For an object to be seen clearly…

The **lens** must adjust its radius of curvature using its **ciliary muscle** to change the curvature of the **lens** so as to form the image sharply on the **retina**.
The Eye

Normal (ciliary muscle is *relaxed*)

Parallel rays from infinity will form a sharp image on the retina.

Accommodation (ciliary muscle *contracts*): rays are not coming in parallel from infinity

*$R$* and *$f$* of lens will need to change to accommodate so that rays from close-by object will again form a sharp image on the retina.
The *perceived size* of an object depends on its actual image size on the retina:

- Both the **blue** (bigger) the **green** (smaller) arrows will be perceived to have the same angular size.
- Moving the **blue** arrow *closer* to the eye will result in a bigger image on the retina and thus a bigger *perceived* angular size.

The perceived **angular size** of an object is determined by the angle $\theta$ subtended by the image on the retina.
Thus, an object can appear to be magnified if it moves closer to the eye and the **Angular Magnification** $M$ is defined as the ratio:

$$M = \frac{\theta'}{\theta}$$

**Note:** The largest angular magnification is achieved at the closest distance from the eye (the **near point**) where the lens can still form a sharp image at the retina.

~ 25 cm (for healthy young adult)
Putting the object near the focal length of a magnifier forms a large virtual image with a larger angular size $\theta' > \theta$ for the eye.
Angular Magnification of a Magnifier

\[ \theta = \frac{y}{25cm} \quad \theta' = \frac{y}{f} \]

\[ M = \frac{\theta'}{\theta} = \frac{y/f}{y/25cm} = \frac{25cm}{f} \]
Compound Microscope

(a) Elements of a microscope

(b) Microscope optics

The objective forms a real, inverted image $I$ inside the focal point $F_2$ of the eyepiece.

The eyepiece uses the image $I$ as an object and creates an enlarged, virtual image $I'$ (still inverted).
Magnification of a Compound Microscope

Angular Magnification of a Compound Microscope:

\[ M_{\text{total}} = m_{\text{objective}} \times M_{\text{eyepiece}} \]

Lateral Magnification from Objective \times Angular Magnification from Eyepiece

\[ m_{\text{objective}} = \frac{s_1'}{s_1} \quad s_1 \approx f_1 = \frac{s_1'}{f_1} \]

\[ M_{\text{eyepiece}} = \frac{25\text{cm}}{f_2} \]

\[ M_{\text{total}} = \frac{(25\text{cm}) s_1'}{f_1 f_2} \]
Fermat’s Principle
Pierre de Fermat (1601-1665)

A general mathematical principle that can be used to analyze light path:

“When a light ray travels between two points, its path is the one that requires the least time.”

Application #1: uniform material \([n \text{ (or } v) \text{ is the same everywhere)!}\]

\[
t = \frac{d}{v} \quad \rightarrow \quad \text{Between any two points, the least time requires the shortest distance in an uniform medium.}
\]

Light will travel in a straight line in an uniform medium.
Application #2: Snell’s Law

Within $n_1$ and $n_2$, light travels in straight lines and total time of travel from $p$ to $q$ is,

$$t = \frac{r_1}{v_1} + \frac{r_2}{v_2} = \frac{\sqrt{a^2 + x^2}}{c/n_1} + \frac{\sqrt{b^2 + (d-x)^2}}{c/n_2}$$

Note: With two different speeds, the fastest way to get from $p$ to $q$ is not necessary a straight line!
Fermat’s Principle
(Application to Snell’s Law)

\[ t(x) = \frac{\sqrt{a^2 + x^2}}{c/n_1} + \frac{\sqrt{b^2 + (d-x)^2}}{c/n_2} \]

Find the value of \( x \) (the crossing point) such that the total travel time is minimized.

\[
\frac{dt}{dx} = 0 \quad \Rightarrow \quad \frac{n_1}{c} \left( \frac{1}{2} \right) \cdot \frac{2x}{\sqrt{a^2 + x^2}} + \frac{n_2}{c} \left( \frac{1}{2} \right) \cdot \frac{2(d-x)(-1)}{\sqrt{b^2 + (d-x)^2}} = 0
\]
Fermat’s Principle
(Application to Snell’s Law)

\[
\frac{n_1 x}{\sqrt{a^2 + x^2}} - \frac{n_2 (d - x)}{\sqrt{b^2 + (d - x)^2}} = 0
\]

\[
r_1^2 = a^2 + x^2
\]
\[
r_2^2 = b^2 + (d - x)^2
\]
\[
\sin \theta_1 = x/r_1
\]
\[
\sin \theta_2 = (d - x)/r_2
\]

\[
n_1 \sin \theta_1 - n_2 \sin \theta_2 = 0
\]
\[
n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \text{(Snell’s Law)}
\]
Physics 262

George Mason University

Prof. Paul So
Chapter 35: Interference

- Interference and Coherent Sources
- Two-Source Interference of Light
- Intensity of Interference Patterns
- Interference in Thin Films
- The Michelson Interferometer
Wave Nature of Light

- Previous Chapters (Geometric Optics) $\lambda << L$
  - Rays Model is an approximation of EM waves with rays pointing in the direction of propagation

- Next Couple of Chapters (Wave/Physical Optics) $\lambda \sim L$
  - Like water waves, light spreads and interferes with each other.
  - Observed phenomena cannot be accounted for by rays:

  - Diffraction
  - Interference

  ![Diffraction Image](image1)
  ![Interference Image](image2)

  spreading

  constructive/destructive interference patterns
Huygens’ Principle

Christiaan Huygens (1629-195): The Huygens’ Principle can be used to predict the spreading of light wave. It is a geometrical construction using every point on a wave front as the source of secondary wavelets that spread out in all directions with a speed equal to the speed of propagation of the wave.
Interference and Superposition

- **Interference** refers to a situation in which two or more waves overlap in space.

  The resultant displacement at any point is governed by the **principle of superposition**.

  “the *resultant* disturbance at any point and at any instant is found by *adding* the instantaneous disturbance that would be produced at the point by the *individual* waves as if each waves was present alone.”
Interference and Superposition

Constructive Interference (+ peaks aligns w/ + peaks)

\[ \text{wave 1} \oplus \text{wave 2} = \text{resulting wave} \]

Destructive Interference (+ peaks aligns w/ - peaks: \( \lambda/2 \) apart)

\[ \text{wave 1} \oplus \text{wave 2} = \text{resulting wave} \]

http://iwant2study.org/ospsg/index.php/interactive-resources/physics/04-waves/01-superposition/384-wave1d01