Physics 123, Fall 2012 Name ________________________________

Geometric Optics Lab Exercises

You are provided with: laser (with diffuser), ray table, smoke lens set, optical bench, converging lenses, variable aperture, white light source. In addition, there are several ray boxes and mirrors to be shared among lab groups.

I. Reflection and Refraction

1. Set up the laser and ray table, with ray platform oriented so that low end of table is facing the laser. Attach the diffuser to the laser with Scotch tape. The diffuser should cause the laser beam to be dispersed along a vertical line (this makes it easier to see the interaction of the beam with the lens).

The ray table should be placed with the grid facing down. Place the rectangular lens on the ray table, with the (long) surface toward the laser. The surface should be aligned with the central hole, perpendicular to the line marked normal (passing through the 0 degree mark). Is there any reflection from the surface of the lens? Try rotating the lens slightly before answering.

2. Now rotate the table through 360° and observe the behavior of the rays which travel through the block.

Measure the index of refraction of the block. (Hint: Try to orient the refracted ray with one of the lines which extends across the ray table. Then look at the angle of the incident ray.) Make a sketch and show your calculation.

3.(a) Explore the behavior of the rays in a prism as you rotate it through 360 degrees. Notice that the beam is not always refracted at each surface; rather the beam is sometimes only reflected. This phenomenon is called total internal reflection. Sketch a configuration where there is total internal reflection from one surface.

(b) Can you see total internal reflection in the rectangular lens? If so, sketch an example.

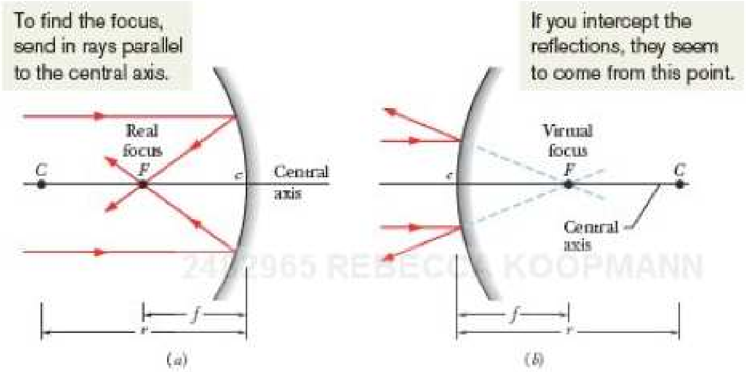
(c) A fiber-optic tube takes advantage of the phenonmenon of total internal reflection. Use your laser to examine how the rays are reflected in a fiber-optic tube. Sketch your observations.

II. Curved Mirror Exercises

Curved mirrors are extremely useful in optical systems like telescopes, since they can be used to collect light and focus the rays to form an image of an object. You will be experimenting with cylindrical and spherical mirrors. Cylindrical mirrors are shaped like sections from the curved surface of a cylinder. Spherical mirrors have shapes like pieces of a sphere. Light can be reflected from either side of the mirror. When light is reflected from the inner curved surface, the mirror is called concave, while if light is reflected from the outer surface, the mirror is called convex.

Please be extremely careful not to touch the mirror and lens surfaces - always grasp the optical component by the edges.

1. You will need to use one of the ray box stations with a cylindrical mirror section for this part. Use the ray box set up to examine the reflection of incident parallel rays in both the concave and convex orientations. Sketch the rays and the location of the mirror in the spaces below. Use these sketches to determine the focal lengths. For the convex orientation, the focal point is called a 'virtual focus' and is located on the side of the mirror opposite the light source. It is found by imagining that the diverging reflected rays are extended to the opposite side of the mirror, as in the figure. To indicate that a focal point is virtual, it is given as a negative quantity.


To find the focus, send in rays parallel to the central axis.

If you intercept the reflections, they seem to come from this point.

Fig. 34-9 (*a*) In a concave mirror, incident parallel light rays are brought to a real focus at *F*, on the same side of the mirror as the incident light rays. (*b*) In a convex mirror, incident parallel light rays seem to diverge from a virtual focus at *F*, on the side of the mirror opposite the light rays.

You may trace the location of the mirror and the rays on this sheet or another piece of paper.
Concave: Focal Length =

Convex: Focal Length =

Spherical aberration means that the rays reflected from the mirror do not all cross at the same focal point. Are these mirrors subject to spherical aberration? Try the larger cylindrical mirror also.

How might the effects of spherical aberration be minimized? Give two suggestions:

(i)

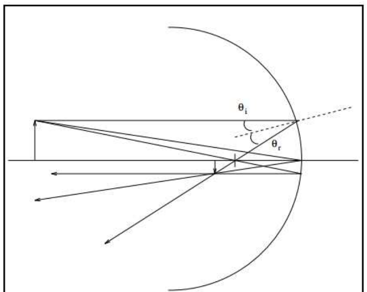
(ii)

2. In order to predict the location of an image formed by a spherical mirror, you must know either the focal length or the radius of curvature. The focal length and radius of curvature are simply related:

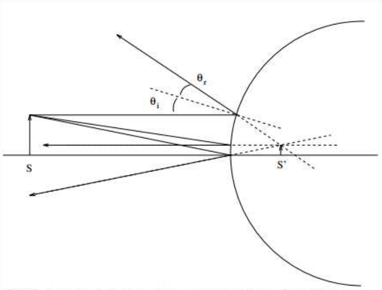
$$\mathrm{f} = \frac{\mathrm{R}}{2}$$

(Note that by a sign convention, R is a positive quantity when it is on the same side as the object, i.e., for a concave mirror.)

Images formed by spherical mirrors may be either virtual or real. An image is real when it exists in space, i.e., it can be seen on an index card because the reflected rays intersect. An image is virtual when reflected rays diverge, appearing to originate from the other side of the mirror. For a concave mirror, the type of image depends on whether the object is located closer to or further from the mirror compared to the focal point, as shown in the figures. When the object is located *at* the focal point, the image location is infinity, i.e, no image is produced.



O2.1 A real object and a concave mirror forming a real image.



O2.2 A real object and a convex mirror forming a virtual image.

Notice in these figures that virtual images are upright and behind the mirror, while real images are upside down and in front of the mirror. For mirrors, the distance between the mirror and the image is defined to be negative for virtual images and positive for real images.

A spherical mirror is set up in the lab room, and there is a spherical mirror at the end of the hallway. Examine your image in each. Determine whether the image is real or virtual and whether the surface is concave or convex. You will want to change your location with respect to the mirror so that you can see if there is a flip associated with passing through a focal point. Write your conclusions in the space below.

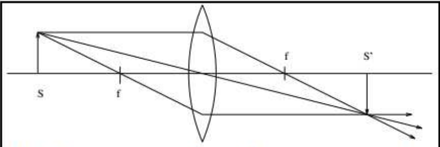
(1)

(2)

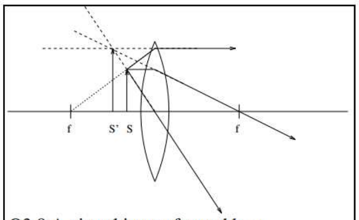
III. Curved Lens Exercises

Lenses form images via refraction, rather than reflection. However, there are many similarities between mirrors and lenses in the formation of images. Like mirrors, there are 2 basic types of lenses: converging and diverging. We define a focal length by tracing parallel rays through lenses and treat the object and image locations in a similar way as we do for mirrors. However there are several important differences. In the following discussion, compare the lens figures with the mirror figures from II.

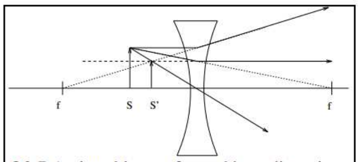
(i) There is a focal point on either side of the lens, since light can travel either way through the lens.
(ii) Real images (formed by converging rays) are found on the side of the lens *opposite* the light source, while virtual images (formed by diverging rays) are found on the *same* side of the lens as the light source. Object and image distances (S and S') and the magnification then have the same sign convention as mirrors. Similarly, the focal length is positive when parallel rays converge to a point on the opposite side of the lens as the light source and the focal length is negative when parallel rays diverge and form a virtual point on the same side as the light source.



O3.9 A real image formed by a converging lens.



O3.8 A virtual image formed by a converging lens.



O3.7 A virtual image formed by a diverging lens.

(iii) A convex refracting surface has a *positive* radius of curvature while a concave refracting surface has a *negative* radius of curvature (this is the **opposite** convention applied to spherical mirrors). The radii of curvature of the two surfaces of a lens may be different and may have different signs. In the approximation of a thin lens (lens thickness << radii of curvature), we can write an equation for the focal length, called the lens makers' equation:

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where n is the index of refraction and R_1 and R_2 are the radii of curvature. In this convention, R_1 is the surface closest to the source.

1. You will need to use a ray box station for this part. You are provided with a variety of converging and diverging lenses, including a biconvex converging lens, a biconcave diverging lens, and a plano-convex lens.

(a) Use the ray box to examine the behavior of parallel rays incident upon the lenses. The point of intersection of incident parallel rays is the focal point. Sketch the ray diagram for the parallel rays and measure the focal lengths. Again, you may simply trace the rays on this sheet:
Biconvex Converging:

Focal Length =

Biconcave Diverging:

Focal Length =

Plano-Convex

Focal Length =

Is the plano-convex lens Converging or Diverging? What do you expect based on the equation? Compare the resulting focal length if you flip the orientation of the lens.

(c) What types of aberrations are lenses subject to? Look at the intersection of rays for the converging lenses. Also look at the image at the focal point, using an index card. You should find two types.

(i)

(ii)

(d) What happens if you combine different lenses? For example, put the biconvex converging lens nearest the ray box. Experiment with different placements of a smaller focal length converging lens until you obtain parallel exiting rays. (An additional small focal length biconvex lens is available from the instructor.) Measure the placement of the 2nd lens with respect to the focal point of the 1st lens. Sketch the arrangement, marking distances. This arrangement is used in the construction of refracting telescopes.

Spend a few minutes observing the behavior of the rays with different arrangements and spacing of the lenses.

IV. Lenses: Ray Diagrams and Images

You will need an optical bench, a convex lens and holder, a screen, a light source (with tape across the aperture for the light - this acts to diffuse the light), a parallel ray lens and holder, a variable-sized aperture and an object (crossed arrows or ruler).

1. No-Lens Imaging! First you will create an image *without* a lens. Set up the light source on the bench. Place an object in front of the light source, a variable-sized aperture beyond the object, and finally a screen. Adjust the aperture so that it is about a mm wide. Describe the image formed on the screen. Make a ray diagram showing the construction of the image.

How is the image clarity affected by changing the aperture size? Why?

This approach can be used to make photographs without a lens! To see some examples, google Pinhole Photography.

2. Imaging using Lenses: Light that passes through a lens from an object will produce an image. This image can be focused onto a screen. We can use the thin lens equation to preduct the location of the image, if we know the focal length of the lens:

$$\frac{1}{\mathrm{S}} + \frac{1}{\mathrm{S'}} = \frac{1}{\mathrm{f}}$$

where S is the distance between the object and the lens and S' is the distance between the lens and the image.

The focal lengths of the lenses are given on the lens cover. Check the focal length experimentally. Use the parallel light lens to construct a light source made up of parallel beams. (Ask if you need help to set this up.) How well determined is the focal length? Estimate the uncertainty.

Set up the light source and object on the optical bench. Place the lens in a lens holder on the bench, at a distance of greater than the focal length away from the object. Place a screen on the opposite side of the lens and move the screen until a clear image is projected. Use the optical bench scale to determine S and S'. Does the S' agree with the value predicted by the thin lens equation? If not, find the percent difference between predicted and observed values of S'. What might cause any differences?

Predict what would happen if you covered half the lens with an index card. Try it. What happens to the image? Why?