Laboratory 4: Geometrical Optics: Lenses and Telescopes

The purpose of this lab is to give you practice working with converging and diverging lenses.

Note: In this discussion, the notation and sign conventions of your text (Serway and Beichner) have been used. It will be helpful if you review the sections in the text which discuss thin lenses and the telescope.

Caution: Lasers will be used in this experiment. They are particularly useful because they provide light beams that diverge only slightly. The beam that exits the laser has a very small cross-sectional area so we will usually pass the beam through a beam expander to get a broader beam. Our lasers produce very low power, about 1 mW, however, it is possible for the unexpanded laser beam to do damage to an eye if the laser light enters directly into it. Therefore, the two following safety rules must be followed at all times:

1) **Never look directly into the laser beam.**
2) **Never point the laser at anyone.**

Part 1: Determining Focal Lengths.

1a: Converging Lenses. The focal length of a converging lense (one thicker in the center than at the edges) is the distance behind the lense where the sun's rays meet. Converging lenses produce real images so it is easy to find their focal points.

Before beginning, make certain that your beam expander (the cylindrical object mounted on the end of your laser) is properly adjusted to produce parallel rays. This can be checked by shining the laser on a card and moving the card away from the laser. If the bright region does not significantly increase or decrease with distance, the beam expander is properly adjusted. If you think the beam expander requires adjusting, the lab instructor will assist you.

Select a converging lense and place it in the lense holder in front of the laser. Place an opaque card behind the lense and move it until you find the place where the image is the smallest. Assuming your beam is parallel, this marks the focal point of your lens. The distance between the lens and the card is the focal length of the lens. Repeat this determination several times with the lense located different distances from the light source. If the beam is parallel, you will determine the same focal length each time. If you find a systematic deviation, you must recollimate the beam by adjusting the beam expander and repeat your measurements; the lab instructor will help you.

Repeat this experiment with several other converging lenses until you have examined three lenses with different focal lengths between 5.00 cm and 50.0 cm.

1b: Forming an Image. Place the transparent target in a holder in front of the laser. Place one of your converging lenses behind the target with the object-lens distance, p, greater than the focal length of the lens. Locate the real image behind the lens with the card. Record the lens-image distance, q, and a convenient length, h_i, in the image of the target. Also measure this length, h_o, on the target itself. Use this data and the basic lens formula to calculate the focal length of the lens and the magnification given by,

$$M = \frac{h_i}{h_o} = -\frac{q}{p}.$$

Repeat this experiment using values of the image distance which are about $1.2\,f$, $2\,f$ and $3\,f$. Note how the height of the image increases as the image distance increases.

1c: Diverging Lenses. Place a diverging lens (one that is thinner in the middle than at the edges) in front of the laser and look for the image of the light source with your card. You will not be able to find it since the diverger bends light away from the axis, as if it were coming from a focal point located between the source and the lens. Determining the focal length of a diverging lens requires the simultaneous use of a more powerful converging lens to bend the diverging light back to the axis.

Leaving the diverging lens in place, position your most powerful converging lens in the second lens holder and slide it as close to the diverger as possible. Then move the card until you find a sharp image. Note the position of both lenses and the card. You have located the focal point for the two lens system, which is not the same as that of the diverging lens alone.

Move the diverger and note how the focal point changes. Can you explain why it moves in the direction that it does?

Using the same diverging lens, replace the converger with your next most powerful lens. Repeat the experiment above so that you have a second set of data. (If you are unable to find an image, it is because the power of the diverger is greater than that of the converger. Use a more powerful converger, or alternatively, a weaker diverger.)

Part 2: Analysis of Your Lens Systems. You should begin the analysis of the simple optical systems in this lab by drawing a ray diagram for each type of system. The details of how to do this are given in your text in the section on thin lenses. In the following, you should pay particular attention to the sign conventions, also described in your text.

All multi-lens systems can be analyzed using two fundamental ideas: the thin lens formula

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f},$$

and the fact that the image of the first lens serves as the object of the second lens.

Consider your measurements for the focal length of a diverging lens above. The diverging lens creates a virtual image of the parallel light a distance $|f_d|$ in front of itself. This virtual image serves as the object for the converger lens and is located a distance $|f_d| + \ell$ in front of the converger, where ℓ is the separation of the two lenses. The image of the converger is located at the location q_i according to the equation

$$\frac{1}{|f_d| + \ell} + \frac{1}{q_i} = \frac{1}{f_c}.$$

In this experiment, you measured ℓ and q_i. Using their values plus the known focal length of the converging lens, f_c, you can solve the above equation for $|f_d|$, the focal length of the diverging lens.

Part 3: The Telescope. A refracting (Keplerian) telescope can be constructed with two converging lenses. Put your most powerful lens in the rear holder with another converging lens in the front holder and position the holders a distance apart equal to the sum of the focal lengths of the two lenses. Using a card, you should be able to trace the image through the system. Record the image distances and take measurements so that you will be able to calculate the magnification of the system.

Carefully remove the laser from your optical bench and place it on the lab table so that it cannot fall over. Remove any other holders from the bench leaving only the two lenses. Now adjust the distance between the lenses (why is this necessary) so that you can clearly see an enlarged image of a distant object while looking along the axis of the lenses. Note that the image is inverted. Draw a ray diagram and analyze this system for your report.

The beam expander used on the laser in this experiment is actually a telescope, but of a slightly different design. It consists of one converging and one diverging lens; a type of telescope called Galilean. The converging lens can be seen on the end of the expander away from the laser. The particular beam expander used in this experiment expands the diameter of the laser beam by about a factor of fifteen. Both the input and output beams are highly collimated. Draw a rough ray diagram for the beam expander and comment on its operation.

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