. Therefore, it is strongly suggested that sections about how to build the bottle organ, how to use the bottle organ, and how/why the bottle organ works be included within your manual. Use of diagrams or pictures is strongly suggested.

Reference

Smith, G. and Holloway, G. (1985). *40 Science Activities*. London: Macmillan Education

What is the Difference Between Noise and Music?

Musical instruments have long been used for entertaining people all over the world. Pianos, guitars, violins, flutes, etc., produce musical sounds that we love to hear. But, what makes their sounds musical? Do you want to know? Follow this experiment and, by using sound and wave generators, produce musical sounds, compare them, and try to understand why they sound musical and not noisy.

Degree of Difficulty

EXPERIMENT: Moderate to Difficult

CONCEPTUAL: Difficult

Objectives

Completion of the activities should enable you to:

- produce chords by using a combination of sound and wave generators.
- understand the relationship between the combination of different frequencies and the chord produced.
- predict the combination of frequencies needed to produce a chord.

Materials: 4 sound and wave generators (Cambridge Physics Outlet, 10 Green St. Bldg. E. Woburn, MA 01801, Toll Free 1-800-932-5227, E-mail: info@cpo.com), computer, sound sensor (universal lab interface is needed), "Interactive Physics" software or "Macmotion" software, 1 plastic tube (1m long, 5cm diameter).

Procedure

Producing a Chord

1. Turn the volume of the Sound and Wave Generator (SWG) all the way down. Tune the frequency of the first SWG to 300 Hz, the second SWG to 375 Hz, the third SWG to 450 Hz, and the fourth SWG to 600 Hz.
2. Place all four SWG a couple of centimeters apart, in any order you want, and turn up the volume on all of them. Describe what you hear.

The combination of the above mentioned frequencies gave a particular sound that many musical instruments can give (i.e. piano). The sound that was produced is called a chord. For the purposes of these experiments the combination of a 300 Hz, a 375 Hz, a 450 Hz, and a 600 Hz frequency will be called Chord A.

3. Repeat Steps 1 and 2 for the chords B, C and D. However, use the frequencies given in the following table:

Chords	Frequencies (Hz)			
Chord B	300	360	450	600
Chord C	300	375	500	600
Chord D	300	400	500	600

Do the chords sound the same?

4. For each one of the four chords, fill in a table like the one shown below. In the third column write down the ratio of the frequencies after you reduced them into fractions by dividing them with the lowest common denominators (Note that the frequencies are not the same for the four chords, thus make sure that the frequencies column is changed each time).

Frequencies	Chord A Ratio	Reduced Ratio
375 Hz and 300 Hz		
450 Hz and 300 Hz		
600 Hz and 300 Hz		
450 Hz and 375 Hz		
600 Hz and 375 Hz		
600 Hz and 450 Hz		

5. After the completion of the four tables, compare the tables among each other and try to come up with the pattern that underlies the creation of chords.

Note: *The structure and procedure of producing a chord by using the sound and waves set of Cambridge Physics Outlet (CPO) was based upon the description that was provided by the manufacturer's online manual (CPO, 2000).*

Activities

1. Use the tables you have created for Step 4 and your findings in Step 5 and develop a mathematical rule that can predict notes that can be played together and give a chord. Put your mathematical rule in test. First, state your predictions (all the combinations that you think that can give a chord) and, then, test them. Make sure that you record all the successful and unsuccessful combinations in a table similar to the one presented in Step 4.
2. Given that the frequency of notes on a scale are as follows,

Notes	**Frequency (Hz)**
doh	264
ray	296

Notes	Frequency (Hz)
me	330
fah	352
soh	396
la	440
te	496
doh	528

Create a new table as you did in Step 4 (add two more columns, one for the ratio and the other for the reduced fraction). To calculate the ratio, divide the frequency by the frequency for the lowest note (Doh at 264 Hz).

To western ears, pleasing combinations of notes are those with frequencies that stand in whole-number ratios, such as 1:2 and 4:5. Which of the notes, in the table you created, have ratios that reduce to simple fractions? Which of these notes have ratios that don't reduce to simple fractions? Which combination(s), if any, of notes can give the four chords you created at the beginning of the experiment? Explain.

3. Describe how sound is produced and how that sound reaches our ear. In addition, explain how our ears work?
4. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—t is suggested that you change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).
   - What are the limits of human hearing?
   - What is the speed of sound in air? (Hint: Use one of the SWGs and a one meter plastic tube, about 5cm in diameter. Put the tube close to the generator and try to find the fundamental frequency. Use the formula Speed of sound = Wavelength x Frequency.) Is the speed of sound constant?

After you find the speed of sound, find all the frequencies for which the tube resonates ('sings') and the corresponding wavelengths.

- Give combination(s) of frequencies that can produce chords, which correspond to a combination of the notes introduced in Activity 2. Are the number of chords that can be played limited? Explain
- What is the minimum frequency that we can use in order to get a scale that gives the four chords of our experiment and which most humans are able to hear?

Final Project/Report

Write a report summarizing all the experiments and the activities and include information on the applications of physics of sound (i.e. programming computers to write music). Have in mind that your report must be descriptive and understandable by people that have never conducted a similar experiment. Use of diagrams, tables or pictures is strongly suggested.

Reference

Cambridge Physics Outlet Online Curriculum (2000). Experiments on waves and sound.

Waves on a String?

Musical instruments have long been used for entertaining people all over the world. Pianos, guitars, violins, etc., produce musical sounds that we love to hear. What do they have in common? Strings! How does a string produce sound? Do you want to know? Follow this experiment and by using a sound and waves set, find out for yourself the answers to these questions or the ones that were troubling you so far!

Degree of Difficulty

EXPERIMENT: Moderate

CONCEPTUAL: Moderate

Objectives

Completion of the activities should enable you to:

- produce waves on a string by using a sound and waves set.
- understand the relationship between frequency and wavelength.
- measure the frequency and wavelength of several wave patterns.
- make predictions about the frequency or the wavelength of wave patterns.

Materials: 1 sound and waves set (includes generator, wiggler, standing wave and resonance experiments, cords, and sturdy case. Requires CPO Timer and Physics Stand - Cambridge Physics Outlet, 10 Green St., Bldg. E., Woburn, MA 01801, Toll Free 1 800 932 5227, E-mail: info@cpo.com), computer, sound sensor (universal lab interface is needed), “Interactive Physics” software or “Macmotion” software.

Procedure

Producing waves on a string

1. Take a stand and place the fiddlehead of your sound and waves set at the top of the stand (see the manual or manufacturer’s instructions for the fiddlehead).
2. Take the wiggler and place it as low as possible to the stand (below the fiddlehead). Make sure that the arm of the wiggler (with the hole at the end) is pointing up (see the manual or manufacturer’s instructions for the wiggler).
3. Find the elastic string that is included in your set and tie it through the hole in the wiggler arm. Thread the other end of the string between the washers of the fiddlehead. Stretch the string until it feels about as tight as a rubber band. Tighten the washers to lock the string in place.
4. Connect the Timer and the Sound and Wave Generator to the wiggler (Use the AC adaptor for the Timer; do not use batteries).
5. Turn on the Timer (the switch is on the left side). Press the Timer select until the “frequency” light is lit. Ignore any sounds that the speaker might make or any numeric indications on the screen. Press the Sound and Wave Generator until the “waves” light is lit. The speaker should be off, and the Sound and

Wave Generator now controls the frequency of the wiggler. The numeric indication on the Timer's screen now displays the frequency of the wiggler.

6. Reduce the frequency until the wiggler is clicking once every second. What does the Timer read? What does this mean? Now put the Timer in period mode. What does the Timer read? What does this mean?
7. Press the MODE button on the Timer until it is back in frequency mode. Start increasing the frequency and record both the frequency value and the corresponding period value in the following table:

Frequency (Hz)	**Period (sec)**	**Frequency x Period**

What do you observe from the findings of this table? Are the frequency and the period related? If yes, give the mathematical formula that relates them. What are the units of their product (column 3)?

8. Press the Mode button on the Timer until it is back in frequency mode. Raise the frequency until you see the string vibrating in some new, clear pattern. Each time that you see a new pattern, it means that you have found a frequency that the string *resonates* (resonance is a natural frequency of vibration of a system). Describe what you observe as the frequency increases. Why does that particular phenomenon happen as the frequency increases? What does this phenomenon have to do with the sound? Explain.

Note: *The structure and procedure of producing waves on a string by using the sound and waves set of Cambridge Physics Outlet (CPO) was based upon the description that was provided by the manufacturer's online manual (CPO, 2000).*

Activities

1. Set the Timer to the frequency mode. Raise the frequency until you excite the *Fundamental Frequency* (the lowest resonance of a system) of the elastic string (probably around 10 to 20 Hz). The string should vibrate back and forth. Where is the string moving the most? Where is the string moving the least? What is the fundamental frequency? What is the period of the vibration?
2. Set the Timer to the frequency mode. Raise the frequency until you excite the fundamental frequency. After you reach the fundamental frequency start increasing the frequency (use increments of 5-10 Hz), and explore what happens. (You will be looking for other resonances of the string and trying to learn rules to help you predict at what frequencies they will occur.) Stop after you find two more resonances, beyond the fundamental frequency. Describe and explain your observations for these two new resonances. Is it possible,

using the data you have collected so far for the first three wave patterns you observed, to develop a mathematical expression or rule that can help you predict the resonances that will follow? If no, how much more data do you need for a mathematical expression that is able to predict the resonances of a string? After your mathematical rule/expression is developed, make your predictions and test them. Were your predictions valid? Explain. Continue finding resonances until you cannot see anymore on your string. For each new string pattern you observe (the moment that the new pattern occurs) record your data in the following table:

Description of Pattern	**Frequency**	**Number of points with maximum amplitude**	**Number of points with minimum amplitude**

Graph frequency versus number of points with maximum amplitude - interpret the resulting graph. What is the relationship between the frequency and the number of points with maximum amplitude?

In this activity the new wave patterns that you observed, after passing the value of the fundamental frequency, are called *harmonics* (resonances which are more complex, or higher frequency, than the fundamental).

3. How many of the points with maximum amplitude fit within one *wavelength*? How many of the points with minimum amplitude fit within one *wavelength*? After you answer this question, fill in the following table based on the results you obtained in Activity 2.

Frequency	**Number of points with maximum amplitude**	**Number of points with minimum amplitude**	**Wavelength**	**Frequency x Wavelength**
F*undamental Frequency*				
...				

Graph frequency versus wavelength - interpret the resulting graph. How does the product, *Frequency x Wavelength*, relate to the graph? What is the relationship between the frequency and the wavelength? Give the mathematical expression that relates the two of them.

4. Use the same string you were using for the previous activities, and vary the length (make sure that the tightness of the string will stay relatively the same; the suggested way to do this is to keep the ratio between the length and the relative diameter of the string constant). Start with the fiddlehead and the figgler being 20cm apart and use increments of 5cm. Record your data in the following table:

Length of the string	Fundamental frequency	1st Harmonic	2nd Harmonic	3rd Harmonic	...
20 cm					
25cm					
30 cm					
...					

Graph fundamental frequency versus length (use Microsoft Excel). What does the graph look like? How does the length of the string relate to the frequency? What do you think happens to the sound that the fundamental frequency is producing as the length is increasing (i.e. loud, soft, high, low, etc.)? Explain. How will the graphs of 1st, 2nd, 3rd, etc., harmonic versus length look like? Explain (make your predictions before plotting your graphs). Compare all the resulting graphs to each other and explain your observations.

5. Repeat the steps of Activity 4, but use strings of different diameters this time. Use the same length, the same tightness, and vary the diameter of the string (use as many strings of different diameter as you have). Does the frequency depend upon the diameter of the string?

6. Describe what happens when a string is plucked. Connect this to how sound is produced and how that sound reaches your ear. In addition, explain how our ears work.

7. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a systematic research method to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested that you change the independent variable by equal increments), (b) your dependent variable (the

variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).

- Does the same mathematical expression for predicting the resonances apply to all strings?
- Is there a minimum length of string we need in order to get the first resonance?
- Is there a maximum number of resonances that a given length of string can give?
- How can we increase the amplitude of the maximum points of a given harmonic?
- Does the fundamental frequency of different lengths of string have the same amplitude?
- How does the amplitude of the maximum points change as the frequency increases?
- Do the minimum points of the previous harmonic change position when the new harmonic appears?
- Does the wavelength of each string changes as the frequency increases?

8. How do you think you play higher frequencies on a guitar? Explain.
9. How do you think you tune a string on a guitar? Explain.
10. Explain the importance of the guitar box?

Final Project/Report

Write a report summarizing all the experiments and the activities and include information on the applications of physics of sound (i.e. how guitars are made). Have in mind that your report must be descriptive and understandable by people that have never conducted a similar experiment. Use of diagrams, tables or pictures is strongly suggested.

Reference

Cambridge Physics Outlet Online Curriculum (2000). Experiments on waves and sound.

Make Your Own Laser Show

People in the music industry in their effort to make music performances more exciting and, visually, more attractive understood that light had to be synchronized with music. In a way, they were looking for a method that will "make light dance" with their music. The most spectacular of all methods has proven to be the laser shows. But, what does make the light dance? Do you want to know? Follow this experiment and by creating your own "laser show device", find out for yourself the answers to these questions.

Degree of Difficulty

EXPERIMENT: Difficult

CONCEPTUAL: Difficult

Objectives

Completion of the activities should enable you to:

- produce Lissajous figures (the series of plane curves traced by an object executing two mutually perpendicular harmonic oscillations) with a laser beam.
- understand the relationship between the combination of different frequencies and the Lissajous figures produced.
- predict the combination of frequencies needed to give a Lissajous figure.

Materials: laser pen (class 2 with power output 1mw), two 3-10 Volt a.c. power supply, 1 signal generator, 1 frequency multiplier/converter, 1 phase converter, a piece of wood (40x40x2cm), 2 thin aluminum levers (19.5cm long each), 2 loudspeakers (13cm), 1 mirror (4x4cm), 1 rubber rod (4x1x1cm), a piece of wood (4x4x2cm), 2 pins, table-tennis ball, araldite, silicon rubber, thin wire (about 2mm in diameter and about 10cm long), 2 pieces of a thin aluminum lever (3cm long), two wooden dowels 5.5x2x2cm (make sure the width of these wooden pieces is slightly bigger than the aluminum lever's width), drill, hammer, nails (2.5cm long), ruler.

Procedure

Constructing the laser show device

1. Put the 40x40x2cm piece of wood on a table. Find the midpoints of two of the longest and opposite sides. Take your ruler and with a pencil draw a line connecting the two points. Repeat the same steps for the other two opposite sides. In this way you are separating the wooden board into four equal pieces. Name each quartile with a different number (1,2,3,4).
2. Take the two dowels and cement with araldite the first one in the center of the second quartile and the second one in the center of the fourth quartile (cement one of dowel's smallest surfaces).
3. Cut the table tennis ball into two equal pieces. Cement each piece of the ball (convex side out) with araldite in the center of the loudspeakers. Cement a pin at the top of the ball with araldite.

4. Place the 2 loudspeakers in front of the already fixed dowels (Step 2). Make sure that the pin lines up with the center of the ball that is positioned upon the loudspeaker, and that it is 8cm away from the wooden dowel and 10cm away from the closest side. At this point check whether the top of the pin and the wooden dowel are at the same height. If not, make the necessary adjustments so both are at the same height.
5. Take a piece of wood (4x4x2cm) and drill a hole (1x1x0.5cm) in its center. Insert one of the rubber rod's ends into the wooden block (use araldite if rod is loose). Cement the center of the back of a mirror to the top of the rubber rod.
6. Drill a hole at one of the ends of each of the 2 thin aluminum levers (about 0.5cm from the lever's end – the diameter of the hole must be much smaller than the width of the lever, but large enough for the wire to go through).
7. Fasten the end (the one without the hole) of each aluminum rod with silicon rubber (do not use araldite) to the top of the wooden dowels (that were fixed on the wooden board at Step 2), and let the levers lie on the top of the pins.
8. Cement the wooden block of Step 5 (in the third quartile) in such a way that the mirror at the top of the rubber rod is 1cm away from the two aluminum levers and at the same height with them.
9. Twist the 3cm long aluminum levers 180˚. Drill a hole at one of their ends (about 0.5cm from the lever's end – the diameter of the hole must be much smaller than the width of the lever). Glue to the back of a mirror the end that does not have the hole and connect to each lever by means of a wire that goes through their tiny holes and the holes of the short twisted aluminum pieces.
10. Connect one of the loudspeakers with the 3 V supply and the other one with a signal generator (or functional generator). Make sure that the output impedance of the power supply and the signal generator matches the input impedance of the loudspeakers (in case you have any questions ask your teacher or read the manual of both the loudspeaker and the generator).
11. Set your device at a certain angle and shine a laser beam on the mirror. Make sure that you see the reflected beam on a big white screen or on a white painted wall. If the reflected beam scatters, use a long focusing lens to focus the beam on the screen.
12. Start changing the frequency of the signal generator (start from zero) by small increments. Record your data in the following table:

Shape Description (Lissajous figures)	**Frequency of the generator**

What do you observe? Is there a relationship between the shapes and the frequency? Are the shapes stationary or moving? Why?

13. Start changing the amplitude of the signal generator (start from zero) by small increments (the frequency must be kept constant). Record your data in the following table:

Shape Description	Amplitude of the generator

What do you observe? Explain. Is there a relationship between the shapes and the amplitude?

Activities

1. Repeat Steps 1-10. However, this time connect both loudspeakers to the same power supply (can you think of a reason for doing this?). Connect a frequency multiplier in series with the power supply for only one of the loudspeakers. Start changing the frequency (start from zero) by small increments. Record your data in the following table:

Shape Description	Frequency of the generator

What do you observe? Is there a relationship between the shapes and the frequency? Are the shapes stationary or moving? Why? How is your current setting different from the one you used at Step 12? Explain.

2. Repeat Steps 1-10. However, this time connect both loudspeakers to the samepower supply. Connect a frequency multiplier and a phase converter in series with the power supply for only one of the loudspeakers (if it is difficult to find a phase converter, ask your teacher to make one for you; it is basically a simple RC circuit that delays the phase of the signal). Start changing the phase by small increments (the frequency must be kept constant). What do you observe? Is it possible to predict the relationship between the shapes and the phase by just looking at the Lissajous figures? Are the shapes stationary or moving? Why?

3. Explain the reasons of using loudspeakers in your device. Can you think of something else that can replace the loudspeakers and still give Lissajous figures as outcomes?
4. Design and perform experiments to answer the following questions. Your experiment's lab report must include: Title, Purpose, Equipment, Procedure and Data Collection, Data Analysis, Results and Conclusion. The Data Collection is the most critical part of a laboratory experiment. You must follow a *systematic research method* to secure valid answers to your questions. In a systematic research method you define, (a) your independent variable (the variable that is controlled by the researcher and is being changed, increased or decreased, in order to measure any changes regarding the variable we are interested in—it is suggested to change the independent variable by equal increments), (b) your dependent variable (the variable that is under investigation and depends upon the changes of the independent variable), (c) control variables (other variables that you assume might affect your experiment and, therefore, are kept constant throughout the whole experiment).
    - Can you repeat the results of Activity 1 by using a signal generator? Explain.
    - Can you repeat the results of Activity 1 by using two signal generators (one for each loudspeaker)? Explain.
    - How can you calibrate a phase converter that is constructed with cooperation with your teacher, by using Lissajous figures?
    - What combinations do you have to make in order to get a rolling ball (hint: use two signal generators)?
    - What combinations have to be made in order to get a moving figure?
    - What combinations have to be made in order to get a stationary figure?
    - Which variable(s) relate to the size of the figures?
    - How does the frequency relate with perfect geometrical figures?
    - How does the phase relate with perfect geometrical figures?

Final Project/Report

Write a report summarizing all the experiments and the activities and include information on the applications of your device in everyday life activities (i.e. musical laser shows). Have in mind that your report must be descriptive and understandable by people that have never conducted a similar experiment. Use of diagrams, tables or pictures is strongly suggested

References

Saba, M. and Corato, L. (1998). A giant laser show. *School Science Review*, 80 (291), p. 108-109.

Piper, G. and Lawton, P. (1988). The Laser show. *School Science Review*, 70 (250), p. 87.