Physics 202, Lecture 25

Today’s Topics

- Image Formation
- Real Image, Virtual Image, and No Image
- Ray Diagram
- Images Formed by:
  - Flat Mirrors, Spherical Mirrors, Refraction, Thin Lenses
  - Camera, Eye, Simple Magnifier, Microscope, Telescope. (Thursday)

Review: Reflection and Refraction

- Law of reflection: \( \theta'_1 = \theta_1 \)
- Law of refraction:
  \[
  \frac{\sin \theta_1}{n_1} = \frac{\sin \theta_2}{n_2}
  \]
  \[
  I_{\text{in}} = I_{\text{reflection}} + I_{\text{refraction}} (\mp I_{\text{absorption}})
  \]
  Neglected unless indicated otherwise.

Note: Frequency (color) is unchanged in reflection and refraction.

Imaging

- Imaging: visible object → optical device → image

  - Optical device
  - Image lights
  - Object lights
  - Real object
  - Image

  Note: If image can be formed, only two rays per point are necessary.

  - No Image: No point to point correspondence
  - Image Aberration (fuzzy): Poorly focused imaged points

Image Properties

- Image properties to be concerned include
  - Location, real/virtual, reduced/enlarged, upright/inverted, similar/distorted, …

Real and Virtual Images

- Real Image:
  - Image lights actually pass through image

- Virtual Image:
  - Image lights appear to have come from the image

  Real images can be formed on a screen.
**Image Formed by Plane Mirrors**

- **Parameters**
  - $d_o$: object distance
  - $d_i$: image distance
  - $h_o$: object height
  - $h_i$: image height
  - $M$: magnification

- **Properties**:
  - Image is virtual and behind the mirror.
  - Object distance = image distance
  - Lateral magnification $M=1$
  - Image is upright (for upright object)
  - Image has front/back reversal.

\[ d_o > 0, d_i < 0 \]
\[ M = \frac{d_i}{d_o} = 1 \]

**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.

- **Notes**:
  - Each mirror has one focal point while each lens has two.
  - Focal points can be “virtual”
  - Lights emitted from focal point will become parallel after mirror (or lens)

**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.

**Mirror Equation and Magnification**

- **Parameters**
  - $d_o$: object distance
  - $d_i$: image distance
  - $h_o$: object height
  - $h_i$: image height
  - $M$: magnification
  - $f$: focal length

- **Equations**:
  \[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]
  \[ d_i = \frac{fd_o}{d_o - f} \]

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

- **Notes**:
  - If $|M|<1 \rightarrow$ Image < Object
  - If $|M|>1 \rightarrow$ Image > Object
  - If $M<0 \rightarrow$ Image ↓↓ Object
  - If $M>0 \rightarrow$ Image ↑↑ Object
Image Formed by Plane Mirrors

In View of Mirror Equation

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

Properties:
- Image is virtual and behind the mirror.
- Object distance = image distance
- Lateral magnification \( M = 1 \)
- Image is upright (for upright object)
- Image has front/back reversal.

\( f = \infty \Rightarrow d_i = -d_o \)
\( d_o > 0, d_i < 0 \)
\( M = -\frac{d_i}{d_o} = 1 \)

Quiz 1: Is there another convenient ray to use?
Quiz 2:
1. Real or virtual?
2. Upright or inverted?
3. Enlarged or reduced?

Answer: Virtual, upright (\( M > 0 \)), reduced (\( |M| < 1 \))

Image Formed by Convex Mirror

\( f = R/2 < 0 \)
\( \frac{1}{p} + \frac{1}{q} = \frac{1}{f} \)
\( q = \frac{np}{p-f} > 0 \)
\( 0 < M = -\frac{d_i}{d_o} < 1 \)

Image Formed by Concave Mirrors

Object (O) in between F and Mirror:
virtual, upright, enlarged

Object in front of Mirror:
real, inverted. Enlarged or reduced, depending on \( p \).

Image Formed by Refraction

\( R = \infty \)
\( q^2 = p(n_2/n_1) \)
\( M = q/p \)
\( n_o/n_i < 1 \)

Example: looking at a fish
Closer, not-inverted, reduced, virtual…
Thin Lenses

- Lenses are refractive optical devices with two spherical sides.

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

Lens maker’s equation

- $F_1, F_2$: Focal points
- $f = f_1 = f_2$: Focal length

- $f > 0$: converging
- $f < 0$: diverging

Images Formed by Converging Lens

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

$$\frac{1}{p} - \frac{1}{q} = \frac{1}{f}$$

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

Images Formed by Diverging Lenses

- Images are always virtual, upright, and reduced
## Sign Conventions (Pan’s version)

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<tr>
<th></th>
<th>&gt;0</th>
<th>&lt;0</th>
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<tr>
<td>f</td>
<td>concave mirrors</td>
<td>convex mirrors</td>
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<tr>
<td></td>
<td>converging lens</td>
<td>diverging lens</td>
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<tr>
<td>R</td>
<td>center at image side</td>
<td>center at other side</td>
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<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>
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<tr>
<td>M=q/p</td>
<td>upright</td>
<td>inverted</td>
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<th>Image Side</th>
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<td>front</td>
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<td>observer's side</td>
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<th>Object Side</th>
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<td>front</td>
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<td>opposite to observer's side</td>
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