Today’s Topics

- Image Formation
- Real Image, Virtual Image
- Images Formed by:
  - Flat Mirrors, Spherical Mirrors,
    Refraction, Thin Lenses

Ray diagrams, Mirror/lenses equations
Basic processes: Reflection and Refraction

Law of reflection:
\[ q_1' = q_1 \]

Law of refraction:
\[
\frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1} = \frac{n_1}{n_2}
\]

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

- Images can result when light rays encounter flat or curved surfaces between two media.

- Images can be formed either by reflection or refraction due to these surfaces.

- Mirrors (reflection) and lenses (refraction) can be designed to form images with desired characteristics.
Imaging

- Imaging: visible object $\rightarrow$ optical device $\rightarrow$ image

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

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

- Images are located either at a point from which the rays of light *actually* diverge or at a point from which they *appear* to diverge.

  → A *real image* is formed when light rays pass through and diverge from the image point.
    - Real images can be displayed on screens.

  → A *virtual image* is formed when light rays do not pass through the image point but only appear to diverge from that point.
    - Virtual images cannot be displayed on screens.
Notation for Mirrors and Lenses

- The object distance is the distance from the object to the mirror or lens.
  - Denoted by $p$

- The image distance is the distance from the image to the mirror or lens.
  - Denoted by $q$

- The lateral magnification of the mirror or lens is the ratio of the image height to the object height.
  - Denoted by $M$
Images Formed by Flat Mirrors: Ray diagram technique

- One ray starts at point $P$, travels to $Q$ and reflects back on itself.

- Another ray follows the path $PR$ and reflects according to the law of reflection.

- The triangles $PQR$ and $P'QR$ are congruent.

Because the triangles $PQR$ and $P'QR$ are congruent, $|p| = |q|$ and $h = h'$.
Properties of the Image by a Flat Mirror

- The image is as far behind the mirror as the object is in front.
  - $|p| = |q|$
- The image is unmagnified.
  - The image height is the same as the object height.
    - $h' = h$
    - Magnification: $M = h'/h = +1$
- The image is virtual.
- The image is upright.
- There is no left-to-right reversal in the image.

The thumb is on the left side of both real hands and on the left side of the image. That the thumb is not on the right side of the image indicates that there is no left-to-right reversal.
Spherical Mirrors

- A spherical mirror has the shape of a section of a sphere.

- A **concave** spherical mirror has the silvered surface of the mirror on the inner, or concave, side of the curve.

- A **convex** spherical mirror has the silvered surface of the mirror on the outer, or convex, side of the curve.

- The mirror focuses incoming parallel rays to a point, the “focal point” F.
Concave Mirror, Notation

- The mirror has a radius of curvature of $R$.
- Its center of curvature is the point $C$.
- Point $V$ is the center of the spherical segment.
- A line drawn from $C$ to $V$ is called the principal axis of the mirror.

- We use only rays that diverge from the object and make a small angle with the principal axis: the paraxial rays.
The Ray Diagram – Concave Mirrors

- Ray 1 is drawn from the top of the object parallel to the principal axis and is reflected through the focal point, $F$.
- Ray 2 is drawn from the top of the object through the focal point and is reflected parallel to the principal axis.
- Ray 3 is drawn through the center of curvature, $C$, and is reflected back on itself.
Image Formed by Concave Mirrors

Object in between F and Mirror:
virtual, upright, enlarged

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

\[ M > 0 \quad (q < 0), \quad |M| > 1 \]

\[ M < 0, \quad |M| > 1 \text{ or } < 1 \]
Three-ray technique (here one more ray available)
1. Real or virtual?
2. Upright or inverted?
3. Enlarged or reduced?
Note: By convention, \( f < 0 \); \( q < 0 \).

- Answer: Virtual, upright (\( M > 0 \)), reduced (\(|M| < 1\))
# Sign Conventions, Summary Table

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Positive When . . .</th>
<th>Negative When . . .</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object location ((p))</td>
<td>object is in front of mirror (real object).</td>
<td>object is in back of mirror (virtual object).</td>
</tr>
<tr>
<td>Image location ((q))</td>
<td>image is in front of mirror (real image).</td>
<td>image is in back of mirror (virtual image).</td>
</tr>
<tr>
<td>Image height ((h'))</td>
<td>image is upright.</td>
<td>image is inverted.</td>
</tr>
<tr>
<td>Focal length ((f)) and radius ((R))</td>
<td>mirror is concave.</td>
<td>mirror is convex.</td>
</tr>
<tr>
<td>Magnification ((M))</td>
<td>image is upright.</td>
<td>image is inverted.</td>
</tr>
</tbody>
</table>

Section 36.2
Image Formed by Refraction

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

Example: looking at a fish

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

\[ \frac{n_1 + n_2}{p} = \frac{n_2 - n_1}{q} = \frac{R}{R} \]

\[ M = \frac{h'}{h} = -\frac{q}{p} \]
Lenses are refractive optical devices with two spherical sides.

$L_1, L_2$: Focal points
$f = f_1 = f_2$: Focal length

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

Lens maker’s equation

$f > 0$: converging
$f < 0$: diverging
Converging and Diverging Lenses

sign convention:
\[ f > 0 \]

sign convention:
\[ f < 0 \]