Experiment #2: Image Formation, Thin Lenses and Mirrors

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1   Purpose

You will be investigating virtual and real images from thin lenses and mirrors. In the process you will be able to verify the thin lens/ mirror equation

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \tag{1}$$

2   Safety and Protocol

There aren't any lasers for this lab so safety is much less of a problem. In fact you will often have your head "down".

Hold lenses and mirrors by their edges to avoid getting fingerprints on them. Don't drop them or leave them in places where they are likely to fall.

3   Preparation/General Instructions

To prepare for this lab, you should read the corresponding sections in your textbook (pages 22-25, 27-32,35-37 in Pedrotti[3]). The important points will include the thin lens formula, aspects of image formation, and using ray diagrams. Don't worry so much about aberrations right now or how a "thick lens" is different from a thin lens.

Often times you quote distances and lengths of "infinity" when dealing with images. This simply means that the quoted length is much larger than other length/distances in the problem. Don't try typing ∞ into your calculator!

The primary thing to keep in mind for this lab is the difference between virtual images ($s' < 0$) and real images ($s' > 0$). The most common example of a virtual image is when you look at yourself in the mirror. There is not another "you" and the location where the other "you" appears to be is completely empty. The light rays from the "real" you have been redirected by the mirror to appear as though they are coming from your image. Also if you wear glasses you aren't actually looking at the "real" world! The (defective) optical system of your eye is looking at a virtual image of the world.

So as an example the optical prescription for my left eye is -5.00 diopters. The focal length in metres is simply the reciprocal $f = -0.2$ m. So suppose I look at a star at night $s = \infty$. [1] Solving equation 1 gives $s' = f = -20$ cm. The negative sign indicates a virtual image and it is only 20 cm away! And my unaided myopic eye *can* focus on things (objects or images) that are only 20 cm away; my vision has been corrected.

The bundles of rays for a virtual image points are typically spreading outward. Extending them backward (to the $s' < 0$ region) allows you to locate the image point.

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[1]This just means the rays from the object are parallel rather than spreading out as they would from a nearby object.

Real images are different. You will have $s' > 0$ and the bundle of rays from the object point pass through the optical system and then reconverge. If you put a white screen at this point then the scattered rays mimic the pattern of the original object. Even without a screen the real image is "there". If you put your eye "there" you don't see the object any more than you would by putting your eye "at" the object. You need to put your eye somewhere where it can capture rays speading out from the real image (roughly in-line with the optical axis and at position past s').

4 Procedure/Analysis

4.1 The parallax method and image formation in a plane mirror

1. Place a plane mirror roughly in the middle of an optical table so that is lines up with one of the sets of mounting holes.

2. Place a 1/2" optical rod in front of the mirror. Screw it into the bench using a 1/4"-20 set screw. This is your object.

3. Take another longer piece of rod (or perhaps two screwed together) and place them in a mount with a flat bottom. Place the mount behind the mirror. You should be able to see the rod extending above the mirror. You will be placing this rod in the same position as the virtual image.

4. It is fairly easy to just "line-up" the long rod and the virtual image if you pick just one viewing angle, but all that guarantees is that your eye, the image, and the long rod are in a line. It doesn't mean that the image and the long rod are in the same place. You need a second viewing angle and "line". The only way that the image and long rod could be lined up for both viewers was if the long rod and image were at the same horizontal position.[2]

5. Rather than trying to be in two places at once you instead look at the *parallax*. The parallax is the apparent shift in position of objects at different distances as you change the viewing angle. See Figure 1 If you know the change in viewing position, the distance of one object (or a distant background), and the angular shift in position you can determine the distance to other object.[3]

6. Ironically after introducing the parallax you actually want move the long rod to a position where you *eliminate* the parallax. Move it around behind the mirror until you get something like Figure 2.

7. Once you have eliminated the parallax step to the side of the mirror. and look at the object rod and the long rod. What conclusions can you draw about s and s'? What would f be to be consistent with equation 1? Quickly verify using a ruler to measure the positions. You might even be able to determine whether or not reflection occurs at the back or front of the mirror.

4.2 Focal length of a convex mirror

1. Use a vertical pin, which should be well illuminated, as the object, placed near the convex mirror. A virtual image will be formed behind the mirror.

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[2]They are of course offest vertically or you wouldn't be able to see the long rod. It would be blocked by the mirror.

[3]The astronomical unit of distance *parsec* refers to a shift of viewing angle of 1 second of arc when you move your viewpoint by the radius of the earth's orbit around the sun.
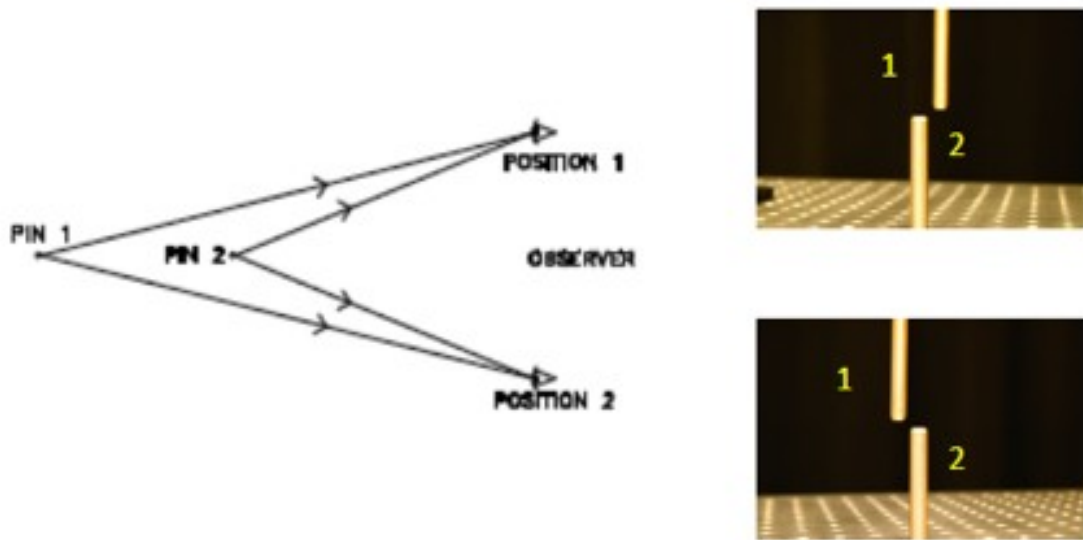
Figure 1: Parallax. When pin 1 and pin 2 are different distances away from an observer they appear to interchange left and right positions as you change viewing position.
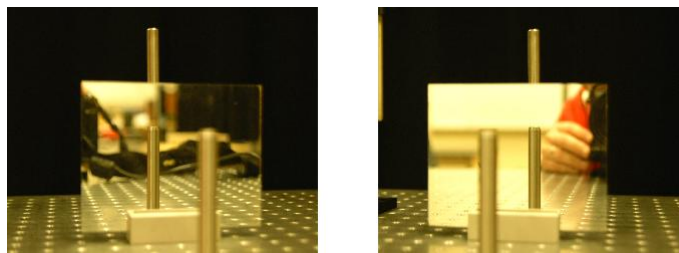

Figure 2: I have moved a camera to two different viewing angles but the long rod and the image are still in line vertically; the parallax has been eliminated. The object does show a parallax. Why?

2. Use a second pin as an image marker. Place it behind the mirror so that while viewing the image you can also see the top of the image marker above the mirror. Eliminate the parallax by placing the image marker at the position where the image appears to be.

3. Measure the distance from the mirror to the image marker to find s'. Measure s. Remember that all distances are measured from the vertex of the reflecting surface of the mirror.

4. Calculate a focal length using equation 1. What is its sign?

5. Repeat for several object distances and use a straight line plot to verify equation 1. Give a refined value of f with an uncertainty.

6. Draw a ray diagram of this arrangement for an extended real object transverse to the principal axis.

7. Is it possible to obtain a real image for some object distance for a convex mirror?

4.3   Focal length of a concave mirror

A concave mirror has a postive f. Provided that $s > f$ there is an $s' > 0$ solution to equation 1. Let's investigate this.

1. Place an luminous object in front of the mirror so that $s > f$. Place it slightly above the optical axis.

2. A real image should be formed at s' and slightly below the optical axis. Move a half screen until you see a sharp image of the object is formed.

3. Measure the object and image distances for several cases.

4. You should also put a distant source (e.g., lamp) far away (5 m) from the concave mirror. This is essentially infinity for the length scales of this experiment. You can now get the focal length essentially in one measurement. Why?

5. Combine your results to give the focal length of the concave mirror.

4.4   Bi-convex lens

Determine the focal length of a bi-convex lenses.

1. Include at least two parallax "virtual" image measurements, three real image measurements, and an infinity measurement.

2. In this experiment, each lens has the actual focal length written on it, so you should relate your measured value with the actual value.

3. During one of your real image measurements block half of the lens. What happens to the image? Why? Illustrate with a ray diagram that is roughly to scale.