OFFICIAL
OPTICS
DISCOVERY
CLASSROOM
KIT

TEACHER’S GUIDE

Education Council of the
Optical Society of America
PROJECTS OF THE EDUCATION COUNCIL OF THE
OPTICAL SOCIETY OF AMERICA

Education Council was created as a response of the Optical Society of America (OSA) to assist those in the critical field of modern science education. This OSA Optics Kit is an example of one of the projects of the Education Council.

The Council is responsible for Educators' Day at OSA's Annual meeting. The purpose is to bring teachers into contact with our members and give them a sense of what optics is like today. The teachers are chosen by their state or province science coordinators. Travel expenses, lodging, and the expense of a substitute teacher are all borne by the Society. A number of outstanding lecturers from the ranks of the Society including Nobel Prize winner, Arthur Schawlow, provide lectures on the various fields of optics. A series of workshops provide the teachers with some demonstrations of optics materials and techniques. Also included during the day is a tour of the exhibit hall, where the educators get a first hand look at the latest optics instrumentation.

The links with teachers are continued beyond Educator's Day. A series of small education grants for optics projects at the K-12 level are funded by OSA through the Education Council. The program consists of $10,000 in grants with a maximum award of $2000. Usually 8 to 10 awards have been made for such diverse projects that range from a holography laboratory to interactive optics exhibits at a small Science center. These links to the educators are also reinforced by offering them an at-cost membership to OSA. These links are also maintained by sponsoring a teacher as an OSA Education Fellow during the Summer. The Fellow works at OSA on a number of education projects for OSA and his own optics-related project. The Fellows that have been part of the program, all high school science teachers, have contributed substantially to the Optics Kit program. One Fellow wrote the Teacher's Guide; another revised some of the experiments and contributed additional revisions to the Guide and the Student Manual.

Another concern of the Education Council is the lack of information on optics for students who might have the talents and interest for this fascinating field. The Education Council has produced a Career Poster with request card and a Career Booklet on optics that features a hologram on the cover. To provide additional information to counselors and others, a database has been developed and maintained. The content of the database has been published as Guide to Optics Courses and Programs in North American Colleges and Universities. There is an Associate and Undergraduate Level Edition and a Master's and Doctoral Level Edition.

Concern with the capability to retain those with postgraduate degrees in the universities and college, the Education Council has sponsored as series of travel grants for graduate students who will give papers at the annual meeting. It is hoped that the involvement of student in the professional activities of the Society will provide incentive to remain in the field of research.

The Council has a number of other initiatives that are examined from time to time and new ones are proposed. None of this would be possible without the good faith and support of the members of OSA, who have on occasion indicated their willingness to support this effort.

Donald C. O'Shea
School of Physics
Georgia Institute of Technology
Chair, OSA Education Council, 1989-90
PHILOSOPHY

The purpose of the optics kit is to stimulate interest in the field of optics rather than to provide a complete course in optics. The kit and the experiments are to serve as a vehicle for exploring optics. We intend for the students to make observations and record them on paper. We hope that you, the teacher, will refrain from being the expert on what the students should see. Too often, students treat science as a course for memorizing facts and laws. Instead, science should be a process of discovering new ideas and new questions. The students need to formulate ways of answering those questions. The class as a whole should arrive at consensus on what should be accepted as an accurate description of experimental fact. The next step is to guess at how or why that phenomenon occurred. Then, they need to devise further experiments to extend their study. The teacher is to act as a guide to discovery and not be a font of all answers. Teaching this way has its risks. As teachers, we find that students resent not being given the "answer". They say things like, "You don't teach me!" and "Why do you always answer a question with a question?". Yet, in the long run, they take great pride in being able to solve their own problems and answer their own questions. It is highly probable that some student questions will arise which they cannot answer and you can't either! Be prepared to humbly say that you don't know the answer and give them guidance as to what resources they might use to find it.

GENERAL NOTES

Because of the number of small parts in the OSA optics kit, you will need to decide how best to distribute and collect materials for each activity. If you pass out the complete kits, be prepared to check them on their return as some of the items are very popular with the students.

Students should be encouraged to record their observations in some organized form which they can refer to during discussions. The details of the format are left to your discretion.

For each experiment some notes have been provided about the set-up and hints about how to make things go smoothly as well as a brief description of expected results for your information. It is hoped that you will personally do each experiment before assigning it to your students. This guide may not have anticipated all of the problems that may be encountered. Remember that when conducting classroom experiments, Murphy's law usually prevails.

The basic experiments described in the student booklet can be used at either the primary or secondary school level. However, the more advanced the students are academically, the further they can carry their investigations and analysis. The sections labelled "Discussion Questions" and "Additional Activities for More Advanced Students" are included so that you can extend the activities to the appropriate level for advanced students that you may be working with. For example, further experimentation might be the appropriate way for students to find an answer to some of the Discussion Questions.
ITEMS IN THE OSA OPTICS KIT

3 Lenses (labeled A, B & C)  Fresnel Lens (flat piece of plastic with circular ridges)

Diffraction Grating  2 Polarizers (remove paper coating)

Optical Fiber  Flexible Mirror

Color filters (red, yellow, green, & blue)  Hologram  Photographic Slide with Optical Illusion

ADDITIONAL MATERIALS NEEDED: White card, Ruler, Flashlight, Tablespoon, Small light with unfrosted bulb, and a Piece of transparent, stretchable plastic.

CAUTION!
Some of these items are made for you to look through. However, you should never look at the sun directly or at the sun through any of these items.
ADDITIONAL MATERIALS

In addition to the materials in the kit, some of the experiments require the use of other materials that can be obtained without too much difficulty.

The following will be needed for each kit:

☐ White Index Card
☐ Meter Stick (or Ruler)
☐ A Few Crystals of Salt and Sugar or Sand
☐ Two Clothespins
☐ Small White Light with Unfrosted (Clear) Bulb
   (A clear 40 watt showcase bulb will work well)
☐ Piece of Transparent, Stretchable Plastic Bag or Wrap
☐ Large Shiny Metal Spoon

If your classroom has no windows, you will also need at least one frosted 40 watt incandescent bulb in a socket for use as a light source.

If you wish to make the color filters in the kit more durable, mount each filter between two 3 x 5 index cards from which you have cut out rectangular windows. Be sure that the windows' dimensions are 1/2 inch smaller in length and width than the dimensions of the filter. This will allow 1/4 inch overlap of the filter with the card on each side. Rubber cement or tape the filters to the cards. The mounting will help prevent the filters from rubbing together and will provide a place to handle them without fingerprinting their surfaces. Mounting the color filters will require eight index cards per kit.
**EXPERIMENT #1 | LENSES**

**EQUIPMENT:** Lenses A, B, and C, Meter Stick (or Ruler), and White Card

---

**DESCRIBE THE IMAGE**

In a dimly lit room find the image formed by lens A of some bright object which is at least a meter (several feet) away from the lens (your teacher will suggest what object to use). The IMAGE (a picture of the object) will appear on the white card when you hold the card at the proper distance from the lens. Move the card closer to and farther from the lens until you get a sharp (FOCUSED) image of the object.

1) Describe the image which you have found. Be sure to note any differences between the image and the object. Repeat the steps above using lens B and then lens C.

2) Describe any differences from the results you got for lens.

---

**STUDY IMAGE LOCATION**

Using lens A, make the distance from the lens to the object less by gradually moving the lens toward the object. Keep checking the image as you do this by moving the white card.

3) What effect does this have on the image size and location?

---

**FIND THE FOCAL LENGTH**

When an image is formed of an object which is very far from a lens, the image is located approximately at the FOCAL POINT of the lens. The distance from the center of the lens to the focal point is called the FOCAL LENGTH of the lens.

4) Find the focal length of lens A as well as lens B.

---

**HOW IS THIS USEFUL?**

Cameras use lenses to focus images on film. Film strip and movie projectors have movable lenses that can form a sharp image on the screen. Your eye is a lens. The image on the back of your eye is upside down, but your brain interprets it as right side up.
EXPERIMENT #1
LENS
NOTES ON SET-UP

Distribute a set of lenses (A, B, C), a meter stick, and a white index card to each student or small group of students. Illustrate (if necessary) how to position the lens and card so that an image appears on the card. In order for the image to be clearly visible it is important that the "object" be much brighter than the general room lighting. The light in the room must be subdued. A good "object" to use would be either of the following: 1) a single window, well-lit from the outside, or 2) a lit frosted 15 watt light bulb which has a large number or letter (a 4, 7 or R for example) written on its surface with a magic marker. When students are finding the focal length of each lens, they should have the lens at least several meters from the object for best results.

EXPECTED RESULTS

This information is provided as a reference for you, the teacher. You are encouraged, however, in each of the experiments to let the students discover as much as they can on their own, both during the activity and in the class discussion afterward. Try not to "give" them the "right" answers!

Describe the Image
1) The image formed by lens A is upside-down. It is smaller than the object. It is reversed left-to-right (students may not notice this).
2) Lens B forms an image similar to that of lens A, only smaller and closer to the lens. Lens C will not form an image on the card. (See discussion below.)

Study Image Location
3) As the object to lens distance decreases, the image to lens distance increases and the image gets larger.

Find the Focal Length
4) Lens A- approximately 12.5 cm (5 in).
   Lens B- approximately 3.5 cm (1.4 in).

DISCUSSION QUESTIONS

1) Why does lens C not form an image on the card?
   Lens C is a different type of lens--shaped differently from A and B. Lenses A and B are double convex (converging) lenses with cross-sections that look like this:
   (Notice the illustration on the lens mount.)

   Lens C is a double concave (diverging) lens with this cross-section shown at the left. A diverging lens does form an image but not one that can be projected on a screen. Projectable images are known as real images. You can see the small, upright image formed by lens C by looking through the lens. This type of image is called a virtual image.
2) If a convex lens is moved very close to the object, what happens to the image?

The image gets much farther away and much larger until it finally "disappears". This happens when the object becomes less than one focal length from the lens (see Experiment #2). The image has not disappeared; it has changed from a real image to a virtual image which can be seen by looking through the lens.

3) Does a concave lens have a focal point? How can it be found?

A concave lens has what is called a virtual focal point and its focal length is assigned a negative value. A technique for finding the focal point involves a parallax test. Another reference should be consulted if you wish to explain this procedure to advanced students.

4) What is the difference between the image location and the focal point of a convex lens?

The image location varies depending on how far the object is from the lens. There is an equation which expresses the relationship between the distance from the object to the center of the lens (o) and the distance from the image to the center of the lens (i). It also involves the focal length, f.

The equation is:

\[
\frac{1}{o} + \frac{1}{i} = \frac{1}{f}
\]

The only time that the image is located at the focal point is when the object is very far from the lens. That is, when the 1/o term in the above equation is very small.

☐ Many objects can act as lenses. Have students find the focal length of such things as a clear glass marble or a water-filled cylindrical glass bottle or round flask.

☐ More quantitative activities can be done using the equation mentioned above. Students can calculate the focal length of a lens by measuring the object and image distances or they can predict in advance where the image will be by using the object distance and the predetermined focal length of the lens.
EXPERIMENT #2 | MAGNIFIERS

EQUIPMENT: Lenses A, B, and C, Some Small Crystals, A Small Ruler

<table>
<thead>
<tr>
<th>Your eye</th>
<th>Printed Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens</td>
<td></td>
</tr>
</tbody>
</table>

**MAGNIFY IMAGES**

Try the following with each of the three lenses:

Place the lens flat on a page of printed words (such as this page).
Lift the lens slowly away from the page.
1) Describe the image of the letters that you see while looking through the lens and how the image changes as you are moving the lens. Continue pulling the lens farther from the page to a distance greater than the lens’s focal length.
2) Describe any new changes that occur to the image as you continue to bring the lens closer to your eye. If the lens can produce an image that is larger than the original object, that lens can be used as a magnifier.
3) Describe differences you notice in the behaviors of the images in the three lenses.
4) Hold the lens very close to your eye and move close to the page to make the letters appear as large as possible. This is the correct way to use a magnifying glass.

**EXPLORE MAGNIFICATION**

Using only the lenses which are magnifiers, observe the different types of crystals you have been given.
5) Describe any differences you can find between crystals of different materials. Select one very small object such as a tiny printed letter to look at with each magnifier.
6) Draw the object the size that it actually is and then draw it the size that it appears through each magnifier.

**HOW IS THIS USEFUL?**

Magnifiers help us to see very small objects. Some magnifiers are made of many lenses and magnify as much as 1000 times.
EXPERIMENT #2
MAGNIFIERS
NOTES ON SET-UP

EXPECTED
RESULTS

In addition to the three lenses each student will need a small ruler for measuring sizes of objects and images and a few crystals of several different materials. Salt, sugar, and sand would be good. Any other very small objects that you might have available can be offered to students to examine with their magnifying lenses when they have finished the experiment.

Magnify Images
1) Using lenses A and B the image of the letters will be right-side up and larger than the actual letters. It will get larger as the lens is moved farther from the page. Lens C will produce an image that is right-side up but smaller than the actual letters and the image will get smaller as the lens is pulled away from the page.
2) As the object (the letters on the page) gets close to one focal length from lens A or B, the image gets very large and blurred and distorted. Once the distance to the page becomes greater than one focal length, the image will be upside-down and get smaller with increasing distance to the page. Note: The focal lengths were determined in Experiment #1. Lens C, alas, does not do anything fancy like lenses A and B.
3) Lenses A and B are magnifiers. Lens C is not. (See Discussion Questions below.)

Measure Magnification
4) Salt crystals should have a rather uniform shape. Sugar will likely have a variety of shapes. Sand will have a variety of shapes and materials.
5) (Drawings) Some students will have a lot of difficulty magnifying a small object and drawing it the size that it appears. They will need encouragement and help.
6) Expect a variety of answers here because of the difficulty of making accurate drawings and because the amount of magnification depends on how far the object is from the lens. If you ask students to determine how many times bigger the image is than the object, reasonable maximum values for sharp images are approximately 4 times for lens A and 7 times for lens B.

DISCUSSION QUESTIONS

1) What property of a lens determines whether or not it can be a magnifier?
   All convex (converging) lenses can be magnifiers. Concave (diverging) lenses cannot.
2) Under what circumstances will a convex lens act as a magnifier?
   The lens must be less than one focal length away from the object. When the lens is between one and two focal lengths from the object, it does form an enlarged image also, but this image is upside-down
and not as easily seen because of its location.

3) **Why did lenses A and B form images that were right-side up in this experiment but upside-down in the previous experiment?**

   The characteristics of the image depend on the distance from the lens to the object. In this experiment when the object was less than one focal length from the lens, the image was upright. In Experiment #1 the object was much farther from the lens and this produces an inverted image. The chapter on ray optics in any high school physics text will have diagrams to show why this occurs.

4) **Why did different students get different magnifications for the same lens?**

   The difficulty in making a drawing that is the same size as the image introduces some variation in answers. Also, the size of the image depends on how far the object is from the lens. The magnification of a lens usually refers to the largest image that can be formed without introducing severe distortion or blurriness.

   - Obtain a compound microscope. Allow students to examine some objects which are too small for the simple magnifier. Ask students to identify the types of lenses used in the microscope.
   - Have students examine various pieces of audio-visual equipment to identify the types of lenses used and the object for each lens.
EXPERIMENT #3 | GALILEAN TELESCOPE

EQUIPMENT: Lenses A and C and Two Clothes pins

Distant object

CAUTION! DO NOT LOOK AT THE SUN!

MAGNIFY IMAGES

Hold lens C very close to one eye so that it almost touches your eyebrow. Put lens A directly behind and very close to lens C so that you can look through C at A. For the next step, close your other eye. Aim the lenses toward some distant object and very slowly move lens A away from lens C (keep lens C right at your eye). At some point you should see a sharp (focused) image of the distant object appear. If the image is too shaky, you can set the lenses on a table using clothespins to make them stand up.

1) Describe the image compared to the object.
2) Draw the image on paper so that your drawing seems the same size as the image you see. Also draw on the paper the object the size it appears when you look at it without using the lenses.
3) Measure the length of your two drawings to find out how much the TELESCOPE you made magnifies the distant object.

HOW IS THIS USEFUL?

BINOCULARS are two telescopes mounted side by side. They enlarge the image of distant objects. TV cameras with long lenses act as telescopes that allow us to view close up pictures of objects distant from the cameraman.
Experiment #3: Galilean Telescope

Notes on Set-Up

Making a telescope out of lenses A and C is a little tricky so try it out yourself and be prepared to assist students in seeing the image. To succeed at seeing the image you must put lens C very close to your eye. Then put lens A very close behind lens C. Look through both lenses toward a distant object (look out a window, if possible). Slowly move lens A away from lens C until you can see a sharp, enlarged image of the object you are looking toward. This should occur when lens A is approximately 10 cm (4 in) from lens C. Using clothespins to make the lenses stand up will be necessary if students are to draw the image they see.

Caution! Do not look at the sun with or without the lenses!

Expected Results

Magnify Images

1) The image is right-side up and enlarged. If the object itself is large, only a small portion of it will be visible at one time. Some students may report seeing colors around the edges of the image (see Discussion Questions below).

2) These drawings require difficult judgments and comparisons on the part of the students so expect a variety of results.

3) This telescope actually magnifies a distant object by a factor of approximately five. If you ask your students to calculate this factor by dividing the object length into the image length, expect a wide range of answers.

Discussion Questions

1) Why are the lenses of most telescopes (and microscopes) mounted in tubes?
   The tubes hold the lenses permanently in the proper alignment while allowing for adjustment of the distance between the lenses. The tubes also help to block out stray distracting light from other sources.

2) As you look at objects which are different distances from the telescope, the distance between the lenses must be changed to focus the image. In what way does the distance between the telescope lenses have to be changed as you look at more distant objects?
   The farther away the object is, the closer together the lenses need to be. After some point, however, no further adjustments in the lenses needs to be made.

3) What happens if you turn the telescope around and look through it the other way (put lens A next to your eye)?
   You will see an image of the object which is smaller than the object but larger than with lens C alone.

4) Why are streaks of color sometimes visible around the edges of images seen in your telescope?
   This is a type of distortion caused by the lens not focusing all the colors of light at the same spot. Thus the colors separate a little.
This distortion is called chromatic aberration. It can be corrected by using additional lenses.

☐ Have students examine a camera which has through-the-lens focusing to see how images of objects at different distances from the camera are focused on the film.

☐ Have students write a report or give a presentation on the lens system in a slide or movie projector.

☐ Ask students to read about and report on Galileo and the discoveries he made using one of the first telescopes.

☐ Determine (or have students do it) some occupations in which the use of lenses is important. Invite someone in to talk to the class about it.
EXPERIMENT #4  KEPLERIAN TELESCOPE

EQUIPMENT: Lenses A and B and Two Clothes pins

CAUTION! DO NOT LOOK AT THE SUN!

MAGNIFY IMAGES

Hold lens B very close to one eye so that it almost touches your eyebrow. Put lens A directly behind and very close to lens B so that you can look through B at A. With your other eye closed, aim the lenses toward some distant object and very slowly move lens A away from lens B (keep lens B right at your eye). At some point you should see a sharp (focused) image of the distant object appear. By using the clothespins as holders, you can make the lenses stand up on a table to get a steadier image.

1) Describe the image that you see compared to the object.
2) Draw the image on paper so that your drawing seems the same size as the image you see. Also draw on the paper the object the size it appears when you look at it without using the lenses.
3) Measure the length of each of your two drawings to find out how much this TELESCOPE you have made magnifies the distant object.
4) How is this telescope different from the one you made in the last experiment?

HOW IS THIS USEFUL?

Telescopes can be designed using several different combinations of lenses. Each style has some advantages and disadvantages. For example, some produce images which are right-side up and others do not. Some produce greater magnification than others. Some allow you to see more area at one time. Binocular makers who use the lens arrangement that you just used will usually add other optical devices to turn the image right-side up.
Again, it may be difficult for students to find the image they are looking for. Lens B must be held very close to the eye. If lens A is held right behind lens B and then moved slowly away, the enlarged image of some distant object should appear when the lenses are about 16 cm (over 6 in) apart. Using clothespins to make the lenses stand up will be necessary if students are to draw the image they see.

**CAUTION! DO NOT LOOK AT THE SUN WITH OR WITHOUT THE LENSES!**

**EXPECTED RESULTS**

**Magnify Images**

1) The image is upside-down and enlarged. Some students may again report seeing colors around the edges of the image. See the Discussion Questions section of the previous experiment for more about this.

2) Expect a lot of variation in the drawings, but at least they should all show an enlarged image which is upside-down.

3) The actual magnification of this telescope is about three. If you have students calculate this by dividing the object length into the image length using their drawings, expect a wide range of answers.

4) Students may indicate differences in the telescopes or differences in the images. Telescope differences - The Keplerian scope is longer; you can see a greater portion of the object at one time than with the Galilean telescope. Image differences: With the Keplerian telescope the image is upside-down; the magnification is less than the Galilean telescope.

**DISCUSSION QUESTIONS**

1) Which of the two types of telescopes that you made is better and why?
   - It depends on what you are using the telescope for. For looking at things on the earth an upside-down image is usually unacceptable. For astronomical viewing this is not a problem.

2) In the Keplerian telescope is the image reversed left-to-right as well as being upside-down?
   - Yes, these two kinds of reversal occur together.

3) What happens if you turn the telescope around and look through it the other way (with lens A next to your eye)?
   - You will still see an upside-down image but smaller than the object.

**ADDITIONAL ACTIVITIES FOR MORE ADVANCED STUDENTS**

- Students can find out whether the images formed by telescopes can be projected onto a white card (are the images real or virtual?).
- Ask students to find out what other types of telescopes there are including some which use curved mirrors.
- Have students find out how the design of microscopes is different from the design of telescopes.
EXPERIMENT #5  FRESNEL (Freh-Nell') LENS

EQUIPMENT: Fresnel Lens, Lenses A, B and C, Ruler and White card

Light from far away

White card

CAUTION! DO NOT LOOK AT THE SUN!

COMPARE LENSES
Look closely and carefully at the Fresnel lens.
1) Tell how the Fresnel lens itself appears different from the other lenses.
2) Is the Fresnel lens a magnifier? (Look back to Experiment #2 if you have forgotten how to tell.)

FIND THE FOCAL LENGTH
In Experiment #1 you found the focal lengths of some of the lenses. Using a small, bright object (such as a light bulb) which is very far from the Fresnel lens, and the white card, find the focal length of the lens.
3) What is the focal length of the Fresnel lens?

MAKE A TELESCOPE
The Fresnel lens can be used along with one of the other lenses to make a telescope (see Experiments #3 and #4). Choose one of the other lenses and make a telescope.
4) Figure out which type of telescope (Galilean or Keplerian) you have made and explain how you know.

HOW IS THIS USEFUL?
The Fresnel lens is a "skinny" lens. Only one side of the lens is curved. This side is made up of a series of rings each of which has a curvature that is the same as the curve of a regular lens with the same focal length. The Fresnel lens is often used where a big lens that is light in weight is needed, for instance in lighthouses.

©1988 Optical Society of America
The Fresnel lens is flat and mounted onto a rectangular piece of clear plastic. The lens appears to have faint circular lines on it. These are the grooves shown in the picture of a Fresnel lens at the bottom of the page in the student experiment. If you look very carefully at an edge view of the lens with a magnifier, you can see the grooves and how their slant changes. If you do not have a window in your classroom, you will need a light bulb for the focal length determination.

**Compare lenses**
1) The lens itself has a bigger diameter. It is thin and flat. It has lines in it.
2) Yes, it is a magnifier (its magnification is about 4).
3) The focal length is about 7.5 cm (3 in).
4) Any of the following combinations will work:
   - Lens C near eye, Fresnel beyond makes a Galilean telescope.
   - Lens B near eye, Fresnel beyond makes a Keplerian telescope.
   - Fresnel near eye, Lens A beyond makes a Keplerian telescope. If the image is right-side up, it is Galilean; if the image is upside-down, it is Keplerian.
   - All other combinations involving the Fresnel lens produce smaller images and are therefore not telescopes.

**Discussion Questions**
1) *Which of the other lenses does the Fresnel lens most behave like?*
   - It behaves most like lens A. It is a magnifier, it can project images onto a card, and it has about the same focal length.
2) *When is a Fresnel-type of lens a better choice to use than a regular type of lens?*
   - It would be better when a large lens is needed. An ordinary large lens is often thick and heavy but the Fresnel lens remains relatively thin and light in weight.

- Have students investigate to find out where Fresnel lenses are used.
  (Some examples are: in overhead projectors, in traffic lights.)
- Have students find out how different types of lenses are manufactured (molded, ground, cut?).
Make a Projector

Using the light source indicated by your teacher, hold the slide you are going to project close to the light source. Place one of the lenses close in front of the slide and a white piece of paper for the screen about one meter away from the lens. Move the lens closer to and farther from the slide until you can see a focused image of the slide on the paper (you may have to move the paper a little too).

1) Describe the image compared to the object. Try the other two lenses as the projection lens.
2) Which lens set gives the best image?
3) What made you decide that image was the best? Try to get an image on your screen when the screen is moved to about two meters from the lens.
4) If you are able to get an image, describe how it has changed.

What is this useful for?

This type of lens arrangement is used for slide projectors, overhead projectors and movie projectors. The light shines through the picture and is then projected by a lens onto a screen. Big screen TV's also use this type of projection system.
EXPERIMENT #6 PROJECTOR

NOTES ON SET-UP

The mounted slide containing a drawing of a geometric shape should be used for this experiment. A regular 40 watt light works well for the light source. Except for lights the students are using as sources, the room should be fairly dark so that the projected images will be more easily visible. For sharp images make sure the students keep the planes of the slide, the lens, and the screen parallel to each other.

EXPECTED RESULTS

Make a Projector

1) The image is larger than the object, but upside-down. The image is also reversed left-to-right but students may not notice this.
2) Probably lens A, but any choice here would be okay as long as they defend this answer in the next answer.
3) Students may give several different answers here, such as:
   The best image is the largest one.
   The best image is the sharpest one (best focused).
   The best image is the brightest one.
4) The image has gotten larger, but it is not as bright.

DISCUSSION QUESTIONS

1) When you watch a movie or look at slides, why don’t they appear upside-down?
   With most projectors the film or slide is simply inserted upside-down to begin with so that when the lens inverts the image, it is then right-side up.
2) When you watch a movie or look at slides, why don’t they appear reversed left-to-right?
   With most projectors the film or slide is reversed before it is put into the projector so that the image comes out correct in the end.
3) What are the most important characteristics for the image to have when you design a projector?
   The main ones are that it be large enough and bright enough for the intended audience to see clearly. It should also be free of color distortions.

ADDITIONAL ACTIVITIES FOR MORE ADVANCED STUDENTS

☐ Have students determine (not by taking them apart!) how many and what kinds of lenses are in some type of projector.
☐ Have students compare the optics of a slide projector, which gives a large image of a small object, with an overhead projector, which uses a larger object.
The slide provided in the optics kit for use in this experiment contains an example of an optical illusion. There are five different slides, one in each kit, so that in a class set of kits you should find several different illusions. A list of the illusions is at the end of this note. At some time while the students are using the slide in the experiment, you can point out to them that it contains an optical illusion and have a separate discussion about this.

There are a number of categories of illusions, including geometric (shape), distance or depth, contrast, and color. The ones on these slides are geometric illusions. There are some naturally occurring illusions, such as the apparent decrease in the size of the sun and moon as they move from near the horizon to positions overhead. Knowledge of optical illusions has many applications in such areas as art, decorating, architecture, and magic.

No attempt is made here to explain why people misinterpret what they see in these illusions. Some explanations are rather simple and straightforward, others are quite complex or unknown. If you wish more information, consult a reference such as *Visual Illusions - Their Causes, Characteristics and Applications* by M. Luckiesh (Dover Publications, Inc., 1965). As with all other parts of the optics kit, it is hoped that the inclusion of an optical illusion will stimulate interest in and generate questions about optics.

**LIST OF ILLUSIONS**

A- Unequal length of equal lines - two lines of the same length appear to have different lengths when different arrowheads are placed at their ends.

B- Curved straight lines - two lines which are straight and parallel appear to be curved, bulging away from each other in the center.

C- Converging parallel lines - two lines which are parallel appear closer together at one end than at the other.

D- Not square square - a true square appears otherwise when angled lines are drawn across it.
EXPERIMENT #7  DIFFRACTION GRATING

EQUIPMENT: Diffraction Grating, Color Filters, and a small bright light

Small, Bright Light  Red  Blue
Blue  Red

Diffraction Grating (Long side of hole should be up and down)
Your eye

CAUTION! DO NOT LOOK AT THE SUN!

SPLIT LIGHT INTO A SPECTRUM
It is possible to make light separate into a band of colors (called a SPECTRUM) by shining it through a DIFFRACTION GRATING. A diffraction grating is a rather ordinary looking piece of plastic which actually has thousands (!) of straight grooves lined up across its surface. They are too thin and close together to see even if you use one of your magnifiers. Hold the grating close to your eye and look through it at a small bright light (not the sun). If you have the grating turned so that the grooves run up and down, you should be able to see a spectrum when you look off to either side of the light source. It helps if the rest of the room is fairly dark. If you cannot find the spectrum, try turning the grating to be sure that its grooves are running up and down.
1) Write down all the colors you see in order. Try to look at some different kinds of lights, if available, such as neon lights, fluorescent lights, or streetlights.
2) Record all of the colors you see in the spectrum of each type of light source.
3) Are all of the same colors present in the spectrum of each light source?

USE COLOR FILTERS
A color filter only lets certain colors of light come through it. Put one of the color filters in front of the diffraction grating. Look through at the light source you first used in this experiment to again see the spectrum. Take the filter away and then put it back.
4) Make two lists: one of the colors which do come through the filter, and one of the colors which are blocked by the filter so that they cannot come through.
5) Make similar lists when you put each of the other color filters, one at a time, in front of the diffraction grating while looking at the light source.

HOW IS THIS USEFUL?
When materials reflect or are made to give off light, the colors present in the spectrum of that light are unique to that material. Scientists attempt to match the color pattern from an unknown material to the pattern of a known material. This process, known as SPECTROSCOPY, can be used in many ways. It can be used to find out what stars are made of without going there! It can help solve crimes by showing that material at a crime scene matches material belonging to a suspect.

©1988 Optical Society of America
EXPERIMENT #7
DIFFRACTION GRATING
NOTES ON SET-UP

If you are unfamiliar with how a diffraction grating breaks light up into colors, you might consult a high school physics book for an explanation. This information is not essential for doing this experiment. This experiment should be done in a room which is dark except for one small bright light bulb (a clear, 40 Watt showcase bulb is ideal). The invisible grooves on the diffraction grating run parallel to the short side of its frame so be sure students are holding the grating with its shorter dimension vertical. Looking through the grating as though it were a window, the color bands which students are looking for are off to the left and right of the bulb at a fairly large angle. If you look directly toward the bulb, you will not see the color bands. If you are able to obtain any other types of lights to view through the grating, be sure they have a narrow appearance (e.g., a neon or fluorescent tube should be oriented so that the tube runs vertically).

EXPECTED RESULTS

Split Light Into a Spectrum
1) On both sides of the light bulb, starting with the color closest to the bulb, the order is blue (B), green (G), yellow (Y), orange (O), red (R).
2) A fluorescent light may contain some violet before the blue. The colors seen in other sources will depend on what the sources are.
3) Different kinds of lights may have less of or be missing some colors, but whatever colors are there should stay in the same order as they were in the first light observed.

Use Color Filters
4) Red filter- removes (blocks) B, G, some part of Y; allows through R, O, some Y.
   Green filter- removes R, O, and part of B; allows through, Y, G, and some B.
   Blue filter- removes most of R, O, and Y; allows through B and G.
   Yellow filter- removes some of B; allows through R, O, Y, and G.

5) (See #4).

DISCUSSION QUESTIONS

1) Since the first light source used looks white, what must white light be made of?
   The white light must contain all of the colors which appeared in the spectrum (red, orange, yellow, green, blue). An incandescent light looks a bit yellowish because of the lack of blue. Because of the way our color vision works, we actually see white light when only red, green, and blue are present if they are in the correct proportions.

2) If you placed the red filter on top of the blue filter and looked through both together at a white light, what would you expect to see?
   You would expect to see almost nothing because the red filter blocks the blue and green from getting through and the blue filter blocks the red, orange, and yellow from getting through.
3) How could a diffraction grating be used to identify the type of light source one is observing? Different types of light sources have spectra which contain different patterns of colors. Since the diffraction grating makes the spectrum visible, one can compare the spectrum of the unknown source to previously identified spectra in order to find a match.

- Both prisms and diffraction gratings can separate white light into a spectrum. Have students find out if there is any difference between the spectra produced in these two ways.
- Students can be asked to find out how diffraction gratings are produced.
- Someone who works with spectral analysis (e.g., an astronomer, a crime lab scientist) could be invited to give a presentation.
- Ask students to examine and describe the spectra of some chemical solutions. The spectra of some colored solutions can be seen by shining a strong white light through the solutions placed in clear glass containers and then examining the light with a diffraction grating.
EXPERIMENT #8  POLARIZERS

EQUIPMENT: Two Polarizers (appear like gray plastic) and Plastic Film

Uncrossed Polarizers

Light reflected off a shiny surface

Your eye

Rotate polarizer

Crossed Polarizers

Observe here

Stretched Plastic Film

LOOK THROUGH ONE POLARIZER

Find some shiny surfaces and look at them through one of the polarizers held in front of your eye. While you continue to look through, turn the polarizer clockwise (like a steering wheel) one full turn.
1) Describe any changes in the way the surface looks as the polarizer is turned.

LOOK THROUGH TWO POLARIZERS

Place the second polarizer on top of the first one (like making a sandwich) and look through them. Turn one of the polarizers a full turn clockwise while you are looking through.
2) Describe what happens as the polarizer is turned.
Adjust the polarizers to a position where you cannot see through them. Without changing their positions, put a piece of stretchable plastic between the two sheets. While you look through the sheets, have someone pull on the ends of the plastic to make it stretch.
3) Describe what you observed.

HOW IS THIS USEFUL?
Polarizers are used in some sunglasses to cut down the light seen from reflected surfaces. They are also used by engineers studying plastic models of buildings and machine parts to discover any weaknesses in design before the real thing is built.
EXPERIMENT #8
POLARIZERS
NOTES ON SET-UP

A light wave produces "vibrations" as it travels along. A polarizer is a type of filter which only allows light to pass through if its "vibrations" are lined up with the filter in a certain way. For the polarizers in this kit the light "vibrations" must be lined up parallel to the longer dimension of the filter in order to get through. If two polarizers are aligned the same way, then all the light that gets through the first one also gets through the second one. However, if the two polarizers are aligned so that their longer dimensions are perpendicular, then none of the light that gets through the first one can get through the second one. In this alignment the polarizers are said to be crossed. The two gray plastic sheets are the polarizers. They may have come with peel-off protective paper on both sides to protect them. Be careful that their surfaces do not get scratched.

EXPECTED RESULTS

Look Through One Polarizer
1) At least for some of the surfaces observed, the amount of reflected light seen coming from the surface will vary as the polarizer is rotated because reflection polarizes some light.

Look Through Two Polarizers
2) When the two polarizers are aligned the same way (their longer sides parallel), you can see through them. As one of them is turned until their long sides are perpendicular, the amount of light seen through them gradually diminishes to approximately zero. Then the amount of light increases again as you continue to turn.

3) As the plastic is stretched, some light (perhaps in the form of bands of color) can be seen through the polarizers where no light was seen before the stretching.

DISCUSSION QUESTIONS

1) How can you use one polarizer to determine if a light you are observing is already polarized?

Light which is not polarized produces "vibrations" in all directions so no matter which way a polarizer is rotated in front of it, some of the light will come through. If the light is polarized in a certain direction, however, that light will come through when the polarizer axis is aligned with that direction and it will be blocked when the polarizer axis is turned 90 degrees from that direction. So the simple answer is: Rotate the polarizer in front of the light. If the brightness changes, the light is polarized.

2) Which direction does the long axis of the polarizer have to be aligned in order to block the most light reflected from a horizontal surface?

Since light reflected from a horizontal surface will be mostly horizontally polarized, it will be blocked when the axis of the polarizer is vertically aligned.
On a sunny day have students check outside to discover what light is naturally polarized. (Most glare-type reflections; also, the blue skylight and white clouds in the part of the sky at right angles to the sun.)

Students can investigate what happens when light passing through different thicknesses of old-style clear cellophane tape is viewed with polarizers. Place different thicknesses of tape on a clear piece of glass. Put the piece of glass between two polarizers, shine a light through from underneath, and rotate the top polarizer. Perhaps a colorful pattern or picture can be produced.
# EXPERIMENT #9 - MIRRORS

**WHAT YOU NEED:** Bendable Plastic Mirror, Large shiny metal Spoon

<table>
<thead>
<tr>
<th>Your eye</th>
<th>Your eye</th>
</tr>
</thead>
</table>

## DESCRIBE IMAGES IN CURVED MIRRORS

Hold the bendable mirror as flat as possible a foot or two in front of your face. Different curved mirrors can be formed by bending the two sides toward you or away from you or by bending the top and bottom toward you or away from you. When the edges are bent away from you, the mirror is called a CONVEX MIRROR. When the edges are bent toward you, the mirror is called a CONCAVE MIRROR. Only a very gentle curving of the surface is needed to produce many different effects. Try to keep your fingers off the mirror surface. See if you can make each of these situations and tell which way you had to bend the mirror surface.

1. Make an image of your head which is right-side up but thinner than normal. Explain how you did it.
2. Make an image of your head which is upside down. Explain how you did it.
3. Make an image of your head which has four eyes. Explain how you did it.
4. Make an image of your head which is right-side up but not as tall as normal. Explain how you did it.
5. Look at the image of a pencil point on the inside of a spoon. Move the pencil close to the spoon and then far away from the spoon. Describe what happens to the image.
6. Turn the spoon around to the outside surface. Look at the image of the pencil point again as you move the pencil close to the spoon and then far away from the spoon. Describe what happens to the image.

## WHAT IS THIS USEFUL FOR?

Mirrors can be used to form images just as lenses are. PARABOLIC (dish-shaped) mirrors can focus energy to a point (the focal point). They can focus sound to a microphone or microwaves to a TV satellite dish aerial. They can focus light and other kinds of waves from stars onto photographic film. Parabolic mirrors can also be used to send energy. Headlights in cars and flashlights have their bulbs at the focal point of a parabolic reflector which causes the light to come out in a parallel beam.
EXPERIMENT #9
MIRRORS
NOTES ON SET-UP

EXPECTED RESULTS

Other than the flexible plastic mirror in the kit, the only other equipment needed is a large shiny metal spoon for each observer. Students could perhaps bring these in from home or else do that part of the experiment at home. The mirror surface only needs a very slight curve to produce the various effects. You may find it easier to get the desired smooth curves if students hold the mirror against a 5x8 inch index card as a backing.

Describe Images on Curved Mirrors
1) A thinner, right-side up image can be formed in either of two ways--bending the left and right sides of the mirror away from you (convex shape) or bending the left and right sides of the mirror toward you (concave shape).

2) The upside-down image is formed by bending the top and bottom of the mirror toward you (concave shape).

3) The "four eye" image is a little tricky to make and can be made two ways. The bending has to be very slight. If the top and bottom of the mirror are bent toward you, you can get one set of eyes above the other; if the left and right sides of the mirror are bent toward you, you can get one set of eyes beside the other. Both methods use a concave mirror.

4) The shorter, right-side up image is made by bending the top and bottom of the mirror away from you (convex mirror).

5) When the pencil is very close to the spoon, the image is right-side up and enlarged (it is distorted, too, but we'll ignore that). When the pencil is a bit further away, the image becomes upside-down and much smaller.

6) Now there is only one type of image. No matter how close to or far from the spoon the pencil is, the image is right-side up and smaller than the pencil.

1) What kinds of images does a convex mirror form?
   The images are always right-side up. They are smaller than the object in height or width or both.

2) What kinds of images does a concave mirror form?
   When the object is close enough to the mirror, the image is right-side up and enlarged. When the object is farther from the mirror, the image is upside-down and may be either larger or smaller than the object.

3) In the first part of this experiment you were able to form a thin, right-side up image with both a convex and a concave mirror. Is there any difference between the two images?
   Yes! The image formed by the concave mirror is reversed.
left-to-right; the one formed by the convex mirror is not.

4) *Can the image formed by a mirror be projected onto a screen?*

It depends. If it is a flat mirror or a convex mirror, no; the image is virtual. If it is a concave mirror and the object is more than one focal length away from the mirror, yes; the image is real and can, therefore, be projected onto a screen.

☐ Have students see how many different situations they can find where mirrors are being used, and report on them.

☐ Have students investigate and report on one of these topics:
  - the use of mirrors in magic tricks
  - mirrors in history (see, for example, Archimedes)
  - mirrors in literature

☐ Draw a maze on paper or on an overhead transparency. Have students try to trace through the maze with a pencil or marker while looking only at the image of the maze seen in a flat mirror.

☐ If you can find large clear marbles, students can make a kaleidoscope by rolling the mylar mirror inside a paper tube. When the marble is held at one end of the tube and they look into the other end of the tube, they will see a display of color from the scene they are facing.
**EXPERIMENT #10**

**HOLOGRAMS**

**WHAT YOU NEED:** Hologram, Cardboard, Bright Light

<table>
<thead>
<tr>
<th>Bright light or the sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your eye</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hologram</th>
<th>Cardboard</th>
</tr>
</thead>
</table>

**VIEW THE HOLOGRAM**

Put the hologram on a piece of cardboard so that it is flat. Hold it so that a single bright light is shining on its surface. Tilt the hologram to different angles until you can see clearly everything which has been recorded on it.

1) What image is on the hologram?
2) What do you see happening to the image as you change the angle of the hologram a little bit?
3) How is the hologram different from an ordinary photograph or slide?

**HOW IS THIS USEFUL?**

Holograms are able to produce 3-dimensional pictures from a flat piece of film. Some holograms can show all sides of an object on one piece of film. They can be used to make very life-like images of many things. Engineers can make holograms of machine parts to test for wear and weak places. Holograms are used on some credit cards to make it difficult for counterfeiters to make fake ones.

©1988 Optical Society of America
EXPERIMENT #10  
HOLOGRAMS

NOTES ON SET-UP

The hologram in the kit is on an aluminized sheet of plastic that looks similar to but is smaller than the flexible mirror. The backing is not transparent so viewing the hologram is not like looking at a slide where light comes through from the other side. For best viewing, the hologram should be illuminated by a single bright incandescent light shining on it. Lights which are too spread out cause the image to appear fuzzy. Try tilting the hologram a little and viewing it from various angles to get the best views. Be prepared to demonstrate viewing techniques to the class.

EXPECTED RESULTS

View the Hologram
1) The hologram shows a Kennedy half dollar (both sides!).
2) The two sides of the coin are alternatively visible. Another more subtle but very significant change is that different parts of the edge of the coin are visible when viewing at different angles. This only occurs when viewing three-dimensional objects and is an example of parallax.
3) Students may come up with other answers but the most important difference is that when you look at a photograph or negative, you are seeing a flat, two-dimensional image. A hologram is more like a window through which you see an actual three-dimensional image.

DISCUSSION QUESTIONS

1) How can you tell whether an image is three-dimensional or not?
   If an image is three-dimensional, you will be able to see different parts of it when you view it from different angles. Objects in the foreground will shift across objects in the background.
2) How are holograms made?
   There are different methods but, in general, this is the technique. A laser beam is split into two beams. One beam shines on the object being holographed. After striking the object, this light is reflected (scattered) to a piece of photographic film placed nearby. The other beam of light shines directly onto the film. No focusing lenses are required. The hologram is the record of light and dark spots on the film created as the arriving light produces an interference pattern.

ADDITIONAL ACTIVITIES FOR MORE ADVANCED STUDENTS

☐ Have students find out how many different types of holograms they can discover.
☐ Have students investigate different ways in which holograms are being used commercially or experimentally.
☐ If you have the necessary equipment, there are commercially available kits which students can use to make holograms.
**EXPERIMENT #11  OPTICAL FIBERS**

**EQUIPMENT:** Optical Fiber, Small Bright Light, Magnifying Lens

![Diagram of optical fiber setup](image)

**DESCRIBE THE FIBER**

The optical fiber is made partly from glass. Try to bend the fiber (gently, not sharply) to see if it is rigid or flexible.
1) Is the fiber rigid like a piece of glass? Use a magnifying lens to look carefully at the end of the fiber.
2) Draw the appearance of the end and show the part which you think is probably the glass.

**SEND LIGHT THROUGH THE FIBER**

Put one end of the fiber near and pointed toward a small bright light.
3) Does light appear to be coming out the other end? Curve the fiber around a corner (keep one end near the light).
4) Does this affect whether light comes out the other end? Place a pencil against the end of the fiber which is pointed at the light source.
5) Can another person who is looking only at the other end of the fiber tell when the pencil is moved in and out of position? Can you send them a coded message?

**HOW IS THIS USEFUL?**

Information can be sent by light beams along optical fibers. A light sensitive microchip has been invented that can read information from the optical fiber at the rate of 9 billion tiny flashes per second. Optical fibers as thin as the one you just used can carry many telephone conversations at one time. Doctors can push optical fibers along blood vessels and look into a patient's heart. New uses of optical fibers are being reported in newspaper and magazine articles.

©1988 Optical Society of America
The optical fiber in the kit is a plastic coated glass fiber. In the experiment, it is intended that the fiber is to be used in 1 meter lengths, although the same experiments work just as well in longer fibers. In some kits, the fiber has been provided in 16 meter lengths. In these cases, you will need to cut the fiber into 1 meter lengths with a scissors.

**CAUTION: THE FIBER WILL BREAK IF IT IS BENT TOO SHARPLY. STUDENTS MUST BE REMINDED TO HANDLE AND BEND IT GENTLY!** When students are sending light through the fibers, they should be using an individual light source in an otherwise darkened room.

**EXPECTED RESULTS**

Describe the Fiber
1) The fiber is quite flexible, not rigid like glass usually is. It is still breakable, like glass, if hit or bent sharply.
2) A magnifying lens will show that the end of the fiber has a clear center (the glass core) surrounded by a not-as-clear coating (the plastic cladding).

Send Light Through the Fiber
3) Light should easily be seen coming out the other end.
4) Curving the fiber around a corner should not cause any decrease in the light coming out the end.
5) There should be a noticeable change in the glow of the far end of the fiber as the pencil covers and uncovers the end of the fiber near the light. A Morse code message could be sent. (This is a very crude method of sending messages through the fiber and is not how it is normally done.)

**DISCUSSION QUESTIONS**

1) **Can you think of any way to get light to go around corners without using an optical fiber?**
   You could position one or more mirrors so that they would reflect the light around a corner.

2) **Why does the light follow the optical fiber around a curve instead of shining out through the side?**
   The light travelling in the glass part of the fiber reflects each time it reaches the surface of the glass. This special type of reflection is known as total internal reflection. An explanation of this can be found in any good high school physics textbook. In any case, the light is reflecting (within the fiber) its way around the corner.

3) **What is the purpose of the plastic coating on the fiber?**
   The plastic acts as a protection for the glass so that its surface does not get scratched or broken. It also keeps other materials from coming in contact with the glass which might interfere with the reflection process.

**ADDITIONAL ACTIVITIES FOR MORE ADVANCED STUDENTS**

- Have students think up a model for how more than one message at a time could be sent through a fiber optic cable. Then have them investigate to find out how it is actually done.
- Have students report on how fiber optics is used in telephone systems.
- Have students investigate other examples of total internal reflection, such as prisms in binoculars or the mirror-like appearance of the underneath side of the water surface in an aquarium.