PRACTICAL APPLICATIONS OF OPTICAL LENSES: TELESCOPES & PROJECTORS

By Diane Kasparie & Mary Young
PRACTICAL APPLICATION OF
OPTICAL LENSES:
TELESCOPES & PROJECTORS

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TEACHER PAGE

CONCEPTS:

- Refraction of light through a lens.
- A convex lens is convergent, can form a real image, and is used in refracting telescopes.
- A meniscus lens is divergent, forms a virtual image, and is used in refracting telescopes.
- The difference between real and virtual images.
- The focal distance of the convex lens can be calculated by finding the image distance, using an optical bench.
- The combination of a convergent and a divergent lens in a refracting telescope will form an upright, magnified image.

DESCRIPTION OF ACTIVITY

Using prior knowledge about the basic properties of convex and concave lenses, students will be able to determine how the combination of lenses can be used to produce images using a telescope. Students will make connections about what they had learned previously about how light refracts through lenses, and determine how light bends through two lenses of a telescope.

QUALITATIVE APPLICATIONS

Students will be able to predict that, in the right combination, two (or more) lenses will affect the image produced by a telescope.

QUANTITATIVE APPLICATIONS

Students will calculate focal length of convex lenses, as well as the magnification factor of lenses.

ACTIVITY INSTRUCTIONS

MATERIALS:

- Meter stick
- Cardboard image screen
- Light source (candle, flashlight, etc.)
- Telescopes

STUDENT MATERIALS:

- Calculator
- Straight edge/ruler

Set up an optical bench with the meter stick, image screen and light source. Allow students to investigate the focal length of the convex lens in the outer housing of each telescope.

Hand out student pages. Allow students to investigate, test, and analyze the information approached in this activity.

Prior knowledge: Students should already have mastered the following concepts prior to this activity:

- The difference between convex and concave lenses.
- The properties of convergent vs. divergent lenses.
- The relationship between focal point, focal distance, image distance, object distance, and center of curvature.
- How to calculate: \[ \frac{1}{i} = \frac{1}{f} - \frac{1}{o} \] to find focal distance, image distance, or object distance.
- How to calculate: \[ m = \frac{-i}{o} \] to find magnification factor.
- How to draw accurate ray diagrams for converging and diverging lenses.
GUIDE QUESTIONS:

- How are convex lenses different from concave lenses? How are they similar?
- What kind of lens(es) do you associate with real images? Why?
- What kind of lens(es) do you associate with virtual images? Why?
- What kind of lens(es) would you expect to find in a refracting telescope?
- Can you determine the focal length of a convex lens? Concave lens?
- Can you determine the magnification factor of the lenses?

EXTENSION ACTIVITIES:

Explore refraction of light through lenses on a simulator. The following sites have simulations that will be helpful:

- [http://micro.magnet.fsu.edu/primer/java/lens/p-meniscus.html](http://micro.magnet.fsu.edu/primer/java/lens/p-meniscus.html)  
  meniscus applet

  biconvex applet

- [http://www.cyberclassrooms.net/~pschweiger/lenses.html](http://www.cyberclassrooms.net/~pschweiger/lenses.html)  
  great tutorial on optics

  lens and other physics/math applets

  good converging lens with rays applet

Below are some sites concerning other telescope construction and history of the telescope:

Telescope history
- [http://es.rice.edu/ES/humsoc/Galileo/Things/telescope.html#fn1](http://es.rice.edu/ES/humsoc/Galileo/Things/telescope.html#fn1)

how to build a telescope

how to build a simple telescope (student)
- [http://howstuffworks.lycoszone.com/question568.htm](http://howstuffworks.lycoszone.com/question568.htm)

how telescopes work (simple)
- [http://howstuffworks.lycoszone.com/telescope1.htm](http://howstuffworks.lycoszone.com/telescope1.htm)

making a telescope with old photocopier lenses
- [http://www.aaa.org/articles/copyscope/](http://www.aaa.org/articles/copyscope/)
ABOVE AND BEYOND: UNDERSTANDING TWO LENS IMAGES

Diagram of two lenses showing the relationships between object distances, image distances, and focal lengths. The diagrams illustrate the principles of lens optics, including the formation of images and the relationship between object sizes and image sizes.
INVESTIGATE:

1. Find the focal length of the two convex lenses (housed in the larger tube in each telescope). Record the numbers in the Lens Data Table below.

Set up an optics bench to find the focal length of each convergent lens. Place the light source on zero centimeters on the meter stick. Lay the tube along the meter stick and an image screen at the 100cm mark on the meter stick.

Move the tube and/or the image screen forward/back until you can find a clear image of the light source. You are free to reverse the direction of the tube as well.

Repeat the procedure for the larger tube of the second telescope.

<table>
<thead>
<tr>
<th>LENS DATA TABLE</th>
<th>Distance from image to lens</th>
<th>Distance from lens to light source</th>
<th>Distance from image to light source</th>
<th>Focal length of lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telescope B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Draw a ray diagram for each lens.
2. Determine the type of lens housed in the smaller tube of each telescope. (The two lenses in the smaller tubes
are the same.)

Look through only the smaller tube of each telescope.

Describe what you see when you look through the lenses.

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Draw a ray diagram to describe the kind of lens in the smaller tubes.

\[\text{Diagram of ray diagram.}\]

**PREDICT:**

1. Which telescope do you think will allow you to view greater distances? Explain your reasons.

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2. Which telescope will require a greater distance between the two lenses to get a clear image? Explain your
reasons.

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3. When using both lenses of the telescope, do you think the image produced will be real or virtual? Larger or
smaller? Explain.

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TEST:
Reassemble the telescopes. Look through one of the telescopes at an object on the other side of the room, approximately 10m away. Adjust the telescope image by sliding the inner tube in or out of the larger tube. Record what you see in the data table below. Use the same telescope to focus an image of something outdoors, at least 50m away. Record what you see in the data table below. Repeat with the other telescope, focusing your image on the same object in the room and the same object outdoors.

TELESCOPE DATA TABLE

<table>
<thead>
<tr>
<th></th>
<th>Can find image indoors?</th>
<th>Can find image outdoors?</th>
<th>Smaller or larger image?</th>
<th>Real or virtual image?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telescope B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ANALYZE:

1. Which lens in each telescope is convergent, the eyepiece lens or the larger lens? Divergent? Explain.

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2. Which telescope allowed you to see the object indoors at a greater magnification? Outdoor object?

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3. How would a convex lens with a longer focal length change the telescope? Explain.

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THINKING FURTHER:

1. What image would be created by a telescope made with two divergent lenses? Two convergent lenses?
2. How does the telescope compare to the microscope?
<table>
<thead>
<tr>
<th>MATERIALS LIST: TELESCOPES (2)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescoping mailing tube</td>
<td>$3.00</td>
</tr>
<tr>
<td>40mm diameter (30cm FL) biconvex lens</td>
<td>$3.25</td>
</tr>
<tr>
<td>40mm diameter (20cm FL) biconvex lens</td>
<td>$3.25</td>
</tr>
<tr>
<td>2 20mm meniscus lenses</td>
<td>$7.00 @ $3.50</td>
</tr>
<tr>
<td>Scraps of rigid cardboard</td>
<td></td>
</tr>
<tr>
<td>TOTAL COST:</td>
<td>$17.00</td>
</tr>
</tbody>
</table>

OTHER ITEMS YOU WILL NEED:
- Coping saw or similar cutting tool for cutting through the cardboard tubes
- Silicone glue or similar adhesive
- Sharp blade such as an Xacto knife or narrow utility blade
- Paint (optional)

CONSTRUCTION

1. Using the coping saw, cut the cardboard mailing tubes to the following lengths:
   a. Out of the outermost tube of the telescoping mailing tube, cut two pieces, each 20cm long.
   b. Out of the inner tube of the telescoping mailing tube, cut two pieces, each 30cm long.

2. Using the scraps of cardboard, you will fashion lens holders.
   a. For each of the two convex lenses that will be housed in the larger, outer tubes, cut two circles out of the cardboard that will fit into the end of the tube. Using your lens as a guide, cut out the center of each circle to form a narrow ring. The rings should be the same size, and the hole should be slightly smaller than the diameter of the lens.
   b. Sandwich the lens between the two rings. Fill the gap around the edges of the lens between the two cardboard rings with silicone glue. Allow to dry.
   c. Repeat the procedure for the meniscus lenses for the smaller, inner tubes. This will be the eyepiece, and the cardboard ring will not be as narrow as those for the convex lenses.

3. Assemble the telescope.
   a. Put a thin ring of silicone glue around the eyepiece lenses structures and push them into one end of the smaller tubes, leaving them close to the opening of the tube.
   b. Put a thin ring of silicone glue around the convex lens structures and push them into one end of the larger tubes. Push them in so that the lens is about .5cm from the end of the tube.
Concepts

Light travels in straight lines but will undergo a process called refraction when it passes at an angle into a different medium. When light enters a medium which has a greater optical density, it is slowed and bends towards the normal (a line drawn perpendicular to the surface).

When light enters a medium with a lesser optical density it speeds up and bends away from the normal.

Lenses are curved pieces of glass which can be concave or convex. Concave lenses cause light rays to diverge. Convex lenses cause light rays to converge to a focal point. See diagram on next page. The focal length is the distance from the center of the lens to the focal point. The optical axis is a line drawn through the center of the lens parallel to the incoming light rays. The image distance is the distance from the image to the center of the lens. The object distance is the distance from the object to the center of the lens.
A simple projector involves a convex lens or combination of lenses used to project a picture on a screen. The projector constructed in this activity uses a single convex lens, a photograph and a screen. The image of the photograph is produced by the lens on the screen through the process of reflection and refraction.
HOW THE ACTIVITY ILLUSTRATES THE CONCEPT

This activity will help students understand how a convex lens can be used in simple pieces of equipment. They should fully grasp what a real image is and how a convex lens produces a real image.

Using just the convex lens and a light source, students will first determine how to find the focal point of a convex lens and then its focal length. By comparing three lenses with different amounts of curvature, they will relate the amount of curvature to focal length.

The ray diagrams will allow students practice at drawing tangents, normals, and focal points found in a real situation.

The last part of this activity will help students partially understand the principles in constructing and using a projector with a convex lens and by selecting the lens which will produce an image clearly on a screen the maximum distance from the lens.

QUALITATIVE AND QUANTITATIVE APPLICATIONS

Qualitative Applications

Students will understand how light behaves when it passes through a convex lens.

Students will be able to draw tangents and normals to determine the refraction of light through a convex lens.

Students will use a convex lens to produce a real image on a screen.

Quantitative Applications

Students will measure the image distance, object distance and focal length.

Students will compare the focal lengths of three convex lens and compare this to their amount of curvature.

Students will use the convex lens in a simple projector to produce a real image and measure the image distance and object distance in the projector.
PROCEDURE/ACTIVITY INSTRUCTIONS

To perform the measurement of focal length, you will need:

- Candles
- Convex lenses
- White index cards
- Meter sticks
- Molding clay

The projector, the lenses and the meter stick are all that is required for the second part of the activity.

Review key concepts before starting the activity:

- Refraction
- Convex lens
- Tangent
- Normal
- Ray diagram
- Focal length
INVESTIGATE:

1. Find the focal length of the three convex lenses used in the projector apparatus. Record the numbers in the Lens Data Table below.

Set up an optics bench to find the focal length of each convex lens. Place the light source on zero centimeters on the meter stick. Start the lens at the 50 cm mark and focus the image on the screen at the 100 cm mark.

Move the lens and/or the image screen forward/back until you can find a clear image of the light source.

LENS DATA TABLE

<table>
<thead>
<tr>
<th>Distance from image to lens</th>
<th>Distance from lens to light source</th>
<th>Distance from image to light source</th>
<th>Focal length of lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most convex lens #1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle convex lens #2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least convex lens #3</td>
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<td></td>
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</tr>
</tbody>
</table>

Draw a ray diagram for each lens.
PREDICT:

1. Which lens has the longest focal length? The shortest focal length? Which do you think would produce a clear image the farthest from the lens?

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2. Do you think there is a relationship between the focal length of a lens to the position of the image on the projector screen?

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3. Describe the position of the photograph inside the projector.

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TEST:

2. Put the most convex lens in the lens holder. Make sure the photograph is upside down on the holder inside the box. Turn the lights on and close the flaps of the box. Aim the projector at the screen and adjust the photograph inside the box with the dowel. Start with the screen about 30 cm from the lens and adjust accordingly.

Describe how the image on the screen compares to the photograph inside the projector.

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_____________________________________________________________________________________________
_____________________________________________________________________________________________

DATA TABLE

<table>
<thead>
<tr>
<th></th>
<th>Distance of photograph to lens</th>
<th>Distance of image from lens</th>
<th>Focal length of lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most convex lens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle convex lens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least convex lens</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Draw a ray diagram to show how the photograph appears on the screen.

ANALYZE:

1. Which lens produces the clearest image the farthest from the lens? Explain.

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2. Is there a relationship between focal length and the distance of the image from the lens? Explain.

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3. Is the image on the screen larger or smaller than the figure in the photograph? What does this suggest about the construction of a commercial projector?

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THINKING FURTHER:

1. What image would be produced using 2 convex lenses?
2. What other instruments use convex lenses?
### Materials for Projector Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dowel Rod</td>
<td>$0.49</td>
</tr>
<tr>
<td>2 Light Sockets</td>
<td>2 x $1.59 = $3.18</td>
</tr>
<tr>
<td>2 Light Bulbs</td>
<td>2 x $0.77 = $1.54</td>
</tr>
<tr>
<td>Light Cord</td>
<td>$2.87</td>
</tr>
<tr>
<td>14 gauge wire</td>
<td>$1.99</td>
</tr>
<tr>
<td>White spray paint</td>
<td>$1.99</td>
</tr>
<tr>
<td>Poster Board</td>
<td>$0.99</td>
</tr>
<tr>
<td>Bi-Convex Lens</td>
<td>$2.35</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$15.40</strong></td>
</tr>
</tbody>
</table>

### Simple Projector Construction

1. Gather the following materials: cardboard box at least 60 cm long and 25 cm wide, 2 light sockets, 14 gauge wire, light cord, white spray paint, bi-convex lenses, two 40 watt bulbs, small dowel rod and one sheet of thick white poster board.

2. Spray paint the inside of the box white. Let dry.

3. Connect the two light sockets with 14 gauge wire in parallel with the light cord. Be sure to make a small opening in the side of the box for the light cord to pass through. Glue the light sockets in the front corners of the box.

4. Cut a hole in the center of the end of the box between the light sockets just smaller than the lenses to be used.

5. Glue a small box (focus chamber) around the hole for the lens so that the light is reflected from the back of the box.

6. Construct a lens holder for the front of the box so that more than one lens may be tested in the device. This device was cut from a piece of thick poster board with small dowels glued to the bottom and sides. This piece was then glued to the front of the box around the hole for the lens.

7. Construct a holder for the photograph for the inside of the box. This device was constructed from two piece of thick poster board glued at right angles to form a base and upright to attach the photograph. Attach a dowel to the back of the holder which projects through a hole in the back of the box. This allows the photograph holder to be moved back and forth.
8. Use a piece of white construction paper for the screen.