Recap

Geometrical Optics:

- Valid for
  1. Light beams with width \( \gg \lambda_{\text{light}} \)
  2. Objects with size \( \gg \lambda_{\text{light}} \)

  \( \Rightarrow \) Light travels in straight lines (rays) through vacuum and homogeneous materials.

- Speed of Light:

  \( v_{\text{light}} = \frac{c}{n} \)

  - Speed of light in vacuum: \( c = 3 \times 10^8 \text{ m/s} \)
  - Index of refraction: \( n \geq 1 \)

  - Law of Reflection: \( \theta' = \theta \)

  - Law of Refraction: \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \) (Snell’s Law)

  - Note: all angles are relative to the normal.
Today:

• Reflection and Refraction
  • Polarization
  • Chromatic dispersion
  • Rainbows
• Images
An inferior mirage on the Mojave Desert
(image seen is under the real object)

- A inferior mirage occurs when the air near the ground is much warmer than the air above.
- In this case the light rays are bent up and so the image appears below the true object.
An superior mirage
(image seen is above the real object)

- A superior mirage occurs when the air below the line of sight is colder than that above (temperature inversion)
- In this case the light rays are bent down and so the image appears above the true object
\( n_1 \sin \theta_1 = n_3 \sin \theta_3 \)

The angle \( \theta_1 \) is the same in both cases A and B.

For case B, how does the angle \( \theta_{3,B} \) that the ray makes with a normal to the interfaces when it’s in the medium with refractive index \( n_3 \) compare with \( \theta_{3,A} \)?

**A.** \( \theta_{3,B} < \theta_{3,A} \)  
**B.** \( \theta_{3,B} = \theta_{3,A} \)  
**C.** \( \theta_{3,B} > \theta_{3,A} \)  
**D.** It depends on the thickness of medium 2.
if \( n_2 > n_1 \Rightarrow \theta_2 < \theta_1 \),

\[ \sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1 \leq 1 \text{ (for some \( n_2 > n_1 \))} \]

\[ \sin \theta_2 = \frac{1}{\sqrt{n_2}} \sin \theta_1 \leq 1 \]

\[ \sin \theta_2 = \frac{1}{n_2} \sin \theta_1 \leq 1 \]

\[ \Rightarrow \] if \( \theta_1 \) is increased, eventually \( \theta_2 \rightarrow 90^\circ \).

\[ \text{at: } \theta_1 = \theta_c \]

This value of \( \theta_1 \) is called the **critical angle**: \( \sin \theta_c = n_2 / n_1 \)
\( \Rightarrow \) for \( \theta > \theta_c \): No refracted ray!

\( \Rightarrow \) all incident light is reflected?

"Total internal reflection"

for \( \theta > \theta_c = \arcsin \left( \frac{n_2}{n_1} \right) \)

(only for case when \( n_2 < n_1 \),
\( \Leftrightarrow \frac{n_2}{n_1} < 1 \))
Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by total internal reflection. This causes the fiber to act as a waveguide.
A right-angle isosceles prism can be used to redirect a high-power laser beam that would destroy a normal silvered mirror.

As shown in the figure, the beam enters the prism normal to one of its equal sides. In order for this to work, the refractive index of the prism must be greater than a particular value. What is this value?

A. 2.00.  B. 1.73.  C. 1.41.  D. 1.33.  E. 1.15.
In general, light reflected from an interface is partially polarized. **At one particular incidence angle** $\theta_B$ (the **Brewster angle**), the reflected light is completely polarized. For light incident at the Brewster angle, the reflected & refracted rays are $\perp$ to each other.
\[ \theta_B + \theta_2 = 90^\circ. \]

\[ n_1 \sin(\theta_B) = n_2 \sin(\theta_2) \]
\[ = n_2 \sin(90^\circ - \theta_B) \]
\[ = n_2 \cos(\theta_B). \]

\[ \tan(\theta_B) = \frac{n_2}{n_1}. \]

For Brewster angle \( \theta_B \).
Refraction of light at an interface between two media. The refractive index $n$ depends on the wavelength $\lambda$ (or frequency $f$) of the light. Generally, $n$ is greater for a shorter wavelength.

-> In general, $n$ (violet) > $n$ (red)
White light is incident on the prism as shown. Which color of light will hit higher (↑) on the screen?

A. Violet  B. Blue  C. Red
Rainbows:

Secondary rainbow:
Images:

- Light rays diverge from an object in all directions.
- We ‘see’ the object because some of these rays enter our eyes.
- We perceive the rays as coming straight from the location of the object / image.

- **Real images**: Perceived location of image is actually a point of convergence of the rays of light that make up the image.
- **Virtual images**: Rays only appear to diverge from a point on the image.
Real image

Real rays do converge at location of image (can put a screen at location of image and form the image)

Virtual image

Rays only appear to converge at location of image (your brain thinks the image is at this location, but it is not real)
Image formation by a plane (flat) mirror:

- Object distance: \( p > 0 \)
- Image distance: \( i < 0 \) here
  - Convention: \( i < 0 \) for virtual images

For plane mirror:

\[ i = -p \]

Define:

Lateral Magnification:

\[ m = \frac{h_i}{h_o} = \frac{\text{image height}}{\text{object height}} \]

- If \( m > 0 \): image is upright
- If \( m < 0 \): image is upside down

For plane mirror: \( m = 1 \)
A six foot tall man wants to buy a (plane) mirror that will allow him to see all of himself at once.

What must be the (approximate) minimum length of the mirror?

A. 3ft  B. 6ft  C. 9ft  D. 12 ft  E. Depends on how far in front of the mirror the man plans to stand.