Simple Lenses and Telescope Design

Introduction

In this activity you will learn about the geometric properties of simple lenses and construct a simple telescope.

Objectives

After completing this activity students will be able to:

- Describe how object distance affects the location of the image formed by a simple double convex lens.
- Describe how the radius of curvature of a lens affects the properties of the image.
- Describe how telescopes aperture and focal length affect the properties of light gathering ability, angular resolution, magnification, and field of view.
- Select a personal telescope based on how they intend to use the telescope, for example viewing planets or view star clusters and nebulae.

Directions

PART A: Geometric Properties of Simple Lenses

In part of the activity you will use PhET Interactive Simulations from the University of Colorado Boulder titled *Geometric Optics* to investigate image formation and properties of simple lenses. Open the following link to get started https://phet.colorado.edu/en/simulation/legacy/geometric-optics . If that does not work google PhET, click on Physics and scroll down the list and click on Geometric Optics.

At the top of the simulation window you will see a green box that allows you to investigate the basic optical properties of lenses. Click on each box, or slide each bar, to learn how to manipulate the simulation. The two x's are located at the lens focal point. The focal point is the location where parallel light rays from a very distant location such as a star are brought to a focus.

Image Formation

Use the simulation to answer the following questions. Set the number of rays to be either marginal or many depending on what you like.

1. How does the image change when the object is moved farther away from the lens?

2. How does the image change when the object gets closer to the lens?

3. When the object is placed at the x representing the lens focal point where is the image formed?

4. When the object is placed between the focal point and the lens what happens to the image? Hint: click on virtual image.

5. Use the slide switch to increase and the diameter of the lens and describe what happens to the image as the lens diameter in increased.

6. What happens to the image when the lens diameter is deceased?

7. Use the slide switch to adjust the curvature (thickness) of the lens. As the lens gets thinner what happens to the image?

8. As the lens gets thinner what happens to the position of the focal points?

9. Why do you think astronomers build large diameter telescopes?

PART B: Properties of Telescopes

In part of the activity you will use a virtual telescope simulator. Open the simulator using the link http://astro.unl.edu/classaction/animations/telescopes/telescope10.html . After the simulator opens you may need to use the slide bar at the top center to focus the image.

Light Gathering Power (LGP)

As you may know a large bucket catches more rain than a smaller bucket. Telescopes can be thought of light buckets and so a larger diameter telescope catches more light than a smaller diameter telescope.

1. Start with the 8-inch diameter (aperture) telescope using a 40mm eyepiece and record the number of light rays entering the telescope and the LGP. Repeat for both the 6-inch and the 4-inch telescopes.

   Table I: Light gathering ability of simulated telescopes.

Telescope	8-inch	6-inch	4-inch
Number of rays			
LGP			

2. Describe how the light gathering ability of these telescope change as the aperture decreases.

3. Again, start with the 8-inch telescope and describe how the brightness of the image changes as the telescope aperture gets smaller.

Angular Resolution

Angular resolution refers to how clearly a telescope will show tiny details such as planetary features and stars that are very close together.

Starting with the 8-inch telescope record the angular resolution in arc seconds and record the results in Table II below.

Table II: Angular resolution of the simulated telescopes.

Telescope	8-inch	6-inch	4-inh
Arc-sec			

4. Starting with the 8-inch telescope using a 40mm eyepiece, describe how the clarity of detail visible and the magnification of the image change as you switch to the 6-inch and then the 4-inch telescopes. You may find it helpful to switch to viewing either Saturn or the star cluster.

5. Which telescope allows you to see the smallest details in its image?

Image Magnification

The magnification of a telescope depends on the focal length of the objective lens, or mirror, and the focal length of the eyepiece being used to view the image. The magnification of a telescope is calculated using the equation **Magnification = Fo/Fe** where Fo = the focal length f the objective lens and Fe = the focal length of the eyepiece.

6. Starting with the 8-inch telescope and the 40mm eyepiece record the magnification for each of the telescope and eyepiece combinations listed in Table III below.

Table III: List of magnifications for the telescopes in the simulation.

Telescope	Eyepiece focal length (mm)	8-inch	6-inch	4-inch
Magnification	40			
	20			
	10			

7. Which of these telescope and eyepiece combinations provides the highest and lowest magnifications?
   a. Highest:
   b. Lowest:

8. View the Moon and Saturn with each telescope and eyepiece combination and decide which telescope provides the best viewing image of planetary detail.

   Using the information previously learned about light gathering ability, angular resolution, and magnification justify your selection for the best planetary telescope.

Angular Field of View

Every telescope and eyepiece combination has a field of view. This basically means that some combinations provide the ability to see the entire moon or only a piece of the moon. The field of view tells you how much of the sky is viewable in the telescope. Usually the field of view is expressed as an angle such as degrees.

9. Starting with the 8-inch telescope and the 40mm eyepiece record the field of view for each of the telescope and eyepiece combinations listed in Table IV below.

Table IV: Field of view for the telescopes and eyepieces in the simulation.

Telescope	Eyepiece focal length (mm)	8-inch	6-inch	4-inch
Field of View (degrees)	40			
	20			
	10			

10. Which of these telescope and eyepiece combinations provides the widest and smallest field of view?

a. widest:

b. smallest:

11. View the Moon and the star cluster with each telescope and eyepiece combination to confirm which telescope provides the widest and smallest field of view. Don't forget to focus the telescope as needed.

12. Using the information in Tables III and IV describe how magnification affects the field of view.

Construction of a Simple Telescope

In the part of the lab you will build a simple refracting telescope similar to the one shown in Figure 1 below.

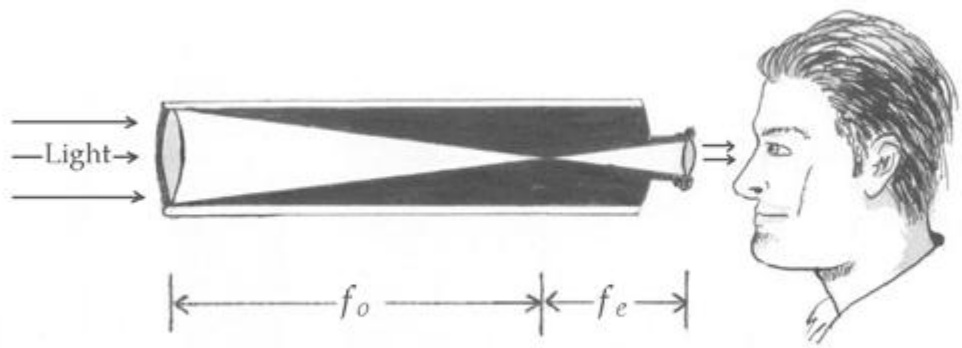

Figure 1: Optical design of a simple telescope.

Telescope Construction

Project Star produced the telescope you will build. Use the directions supplied by Project Star to construct this telescope.

Measuring the Telescope Properties

The three most important properties of a telescope include its angular resolution, light gathering ability, and its magnification.

Angular Resolution

A telescope's angular resolution is its ability to see tiny angles. The smaller the angle that a telescope can clearly resolve the smaller the details it can show the observer. Before Galileo used a telescope on the Moon the human eye could not resolve craters on the moon because the eye's diameter does not give it enough resolving power. The larger diameter objective of a telescope improves the angular resolution visible. Therefore, when Galileo first pointed a telescope at the moon he became the first person to resolve lunar craters. Usually, the resolution is expressed as an angle in arc seconds. For most optical telescopes the angular resolution can be calculated using

angular resolution = 11.6/D, where D is the telescope's aperture in centimeters.

Measure the diameter of your telescopes objective lens in cm. You should exclude the outer edge covered by the cardboard ring. Use this diameter and calculate the telescope's angular resolution. Show your work.

D = ____________ cm angular resolution = ____________ arc seconds.

Light Gathering Ability

Calculate the surface area of your telescope's objective lens using your previous value for D. Show your work.

telescope surface area = $\pi(D/2)^2$ where $\pi = 3.14$ and D = telescope's aperture in cm.

Surface area of telescope = _______________ cm^2.

When fully dilated the human eye has an average diameter of 8 mm. Calculate the surface area of a dilated human eye. Show your work.

Surface area of a human eye = ____________ cm^2.

Your telescope's larger diameter objective allows it to see fainter stars than your smaller diameter eye. By comparing the surface area of your telescope to that of the average human eye the light gathering power of your telescope can be estimated. Calculate the ratio of the telescopes surface area to that of the average human eye. Show your work.

How many times fainter can this telescope see than can be seen by the unaided eye?

Magnification

Magnification is simply the ratio of the telescope's focal length, fo, to the eyepiece's focal length, fe and can be written as magnification = fo/ fe , where fo and fe must be expressed in the same units. Notice that magnification is a ratio and therefore has no units. However, the symbol X is sometimes used to indicate how many times the object is enlarged. An example would be 10X for a magnification of 10 times. The focal length of your telescope's objective lens, fo, is about 45mm and the eyepiece focal length, fe, is about 3.5mm. Calculate your telescope's magnification. Show your work.

Mag. = ____________X

QUESTIONS

1. What are the two main differences between a telescopes objective lens and its eyepiece lens?

2. Look through your telescope and determine if the image is right side up or upside down?

3. In the space below make a sketch of the optical path of your telescope that shows why the image is right side up or upside down as stated in your answer to question 2.