Lab 12. Images with Thin Lenses

Goals

- To learn experimental techniques for determining the focal lengths of positive (converging) and negative (diverging) lenses in conjunction with the thin-lens equation.
- To learn how to make a scale "ray diagram" for a combination of a positive and negative lens using three principle rays for each lens and interpret it.
- To understand the specific meaning of the term "magnification" as applied to optical systems and to determine its value by three methods: (a) direct measurement, (b) calculation using the thin lens equation, and (c) using a ray diagram.

Introduction

For a simple focusing element with focal length f, it can be shown that

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f} \tag{12.1}$$

where s and s' are the object and image distances respectively. This is called the thin-lens equation. The object distance is measured from the light source to the center of the lens, and the image distance is measured from the viewing screen, where the real image is displayed, to the center of the lens.

An optical bench with a metric length scale attached to it, two lenses and holders, a light source, and a viewing screen are provided. The ray box light source is provided with crossed arrows that serve as the object to be imaged.For clearer view of the image, hang a clean sheet of paper over the viewing screen on the side facing toward the ray box.

Caution: Always secure (but not too tightly) the optical mounts on the optics bench so that the optical elements do not fall and break. Handle the lenses using the edges only. Your TA will demonstrate how to put a lens in the lens holder. Also be cautious not to let the optical bench near the table edges, the bench must remain perfectly level for the optics to align and measure properly, additionally the older benches are solid steel and will easily lead to injury.

Determining the focal length of a converging lens

Use the optical bench with the light source and the viewing screen to determine the focal lengths of the two lenses provided, one a converging lens (positive focal length) and the other a diverging lens (negative focal length). You should be able to tell which is which by looking at their cross-sections, a converging lens is thicker in the middle than along the edges. The focal length of the converging lens should be determined first. This can be done experimentally by finding pairs of object and image distances that give clear real images of the light source on the viewing screen. (A "real" image can be projected onto a screen.) Then use the thin lens equation to calculate the focal length. Repeat this several times using significantly different values of s and s'.

Find the mean value of the focal length and compute its standard deviation. If you do not know the how to compute a standard deviation, consult the Uncertainty/Graphical Analysis supplement to the lab manual.

What happens when you try the same procedure for the negative (diverging) lens?

Determining the focal length of a diverging lens

A diverging lens forms a real image only when used in conjunction with a converging lens. This is because the diverging lens forms the image on the same side that of the lens as the object being imaged. But if you place a screen between the object and lens, then you prevent image formation.

So, in order to view the image of the diverging lens, you must have an object which is not blocked by your screen. If we use the image which would be formed by a converging lens as the object of our diverging lens, then we can place the viewing screen on the opposite side of both lenses from the light source.

Using both lenses (place the converging lens nearest the light source), find lens and screen positions that yield clear images. In this configuration we can measure only the object distance of the converging lens and the image distance of the diverging lens. Knowing the focal length of the converging lens from previous measurements, the thin lens equation can be used to find the location of the image formed by the converging lens. Then treat the image of the converging lens as an object (be careful of the sign of the object distance) for the diverging lens. Apply the thin lens equation again to find the focal length of the diverging lens. Note that the sign conventions used in the thin lens equation demand that the focal length for a diverging lens be a negative number. Repeat this process for several significantly different lens and viewing screen positions. Calculate the mean focal length and the corresponding standard deviation.

Drawing a ray diagram for a two-lens system

Pick one configuration of lenses and viewing screen from your measurements on the diverging lens and draw a complete ray diagram to scale showing the formation of the intermediate image from the converging lens and the final image of the diverging lens. Ray diagrams for single converging and diverging lenses are shown in your textbook.

A simple ray diagram treats the object as a single point at the tip of an arrow drawn extending from the perpendicular line through the center of the lens. From the tip of this arrow you draw three lines:

1. A line perpendicular to the lens, which bends at the middle of the lens to pass through the focal point on the image side of the lens
2. A line through the focal point on the object side of the lens, which bends at the middle of the lens to run perpendicular to the lens
3. A line through the center of the lens, which continues straight through without bending to the image side of the lens.

While these three lines are sufficient to find the image formation, they are a simplification of how lenses work. Light from every point on the surface of the actual image used in real life is emitted in every direction at all times, and each light ray bends through the lens wherever it strikes the lens to wind up at the appropriate location on the final image.

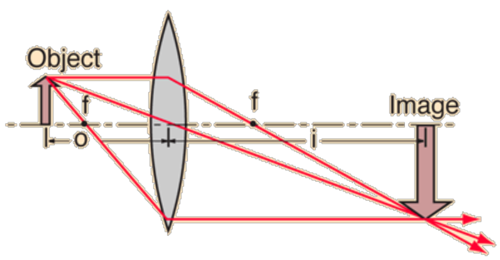

Figure 12.1. A sample Ray Diagram for a Converging lens.

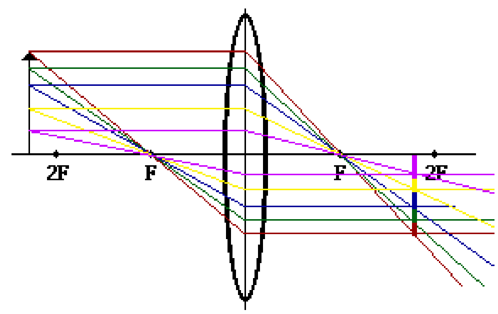

Figure 12.2. A sample of additional lines which appear in non-point objects.

Trace the rays for the lens closest to the light source first; then use the resulting image as the object for the second lens. Use your experimental values of focal lengths as given values on your diagram (This drawing needs to be done to scale so you can measure results from it). Does your ray diagram predict the correct location for the final image? Compare the result to your experimental value using the diverging lens.

Magnification

Magnification is defined as the ratio of the size of the image to the size of the object being imaged. When the image is upside down, the magnification is negative. If the image is upright, having the same orientation as the object, the magnification is positive. Using ray diagrams, one can show that the magnification (sometimes called the transverse magnification), m, is equal to $\frac{-s'}{s}$ for both positive and negative lenses. Compare the heights of the object and image in your ray diagram to determine magnification of the two-lens combination. Compare this value with the magnification calculated using the thin-lens equation for the same lens configuration, knowing the focal lengths and positions of the lenses relative to the object and the final image.

	No Effort	Progressing	Expectation	Scientific
SL.A.a Is able to analyze the experiment and recommend improvements Labs: 1-3, 5, 7, 9, 11, 12	No deliberately identified reflection on the efficacy of the experiment can be found in the report	Description of experimental procedure leaves it unclear what could be improved upon.	Some aspects of the experiment may not have been considered in terms of shortcomings or improvements, but some are identified and discussed.	All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made. Justification is provided for certainty of no shortcomings in the rare case there are none.
CT.B.a Is able to describe physics concepts underlying experiment Labs: 1-3, 5, 7, 9-12	No explicitly identified attempt to describe the physics concepts involved in the experiment using student's own words.	The description of the physics concepts underlying the experiment is confusing, or the physics concepts described are not pertinent to the experiment for this week.	The description of the physics concepts in play for the week is vague or incomplete, but can be understood in the broader context of the lab.	The physics concepts underlying the experiment are clearly stated.
QR.A Is able to perform algebraic steps in mathematical work. Labs: 3, 6, 9-12	No equations are presented in algebraic form with known values isolated on the right and unknown values on the left.	Some equations are recorded in algebraic form, but not all equations needed for the experiment.	All the required equations for the experiment are written in algebraic form with unknown values on the left and known values on the right. Some algebraic manipulation is not recorded, but most is.	All equations required for the experiment are presented in standard form and full steps are shown to derive final form with unknown values on the left and known values on the right. Substitutions are made to place all unknown values in terms of measured values and constants.
IL.A Is able to record data and observations from the experiment Labs: 1-12	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.

	No Effort	Progressing	Expectation	Scientific
WC.C Is able to construct a ray diagram Labs: 12	No Ray Diagram is constructed.	Some Ray Diagrams are constructed, but not for all cases considered during the experiments. OR Rays drawn in the Ray Diagram do not follow the correct paths. Object or image may be located at the wrong position.	"Ray diagram is missing key features, but contains no errors. One example could be the object is drawn with the correct lens/mirror, but rays are not drawn to show image. Or the rays are too far from the main axis to have a small-angle approximation. Or the diagram was drawn without the aid of a straight-edge. "	"Ray diagram has object and image located in the correct spot with the proper labels. Rays are correctly drawn with arrows and contains at least two rays per object/image pair. A ruler was used to draw the images. "

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 12 Images with Thin Lenses:

Name: ______________________ Lab Partner: ______________________

EXIT TICKET:

- ☐ Remove the lenses from the lens holders, place them in protective bags, and then place them in the plastic tray provided.
- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Required Level of Effort.
  - ☐ Complete the pre-lab assignment ☐ Arrive on time
  - ☐ Work well with your partner ☐ Complete the lab or run out of time

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CT.B.a	

QR.A	

IL.A	
WC.C	

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