Pre-Lab Preparation Sheet for Lab 3: 
Geometric Optics - Lenses 
(Due at the beginning of lab)

Watch the following tutorial on lenses.
https://www.youtube.com/watch?v=q1wzdblPQ3A

Play with the following animation. The slider labeled Magnification should be labeled Focal Length. Note that you can move both Psy and the screen.
http://labs.minutelabs.io/Lenses/

1. How does the image distance (the distance from the lens to the focused image) change with the object distance (the distance from Psy to the lens)?

2. Explain the Thin Lens Approximation.

3. Light rays coming from an object are observed to be parallel. What does this imply about the distance to the object?
xkcd.com
Objectives:

To understand the basic properties of lenses: focal length and aperture.

To apply the rules of ray optics to understand imaging and the effects of combining lenses.

Equipment

Mounted Lenses: 20 cm, 10 cm, -15 cm  Un-mounted Lenses
Optical track Screen
Light box with power supply Aperture card
Meter stick and ruler white/red bulb pair
Flat lenses

Introduction

With geometric optics, we treat light as rays which travel in straight lines until they . . .

a. reflect off a surface (angle of reflection = angle of incidence), or
b. refract at an interface (Snell’s Law). *

The wave-like properties of interference and diffraction are ignored. This is equivalent to saying that your optical elements (mirrors, lenses, apertures†, etc.) are much larger than the wavelength of light.

* In principle, you could design a telescope with nothing but a straight edge, a protractor, and a really sharp pencil.
† An aperture is the opening through which light can pass.
As light rays move further from a point source, they diverge from their neighboring rays. However, at large distances the rays diverge slowly, and they become more parallel. As the range approaches infinity, the rays become perfectly parallel.

With a lens, we can modify the direction of these rays to create one of two devices

1. A camera.
2. An eyepiece (such as a magnifying glass).

**Focal Length**

Consider Figure 1 below. A set of parallel beams are bent in different directions depending on the incident angle of the glass.

Consider Figure 2 below. If we curved the surface of the glass *just right*, all of the parallel rays will be bent toward a single **focal point**. This is a **convex** or **positive lens**.

The distance from the lens to the focal point of the parallel rays is the **focal length** \( f \) of the lens.

**Exercise 1: Focal length**
a. Adjust the light box to produce three slits of light. Send the beams through one of your 2D lenses and measure the focal length.

b. Reverse the direction the lens faces and measure the resulting focal length. Does this significantly affect the result?

c. Place the other 2D lens beside the first and measure the focal length of the combined lenses.
A concave (or negative) lens diverges the light rays. We measure the focal length of such lenses by tracing the rays backward to the point where they appear to come to a focus. We define such a focal length to be negative.

d. Measure the focal length of the concave lens.

Note: Throughout this lab, we will apply the thin lens approximation: The thickness of the lens is much less than the focal length. Most of the errors you will find in your calculations arise from the shortcomings of this approximation.

Imaging

A focused image is formed when light rays from each point on an object converge at a corresponding point on the image. This is called a real image, as the light rays really do converge at a point in space.

Note in the middle of the lens, the glass is flat. Hence, rays passing through the center of the lens are not deflected. The position of the object and image are given by the Lens Equation:

\[
\frac{1}{f} = \frac{1}{p} + \frac{1}{i}
\]  

(1)
Exercise 3: Imaging

You will first image a “distant” object.

1. Attach the screen and the 10 cm lens to the track.

2. Project an image of your neighbor’s computer screen on the opposite side of the lab. Describe the orientation of the image.

3. Measure the image distance and the size of the image.

4. How does the image distance compare to the focal length? Explain.

5. Replace the lens with the 20 cm lens.
6. Measure the image distance and size. How does the size of the image scale with focal length?
7. Replace the lens with the -15 cm lens. Describe and explain your observations.

Now, you will image a nearby object.

8. Assemble the object (light box), 20 cm lens, and screen on the track as shown below.

9. Measure the object \( p \) and image \( i \) distances and calculate the focal length \( f \). Enter the data onto Table 1 below.

10. Calculate the magnification \( M \equiv \frac{\text{image height}}{\text{object height}} \) of the object and record the result in the table. Mathematically, how does the magnification relate to \( p \) and \( i \) found above?

11. With the object and screen fixed, move the lens to locate another point on the track where a focused image is formed. Again, record the results in the table. How do the image and object distances for this case relate to the previous focal position?
Table 1: 20 cm lens, fixed object

<table>
<thead>
<tr>
<th></th>
<th>$p$</th>
<th>$i$</th>
<th>$M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position 2</td>
<td></td>
<td></td>
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</tbody>
</table>

**Exercise 4: Changing the object distance**

Continue using the 20 cm lens.

12. In approximately 5 cm increments, move the object forward, refocus, and record $p$ and $i$. Continue until you can no longer focus an image.

13. Find the closest possible screen\object distance and record the result.
14. Create a scatter plot from the data points and print the result. Include all image distances from the **very distant object** (your neighbor’s screen) to the **closest possible focus**. On the printout, annotate the plot noting the extremes of distant and close imaging. How far have you moved the lens?
Exercise 5: Changing the aperture

15. Place the object 30 cm from the end of the track. With the lens relatively close to the screen, focus the image.
16. Move the object back and forth to note the range over which the object can move while remaining in focus. This range is called the depth of field. Record the result in Table 2 below.

17. With the aperture card (the card with the holes), cover the lens with the largest hole. Again, measure the depth of field and record the result. Repeat with the other holes.

Table 2: Changing the aperture

<table>
<thead>
<tr>
<th>No masking</th>
<th>Near focus</th>
<th>Far focus</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large aperture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle aperture</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Small aperture</td>
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18. Now, remove the lens and form an image with just the aperture. This is a **pinhole camera**. Describe the result with the different apertures. What does this mean about the focal length of a pinhole? Describe the depth of field of a pinhole camera? How are these related?

**Exercise 6: The magnifying lens.**

If you want to magnify some object, the simplest thing to do is bring it closer to your eye. *(Well, duhh!)* However, get too close and we run into a problem. A normal, relaxed human eye will focus on distant objects. That is, it will bring parallel light rays to a point on the retina (the back of the eyeball). To focus on close objects, muscles in the eye squeeze on the lens to shorten the focal length.

Of course, you can only squeeze your lens so much. A magnifying lens works by bending the rays from a nearby object so they are parallel. The relaxed eye can focus these parallel rays as though the object were infinitely distant.
19. Hold the 10 cm lens directly in front of your eye and observe this text. How close to the text must you hold the lens?

20. Repeat with the 20 cm lens. Which lens makes things look bigger? Why?
Exercise 7: Combining lenses and Eyeglasses

21. Position the 10 and 20 cm lenses side by side. What is the effective focal length of the combined lenses?

22. Position the 10 and -15 cm lenses side by side. What is the effective focal length of the combined lenses?

A person with myopia (near-sightedness) can only focus on nearby objects. Distant objects remain blurry.

23. Is the focal length of his too long or too short? Explain.

24. What type of eyeglass lens could correct myopia?
25. A person with hyperopia (far-sightedness) cannot focus on nearby objects. What’s wrong with the lens, and what type of eyeglass could correct for it?