Chapter 25: Applied Optics
Operation of the Eye
Structure of the Eye

- **Essential parts of the eye**
  - Cornea – transparent outer structure
  - Pupil – opening for light
  - Lens – partially focuses light
  - Retina – location of image
  - Optic nerve – sends image to brain

- **Eye focuses light on retina**
  - Most refraction at cornea
  - Rest of refraction at lens
Iris Regulates Light Entering Eye

The iris is the colored portion of the eye

- A muscular diaphragm controlling pupil size (regulates amount of light entering eye)
- Dilates the pupil in low light conditions
-Contracts the pupil in high-light conditions
Operation of Eye

- Cornea-lens system focuses light onto retina (back surface)
  - Retina contains receptors called rods (110M) and cones (7M)
  - Rods & cones send impulses to brain via optic nerve (1M fibers)
  - Brain converts impulses into our conscious view of the world
Picture of Retina (Seen Through Pupil)
Rods Close Up (Retina Cross Section)
Structure of Rods and Cones

[Diagram showing the structure of rods and cones, including photoreceptor, plasma membrane, rhodopsin, retinal, and various cellular components like mitochondria and Golgi.

Hargrave, 1996]
Color Perception in Rods and Cones

- One type of rod
  - Monochromatic vision
  - Only used for night vision
  - Highly sensitive

- 3 types of cones
  - 3 primary colors ⇒ color vision
  - Not as sensitive as rods

After Bowmaker & Dartnall, 1980
The Eye: Focusing

→ Distant objects
  - The ciliary muscle is relaxed
  - Maximum focal length of eye

→ Near objects
  - The ciliary muscles tenses
  - The lens bulges a bit and the focal length decreases
  - Process is called “accommodation”

→ Focal length of eye (normal)
  - \( f \approx 16.3 \text{ mm} \)
  - \( 1/f \approx 1 / 0.0163\text{m} = 60 \, \text{“diopters”} \) (= lens “power”)
  - During accommodation, power \((1/f)\) increases
Example of Image Size on Retina

Example: A tree is 50m tall and 2 km distant. How big is the image on the retina?

\[
\frac{h'}{16} = \frac{50}{2000} \quad h' = 0.4 \text{ mm}
\]
The Eye: Near and Far Points

→ **Near point** is the closest distance for which the lens can accommodate to focus light on the retina
  ◆ Typically at age 10, $p_{\text{near}} \sim 18 \text{ cm}$ (use $p_{\text{near}} = 25 \text{ cm}$ as average)
  ◆ It increases with age (presbyopia)
  ◆ If farsighted, then $p_{\text{near}} > 25$

→ **Far point** is the largest distance for which the lens of the relaxed eye can focus light on the retina
  ◆ For normal vision, far point is at infinity ($p_{\text{far}} = \infty$)
  ◆ If nearsighted, then $p_{\text{far}}$ is finite
Farsightedness (Hyperopia)

- The image focuses behind the retina
- See far objects clearly, but not nearby objects ($p_{\text{near}} > 25 \text{ cm}$)
- Not as common as nearsightedness
Correcting Farsightedness

→ A converging lens placed in front of the eye can correct hyperopia
  ◆ $1/f > 0$, rays converge and focus on retina

→ Example: assume $p_{\text{near}} = 200 \text{ cm} = 2 \text{ m}$
  ◆ Goal: See object at 25 cm (normal near point)
  ◆ Strategy: For object at 25 cm, make image appear at near point

\[
\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{0.25} + \frac{1}{-2.0} = 4 - 0.5 = +3.5 \text{ diopters}
\]
Nearsightedness (Myopia)

→ See near objects clearly, but not distant objects \((p_{\text{far}} < \infty)\)

→ Most common condition (reading, etc)
Correcting Nearsightedness

✍ A diverging lens can be used to correct the condition
  ◆ $1/f < 0$, rays diverge (spread out) and focus on retina

✍ Example: assume $p_{\text{far}} = 50 \text{ cm} = 0.5 \text{ m}$
  ◆ **Goal:** See objects at infinity (normal far point)
  ◆ **Strategy:** For object at infinity, make image appear at eye’s far point

\[
\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{\infty} + \frac{1}{-0.5} = -2.0 \text{ diopters}
\]
Presbyopia and Age

- Presbyopia is due to a reduction in accommodation range
  - Accommodation range is max for infants (60 – 73 diopters)
  - Shrinks with age, noticeable effect on reading after 40
  - Can be corrected with converging lenses (reading glasses)
Magnifier

- Consider small object held in front of eye
  - Height $y$
  - Makes an angle $\theta$ at given distance from the eye

- Goal is to make object "appear bigger" $\Rightarrow$ Larger $\theta$
Magnifier

- Single converging lens
  - Simple analysis: put eye right behind lens
  - Put object at focal point and image at infinity
  - Angular size of object is $\theta'$, bigger!

\[ p = f \]
\[ q = \infty \]
Angular Magnification (Simple)

- **Without magnifier:** 25 cm is closest distance to view
  - Defined by average near point (younger people can do closer)
  - \( \theta \approx \tan \theta = \frac{y}{25} \)

- **With magnifier:** put object at distance \( p = f \)
  - Image at infinity
  - \( \theta' \approx \tan \theta' = \frac{y}{f} \)

- Define “angular magnification” \( m_\theta = \frac{\theta'}{\theta} \)

\[
\begin{align*}
\theta & \quad \frac{y}{25} & \quad \theta' & \quad \frac{y}{f} \\
\frac{m_\theta}{\theta} & = \frac{\frac{\theta'}{\theta}}{f} & = \frac{25}{f}
\end{align*}
\]
Angular Magnification (Maximum)

- Can do better by bringing object closer to lens
  - Put image at near point, \( q = -25 \) cm
- Analysis
  - \( \theta \approx \tan \theta = y / 25 \)
  - \( \theta' \approx \tan \theta' = y / p \)
  - \( m_\theta = \theta' / \theta = 25 / p \)

\[
\frac{1}{p} + \frac{1}{-25} = \frac{1}{f} \\
\frac{1}{p} = \frac{1}{f} + \frac{1}{25} \\
m_\theta = \frac{25}{p} = \frac{25}{f} + 1
\]
Example

Find angular magnification of lens with $f = 4$ cm

$$m_\theta = \frac{25}{4} = 6.3 \quad \text{Simple}$$

$$m_\theta = \frac{25}{4} + 1 = 7.3 \quad \text{Maximum}$$
Example: Image Size of Magnifier

- How big is projected image of sun?
  - Sun is 0.5° in diameter (0.0087 rad)
  - Image located at focal point. (Why?)
  - Assume f = 5 cm
  - Size is $f \times \theta = 5 \times 0.0087 = 0.0435$ cm

- Energy concentration of 10 cm lens?
  - All solar rays focused on image
  - Energy concentration is ratio of areas
  - Concentration $= (10 / 0.0435)^2 = 53,000!$
  - Principle of solar furnace (mirrors)
Projectors

⇒ Idea: project image of slide onto distant screen

⇒ Put slide near focal point of lens
  ◆ Upside down to make image upright

![Diagram of Projector](image)

\[ q = \frac{pf}{p - f} \]
Projector Example

**Problem**
- Lens of 5 cm focal length
- Lens is 3 m from screen
- Where and how should slide be placed?

**Solution: real image required. Why?**
- \( q = 3 \text{ m} = +300 \text{ cm} \)
- \( f = 5 \text{ cm} \)
- Find \( p \) from lens equation
  \[
  \frac{1}{p} = \frac{1}{f} - \frac{1}{q}
  \]

\[
 p = \frac{qf}{q-f} = \frac{(300)(5)}{300-5} = 5.085 \text{ cm}
\]

**So 5.085 cm from lens, just past focal point**