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ABSTRACT

This booklet, one of a series developed by the Frederick County Board of Education, Frederick, Maryland, provides an instruction module for an individualized or flexible approach to secondary science teaching. Subjects and activities in this series of booklets are designed to supplement a basic curriculum or to form a total curriculum, and relate to practical process oriented science instruction rather than theory or module building. Included in each booklet is a student section with an introduction, performance objectives, and science activities which can be performed individually or as a class, and a teacher section containing notes on the science activities, resource lists, and references. This booklet presents a study of physical optics including nature of light, measurement of light, reflection, and refraction. The estimated time for completing the activities in this module is 2-3 weeks. (SL)

Physical Optics

AIDS TO INDIVIDUALIZE THE TEACHING OF SCIENCE

MINI-COURSE UNITS

BOARD OF EDUCATION OF FREDERICK COUNTY

1974

Marvin G. Spencer

PHYSICAL OPTICS

Prepared by

Walt Brilhart

Estimated Time for Completion

2-3 weeks

Frederick County Board of Education

Frederick, Maryland

Frederick County Board of Education

Mini Courses for

Physical Science, Biology, Science Survey,

Chemistry and Physics

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1974

FOREWORD

The writing of these instructional units represents Phase II of our science curriculum mini-course development. In Phase I, modules were written that involved the junior high disciplines, life, earth and physical science. Phase II involves senior high physical science, biology, chemistry, physics and science survey.

The rationale used in the selection of topics was to identify instructional areas somewhat difficult to teach and where limited resources exist. Efforts were made by the writers of the mini-courses to relate their subject to the practical, real world rather than deal primarily in theory and model building.

It is anticipated that a teacher could use these modules as a supplement to a basic curriculum that has already been outlined, or they could almost be used to make up a total curriculum for the entire year in a couple of disciplines. It is expected that the approach used by teachers will vary from school to school. Some may wish to use them to individualize instruction, while others may prefer to use an even-front approach.

Primarily, I hope these courses will help facilitate more process (hands on) oriented science instruction. Science teachers have at their disposal many "props" in the form of equipment and materials to help them make their instructional program real and interesting. You would be remiss not to take advantage of these aids.

It probably should be noted that one of our courses formerly called senior high physical science, has been changed to science survey. The intent being to broaden the content base and use a multi-discipline approach that involves the life, earth and physical sciences. It is recommended that relevant topics be identified within this broad domain that will result in a meaningful, high interest course for the non-academic student.

ALFRED THACKSTON, JR.
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CONTENTS

PHYSICAL OPTICS

Most of what we learn comes to us through the use of light energy as we see materials and objects in space around us, read books, look through lenses in microscopes and telescopes, see films, motion pictures and television screens, and read various scientific measuring instruments. However, the exact cause and nature of light has long been a rather complicated mystery to man. Lately in the history of science, some very interesting hypotheses and theories about light have been proposed. While these theories seem to substantiate fairly well the evidence about light which has been gathered, there are still many questions to be asked. Perhaps as we observe and think about the behavior of light energy around us, we shall be able to formulate our own ideas more effectively. Through a study of the nature and the behavior of light, we shall be able to answer more fully such questions as the following: Why do we see objects apparently reversed in mirrors? Why do objects appear as they do in curved mirrors? Why do objects under water appear to be distorted? How does the world appear to fish looking from beneath the surface of the water? How are lenses used to form images as the lenses which are used in cameras, microscopes and telescopes? What is the true cause of color in objects? Finally, what is the true nature of light? Is light really made up of particles or does it act more like waves? Think carefully about even the most commonplace observations as you investigate light because a thorough understanding of optics is the basis of many other aspects of our physical world.

A. Nature of Light

OBJECTIVE

Upon completion of this unit, the student should be able to:

1. distinguish between luminous and illuminated, opaque and transparent, incandescent and luminescent sources.

ACTIVITIES

Complete Activities 1 and 2.

Activity 1:

Examine carefully the light from a burning candle and burning magnesium ribbon and compare this light with the light produced by an incandescent lamp and fluorescent lamp. Compare the brightness of the candle and ribbon with that of the two lamps. How does the brightness of the lights compare? What changes occur when each of the lamps are turned off and on?

Heat a thin piece of nickel-silver wire or nichrome wire with a burner flame until it begins to glow. What color changes does the wire go through? List the reasons why the wire glows "red hot" and "white hot".

How does sunlight compare with each of the previous sources of light?

Name at least one other method for producing a source of light and compare it with each of the other sources you tested.

Complete the table below:

Source tested	Brightness	Color	Type of light source
Candle			
Mg. ribbon			
Incandescent lamp			
Fluorescent lamp			
Nickle-silver wire			
Nichrome wire			
Sunlight			
........other			

Write a brief discussion of your observations and conclusions regarding this experimental work.

Materials needed for Activity 1:

lamp socket
lamp, clear bulb, 20 or 40 watt
candle
nickle-silver or nichrome wire
Bunsen burner
fluorescent lamp
Mg. ribbon, 10 cm
tongs
matches

Activity 2:

Using an incandescent or fluorescent lamp, produce an illuminated body. Illuminate various objects with this light source, noting the intensity and color of the reflected light. Describe the differences, if any, in the type of light these objects absorb and reflect. Which object reflects light in the most regular pattern?

Observe several light sources through transparent clear and colored glass plates, and translucent surfaces. (A translucent surface can be easily made by placing a small drop of oil on a sheet of notebook paper. Onionskin paper is also a suitable surface.) How do these various surfaces transmit light? Observe a white piece of paper or object through a colored glass. Why does the object appear colored? Using several plates of clear glass and colored glass, observe the same white object separately. Does the intensity of the transmitted light appear to change?

Complete the following charts - using the descriptive information below:

Observation of objects using lamp	Intensity of Reflected Light	Color of Reflected Light
Rough object		
Smooth object		

Observation of objects through different media	Transmission of Light	Absorption of Light	Reflection of Light
Clear glass plate			
Colored glass plate			
Transluscent surface			

Intensity of light reflected - Very bright
Bright
Dim

Color of light reflected - Red, white, blue
green, yellow, etc.

Transmission of light - Complete
Partial
None

Absorption of light - Complete
Partial
None

Reflection of light - Complete
Partial
None

Write a brief discussion of your observations and conclusions regarding this experimental work.

Materials needed for Activity 2:

- lamp socket
- lamp, clear bulb
- notebook paper
- oil
- clear glass plates
- colored glass plates

OBJECTIVE

Upon completion of this unit, the student should be able to:

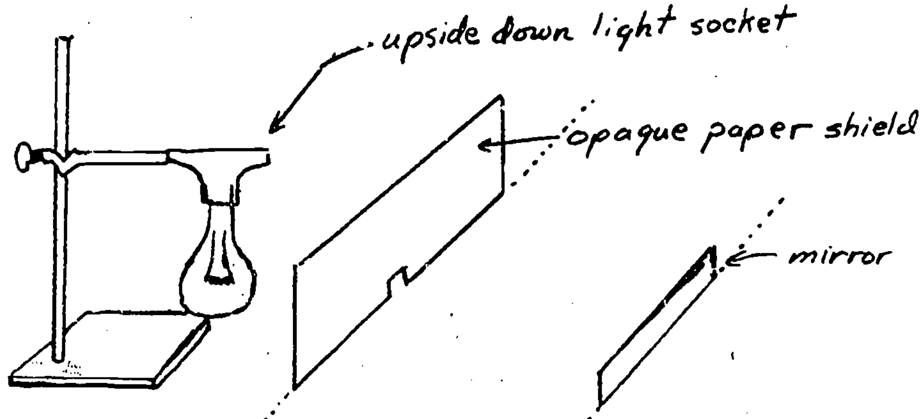
2. demonstrate the basic principles of diffusion, formation of shadows, and accurate definition of umbra and penumbra.

ACTIVITY

Activity 3:

Construct a narrow beam of light from an opaque paper shield with a small hole through it, and an incandescent lamp. Allow this narrow beam to shine against a plane mirror and observe the manner in which the light is reflected. What accounts for the spreading of this light before it strikes the mirror? Vary the angle at which the beam strikes the mirror and observe the angle of the reflected beam of light. Can you physically measure these angles? Note carefully both the size and the position of the images of objects as seen in the plane mirror. Place a sheet of white paper next to the mirror and observe the light which both the mirror and paper reflect. Which reflects more light to your eye?

Diagram 3a



Write a brief discussion, including diagram, of your observations and conclusions regarding this experimental work.

Materials needed for Activity 3:

- ring stand
- ring clamp
- lamp socket
- lamp, clear bulb
- white sheet of paper
- opaque paper shield
- mirror
- protractor and ruler

Activity 4:

Place a metal disk or coin in the middle of an empty 250 ml beaker. Note the apparent size of the coin, keeping your eye at a constant distance above the rim of the beaker. Slowly pour water into the beaker until the beaker is nearly full. Again, note the apparent size of the coin. Record its apparent size in table below. List any other observations. With one eye closed, try to judge the bottom of the beaker by trying to touch where the bottom appears to be. Repeat this experiment now with 2 larger and 2 smaller beakers. Are your results consistent?

Using the 250 ml beaker half-filled with water, place a pencil in the water at various angles. What do you observe? Observe the pencil from the side of the beaker. Observe other objects looking through the air filled portion and water filled portion of the beaker. List each and all observations. Place a small clear glass plate on the bottom of the water filled beaker. What do you observe?

Complete the chart on the next page.

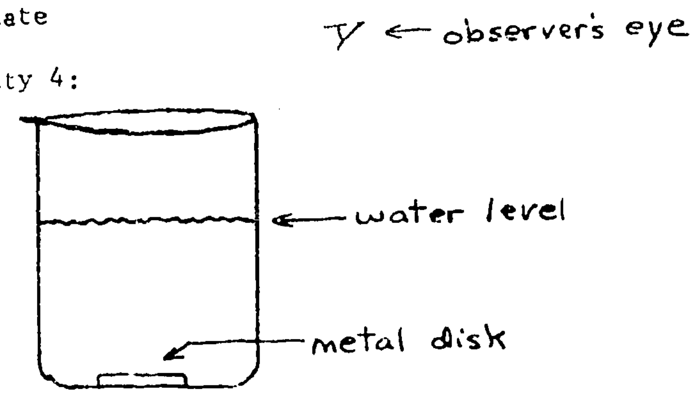
Objects	Actual size	Observed size
coin		
pencil		
glass plate		

Write a brief analysis of your observations and conclusion.

Materials needed for Activity 4:

50 ml beaker
100 ml beaker
250 ml beaker
400 ml beaker
600 ml beaker
coin or metal dish
pencil
glear glass plate

Diagram for Activity 4:



Activity 5:

Use an opaque white object and an incandescent light source to form shadows. Observe all parts of the shadows. Are all parts of the shadow of equal darkness? Are the edges clearly defined. Compare shadows formed by a large source of light to those formed by a small pinpoint source of light. Again observe shadows and their edges. Which type of light has more clearly defined edges? Trace the light rays as these shadows are formed. State the difference in your observations between the umbra and penumbra. Construct a diagram to show how the moon might cast a shadow on the earth, using the sun as a light source.

Write a brief discussion of the apparent behavior of light from your observations. Draw diagrams to support your conclusion.

Materials needed for Activity 5:

opaque white object
incandescent lamp
candle or other point of light

Complete Worksheet #1.

Worksheet #1

Nature of Light

. Classify each of the following substances or situations as to whether they are luminous, nonluminous, incandescent or combinations of these three.

a. the sun
b. the moon
c. a galaxy
d. a candle flame
e. a 40 watt light bulb
f. neon light
g. a wood fire
h. a welder's arc
i. a lit cigar
j. burning Mg ribbon

. When light is emitted by a source, it travels in ____________________ as long as the medium through which it passes remains uniform in optical density.

. a. The umbra is that part of a shadow which (1) receives some light from all parts of the source, (2) receives some light from some parts of the source, but not from all parts of the source, (3) receives no light from any part of the source. ______________

b. The penumbra is that part of a shadow which ________________.

. In the space below, draw a diagram to show the relative positions of earth, moon, and sun during a solar eclipse.

. A(an) ___________ body emits light. An example of such a body is the ________.

. A(an) __________ body can be seen because it reflects light from some source. An example is the _____________.

. A(an) _________ body allows light to pass through it so that objects beyond it can be seen clearly. An example is __________.

. A(an) ________ body diffuse some of the light passing through it; the rest of the light incident upon it is reflected or absorbed. An example is ___________________________.

. A(an) ________ body does not allow light to pass through it. An example is ___________________________________.

0. A sharp shadow is produced from ________________ source of light. A dull or fuzzy shadow is produced from ______________ source of light.

11. We can see most objects because they ____________ light.

12. Which of the following objects is luminous and which is illuminated?

a. burner flame
b. this printed page
c. unlit fluorescent lamp
d. incandescent filament
e. the sun
f. an unlit match
g. a glowing lighteningbug

13. The speed of light in free space is ___________ m/sec.

14. How far does light travel in free space in 2.5 seconds?

15. Light does not pass through an apple; for this reason we say it is an ___________ object. We see an apple by the light it ___________ to our eyes; for this reason we call it an ___________ object.

B. Photometry - The Measurement of Light

If we can measure the intensity of light from a source of light as well as the amount of light enery which falls upon a given surface, we shall be able to predict exactly how much light is necessary for doing certain types of work and also the intensity of the source of light needed in order to provide this much light. The strength of a light source is called the intensity of the source and is measured in terms of candles. The fraction of the total light energy which is given off per unit of time from a light source and which is visible to the human eye is called the luminous flux; the luminous flux is measured in terms of lumens. The quantity of luminous flux which falls upon a unit area of surface is called the illumination on the surface and is measured in lumens per square meter, or lumens per square foot; the unit of lumens per square foot is often called foot-candles. The illumination on the surface varies directly with the intensity of the light source, directly at the cosine of the angle from the normal at which the light strikes the surface and inversely as the square of the distance of the surface from the source of light. The intensity of a light source can be measured with an instrument known as a photometer. The photometer compares the amount of illumination produced by a light source of unknown intensity with the illumination produced by a light source of known or standard intensity

OBJECTIVES

Upon the completion of this unit, the student should be able to:

3. measure the quantity of light produced by a light source and compare it with other sources of light.

4. determine the intensity of a light source and the amount of illumination received by an object.

5. describe the construction of a photometer and demonstrate its use.

6. write and demonstrate the law of inverse squares.

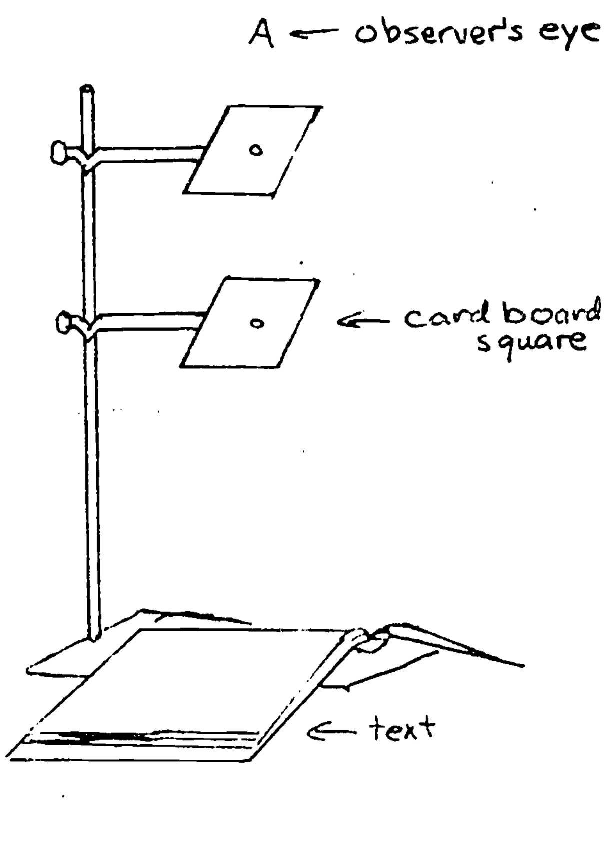
ACTIVITIES

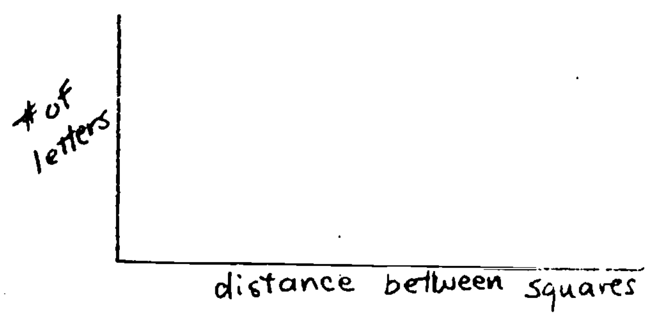
Complete Activities 1, 2 and 3.

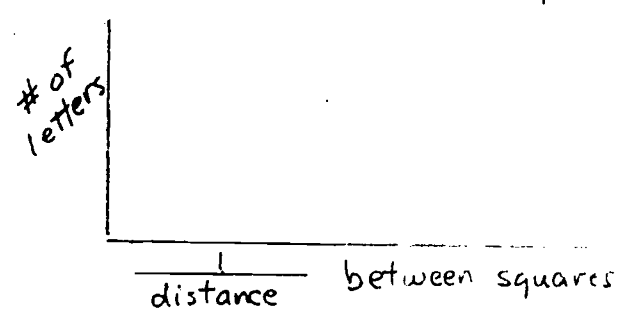
Activity 1 - Inverse Square Law:

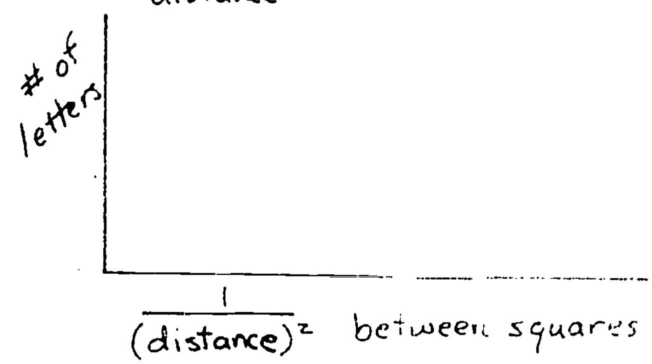
Obtain two small squares of cardboard and make a neat circular hole with a diameter of about 4.0 to 6.0 mm. in the center of each cardboard square. Align the holes and place both cardboard squares, held tightly against each other, against your right eye. Sight through the holes on the page of the physics text which is about 30.0 cm from the two squares. Count the number of letters in a straight line on the page of the book. Holding one cardboard square against your eye, slowly move the lower cardboard square closer to the page of the book. Note the change in the number of letters visible as the second cardboard square approaches the page of the book. Record the number of letters visible at varying distances between the cardboard squares. What does this indicate about the way in which light travels? From an analysis of your distance measurements and the number of letters visible, and the distance from your eye to the second square, does there appear to be any relationship between the area of the page which is visible and the distance from your eye to the second cardboard square? How do your observations compare with the law of inverse squares? How could you test this more accurately?

In order to graph the above relationship, you'll need to organize your recorded data. GRAPH 1 - on the x-axis, place the distance between squares, e.g. 0 cm, 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm, etc.; on the y-axis, place the number of letters read, e.g., 0 to 100 letter. Graph the number of letters read for each of the above distances. GRAPH 2 - on the x-axis, place the reciprocal of the distance $\frac{1}{0\text{ cm}}$, $\frac{1}{5\text{ cm}}$, $\frac{1}{10\text{ cm}}$, $\frac{1}{15\text{ cm}}$, etc. (express as decimal equivalents); on the y-axis, place the number of letters read (same as GRAPH 1). GRAPH 3 - on the x-axis, place the reciprocal of the distance squared, $\left(\frac{1}{\text{distance}^2}\right)$, e.g., $\frac{1}{(0)^2}$, $\frac{1}{(5)^2}$, $\frac{1}{(10)^2}$, $\frac{1}{(15)^2}$, etc. (express as decimal equivalents in increasing order); on the y-axis, place the number of letters read.









1. Write a brief discussion of your observations and conclusions regarding this experimental work.

2. Select the best graph which most likely explains the inverse square law.

3. State in your own words the inverse square law.

4. Answer all questions within the activity.

Materials needed for Activity 1:

ring stand
2 ring clamps
2 cardboard 4 x 4 inch squares
graph paper
physics text

Activity 2:

Obtain a filmstrip projector from the school library. Set this projector at a distance of 1 meter from an observing screen. When observing the square pattern formed on the screen, measure the area of the lighted portion. Now move the projector to a distance of 2 meters from the observing screen and again determine the area of the lighted portion. Finally move the projector to a distance of 3 meters and then some unknown distance, each time measuring the area of the lighted portion. Record your data in the chart below. Make a graph of your data. On the x-axis, place the area of the lighted portion of the screen, on the y axis, place the $(\text{distance})^2$ of the projector from the screen.

Distance of projector	Measured area

Write a brief discussion of your observations and conclusions regarding this experimental work. Make a conclusive statement regarding the outcome of your graph.

Materials needed for Activity 2:

filmstrip projector
observation screen
meter stick
graph paper

Activity 3:

Set up an optical bench as illustrated in the diagram on the next page, making the length of the bench as large as possible. Obtain a Bunsen photometer head and study carefully its construction and use. Where will the light from the light sources enter the photometer? Using two electric lamps of different power (wattage), place a lamp in the socket at each end of the optical bench. Place a non-reflecting, opaque screen, such as a dark book or a dark cloth behind and around each lamp so that the diffusion of light in the room will be kept at a minimum. Move the photometer between the lamps until its two screens are equally illuminated by both lamps. This equality will be recognized when each grease spot on the screen merges with its surroundings and seems to disappear. Measure the distances between the lamps and the screen and enter them in the table below. Note the wattage of each lamp and record it. Repeat this procedure with the other lamps to be measured.

Table 3-1

	Wattage Rating (watts)	Candle Power of Known Lamp (cp)	Distance of Known Lamp d_s (cm)	Distance of Unknown Lamp d_x (cm)
Lamp 1				
Lamp 2				
Lamp 3				

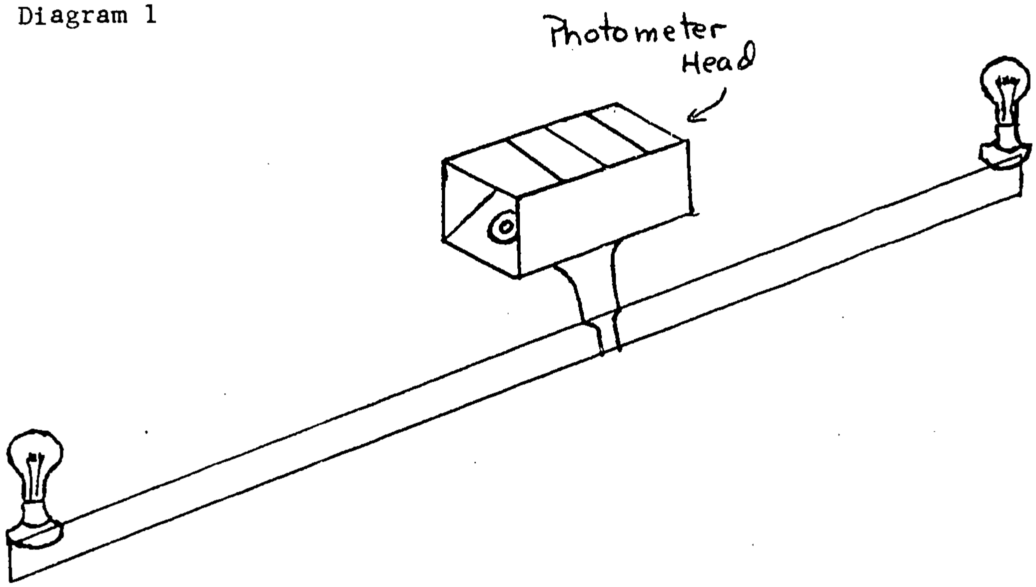
Using your collected data, solve in each case for the candlepower of the unknown lamp using the formula below.

$$\frac{\text{Candlepower of known lamp}}{(\text{Distance of known lamp from screen})^2} = \frac{\text{Candlepower of unknown lamp}}{(\text{Distance of unknown lamp from screen})^2}$$

or

$$\text{Candlepower of unknown lamp} = \text{Candlepower of known lamp} \times \frac{(\text{distance of known lamp})^2}{(\text{distance of unknown lamp})^2}$$

Diagram 1



Further Investigation:

The rate at which electrical energy is furnished to a lamp is measured in <u>watts</u>. The wattage rating of each lamp is generally printed by the manufacturer on the lamp. A measure of the efficiency of a lamp is obtained by dividing its candlepower by its wattage. The unit is candlepower per watt. A 1-cp point source of light emits 12.56 lumens.

Complete the chart below with your recorded data:

	Input (watts)	Candle Power Output (cp)	Efficiency (cp per watt)
Lamp 1			
Lamp 2			
Lamp 3			

Write a brief summary from your observations and data regarding this experimental work.

Materials needed for Activity 3:

- 2 incandescent lamps
- 1 Bunsen Photometer
- meter stick
- meter stick stands

Worksheet #2

Photometry

1. Intensity of illumination varies ____________________ the distance from the light source.

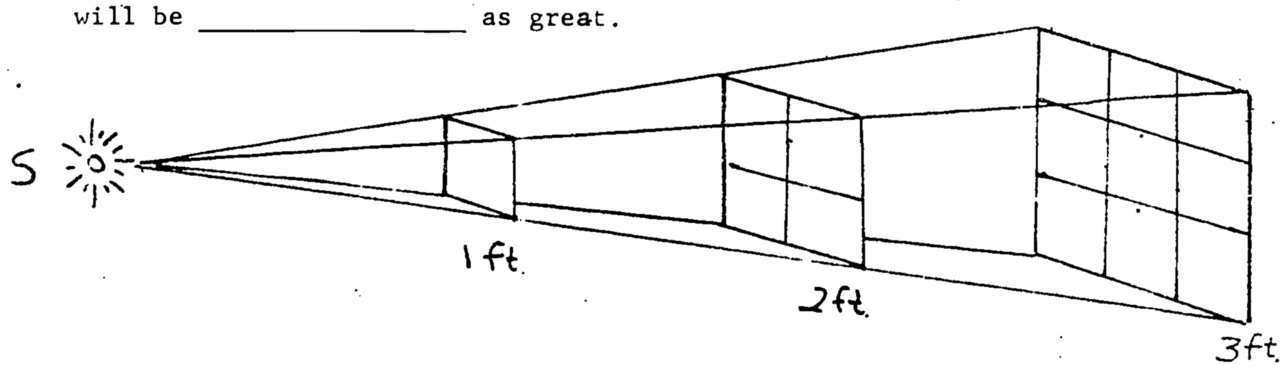
2. When a book is held 1 foot from a clear, incandescent lamp, it receives ____________________ times as much light as when held 5 feet from the lamp.

3. As the brightness of a lamp increases, the speed that light travels from it ____________________.

4. Intensity of illumination varies __________________ as the candlepower of the source.

5. How would you measure the candlepower of a light bulb?

If a person who is reading at a distance of 2 feet from a 100 watt incandescent lamp moves to a distance of 4 feet from the lamp, the illumination will be __________________ as great.



S is a point source of light. Light from S must cover ________ times the area 2 feet away as it does 1 foot away.

Refer to diagram in previous question. Light from S must illuminate ____________ times the area 3 feet away as it does 1 foot away.

In other words, 2 feet away the light spread over one unit of area 1 foot away is spread over 4 units of area. The illuminance 2 feet away is ___(fraction)___ that provided foot away.

The illuminance provided by a point source 3 meters away is ___(fraction)___ of the illuminance a source of the same luminous intensity provides when it is placed a distance of 1 meter.

E = illuminance
I = luminous intensity
d = distance of illuminated surface from the point source

Assuming a constant proportionality equal to one E = ___?___

12. A light meter directly measures ______________________.

13. A 25 watt electric lamp emits 25 candles. How much illumination falls on a table that is 5 feet below such a lamp?

14. If a large street lamp that is 16 feet above the road provides an illumination of 8 foot-candles, what is the luminous intensity of the lamp?

15. A light meter is placed 16 feet from a 20-candle source. How many foot-candles should the light meter read?

C. Reflection of Light

The basic principles and equations of reflection are derived from the assumption of simple geometric relations between incident and reflected light rays.

Each time that you use a mirror to observe an image, you are making practical use of the laws of reflection of light. Light reflecting from a smooth, polished surface produces regular reflection, whereas light reflecting from a rough, irregular surface produces diffuse reflection.

OBJECTIVES

Upon the completion of this unit, the student should be able to:

7. distinguish between regular and diffuse reflection.
8. state the laws of regular reflection.
9. describe and locate an image in a plane mirror.
10. apply the concepts "incident ray, reflected ray, and normal" to a flat surface.

ACTIVITIES

Complete Activities 1 and 2.

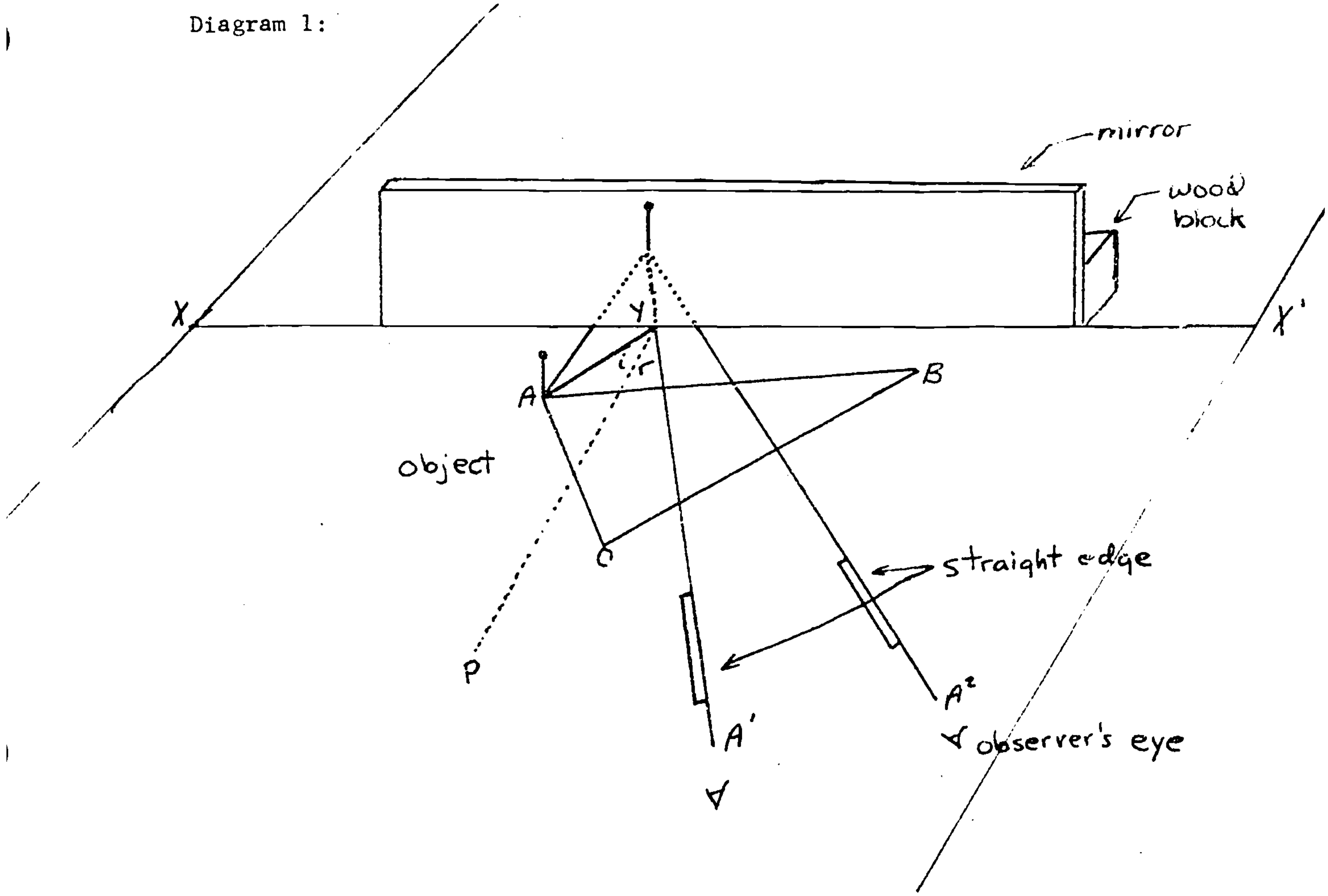
Activity 1:

Obtain a sheet of white paper. Fold in half and draw a line XX' along the fold. Place the silvered edge of a plane mirror along this line. You may use a wooden block with a piece of tape or rubberband for support. (Use a piece of cardboard as your work surface.) Draw an oblique triangle ABC on the paper in front of the mirror. This triangle is your object, whose image you will study in the mirror. Place a pin at the vertex A of the triangle. Using a straightedge on the paper, sight along one edge of the straightedge into the mirror until you are sighting the image of pin A. Draw a line to the mirrors surface to represent this ray of light. Label it A. Now, move the straightedge to another position apart from your original sighting and again sight on pin A. Draw a line along this path and label it A_2. Next place a pin vertically at vertex B and obtain two sight lines. Label these lines carefully B_1 and B_2, then move the pin to vertex C and obtain two more lines of sight C_1 and C_2.

Remove the mirror and continue each of the lines of sight until they meet. Label their meeting points A', B', and C' respectively. Describe the image formed. Draw lines AY and YA'. Construct line YP, perpendicular to line XX'. Locate and measure the angle of incidence and the angle of reflection. Construct lines AD and DA'. Where do they meet line XX'?

Repeat the same instructions for point B and C. Complete the chart below. Draw triangle A'B'C' and compare its area with triangle ABC.

Diagram 1:



Complete the chart.

	Angle i	Angle r	AD = ______cm	A'D = ___ cm	Area ABC in cm^2	Area A'B'C' in cm^2
Point A						
Point B			BD = ______cm	B'D = ___ cm		
Point C			CD = _____cm	C'D = ___ cm		

Turn in a neatly <u>labeled</u> diagram of your observations. Describe from your observations: the laws of reflection from a plane mirror and how images are formed in plane mirrors.

Write a brief summary of your observations and conclusions relating to this lab experience.

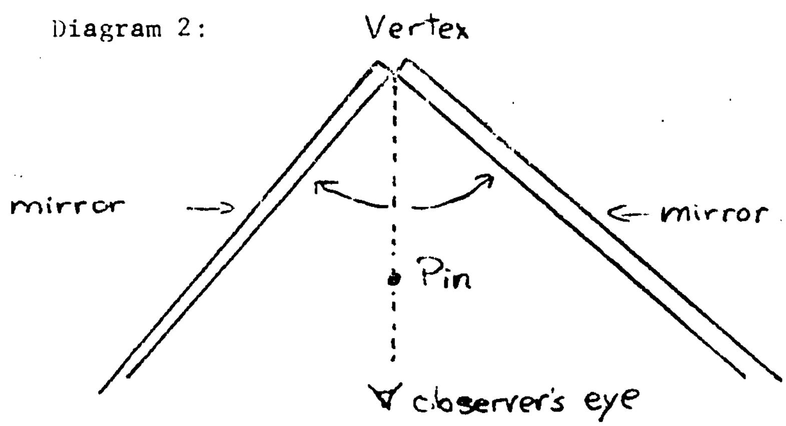
Materials needed for Activity 1:

- cardboard workboard
- plane mirror
- straight pins
- straightedge
- wooden block
- white sheet of paper

Activity 2:

Obtain two plane mirrors and place them vertically on a horizontal sheet of white paper on your cardboard workboard. Bring the mirrors together end to end to form a dihedral angle as shown in the diagram below. On the white paper, construct a line which bisects the angle of the plane mirrors. Place a pin vertically on this line, approximately 1/2 to 3/4" from the vertex of the mirrors. Looking down over the pin head into the vertex, count the number of images which you can see in both plane mirrors as the dihedral angle varies from 180° to 0°. Record carefully both the angle and number of images visible from each angle.

Diagram 2:



Fill in the chart below.

θ (degrees)	Number of Observed Images (N)
180	
160	
140	
etc.	

1. Does the number of images vary as the distance of your eye from the vertex of the mirror varies?

2. Draw carefully labeled diagrams to explain the cause of each multiple reflection which you observed.

3. Does there appear to be a relationship between the dihedral angle and the number of images observed?

4. Write a mathematical formula which expresses the number of images (N) as a function of the dihedral angle (Θ). Is this equation valid for each observation?

Write a brief summary from your observations and conclusions relating to this lab experience.

Materials needed for Activity 2:

- 2 plane mirrors
- 1 straight pin
- 1 sheet of white paper
- 1 cardboard workboard
- 1 protractor

OBJECTIVES

Upon the completion of this unit, the student should be able to:

11. describe the images formed by concave and convex spherical mirrors at various distances from the vertices of the mirrors.

12. use the mirror equation to locate images, focal points, and objects relative to spherical mirrors.

ACTIVITIES

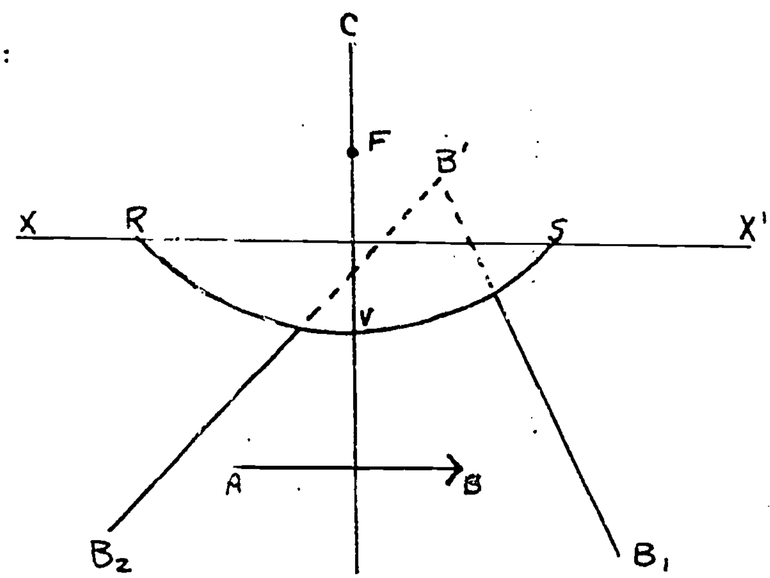
Complete Activities 3 and 4.

Activity 3:

Obtain a curved mirror, and observe your image from both sides of the mirror. Using diagram 1a, carefully draw line XX' in the middle of your sheet of paper. Place the curved mirror on this so that its ends just touch the line. Now trace the convex side of the mirror. Using references and geometry, locate the center of curvature, which will be referred to as C. Also locate the focus and label it F. Construct a line perpendicular to line XX', on which the center of curvature and the focus will be found. This line will be referred to as the principle axis. With the mirror in place, draw an arrow AB parallel to line XX' about 2 inches from the mirror's surface. The arrow AB should be, as nearly as possible, perpendicular to the principle axis. The arrow AB is an object whose image may be located in the convex mirror. With the mirror on the cardboard workboard, place a pin vertically at point A. Using a straightedge, sight accurately the image of point A in the mirror. Draw a line of sight to the mirror and label it A_1. From another location, obtain a second sighting of the image of point A. Using a straightedge, again draw another line of sight for point A, label this A_2. Move the pin to point B, obtain two sightings and label lines B_1 and B_2. With the mirror removed, extend each set of sight lines until they cross. Use dotted lines or multiple colored lines to represent the lines behind the mirror. Where the sets of lines cross, construct the image of object AB, labeling it A'B'. Describe the image formed by the convex mirror. Is it larger or smaller than the object? Is the image real or vitual? Is the image inverted or erect? Is it in front of or behind the focus? Now locate an arrow at two other places either in front of or behind arrow AB, and use the same procedure to locate each of their images.

Draw carefully labeled diagrams with sight lines for 3 objects in front of the convex mirror.

Figure 3a:



Write a brief summary of your observations and conclusions regarding this lab experience.

Materials needed for Activity 3:

- cardboard workboard
- curved cylindrical mirror
- ruler or straightedge
- pencil
- straight pin

Activity 4:

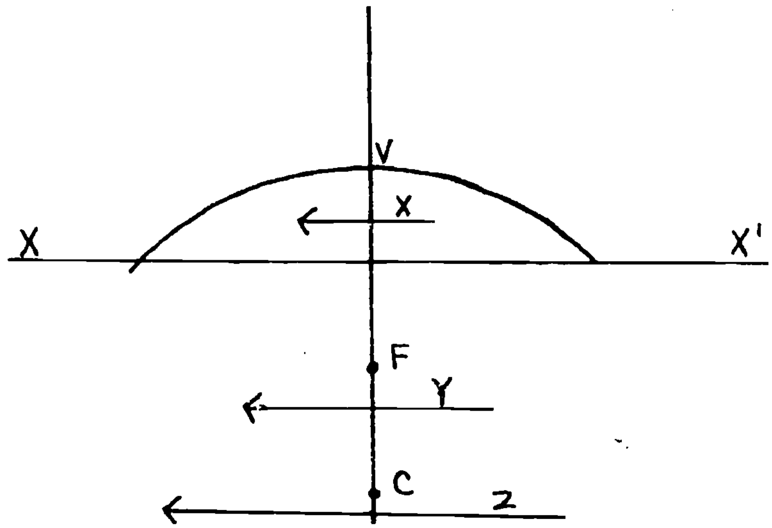
Refer to Figure 2a. Draw a line XX' and place a curved mirror on this line so that its ends just touch the line. Draw a line which is perpendicular to line XX' and also bisects the curved mirror. This line represents the principle axis. Locate the center of curvature and the focus geometrically. Construct three arrows, as objects, in front of the curved concave surface. These arrows must be perpendicular to and bisected by the principle axis. Locate the arrows (as objects) as follows, one between the mirror and F, one between F and C, one in back of C. Using a straight pin and lines of sight, locate the image of each arrow in the mirror as suggested in Activity 1. Label the image of each clearly. Use alphabetical letters or different colored pencils to separate images. Suggest a means of how to check for accuracy. Is there a better method of locating images in curved mirrors? Using the following symbols, make careful measurements and record your data in the chart below.

D_o = Distance of object from vertex of mirror;
D_i = Distance of image from vertex of mirror;
F = Focal length of mirror;
S_o = Size of object;
S_i = Size of image.

Use proper units in recording each of these experimental data. Complete the following data table by using both measured and calculated information:

Object Location	D_o (cm)	D_i (cm)	$\frac{1}{D_o} + \frac{1}{D_i}$	$\frac{1}{F}$	S_o (cm)	S_i (cm)	$\frac{S_o}{S_i}$	$\frac{D_o}{D_i}$
Beyond C								
Between F and C								
Between V and F								

Figure 4a:



1. Describe the images formed at each location. (larger, smaller, real, virtual, erect, inverted)

2. State and discuss 3 practical applications of concave mirrors.

Write a brief summary of your observations and conclusions regarding this lab experience.

Materials needed for Activity 4:

curved cylindrical mirror
cardboard workboard
ruler or straightedge
pencil
straight pin

Complete Worksheet #3.

Worksheet #3

Reflection

DIRECTIONS: Write on the line at the right of each statement the number preceding the word or expression that best completes the statement.

1. In regular reflection the scattering of reflected rays is (1) 100%, (2) highly diffuse, (3) negligible, (4) dazzling. ________ 1

2. All of the following are characteristic of diffused reflection except (1) an irregular surface, (2) normals to the surface are parallel to each other, (3) for each particular ray of light, the angle of incidence equals the angle of reflection, (4) light is reflected in many directions. ________ 2

3. When a beam of light hits a clear glass plate (1) all the light is transmitted, (2) all the light is reflected, (3) all the light is absorbed, (4) part of the light is reflected. ________ 3

4. The material of highest reflectance is (1) magnesium carbonate, (2) vaporized silver, (3) water, (4) a black surface. ________ 4

5. On a flat reflecting surface, the line which is perpendicular to the surface at the point of incidence is (1) focus, (2) normal, (3) incident ay, (4) virtual image. ________ 5

6. The images formed by plane mirrors are always (1) larger than the object, (2) smaller than the object, (3) the same size as the object and inverted, (4) the same size as the object and reversed left and right. ________ 6

7. The line drawn through the vertex and the center of curvature is the (1) principal axis, (2) secondary axis (3) aperture, (4) principal focus. ________ 7

8. For spherical mirrors of small aperture, the focal length is (1) equal to the radius of curvature, (2) one-half the radius of curvature, (3) greater than the radius of curvature (4) bears no specific relationship to the radius of curvature. ________ 8

9. Rays parallel to the principal axis of a convex mirror appear to (1) go through undeflected, (2) converge toward the principal focus. (3) diverge from the principal focus, (4) disappear. ________ 9

10. Diverging rays from a point on the principal axis of a concave mirror will be brough to a focus on the principal axis (1) at a point beyond the principal focus, (2) at a point between the vertex and the principal focus, (3) at a point at the principal focus, (4) as parallel rays. ________ 10

11. In constructing the image of a point in a concave mirror, a ray directed parallel to the principal axis is reflected (1) back along itself, (2) back along a secondary axis, (3) through the vertex, (4) through the principal focus. ________ 11

12. The image formed by a concave mirror is a point at the principal focus when the object distance is (1) at a finue distance beyond the center of curvature, (2) at the center of curvature, (3) at an infinue distance, (4) between the center of curvature and the principal focus. ____________ 12

13. When the object is between the principal focus and a concave mirror, the image is (1) virtual, (2) inverted, (3) reduced in size, (4) located in front of the mirror. ____________ 13

14. When the object is at the center of curvature of a concave mirror, the size of the image is (1) enlarged, (2) reduced, (3) a point, (4) identical. ____________ 14

15. The largest telescopes in the world used to collect and focus light rays are (1) lens telescopes, (2) refracting telescopes, (3) reflecting telescopes using convex mirrors, (4) reflecting telescopes using concave mirrors. ____________ 15

16. When the mirror formula is applied to convex mirrors, the quantity or quantities that is (are) negative are (1) only s_o, (2) only s_i, (3) both f and s_i, (4) both f and s_o. ____________ 16

17. The relationship which represents the relative heights of object and image is valid for images formed (1) only in spherical mirrors of small aperture, (2) only through small openings, (3) only in concave mirrors of small aperture, (4) either through small openings or in spherical mirrors of small aperture. ____________ 17

18. Which statement concerning specular reflection and its support of wave and or particle models of light is true? (1) It supports either model equally well, (2) It supports only the wave model, (3) It supports only the particle model, (4) It does not support either model. ____________ 18

19. The image formed by a convex mirror is (1) larger than the object and real, (2) larger than the object and virtual, (3) smaller than the object and real, (4) smaller than the object and virtual. ____________ 19

20. Convex rear view mirrors give drivers of automobiles (1) a narrow field of vision, (2) an enlarged image, (3) images which are smaller than the object, (4) real images. ____________ 20

21. When the object distance is 60 cm, a concave mirror of 10 cm focal length forms an image 12 cm from the mirror. If the experiment is repeated with the object distance 12 cm, the new image distance will be (1) 10 cm, (2) 12 cm, (3) 30 cm, (4) 60 cm. ____________ 21

22. An image is formed by a concave mirror when the object is placed at the center of curvature. The image is (1) real and inverted, (2) real and erect, (3) virtual and inverted, (4) virtual and erect. ____________ 22

23. Real images can be formed by (1) plane mirrors but not by convex mirrors, (2) convex mirrors but not plane mirrors, (3) concave mirrors but not plane mirrors, (4) plane mirrors but not concave mirrors. ________ 23

24. A projector produces an image on the screen 64 times taller than the height of the object. How many times greater than the object distance must the image distance be? (1) 8, (2) 16, (3) 32, (4) 64 ________ 24

25. A ray of light strikes a plane mirror at an angle of 40° with the perpendicular to the mirror. The angle of reflections is (1) 10 (2) 50°, (3) 80°, (4) 40°. ________ 25

Worksheet #4

Reflection of Light

QUESTIONS

1. A ray of light that strikes a surface is called the ________________ ray, while the ray that rebounds from the surface is the ____________________ray.

2. a. When light strikes a surface, the ray's angle of ______________ equals the angle of ________________.

   b. This is known as the Law of ________________.

3. The perpendicular drawn to the surface at the point where a ray strikes it is called the ___________________.

4. The angle of reflection is the angle between the reflected ray and (1) the incident ray, (2) the surface, (3) the normal, (4) the perpendicular to the normal. ___________

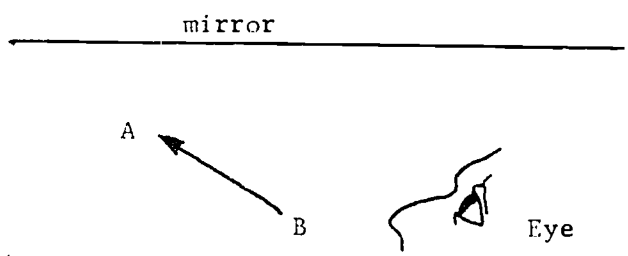
5. The angle of incidence is the angle between the incident ray and (1) the reflected ray, (2) the surface, (3) the normal, (4) the perpendicular to the normal. ______________

6. A sheet of unglazed paper (1) refracts, (2) disperse, (3) diffuses light incident upon it. _______________

7. When parallel rays of light strike a smooth surface ______________(regular, diffused) reflection results. When they strike a rough surface, __________________ reflection results.

8. A picture covered with a glass plate cannot be seen so distinctly as one not so covered because the glass (1) is opaque, (2) is transparent, (3) reflects part of the light, (4) reflects no light. _____________

9. a. Using solid lines, show how rays of light are reflected to the eye from points A and B in the diagram below.



   b. Using dotted lines, show how the eye sees a virtual image behind the mirror.

10. A person may see his image in a mirror because the mirror (1) reflects light, (2) absorbs light, (3) diffuses light, (4) transmit light. __________

11. Describe the image produced by a plane mirror, stating three of its characteristics. ____
____

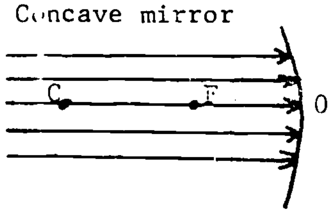
12. A beam of parallel rays is reflected from a plane mirror. After reflection, the rays will (1) be diffused, (2) converge, (3) diverge, (4) remain parallel.
____

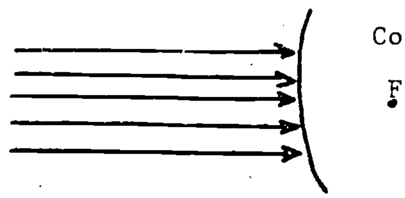
13. The minimum length of plane mirror you need to see your complete image is (1) equal to, (2) one half, (3) one-third, (4) one-fourth your height.
____

14. A pinhole camera will take pictures because (1) a small hole acts as a lens, (2) a pinhole requires a very small lens, (3) light travels in straight lines, (4) small openings allow short exposures. ____________

15. In a ______________ mirror, the reflecting surface is the inside of an arc, while in a ______________ mirror, the reflecting surface is the outside of an arc.

16. Complete the following diagrams to show the rays of light after reflection.





17. An image that cannot be projected on a screen is called a ______________ (real, virtual) image.

18. Both a plane and a convex mirror produce a __________ (real, virtual) image.

19. a. The point where parallel rays converge after being reflected from a concave mirror is the ________________________.

b. The distance from the above point to the center of the mirror is the ________________ of the mirror.

c. The line through the center of curvature and the center of the mirror is called the ________________________.

20. The image produced by a convex mirror when the object is placed any distance from the mirror is __________ (real, virtual), ______________(erect, inverted) and ______________________(larger than, smaller than, the same size as) the object and located ____________ (in front of, behind) the mirror).

21. When the object is located at a distance greater than C from a concave mirror, the image is ________________________, and ____________________ the object, and located between ____________ and ____________.

22. When the object in front of a concave mirror is located between F and the mirror the image is ________________________ and ____________________ the object and located _____________________ the mirror.

23. The distortion of an image which results when all rays parallel to the principal axis do not pass through the principal focus when reflected from a spherical mirror is known as ________________________.

D. Refraction of Light

As you look through an ordinary glass window, you notice the wavy lines or ripples in the glass. This appearance is caused by the bending of light rays as they travel from the air into the glass and out of the glass into the air again. Light rays bend (refract) when they travel from one medium (such as air) into another medium (such as glass), providing that they strike the glass at some angle other than the perpendicular to the glass. Other phenomena that are caused by the refracting (bending) of light are these: apparent pools of water on the surface of a hot highway during the summer; the strange appearance of objects under the surface of water in a swimming pool; the twinkling of the stars at night.

The actual amount by which light bends is measured by the index of refraction of the substance through which the light is traveling. The laws of refraction of light may be discovered by making careful observations and measurements as you conduct this experimental work. The fundamental law governing the refraction of light is known as Snell's Law. An interesting phenomenon caused by the refraction of light is known as total internal reflection. Light passing into a substance may be totally reflected inside that substance if the critical angle of the substance is less than the angle of incidence of the light.

OBJECTIVE

Upon the completion of this unit, the student will be able to:

13. demonstrate the laws of index of refraction of glass, using the "semi-chord" method, plate glass and some straight pins.

ACTIVITY

Complete Activity 1.

Activity 1:

Refer to Diagram 1.

Obtain a rectangular glass prism and place it on a sheet of white paper or a cardboard work surface. Outline the glass prism. Place a straight pin at D and one at A. On the opposite side of the prism, sight along a straightedge until the edge, pins D and A, appear to be in a straight line. Place a pin at G, along the edge of the prism so that the straightedge, pin G, pin D and pin A, all appear in the same line. Draw line GH. Now remove the glass prism and draw the normals N and N'. Using D as the center of a circle, construct arcs at a convenient length. Label the arcs BR and FS so that BD and DF are equal in length. Construct line BC, perpendicular to N and FE perpendicular to N.

Using AD as the incident ray of light, DF becomes the refracted ray. Therefore, angle i is the angle of incidence and angle r is the angle of refraction.

Using the diagram, observe that $\sin i = \frac{BC}{BD}$ and $\sin r = \frac{EF}{DF}$

Remember BD = DF. Now measure lines BC and EF to the nearest 0.1 mm and complete the index of refraction for the glass prism.

$$\text{Index of refraction} = \frac{\sin i}{\sin r} = \frac{BC}{EF}$$

1. Why should this ratio be equal to the index of refraction?

Observe angles y and x. Using the same method as before, determine the value of $\frac{\sin y}{\sin x}$. What are your observations?

What is the value of $\frac{\sin y}{\sin x}$?

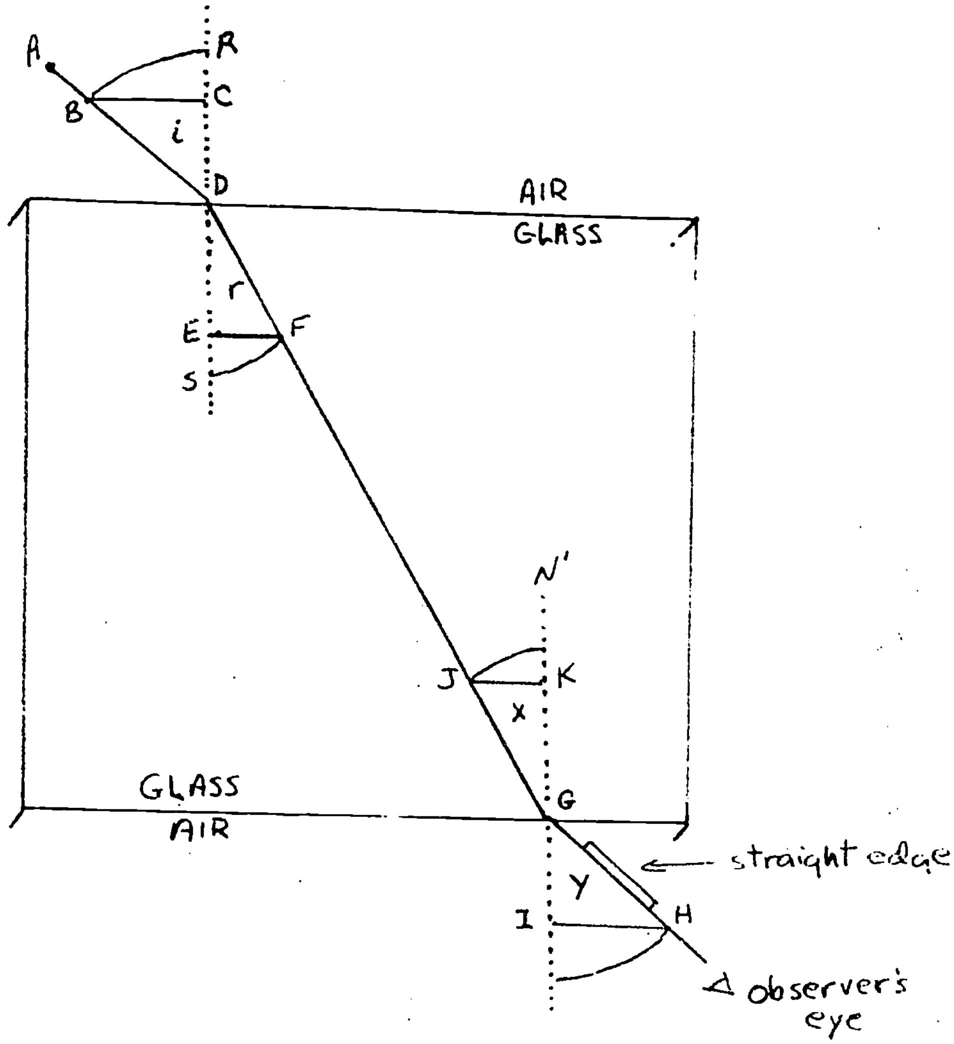
Record your data in the table below.

length in mm	
BD =	
DF =	$\frac{BC}{EF}$ = ?
BC =	
EF =	$\frac{\sin i}{\sin r}$ = ?
GH =	
GJ =	$\frac{HI}{JK}$ = ?
HI =	$\frac{\sin y}{\sin x}$ = ?
JK =	

Using a protractor, measure each angle, i, r, y and x. Look up on a sine table, the sine of each angle and place its numerical value in the equations $\frac{\sin i}{\sin r}$ and $\frac{\sin y}{\sin x}$ and solve.

2. What do you observe?

Diagram 1:



Make a careful diagram of your experimental work.

Write a brief summary of your observations and conclusions regarding this lab exercise.

OBJECTIVE

Upon completion of this unit, the student will be able to:

14. demonstrate the refraction of light as it passes from air to water measuring the angles of incidence, Θ i, and the angles of refraction, Θ r, for angles of incidence varying from 0° to 80°.

ACTIVITY

Complete Activity 2.

Activity 2:

Refer to Diagram 2.

Obtain a semi-circular plastic box, straight pins and a piece of circular graph paper. Fill the plastic box half full of water and align it on a piece of graph paper resting on a cardboard workboard, as shown in Figure 2. Scratch a vertical line down the middle of the straight side of the box. Carefully align the box such that the vertical line on the box falls on the intersection of the center lines of the graph paper. Place a pin on the straight line passing beneath the center of the box, as shown in the figure.

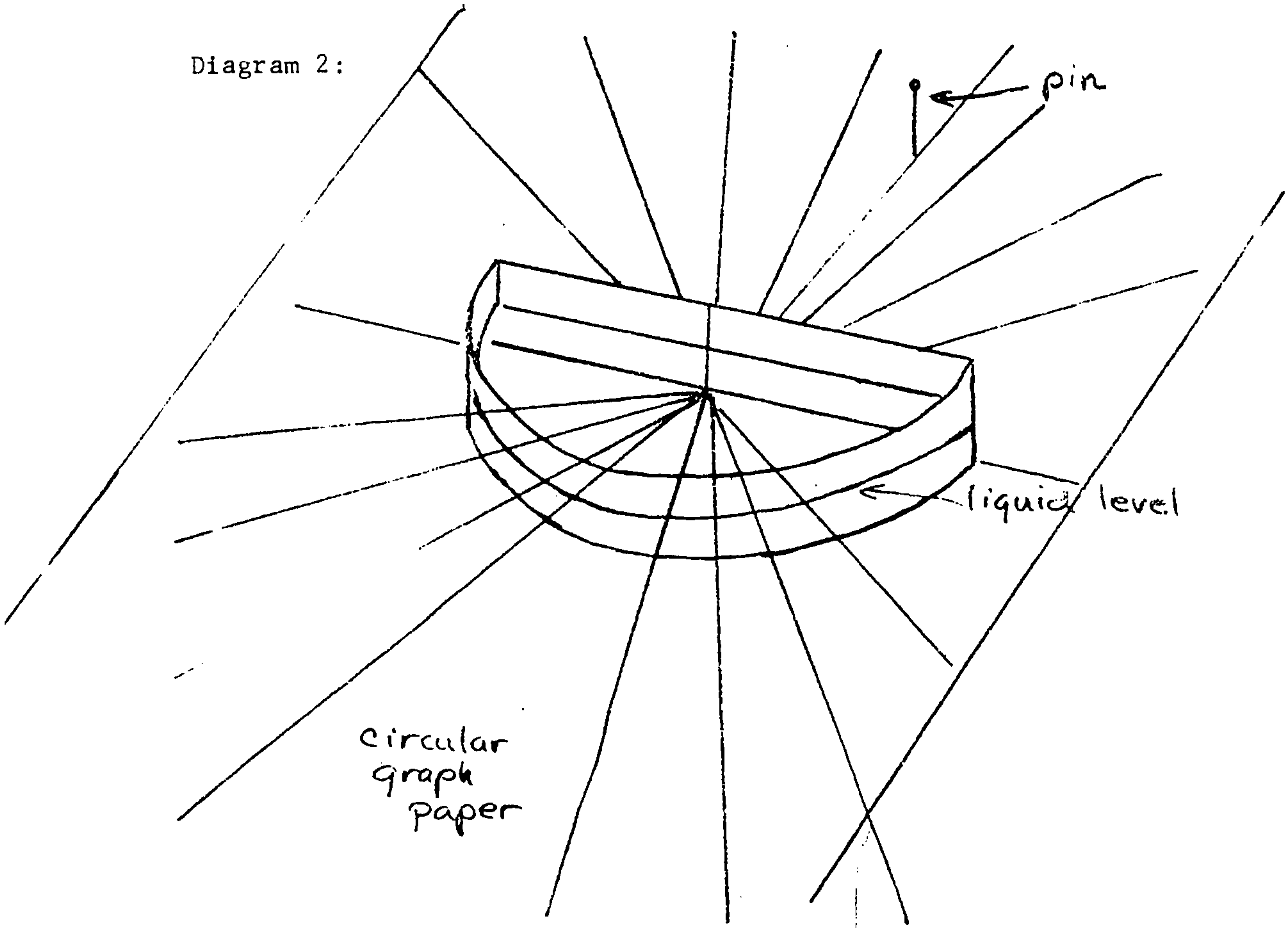
Observe the pin through the water from the curved side of the box and move your head until the pin and the vertical mark on the box are in line. Mark this line of sight with another pin. What are your observations about the bending of light as it passes from air into water and water into air at an angle of incidence of 0° ?

Now change the position of the first pin so that it makes an angle of incidence equal to 20° . Mark the sight line with a second pin, so that both pins and the scratch appear all in line. Repeat this procedure for various angles of incidence up to about 80° . Make sure your pins are about 4 cm from both sides of the box to insure accuracy.

Record your data on the chart below.

Angle of incidence	Sin of Angle	Angle of refraction	Sin of Angle	$\frac{\sin i}{\sin r}$
0°		0°		
20°	⟵⟶ (expanded)		⟵⟶ (expanded)	
30°				
40°				
50°				
60°				
70°				
80°				

Diagram 2:



1. Is there an observed difference between the angle of incidence and the angle of refraction? Is the difference constant?

2. Is the ratio of the sines of the angle of incidence to the angle of refraction constant?

3. Is the path of the light through the water the same when its direction is reversed? Investigate this with your equipment.

If time permits, repeat this experiment using another liquid other than water, e.g., Karo syrup, ethyl alcohol, glycerol, etc.

Make a neat diagram of your lab experiment.

Write a brief summary of your observations and conclusions regarding this lab experience.

Materials needed for Activity 2:

sheet of circular graph paper
plastic, semi-circular box
straight pins
water, other liquids
c board workboard

OBJECTIVE

Upon the completion of this unit, the student will be able to:

15. demonstrate how the particle theory of light obeys the laws of refraction of light.

ACTIVITY

Introduction: A steel ball rolling across a horizontal surface moves in a straight line at nearly constant speed. If the ball intercepts a slope obliquely, the speed it gains as it rolls down the slope will change its direction. At the bottom of the slope it will move off in a straight line in a direction different from its original direction.

The path of a ball moving this way resembles the path of light as it is refracted in going, for example, from air into glass. In going from the top to the bottom of the slope, the ball changes direction; at the interface between two media, light changes direction. In the model, therefore, the upper level corresponds to one medium (air); the lower level corresponds to the other medium (glass); the slope corresponds to the interface between them. We shall examine the paths of "refracted" particles to see if they change direction according to Snell's law, with the apparatus shown in Figure 3.

Activity 3:

Obtain two flat surfaces and arrange them as in Figure 3. Cover each surface with white paper and a sheet of carbon paper, so that the path of the rolling ball can be easily traced. Using a launching ramp, roll the ball down the full length of the launching ramp on the upper level so it strikes the slope at a slight angle. Remove carbon paper and label each track made by the ball. Repeat the procedure five or six times at different angles of incidence, always being careful to start the ball from the same point on the launching ramp to give it the same initial speed each time.

Measure and record each angle of incidence and angle of refraction in the table below. Be sure to keep the normal perpendicular to the edge of the paper.

Now change the height of the upper level and proceed as before in your investigation.

Trial	Angle of incidence	Sine of L of incidence	Angle of refraction	Sine of refraction
1				
2				
3				
4				
5				
6				

Different Height

Trial	L of incidence	Sine of L of incidence	L of refraction	Sine of L of refraction
1				
2				
3				
4				
5				
6				

Using the sine values in each set of trials, determine the ratio of $\frac{\sin i}{\sin r}$ for each.

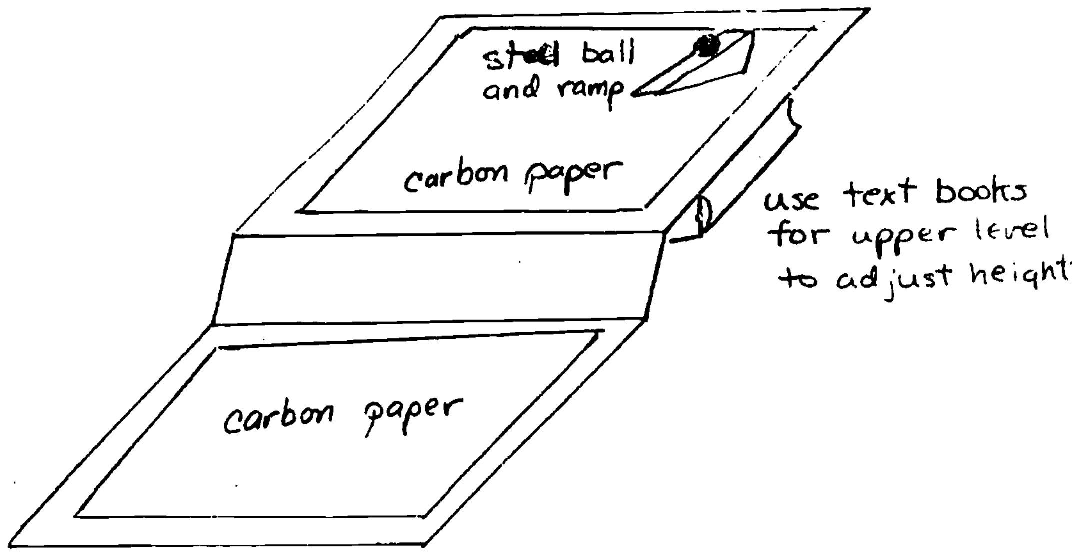
1. Can the change in direction be explained by Snell's Law?

2. Is the ratio $\frac{\sin i}{\sin r}$ consistent with Snell's Law?

3. On which level is the speed of the rolling ball greatest, least?

4. Based on your answers to question 3, are your results consistent with Snell's Law?

Figure 3:



Be sure two surfaces are level. Tape white paper on each surface with carbon paper covering each.

Write a brief summary of your observations and conclusions regarding this lab experience.

Materials needed for Activity 3:

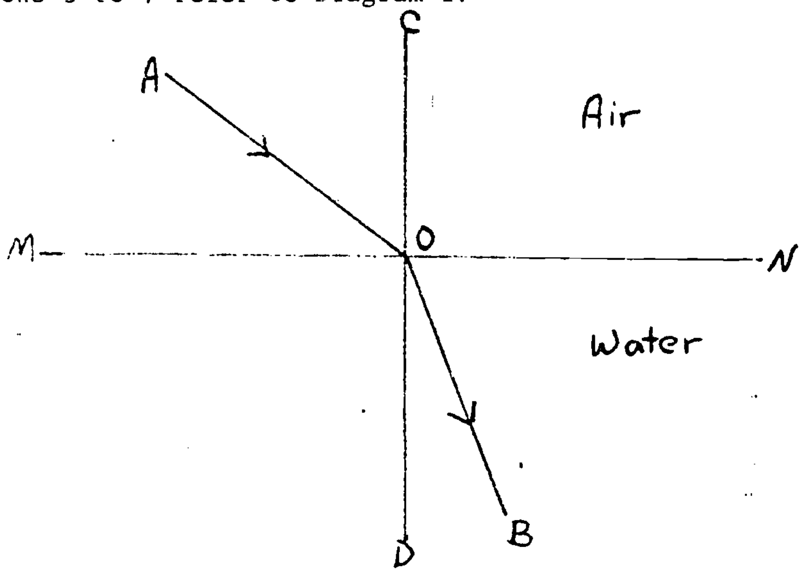
- 2 flat work surfaces
- carbon paper
- white paper
- launching ramp (refraction of particles ramp)
- steel ball

Refraction

1. Light travels in straight lines only when the medium through which it travels is of the same ______________________ throughout.

2. The bending of light rays in passing obliquely from one medium into another is called ______________________.

Questions 3 to 7 refer to Diagram 1.



3. In Diagram 3, which illustrates the path of a light ray from air into water AO is known as the ________________ ray.

4. Ray OB is known as the ____________________ ray.

5. The line CO is the ______________ drawn to the point of refraction and OD is the ________________.

6. Angle ________________ is the angle of incidence.

7. Angle ____________________ is the angle of refraction.

8. A ray of light passing from one medium to another along the ____________ is not refracted.

9. When a ray of light passes obliquely from air into water, the ray is bent ______________ the normal.

10. When a beam of light passes from air into water, its speed is ________________.

11. Explain or define the law of refraction of light.

12. The index of refraction of one type of glass is 1.5. Calculate the velocity of light in the glass.

OBJECTIVES

Upon completion of this unit, the student will be able to:

1. distinguish between luminous and illuminated, opaque and transparent, incandescent and luminescent sources.

2. demonstrate the basic principles of diffusion, formation of shadows and accurate definition of umbra and penumbra.

3. measure the quantity of light produced by a light source and compare it with other sources of light.

4. determine the intensity of a light source and the amount of illumination received by an object.

5. describe the construction of a photometer and demonstrate its use.

6. write and demonstrate the law of inverse squares.

7. distinguish between regular and diffuse reflection.

8. state the laws of regular reflection.

9. describe and locate an image in a plane mirror.

10. apply the concepts "incident ray, reflected ray, and normal" to a flat surface.

11. describe the images formed by concave and convex spherical mirrors at various distances from the vertices of the mirrors.

12. use the mirror equation to locate images, focal points, and objects relative to spherical mirrors.

13. demonstrate the law of index of refraction of glass, using the "semi-chord" method, plate glass and some straight pins.

14. demonstrate the refraction of light as it passes from air to water measuring the angles of incidence, Θi, and the angles of refraction, Θr, for angles of incidence varying from $0°$ to $80°$.

15. demonstrate how the particle theory of light obeys the laws of refraction of light.

GENERAL UNIT INSTRUCTIONS

Unit A - Nature of Light

1. Materials needed for each activity are listed at end of lab activity.

2. Using pre-arranged tote trays facilitates ease of handling and general organization.

3. Have students turn in all written work regarding lab activities for possible evaluation.

4. Cardboard boxes, cut up, make excellent work surfaces for most activities.

5. Use worksheet as unit summary or pre-evaluation material.

Unit B - Photometry - The Measurement of Light

1. Careful graphing techniques in Activity 1. Graph 3 should reveal the only direct relationship if done correctly.

2. Students may have difficulty establishing what the equation for Inverse Square Law really is.

3. Obtain accurate measurements of distance and area in Activity 2 for good graphing results.

4. Activity 3 - if Bunsen Photometers are not available, a practical photometer (Joly) can be built using parafin wax blocks and aluminum foil. Sandwich a piece of foil between parfin blocks, melt together slightly - mount on optical bench - look for equal illumination instead of dissolving grease spot.

5. For accurate calculations, obtain a wattage to candle power conversion chart.

6. Have students turn in all written work for possible evaluation.

Unit C - Reflection of Light

1. Mirrors taped to wooden blocks serve well for all purposes of Activity 1.

2. Students should pay particular attention to alignment of straightedge with actual image. Discrepencies here lead to totally erroneous results.

3. Activity 2 - suitable equation for observed images is $\frac{360^\circ}{\theta^\circ} = n - 1$

4. Careful line construction need be observed in obtaining image formation with curved mirrors in Activity 4. Avoid images near edges, results in spherical abberation zones of mirror distort real calculations.

Unit D - R fraction of Light

1. Rectangular glass prisms with ground edges must be used for Activity 1.

2. Assist students with careful diagramming and results.

3. Plastic pie boxes can be substituted in Activity 2.

4. Circular graph paper is not essential, however, eliminates the need for a protractor to measure angles.

5. The PSSC Dynamics and Refraction of Particles Kit may be used in Activity 3. Use soft carbon paper and a heavy steel ball to achieve successful tracking.

SUGGESTED REFERENCE MATERIALS

PSSC text

Harvard Projects text

Modern Physics

Experiment Guide for High School Physics by Groehring

A Sourcebook for the Physical Sciences

Evaluation Form for Teachers

Name of mini-course ______________________________

Evaluation Questions	Yes	No	Comments
1. Did this unit accomplish its objectives with your students?			
2. Did you add any of your own activities? If so, please include with the return of this form.			
3. Did you add any films that other teachers would find useful? Please mention source.			
4. Were the student instructions clear?			
5. Was there enough information in the teacher's section?			
6. Do you plan to use this unit again?			

7. Which level of student used this unit? ______________________________

8. How did you use this unit - class, small group, individual? __________

____

PLEASE RETURN TO SCIENCE SUPERVISOR'S OFFICE AS SOON AS YOU COMPLETE THE COURSE.

SCIENCE MINI-COURSES

PHYSICAL SCIENCE	**Prepared by**
ELECTRICITY: Part 1 (Types of Generation of Electricity)	Marvin Blickenstaff
ELECTRICITY: Part 2 (The Control and Measurement of Electricity	Marvin Blickenstaff
ELECTRICITY: Part 3 (Applications for Electricity)	Marvin Blickenstaff
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