Lab 1

Geometric and Wave Optics

Optical phenomena are an important part of many experiments, and often require only simple equipment. In this lab, you will explore image formation by lenses and mirrors as well as some of the physical properties of light, namely wavelength and polarization.

1.1 Ray Optics

Become familiar with the image-forming properties of thin lenses and concave/convex mirrors. An excellent tutorial is available at the Hyperphysics website created by Georgia State University: http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html. (Alternatively, you may wish to refer to the Physics 123 textbook.) During class, please spend a while in the section on Light and Vision at the website. Note the links to topics such as Reflection, Lenses, Lens Equation and Mirrors.

It is important to gain a solid appreciation for the image-formation equation

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad (1.1)$$

which relates the location of an image $d_i$ to the location of an original object $d_o$. Of course, this is controlled by the focal length $f$ of the lens. The lens equation also works with spherical mirrors, where $f$ is equal to half the radius of curvature of the mirror.

When an image is formed, it means that the many rays of light emitted from each point on an object converge to a corresponding point at the image. It is often helpful to draw a ray diagram such as shown in Fig. 1.1. Note that a ray that travels parallel to the axis before the lens goes through the focus after the lens (assuming positive focal length). A ray that goes through the focus before the lens travels parallel to the axis afterwards. A ray that goes through the center of a lens is always un-deflected.

Note that $d_i$ and $d_o$ (as well as $f$) can be either positive or negative, depending on which side of the lens they are located on. If an image cannot be displayed on
a screen (i.e. it must be observed by looking into the lens or mirror), we say that
the image is *virtual*. This happens when \( d_i \) is negative.

**Sign conventions for lenses and mirrors**

*Focal length*: convex lens (+), concave lens (−), convex mirror (−), concave mirror (+)

*Object*: (+) is always the source side (upstream).

*Real Image*: far side of lens (downstream) (+); source side of mirror (downstream after reflection) (+).

*Virtual Image*: source side of lens (upstream) (−); behind mirror surface (−).

Also spend some time exploring a variety of lens and mirror focal lengths (positive and negative) using the **Optics Bench Physlet** resource created by Davidson College: [http://webphysics.davidson.edu/Applets/optics4/default.html](http://webphysics.davidson.edu/Applets/optics4/default.html). Insert objects and find the relative sizes and locations of the resulting images. Insert point sources and parallel light sources (i.e. beams) and see how lenses and mirrors affect them.

The size of an image \( h_i \) is not necessarily the same as the size of the object \( h_o \). The image is either enlarged or shrunken in proportion to its distance from the lens. The *magnification* is the ratio of the image size to the size of the original object, and it is given by

\[
M \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad (1.2)
\]

If it is negative, it means that the image is ‘upside down’.

### 1.2 Compound Lens System: Telescope

For instruments containing more than one lens, *angular magnification* is also an important concept – by magnifying the angular width of an object, a telescope or microscope makes an object appear larger. For small angles, \( \theta \approx \tan \theta = h/d \), so that angular magnification can be computed as \( \theta_i/\theta_o = (h_i/d_i)/(h_o/d_o) \). In the case of a telescope, comprised of two lenses separated by the sum of their focal lengths, the angular magnification becomes

\[
m_\theta \equiv \frac{\theta_i}{\theta_o} = -\frac{f_1}{f_2} \quad (1.3)
\]

### 1.3 Physical Optics

The wave optics portion of the lab (Part II) reveals that microwaves have much in common with visible light, while also permitting a direct measurement of wavelength. Because of their convenient wavelength range (millimeters to centimeters), working with microwaves allows one to build intuition in a way that isn’t possible with visible electromagnetic radiation.
1.4 Equipment

Part A: desk lamp, optical bench with lens holders, lens and mirror set, large and small magnification scales. Part B: Microwave generator and detector with digital multimeter, microwave polarizer, microwave reflector with tape measure, curved microwave mirror, microwave prism.
Quiz

Q1.1 The focal length of the lens shown in Fig. 1.2 is
(a) positive.
(b) negative.
(c) concave.
(d) convex.

Q1.2 For the object and lens shown in Fig. 1.2, the image is
(a) real.
(b) virtual.
(c) inverted.
(d) all of the above.

Q1.3 The focal length of the lens above has a magnitude of 10 cm. The object is $d_o = +20$ cm from the lens and has a height of $h_o = 5$ cm. Calculate the location ($d_i$) and the height ($h_i$) of the image (both signs and magnitudes).

Q1.4 Explain the difference between lateral and angular magnification.
Exercises

A. Geometric Optics.

L1.1 Measure the focal length of a positive lens or mirror. The focal length of a positive mirror or lens is the distance from the lens center or mirror surface to the point where parallel light rays converge. You can obtain an approximately parallel beam of light rays by using a distant lamp as a source.

L1.2 Experimentally verify the lens and lateral-magnification equations for a positive lens.

L1.3 With a positive lens of focal length f, determine the minimum possible distance between an object and its real image? Hint: use a lens with a fairly short focal length, and move the lens between the object and a screen to find an image at two locations of the lens. Then move the screen closer and repeat the procedure to experimentally determine the answer to the question. The theoretical limit is $4f$. Explain this result in terms of the lens equation.

L1.4 Create a simple telescope and demonstrate that its angular magnification is $m = f_{\text{obj}} / f_{\text{eye}}$. Here, $f_{\text{obj}}$ and $f_{\text{eye}}$ are the focal lengths of the objective and eyepiece lenses, respectively. A high angular magnification is obtained by using a short eyepiece focal length and a long objective focal length, and arranging the lenses so that they share a common focal point. Try using a few different lens combinations to read some small print from across the room. With a little practice you can simultaneously look through the telescope with one eye and past the telescope with the other and let your brain superimpose the images for visual comparison. The large scale on the wall should help.

B. Wave Optics.

L1.5 Explore the polarization state of the microwaves being emitted by the generator. A beam of electromagnetic radiation is said to be linearly polarized if the electric field of the beam has a well-defined direction. Your microwave detector measures the potential difference (i.e. voltage) between the ends of a small antenna, and responds most strongly when the antenna is parallel to the polarization direction.

(a) Vary the antenna orientation to determine the polarization direction. Do you find the microwave polarization to be transverse (i.e. perpendicular to the beam direction) or longitudinal (parallel to the beam direction)?

(b) Use a stand to fix the antenna parallel to the microwave polarization direction, insert the polarizer into the beam between the source and
the antenna, and vary the polarizer angle. To avoid interference, try to keep other metal objects out of the vicinity of the microwave beam path. Verify that the signal detected is proportional to $\cos^2 \phi$, where $\phi$ is the angle of the polarizer relative to the maximum intensity position. Can you explain the effect of the wires?

(c) Now rotate the antenna direction to be perpendicular to the microwave polarization and also perpendicular to the beam direction, which should yield a zero signal. Try slowly rotating the polarizer again. Describe and explain what you observe?

L1.6 Measure the wavelength of the microwave radiation. Set up a standing wave by reflecting the microwave beam from a metal sheet back towards the source. Place the metal sheet at least 60 cm from the source, and place the detector, which should be oriented parallel to the microwave polarization direction, close to the metal sheet. You should see a series of peaks in the detected microwave intensity when scanning the detector towards the source, where two adjacent peaks are separated by half a microwave wavelength. Mounting your detector on the optical bench may make it easier to maintain proper position and alignment while scanning. Adjusting the position of the metal sheet slightly may also improve the contrast of the peaks. Now measure the wavelength. To improve accuracy, you can measure the distance that spans five peaks and divide accordingly.