Physics 202, Lecture 26

Today’s Topics

- Lenses
  - Reminder of Sign Conventions
  - Combination of Lenses
  - Cameras
  - The Human Eye, Lenses and Magnifiers
  - Telescopes
  - Microscopes
- Lens Maker’s Equation
Exam 3 Result

Average 76.7
Median 80

Rough curving:
Bottom A: 90-95
Bottom B: 75-80
Bottom C: 50-55
Review: Ray Diagrams

- If image can be formed, only two rays are necessary to determine an image point.

- Useful rays:
  - Object ray pointing to the center (C)
    - image ray inline with the object ray
  - Object ray parallel to principal axis
    - image ray “pointing to” a focal point (F)
  - Object ray passing through a focal point
    - image ray parallel to principal axis.

![Diagram showing useful rays for ray diagrams]
Example:
Images Formed by Converging Lens

- Object (O) is in front of \( F_1 \) : real, inverted, enlarged or reduced

- Object (O) in between \( F_1 \) and lens: virtual, upright, enlarged.

\[
f > 0 \\
\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \\
M = \frac{h'}{h} = -\frac{q}{p}
\]
Review:
Thin Lens/Mirror Equation and Magnification

\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad \Rightarrow \quad d_i = \frac{fd_o}{d_o - f} \]

Magnification:

\[ M = \frac{h_i}{h_o} = -\frac{d_i}{d_o} = \frac{f}{f - d_o} \]

Parameters
- \( d_o \): object distance
- \( d_i \): image distance
- \( f \): focal length
- \( h_o \): object height
- \( h_i \): image height
- \( M \): magnification

All parameters are signed!
# Sign Conventions for Mirrors and Lenses

<table>
<thead>
<tr>
<th></th>
<th>&gt;0</th>
<th>&lt;0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$</td>
<td>concave mirrors</td>
<td>convex mirrors</td>
</tr>
<tr>
<td></td>
<td>converging lens</td>
<td>diverging lens</td>
</tr>
<tr>
<td>$R$</td>
<td>center at image side</td>
<td>center at other side</td>
</tr>
<tr>
<td>$d_0$</td>
<td>object side</td>
<td>the other side</td>
</tr>
<tr>
<td>$d_I$</td>
<td>image side (real)</td>
<td>the other side (virtual)</td>
</tr>
<tr>
<td>$M=-\frac{d_I}{d_o}$</td>
<td>upright</td>
<td>inverted</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Object Side</th>
<th>Image Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>mirrors</td>
<td>front</td>
</tr>
<tr>
<td>lenses</td>
<td>front</td>
</tr>
<tr>
<td>refraction surface</td>
<td>opposite to observer’s side</td>
</tr>
</tbody>
</table>
Combination of Lenses

- Optical instruments typically use lenses in combination. When light passes through more than one lens, we find the image formed by the first lens becomes the object to the second lens, etc…

- Let's do this exercise on the board:
Exercise: Where Is the Final Image

- As shown, two converging lenses, each with a focal length of 10cm, are separated by 50cm. An object is 15cm in front of the first lens.

- Use ray diagram to find the final image.
- Use lens equation to find the final image (see board).
- What is the path for ray 1?
Converging Lens and Object at Large Distance

When the object is at a large distance from the converging lens the following expressions apply:

\[ d_o \gg f \]

\[
\begin{align*}
d_i &= \frac{fd_o}{d_o - f} \\
&\approx \frac{fd_o}{d_o} = f\;
\end{align*}
\]

\[
M = \frac{f}{f - d_o} \approx -\frac{f}{d_o}
\]
A camera is essentially a converging lens with a short focal length. (Operating condition: \( d_o \gg f \rightarrow d_i \sim f \) )
Eyes

- Eye is essentially an auto-focus camera

Psychological size (image size on retinal) is determined by $\theta$

Quick quiz: Is the image on retina real/virtual, upright/inverted?

$f_{\text{human\_eye}} \sim 17\text{mm}$
A simple magnifier is essentially also a converging lens with a short focal length.

- Operating condition: $d_o \sim f (< f)$ and $d_i \sim 25$ cm
- Simple magnifiers magnify the opening angle an object subtends at the eye (i.e., psychological size)

angular magnification or magnifying power:

$$M = \frac{\theta'}{\theta} = \frac{25\text{cm}}{f} \text{ for near point}$$
Telescopes

- Telescope is another type of angular magnification device with configuration $L \approx f_e + f_o$

Note:

For telescope application, object distance can not be adjusted.

$$M_o = -\frac{f_o}{f_e}$$
Telescopes (cont)

Galileo’s Telescope
Telescopes (cont)
Compound Microscopes

- Compound microscope also does angular magnification.
- Configuration: $L >> f_e + f_o$

$$m_o \approx \frac{L}{f_o}$$
$$M_e = 25 \text{ cm/f}_e$$
$$M = m_o M_e = \left(\frac{L}{f_o}\right) \left(25 \text{ cm/f}_e\right)$$

**Final Image:**
Virtual, inverted
Compound Microscopes (cont)

Robert Hooke’s Microscope (1665)