Physics 202, Lecture 25

Today’s Topics

- Thin Lenses
- Lens Maker’s Equation
- Ray Diagrams and Thin Lens Eqs.
- Sign Conventions
- Combination of Lenses
  - Cameras
  - The Human Eye, Lenses and Magnifiers
  - Telescopes
  - Microscopes

Thin Lenses

- Lenses are refractive optical devices with two spherical sides.

![Image of thin lenses](image)

**Focal Point and Focal Length**

- **Focal point (F):** The point to which light beam parallel to principal axis converge.
- **Focal Length (f):** Distance between focal point and the mirror or lens.
  - Each lens has two focal points (each mirror has one).
  - Focal points can be “virtual” (light rays don’t meet there).

![Image of focal points and focal lengths](image)

**Ray Diagram for lenses**

- If an image is formed, only two rays are necessary to determine the image point.
- **Useful rays:**
  - Object ray parallel to principal axis
  - Image ray "pointing to" a focal point (F2)
  - Object ray pointing to the center (C)
  - Image ray inline with the object ray
  - Object ray passing through a focal point (F1)
  - Image ray parallel to principal axis.

![Image of ray diagrams](image)

Lens maker’s equation

\[
\frac{1}{f} = (n-1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)
\]

\( f > 0 \): converging
\( f < 0 \): diverging

**Focal length**

- Distance between focal point and the mirror or lens.
- Each lens has two focal points (each mirror has one).
- Focal points can be “virtual” (light rays don’t meet there).
Images Formed by Converging Lens

- Object (O) is in front of F: real, inverted, enlarged or reduced
- Object (O) in between F and lens: virtual, upright, enlarged.

Images Formed by Diverging Lenses

- Images are always virtual, upright, and reduced

Thin lens Eq:

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

Sign Conventions (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>p</td>
<td>object side</td>
<td>the other side</td>
</tr>
<tr>
<td>q</td>
<td>image side (real)</td>
<td>the other side (virtual)</td>
</tr>
<tr>
<td>M = -q/p</td>
<td>upright</td>
<td>inverted</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...

Thus, an object CAN be virtual!
Exercise: Where Is the Final Image

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

- Use ray diagram to find the final image.
- Use lens equation to find the final image

\[ M = \frac{I_2}{O} = \left( \frac{I_2}{I_1} \right) \left( \frac{I_1}{O} \right) = M_1 \times M_2 \]

Cameras

- A camera is essentially a converging lens with a short focal length. Operating condition: \( p \gg f \rightarrow q \sim f \).

The f-number of a camera lens is the ratio of the focal length of the lens to its diameter.

\[ f-number \equiv \frac{f}{D} \]

The f-number is often given as a description of the lens “speed”.

A lens with a low f-number is a “fast” lens.

Eyes

- Eye is essentially an auto-focus camera

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

The Eye – Near and Far Points

- The near point is the closest distance for which the lens can accommodate to focus light on the retina.
  - Typically at age 10, this is about 18 cm
  - The average value is about 25 cm.
  - It increases with age.
    - Up to 500 cm or greater at age 60

- The far point of the eye represents the largest distance for which the lens of the relaxed eye can focus light on the retina.
  - Normal vision has a far point of infinity.

Farsighted:
Light rays reach the retina before they converge to form an image.

Nearsighted:
Person can focus on nearby objects but not those far away.
Nearsightedness

- Also called myopia
- The far point of the nearsighted person is not infinity and may be less than one meter.
- The nearsighted person can focus on nearby objects but not those far away.
- A diverging lens can be used to correct the condition.

Farsightedness

- Also called hyperopia
- The near point of the farsighted person is much farther away than that of the normal eye.
- Can usually see far away objects clearly, but not nearby objects
- A converging lens placed in front of the eye can correct the condition.

Simple Magnifier

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

  \[
m = \frac{q_p}{p} = 25 \text{ cm}/f \text{ for near point}
\]

Telescopes

- Telescope is another type of angular magnification device with configuration \( L \approx \frac{f_o + f}{-f} \)

  \[
m = \frac{f}{f_o}
\]

Note:
For telescope application, object distance cannot be adjusted.
Compound Microscopes

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

Final Image:
Virtual, inverted

$$m_e = \frac{L}{f_o}$$
$$M_e = 25 \, \text{cm} / f_o$$
$$M = m_o M_e = \left( \frac{L}{f_o} \right) \left( 25 \, \text{cm} / f_o \right)$$