

## Geometric Optics



**Objective:** To study the basics of geometric optics and to observe the function of some simple and compound optical devices.

**Apparatus:** Pasco optical bench, mounted lenses ( $f = A, B, D$  unknown focal lengths), concave/convex mirror, mounted half-circle screen, cylindrical convex lens, cylindrical concave lens, cylindrical concave/convex mirror, projection screen and paper, light source and powers supply, meter stick, ruler

### Introduction

Optical instruments serve many functions. They can enlarge or magnify as in microscopes, making visible extremely small objects. Or, as in telescopes they can collect and concentrate light from very faint and distant objects. Or, they are used to form images that can be recorded as in photographic and video cameras.

Optical elements depend on changing the direction of rays, by refraction (glass or plastic) or by reflection (mirrors). Some compound instruments combine both types. In geometric optics there is always an object (target) and an image. For reflective elements, the observer is on the same side as the object. On the other hand, light must pass through a refractive element; thus, the observer must be on the opposite side.

**Geometric optics uses light rays to calculate and analyze images. The true electromagnetic wave nature of light is ignored at first although the ultimate performance of the optical instrument is limited by the wave nature of light.**

### Theory

Since you have covered much of the theory in your lecture course, below we summarize some important equations that you will need in this lab:

$$f = -\frac{1}{2}R$$

The focal length of a convex mirror as it relates to its radius

$$f = \frac{1}{2}R$$

The focal length of a concave mirror as it relates to its radius

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Magnification is defined either as the ratio of the image and object heights, or as negative ratio of the image and object distances. **It is highly dependent on lens positions and is not fixed for lenses that can change in position.** Note that the magnification can either positive or negative; positive magnifications result in upright images and negative magnifications result in inverted images. The image distance can also be positive or negative, depending on whether it is real (can be projected onto a screen) or virtual (cannot be projected onto a screen), respectively.

$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$  This is the **Thin Lens Equation**. The sum of the reciprocal of the object and image distances equals the reciprocal of the focal length. This approximation assumes that the idealized lens or mirror has negligible width. All distances are therefore measured from the *center* of the actual lens or mirror. Note that the focal length can either be positive or negative depending on the lens being convex or concave, respectively. You should use the following sign convention:

$f$  is + for a converging lens

$f$  is – for a diverging lens

$d_o$  is + if the object is to the left of the lens (real object), as is usual

$d_o$  is – if the object is to the right of the lens (virtual object)

$d_i$  is + for an image (real) formed to the right of the lens by a real object

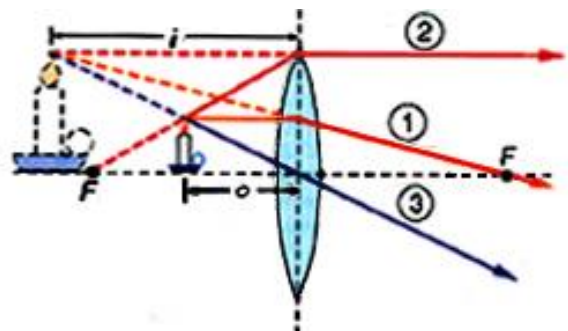
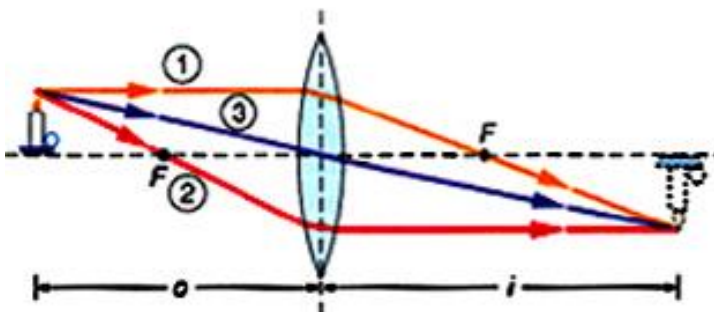
$d_i$  is – for an image (virtual) formed to the left of the lens by a real object

$m$  is + for an image that is upright with respect to the object

$m$  is – for an image that is inverted with respect to the object

For a mirror, treat the reflected image as appearing to the “right” of the “lens” for an object on the left.

The image produced by a convex lens, which always converges light rays, doesn't always produce a real image. The distance of the object from the lens can determine the sign of the distance of the image from the lens, and hence whether it is real or virtual. See ray tracing examples below, using the same object and lens (focal lengths), but for two different object distances (the dotted candle is the image):



## The Optical Bench

See the figure in the title graphic. The bench is a ruled track on which groove exists that allow mounted lenses/mirrors/screens/light sources to move on. Note that if you look at the profile of each mounted lens/mirror element, the position of the element **center** is denoted by a triangular notch that, when placed on the bench, indicates its position on it (in cm). By noting the positions of the light source (see arrow marking on the light source for the position of the “object”), one can easily determine the distances between the lens/mirror elements and the object (light source) and image (screen). See below:

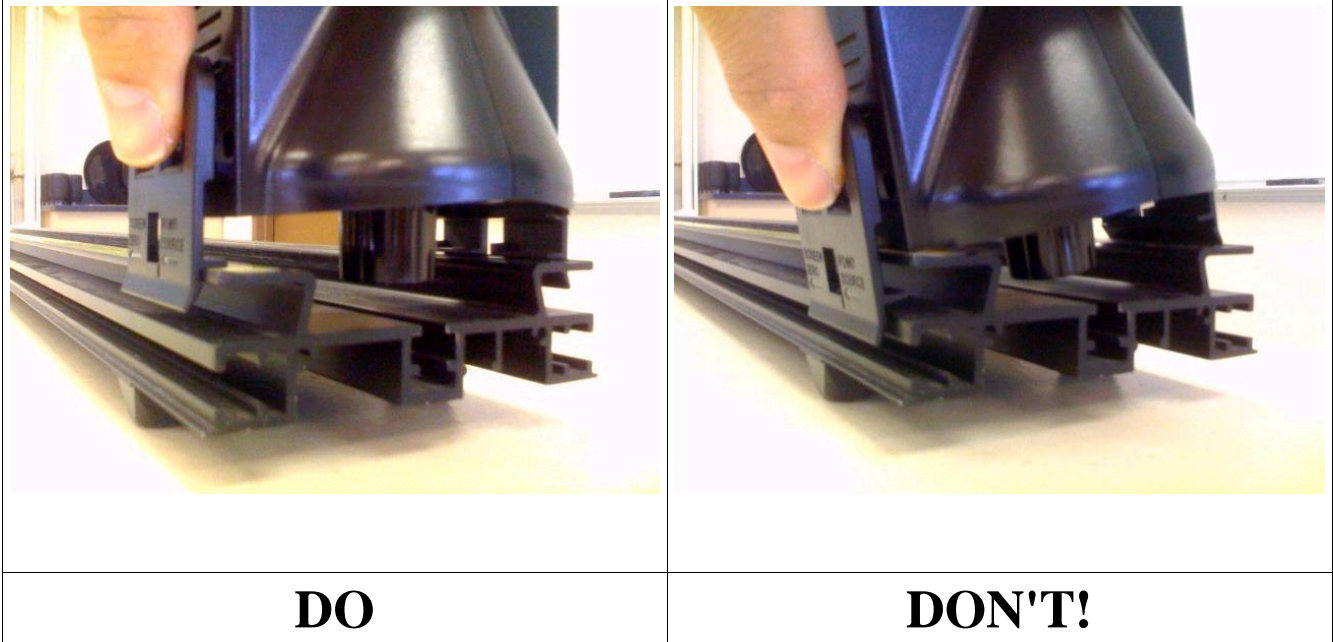


Here the thumb is right next to the triangular notch. Notice that the when the thumb squeezes the flexible arm, the mounted device can be easily slid along the bench; when it is released it stays in place:



See the graphic of the light source below. **IMPORTANT: IT IS EASY TO DAMAGE THE LIGHT SOURCE IF YOU ARE NOT CAREFUL. YOU MUST FIRST DEPRESS THE SPRING-LOADED CLAMP ON ITS SIDE BEFORE YOU ATTACH OR DETACH IT FROM THE OPTICAL BENCH.**

**DO NOT ATTEMPT TO SLIDE ITS GROOVE ONTO ANY RAIL ON THE BENCH; IT SHOULD JUST SNAP ON OR OFF FROM THE TOP WHEN THE CLAMP IS DEPRESSED. SEE BELOW:**



In the graphic below, you can see the AC power cord attached on the right – this has to be plugged in for the bulb inside to light up, since there is no power switch on the unit. **Make sure you unplug this when you are done with your experiment.** The graphic shows the light source standing up, with the perpendicular arrows pattern facing the screen – this will serve as your “object”. Distances will be measured to/from the plane of this pattern, and the object height is simply its height.



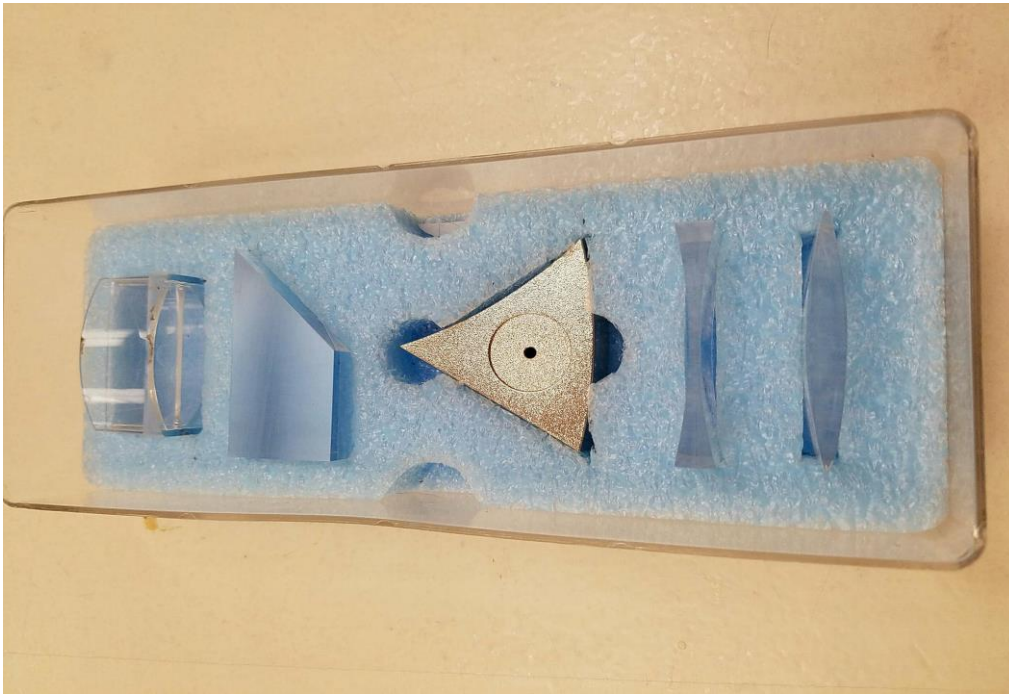


When the light source is lying down, with the circular part facing the screen, the source now emits lines of monochromatic or red-green-blue light. You can select the pattern by turning the knob in the middle of the circular part. For this lab we will use the 5-line pattern, which emits five parallel beams of light.

## Procedure

As usual, record all your data, observations and answers to questions in your Google Sheets lab report, shared with your lab partners, TA and LA.

### A. Cylindrical lenses and mirror (33 pts)



1. Set up the light source so that it is plugged in and lying down on the table (not on the bench), with the 5-line pattern selected so that it projects five beams of light. Place the cylindrical convex lens, standing up on the table, in front of it so that the middle beam goes right through the center of the lens (the beams should be perpendicular to the length of the flattened lens). **Which beams are deviated? Which beams are not deviated?** The five beams (simulating a very distant light source – see what happens in the thin lens equation if the object distance goes to infinity) should meet at the **focus**. The distance from the focus to the center of the lens is the focal length  $f$ . **What is the focal length of this lens?** (2 + 2 + 6 = 10 pts total)
2. Repeat the above, this time for the cylindrical concave lens. **Which beams are deviated? Which beams are not deviated?** (2 + 2 + 6 free pts = 10 pts total)
3. Repeat again, this time for the cylindrical concave mirror. **Which beams are deviated? Which beams are not deviated?** Noting the point where the light rays converge from the mirror and measuring to from the appropriate spot, **what is the focal length of this mirror**, again using the approximation that the object distance is infinite (because the incoming light rays are parallel)? **What is its radius?** (2 + 2 + 6 + 3 pts = 13 pts total)

#### B. Mounted lenses and mirror (47 pts)

**Do not use the cylindrical lenses/mirror (in the box) in this part; use the mounted ones.**

The setup for lenses will have the light source (object “target”) pointing toward the rectangular screen, with mounted lenses between them. The light source stays put (usually at position 0 cm), while the lenses and screen moved about until the image on the screen is sharpest (it is at the lens' **focus**). The object and image distance measurements are then taken.

For the mirror, the half-circle screen is placed *between* the light source and mirror because the mirror only reflects light (cannot transmit it) towards the half-circle screen, which is capable of both transmitting light and blocking (reflecting) it.

1. Place the A lens between the light source and rectangular screen and find two object distances where the image is sharp. Take note of the object and image distances and use the thin-lens equation to calculate the focal length and magnification each time. **Average the two f values and record them in your lab report. Why should you NOT average the two m values?** (6 + 4 pts = 10 pts)
2. **Repeat the measurements for the B lens for two object positions and obtain the f and m values.** (6 pts)
3. For one of the in-focus arrangements above, place the half-circle screen directly in front of the lens (to the left or to the right of it). **Do you cut off half the image? If not, explain why (the ray tracing diagram earlier may give a clue).** (2 + 4 = 6 pts)
4. Now you will measure the focal length of the D lens, which is concave. **Again, use the mounted lenses, not the cylindrical ones.** You cannot measure this directly since the light rays passing through this lens diverge and do not project onto a screen (virtual image). However, you can measure the focal length indirectly with the aid of a convex lens – you will use the image produced by the convex lens as the object of the concave lens, as follows:
  - a. Place the light source at 0 cm and the rectangular screen at 40 cm. Put the A lens in between them and position it such that you get a sharp image. Note object and image distances.
  - b. Now place the concave lens halfway between the A lens and screen. The image will now be blurry. Move the screen away from the lenses until it is again sharp. Note the new positions. Remember that the **image is virtual if the image distance is negative.**
  - c. **You can now solve for the focal length of the concave lens**, since you can measure its distance to the (real) image it produces as well as its distance to the “object” that produces it (the image from the convex lens). **Include 2 pictures of your setup – one with just the convex lens, and one with just the concave lens, and show your calculations for each.** (15 pts)
5. Determine the focal length of the mounted concave mirror using the half-circle screen, by averaging focal lengths calculated from two object distances. (10 pts)

### C. Building compound optical devices – Telescope, Microscope (20 pts)

The purpose of both these devices is to produce a magnified, virtual image for your eye; the telescope magnifies distant object while the microscope magnifies near ones. In either case, the image produced needs to be virtual because the eye itself has a convex lens that converges light rays onto the retina. Remember that although a concave lens always produces a virtual image, a convex lens can also do the same depending on where the object is placed.

Here you will use two lenses (A, B) for both telescope and microscope. One of them will be right next to your eye (the eyepiece) and the other one farther away (the objective).

If you use eyeglasses and have trouble getting a focused image looking through your microscope/telescope, try removing them.

1. Hold both lenses in your two hands and put one up to your eye to experiment (the other farther away), then switch lenses – **which one is the eyepiece for a telescope? Which one is the eyepiece for a microscope?** (4 pts)
2. Remove everything from the optical bench except the rectangular screen and place the two lenses on it, in the configuration for a telescope pointed at the screen. Print out “grid.pdf” which is a file in the same folder as this write-up. Tape the printed grid pattern to the rectangular screen. Move the lenses so that the grid pattern appears bigger through the telescope compared to our naked eye – it might be easiest if you open both eyes while using one eye next to the eyepiece. You may find it useful to just keep one eye open in the beginning – the one looking through the lenses; once you have identified the squares, open your other eye and try to “see” both in your mind. **Keep your viewing eye close to the eyepiece lens and keep the grid pattern on the optical bench.** Compare the height of the object (size of grid squares) through the telescope to that observed with the naked eye and *estimate* the magnification of your telescope *at the lens positions where the image appears sharp*. If the magnified squares look twice as tall as the unmagnified ones, then the magnification of the telescope is 2 (linear magnification, not areal). **In your report, draw 2 pictures – one as seen by the naked eye, one with the lens-aided eye. What is the magnification?** (6 pts)

You can also take the mounted lenses off the optical bench and aim them (one near your eye, the other farther away from it) at objects around the room.

3. Replace the A lens in your telescope with the D lens and describe what happens to the *orientation* of your image. Note that you have now constructed a **Galilean** telescope, whereas you previously built a **Keplerian** telescope. **Can you explain why the Galilean one is useful viewing objects on the earth, while the Keplerian one is not as useful?** (4 pts)
4. Do the same (but do not swap the A lens for the D lens) for the microscope (but bring your object closer), by positioning the lenses such that the image appears larger than the naked eye's and estimate its *m at the lens positions where the image appears sharp*. You can also take the mounted lenses off the optical bench and aim them (one near your eye, the other farther away from it) at **nearby** objects. In the hand-in sheet, draw 2 pictures – one seen by the naked eye, one with the lens-aided eye. **In your report, draw 2 pictures – one as seen by the naked eye, one with the lens-aided eye. What is the magnification?** (6 pts)