Physics 202, Lecture 23

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. (Next Tuesday)

Review: Reflection and Refraction

Law of reflection:
\[ \theta_1' = \theta_1 \]

Law of refraction:
\[ \frac{\sin \theta_1}{n_1} = \frac{\sin \theta_2}{n_2} \]

\[ I_{\text{in}} = I_{\text{reflection}} + I_{\text{refraction}} (+ I_{\text{absorption}}) \]

neglected unless indicated otherwise

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

Imaging

- Imaging: visible object → optical device → image

Real and Virtual Images

- Real Image: image lights actually pass through image
- Virtual Image: image lights appear to have come from the image

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

Imaging

- 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 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

\[
\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}
\]

\[
d_i = \frac{fd_o}{d_o - f}
\]

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

- If \(|M|<1\) → Image < Object
- If \(|M|>1\) → Image > Object
- If \(M<0\) → Image ↓↑ Object
- If \(M>0\) → 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

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

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 \( p \).

\[
f = R/2
\]
\[
\frac{1}{p} + \frac{1}{q} = \frac{1}{f}
\]
\[
M = \frac{h_i}{h_o} = -\frac{q}{p}
\]

Image Formed by Refraction

\[
R = \infty
\]
\[
q = -p(n_2/n_1)
\]
\[
M = \frac{q}{p} = n_2/n_1 < 1
\]

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

- Lenses are refractive optical devices with two spherical sides.

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

- \( F_1, F_2 \): Focal points
- \( f = f_1 = f_2 \): Focal length
- \( f > 0 \): converging
- \( f < 0 \): diverging

Lens maker’s equation

**Converging and Diverging Lenses**

- **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.

- **Images Formed by Diverging Lenses**
  - Images are always virtual, upright, and reduced
### Sign Conventions (Pan’s version)

<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, converging lens</td>
<td>convex mirrors, 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>

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