Geometric Optics

• Ray Model
  • assume light travels in straight line
  • uses rays to understand and predict reflection & refraction
Reflection

- Law of reflection
  - the angle of incidence equals angle of reflection
  - angles are measured from normal
Reflection

Diffuse reflection

Specular reflection

(a) Eye at both positions sees the reflected light

(b) This eye does not see the light

This eye sees the light

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Plane Mirrors

A

\[ d_0 \]

\[ \theta_i \]

\[ \theta_f \]

B

D

B'

C

\[ d_i \]

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Plane Mirrors

The rays from P and Q that reach your eye reflect from different areas of the mirror.

Your eye intercepts only a very small fraction of all the reflected rays.
Think-Pair-Share

- How large a mirror do you need to see your whole body?
Spherical Mirrors

By using ray tracing and the law of reflection, you can figure out where the incoming rays are reflected.
Focal Point & Focal Length

- Parallel rays striking a concave mirror come together at focal point

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

- \( f \) = focal length
- \( r \) = radius of sphere

\[ r = 2f \]
Refraction

- index of refraction, $n$, where $c =$ speed of light in a vacuum and $v =$ speed of light in that medium

  \[ n = \frac{c}{v} \]

  - $n_{\text{air}} = 1$
  - $n_{\text{glass}} = 1.5$
  - Snell’s Law

  \[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

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# Indices of Refraction

<table>
<thead>
<tr>
<th>Substance</th>
<th>Index of Refraction</th>
<th>Substance</th>
<th>Index of Refraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solids at 20°C</strong></td>
<td></td>
<td><strong>Liquids at 20°C</strong></td>
<td></td>
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<tr>
<td>Cubic zirconia</td>
<td>2.20</td>
<td>Benzene</td>
<td>1.501</td>
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<tr>
<td>Diamond (C)</td>
<td>2.419</td>
<td>Carbon disulfide</td>
<td>1.628</td>
</tr>
<tr>
<td>Fluorite (CaF₂)</td>
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<td>Carbon tetrachloride</td>
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<tr>
<td>Fused quartz (SiO₂)</td>
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<td>Ethyl alcohol</td>
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<tr>
<td>Gallium phosphate</td>
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<td>Glycerin</td>
<td>1.473</td>
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<tr>
<td>Glass, crown</td>
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<td>Water</td>
<td>1.333</td>
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<tr>
<td>Glass, flint</td>
<td>1.66</td>
<td><strong>Gases at 0°C, 1 atm</strong></td>
<td></td>
</tr>
<tr>
<td>Ice (H₂O)</td>
<td>1.309</td>
<td>Air</td>
<td>1.000 293</td>
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<tr>
<td>Polystyrene</td>
<td>1.49</td>
<td>Carbon dioxide</td>
<td>1.000 45</td>
</tr>
<tr>
<td>Sodium chloride (NaCl)</td>
<td>1.544</td>
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</tbody>
</table>

*a* All values are for light having a wavelength of 589 nm in vacuum.

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Total Internal Reflection

- Incident angle where refracted angle ($\theta_2$) is 90 is the critical angle

\[ \sin \theta_C = \frac{n_2}{n_1} \sin 90^\circ = \frac{n_2}{n_1} \]

- At incident angles greater than critical angle, light is totally internally reflected

Important for fiber optic technology (endoscope)
**Thin Lenses**

(a) Converging lenses

Double convex  Planoconvex  Convex meniscus

(b) Diverging lenses

Double concave  Planoconcave  Concave meniscus

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Focal Length, Focal Plane and Power

- $f =$ focal length
- **Power**
  - inverse of focal length
  - $P = \frac{1}{f}$
  - measured in **diopter** (D)
  - $1 \text{ D} = 1 \text{ m}^{-1}$
Ray Tracing

(a) Ray 1 leaves one point on object going parallel to the axis, then refracts through focal point behind.

(b) Ray 2 passes through F’ in front of the lens; therefore it is parallel to the axis behind the lens.

(c) Ray 3 passes straight through the center of the lens (assumed very thin).

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Thin Lens Equation

\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]

Magnification

\[ m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \]
Sign Conventions

- focal length
  - positive for converging lenses
  - negative for diverging lenses
- object distance
  - positive if the object is on the side of the lens from which the light is coming (this is usually the case)
  - otherwise, it is negative (virtual object).
- image distance
  - positive if the image is on the opposite side of lens from where light is coming
  - positive for real images, negative for virtual images
- image height
  - positive if image is upright relative to object, negative for inverted images
  - $h_0$ is always positive
Combination of Lenses

- When adding two or more lenses in series, the focal length of the combined lenses, $f$, is:

\[
\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}
\]
Combining Lenses

- Measure the focal length of the two double-convex lenses individually.
- Combine the lenses together and **measure** the combined focal length.
- **Calculate** the combined focal length using the equation:
  \[
  \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}
  \]
- **Calculate** the percent error of your measured value.
Activity

- Handout with practice problems
  - Optics Worksheet 1