Lenses

Reminder

Cameras

The Human Eye, Lenses and Magnifiers

Combination of Lenses

Microscopes

Telescopes
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.
Image Formation Equation and Magnification

Parameters
- \( p \): object distance
- \( q \): image distance
- \( h \): object height
- \( h' \): image height
- \( M \): magnification
- \( f \): focal length

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

\[
q = \frac{fp}{p - f}
\]

If \(|M| < 1\) \(\rightarrow\) Image < Object

If \(|M| > 1\) \(\rightarrow\) Image > Object

If \(M < 0\) \(\rightarrow\) Image \(\downarrow\uparrow\) Object

If \(M > 0\) \(\rightarrow\) Image \(\uparrow\uparrow\) Object

Mirrors and Thin Lenses
## Sign Conventions

<table>
<thead>
<tr>
<th></th>
<th>&gt;0</th>
<th>&lt;0</th>
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<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>( p )</td>
<td>object side</td>
<td>the other side</td>
</tr>
<tr>
<td>( q )</td>
<td>real</td>
<td>virtual</td>
</tr>
<tr>
<td>( M=\frac{-q}{p} )</td>
<td>upright</td>
<td>inverted</td>
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<table>
<thead>
<tr>
<th></th>
<th>Real</th>
<th>Virtual</th>
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<tbody>
<tr>
<td>mirrors</td>
<td>front</td>
<td>behind</td>
</tr>
<tr>
<td>lenses</td>
<td>behind</td>
<td>font</td>
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</table>
A camera is essentially a converging lens with a short focal length. (Operating condition: $p >> f \Rightarrow q \sim f$)
Eyes

- **Eye is essentially an auto-focus camera**

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

- A simple magnifier is essentially also a converging lens with a short focal length.
  - Operating condition: \( p < f \) and \( q \sim -25 \text{ cm} \)
  - Simple magnifiers magnify the opening angle an object subtends at the eye (i.e. psychological size)

\[
\text{angular magnification: } m = \frac{\theta}{\theta_0} = \frac{25 \text{ cm}}{f} \text{ for near point}
\]
Combination of Lenses

\[ M = M_1 M_2 \]

\[ \frac{1}{p} + \frac{1}{q} = \frac{1}{f_1} + \frac{1}{f_2} \]
Compound Microscopes (cont)

Robert Hooke’s Microscope (1665)
Compound Microscopes

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

Final Image:
Virtual, inverted
Telescopes (cont)

Galileo’s Telescope
Telescopes

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

Note:
For telescope application, object distance can not be adjusted.