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

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

Imaging

- Imaging: visible object → optical device → image

- Real image: image lights actually pass through image
  - Location, real/virtual, reduced/enlarged, upright/inverted, similar/distorted...

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

Image Properties

- 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.
**Image Formed by Plane Mirrors**

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 left/right 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

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

If $|M| < 1 \rightarrow \text{Image} < \text{Object}$
If $|M| > 1 \rightarrow \text{Image} > \text{Object}$
If $M < 0 \rightarrow \text{Image} \downarrow \text{Object}$
If $M > 0 \rightarrow \text{Image} \uparrow \text{Object}$
Image Formed by Plane Mirrors

In View of Mirror Equation

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, left/right reversal.

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

Image Formed by Convex Mirror

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 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

Example: looking at a fish

$R = \infty$, $q^e = p(n_2/n_1)$, $M=q/p =n_2/n_1<1$

Closer, not-inverted, reduced, virtual...
Thin Lenses

- Lenses are refractive optical devices with two spherical sides.

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

- Focal points: \( F_1, F_2 \)
- Focal length: \( f \)
- \( f > 0 \): 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)

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<thead>
<tr>
<th></th>
<th>&gt;0</th>
<th>&lt;0</th>
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<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>
</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>
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<table>
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<th>Object Side</th>
<th>Image Side</th>
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<tr>
<td>lenses</td>
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<td>refraction surface</td>
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