Chapter 34

Images

One of the most important uses of the basic laws governing light is the production of images. Images are critical to a variety of fields and industries ranging from entertainment, to security, to medicine.

In this chapter we define and classify images, and then classify several basic ways in which they can be produced.
Two Types of Images

Image: A reproduction derived from light.

Real Image: Light rays actually pass through image, really exist in space (or on a screen for example) whether you are looking or not.

Virtual Image: No light rays actually pass through image. Only appear to be coming from image. Image only exists when rays are traced back to perceived location of source.
A Common Mirage

Light travels faster through warm air → warmer air has smaller index of refraction than colder air → refraction of light near hot surfaces.

For observer in car, light appears to be coming from the road top ahead, but is really coming from the sky.

Fig. 34-1
Plane Mirror:  \( i = -p \)

Since \( I \) is a virtual image, \( i < 0 \).
Plane Mirrors, Extended Object

Each point source of light in the extended object is mapped to a point in the image.
Plane Mirrors, Mirror Maze

Your eye traces incoming rays straight back, and cannot know that the rays may have actually been reflected many times.

Fig. 34-6
Spherical Mirrors, Making a Spherical Mirror

Plane mirror → concave mirror
1. Center of curvature C:
   in front at infinity → in front but closer
2. Field of view
   wide → smaller
3. Image
   $i = p \rightarrow |i| > p$
4. Image height
   image height = object height → image height > object height

Plane mirror → convex mirror
1. Center of curvature C:
   in front at infinity → behind mirror and closer
2. Field of view
   wide → larger
3. Image
   $i = p \rightarrow |i| < p$
4. Image height
   image height = object height → image height < object height

Fig. 34-7
Spherical Mirrors, Focal Points of Spherical Mirrors

Fig. 34-8

Spherical Mirror: \( f = \frac{1}{2} r \)

- \( r > 0 \) for concave (real focal point)
- \( r < 0 \) for convex (virtual focal point)
Images from Spherical Mirrors

Start with rays leaving a point on object, where they intersect, or appear to intersect, marks the corresponding point on the image.

Real images form on the side where the object is located (side to which light is going). Virtual images form on the opposite side.

Spherical Mirror: \( \frac{1}{p} + \frac{1}{i} = \frac{1}{f} \)

Lateral Magnification: \( m = \frac{h'}{h} \)

Lateral Magnification: \( m = -\frac{i}{p} \)
1. A ray that is parallel to central axis reflects through $F$.
2. A ray that reflects from mirror after passing through $F$ emerges parallel to central axis.
3. A ray that reflects from mirror after passing through $C$ returns along itself.
4. A ray that reflects from mirror after passing through $c$ is reflected symmetrically about the central axis.
Proof of the Magnification Equation

Similar triangles (are angles same?)

\[
\frac{de}{ab} = \frac{cd}{ca} \quad cd = i, \quad ca = p, \quad \frac{de}{ab} = -m
\]

\[\rightarrow m = -\frac{i}{p} \quad \text{(magnification)}\]
Real images form on the side of a refracting surface that is opposite the object (side to which light is going). Virtual images form on the same side as the object.

**Spherical Refracting Surface:**

\[
\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}
\]

When object faces a convex refracting surface, \( r \) is positive. When it faces a concave surface, \( r \) is negative. CAUTION: This is reverse of mirror sign convention!

---

(34-12)
Thin Lenses

**Converging lens**

![Converging lens diagram](image)

**Diverging lens**

![Diverging lens diagram](image)

**Thin Lens:** \( \frac{1}{f} = \frac{1}{p} + \frac{1}{i} \)

**Thin Lens in Air:** \( \frac{1}{f} = n - 1 \left( \frac{1}{r_1} - \frac{1}{r_2} \right) \)

Lens only can function if the index of the lens is different from that of its surrounding medium.

*(34-13)*
Images from Thin Lenses

Real images form on the side of a lens that is opposite the object (side to which light is going). Virtual images form on the same side as the object.
1. A ray initially parallel to central axis will pass through $F_2$.
2. A ray that initially passes through $F_1$, will emerge parallel to central axis.
3. A ray that initially is directed toward the center of the lens will emerge from the lens with no change in its direction (the two sides of the lens at the center are almost parallel).
1. Let $p_1$ be the distance of object $O$ from Lens 1. Use equation and/or principle rays to determine the distance to the image of Lens 1, $i_1$.

2. Ignore Lens 1, and use $I_1$ as the object $O_2$. If $O_2$ is located beyond Lens 2, then use a negative object distance $p_1$. Determine $i_2$ using the equation and/or principle rays to locate the final image $I_2$.

The net magnification is: $M = m_1 m_2$
Optical Instruments, Simple Magnifying Lens

You can make an object appear larger (greater angular magnification) by simply bringing it closer to your eye. However, the eye cannot focus on objects closer than the near point: $p_n \approx 25 \text{ cm} \rightarrow \text{BIG & BLURRY IMAGE}$

A simple magnifying lens allows the object to be placed close by making a large virtual image that is far away.

Simple Magnifier: $m_\theta \approx \frac{25 \text{ cm}}{f}$
Optical Instruments, Compound Microscope

Fig. 34-18

$$m = -\frac{i}{p} = -\frac{s}{f_{ob}}$$ since $i \approx s$ and $p \approx f_{ob}$

$$M = mm_{o} = -\frac{s}{f_{ob}} \cdot \frac{25 \text{ cm}}{f_{ey}}$$ magnification compounded (microscope)
Optical Instruments, Refracting Telescope

**Fig. 34-19**

\[ m_\theta = -\frac{\theta_{ey}}{\theta_{ob}}, \quad \theta_{ob} = \frac{h'}{f_{ob}}, \quad \theta_{ey} \approx \frac{h'}{f_{ey}} \]

\[ \rightarrow m_\theta = -\frac{f_{ob}}{f_{ey}} \quad \text{(telescope)} \]
Three Proofs, The Spherical Mirror Formula

\[
\beta = \alpha + \theta \quad \text{and} \quad \gamma = \alpha + 2\theta
\]

\[
\theta = \beta - \alpha = \frac{1}{2} \gamma - \alpha \quad \rightarrow \quad \alpha + \gamma = 2\beta
\]

\[
\alpha \approx \frac{ac}{cO} = \frac{ac}{p}, \quad \beta = \frac{ac}{cC} = \frac{ac}{r}
\]

\[
\gamma = \frac{ac}{CI} = \frac{ac}{i}
\]

\[
f = \frac{1}{2} r \rightarrow r = 2f
\]

\[
\frac{ac}{p} + \frac{ac}{i} = 2 \frac{ac}{2f} \rightarrow \frac{1}{p} + \frac{1}{i} = \frac{1}{f}
\]

(34-20)
Three Proofs, The Refracting Surface Formula

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
\[ n_1 \theta_1 \approx n_2 \theta_2 \quad \text{if } \theta_1 \text{ and } \theta_2 \text{ are small} \]
\[ \theta_1 = \alpha + \beta \quad \text{and} \quad \beta = \theta_2 + \gamma \]
\[ n_1 \alpha + \beta = n_2 \beta - \gamma \]
\[ \rightarrow n_1 \alpha + n_2 \gamma = n_2 - n_1 \beta \]
\[ \alpha \approx \frac{ac}{p}; \quad \beta = \frac{ac}{r}; \quad \gamma \approx \frac{ac}{i} \]
\[ n_1 \frac{ac}{p} + n_2 \frac{ac}{i} = n_2 - n_1 \frac{ac}{r} \]
\[ \rightarrow \frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r} \]

(34-21)
Three Proofs, The Thin Lens Formulas

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

where \( n_1 = 1 \) and \( n_2 = n \)

\[ \frac{1}{p'} + \frac{n}{i'} = \frac{n-1}{r'} \]

Eq. 34-22

\[ p'' = i' + L \]

\[ \frac{n}{i' + L} + \frac{1}{i''} = \frac{1-n}{r''} \]; if \( L \) small \( \rightarrow \frac{n}{i'} + \frac{1}{i''} = -\frac{n-1}{r''} \)

Eq. 34-25

\[ \frac{1}{p'} + \frac{n}{i''} = n-1 \left( \frac{1}{r'} - \frac{1}{r''} \right) \rightarrow \frac{1}{p} + \frac{1}{i} = n-1 \left( \frac{1}{r} - \frac{1}{r''} \right) \]