Refraction of Light

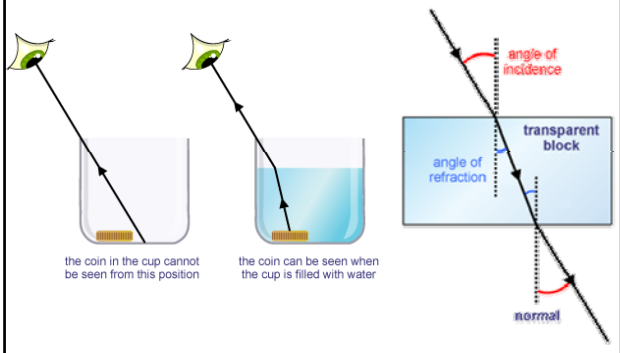
Refraction– is the bending of the path of a light wave as it passes from one material into another material.

Refraction occurs at the boundary and is caused by a change in the speed of the light wave upon crossing the boundary.

When the angle of incidence is 0° then refraction will **not** occur.

1

Refraction of Light



2

Index of Refraction

Index of Refraction (n)– measure of speed change of light from traveling through the medium

$$n = \frac{c}{v}$$

c = speed of light in vacuum

v = speed of light in medium

Medium	n
Vacuum	1.00
Air	1.0003
Water	1.33
Quartz	1.54
Diamond	2.42

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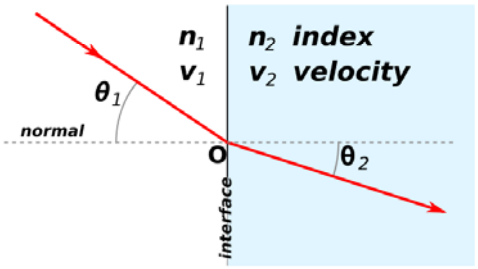
Snell's Law or Refraction

Snell's Law – $n_1 \sin\theta_1 = n_2 \sin\theta_2$



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Example Problem

The incident angle is 52° for a ray of light in air approaching water.

Determine the angle of refraction.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\frac{n_1 \sin\theta_1}{n_2} = \sin\theta_2$$

$$\frac{1.0003 \sin 52°}{1.33} = 0.59$$

$$\theta_2 = \text{Sin}^{-1}(0.59) = 36.35°$$

* **Set calculator mode to degrees!!**

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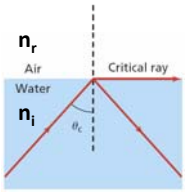
Total Internal Reflection

Critical Angle – Angle where refracted ray lies on boundary of mediums

$$\text{Sin}\,\theta_c = \frac{n_r}{n_i}$$

n_r = refractive medium

n_i = incident medium



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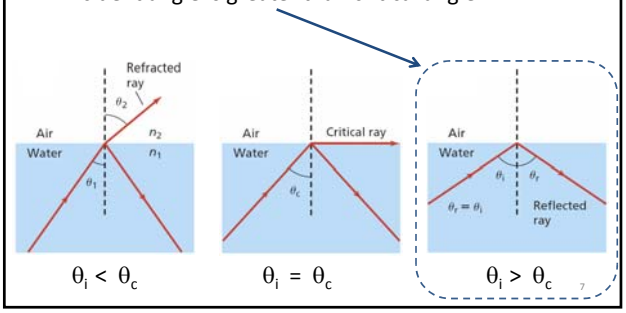
Total Internal Reflection

Total Internal Reflection – Light is completely reflected in medium with greater index of refraction when incident angle is greater than critical angle



$\theta_i < \theta_c$ $\theta_i = \theta_c$ $\theta_i > \theta_c$

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Total Internal Reflection

Looking up with an underwater camera

Refraction

Critical Angle

Total Internal Reflection

Taken at Valentin Imperial Maya, Riviera Maya, Mexico

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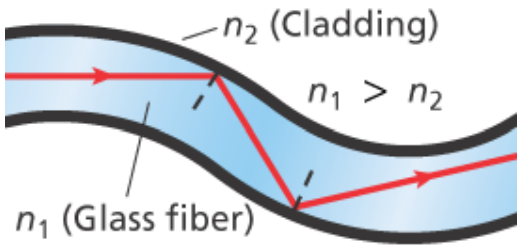
Total Internal Reflection



Fiber Optic Cable

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Example Problem

The critical angle for a special glass in air is 41°.

What is the critical angle of the glass in water?

$n_{air} = 1.0003$ $n_{water} = 1.33$

First Find n_i

$\sin\theta_c = \frac{n_r}{n_i}$ $\sin 41° = \frac{n_r}{n_i}$ $n_i = \frac{1.0003}{\text{Sin }(41°)} = 1.52$

Next Find θ_c in water

$\frac{n_r}{n_i} \frac{1.33}{1.52} = 0.87$ $\theta_c = \text{Sin}^{-1}(0.87) = 60.8°$

∗ **Set calculator mode to degrees!!**

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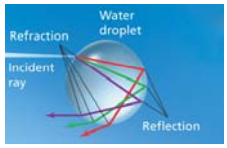
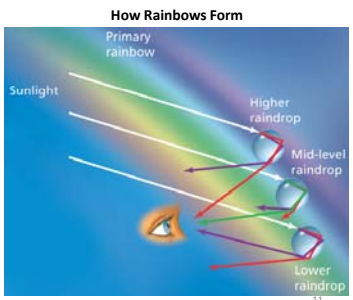
Refraction of Light

Dispersion – when light is separated into a spectrum of colors such as with a prism or raindrop.





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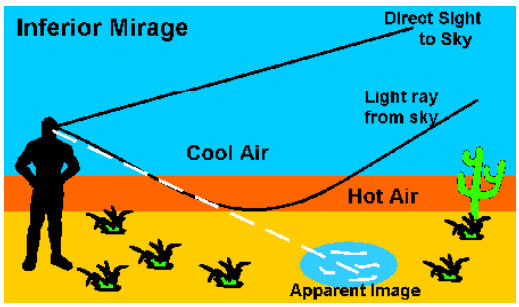
Mirages

Mirages occur when air masses with large differences in density refract the light



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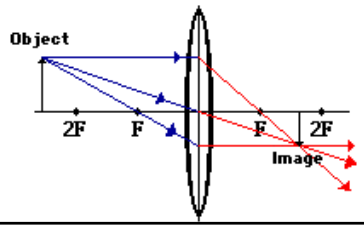
Convex Lenses

– thicker in the middle than the edges
– converges parallel light rays to a focal point
– focal length factors
- shape of the lens
- index of refraction of the material



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Rules for Convex Lens Ray Diagrams

- Parallel rays parallel refract through the lens and travel through the opposite focal point.
- Rays traveling through the focal point before the lens will refract through the lens and travel parallel.
- Rays passing through the center of the lens will continue in the same direction that it entered the lens.
- Objects in front of F will have image converge on the same side of the lens to form a virtual image. (Use dotted lines)

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Lens Equation and Magnification

This image size and location can be found mathematically as well

- Lens Equation : $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$
- Magnification : $m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$

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Sign Conventions for Lenses

Used in the lens and magnification equations:

f
+ for convex lenses (converging lens)
- for concave lenses (diverging lens)

d_i
+ if located on the opposite side (real image)
- if located on the object's side (virtual image)

h_i
+ if upright image (also virtual)
- if inverted image (also real)

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Object Locations (Convex Lens)

- Between F and 2F → a larger inverted image found past 2F on other side
- At 2F → same size, inverted image that is at 2F on the other side
- Past 2F → smaller inverted image found between F and 2F on the other side
- Before F → larger erect virtual image on same side

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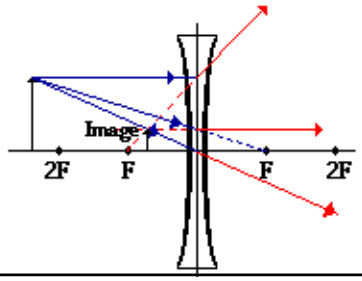
Concave Lenses

– thinner in the middle than the edges
– diverges parallel light rays from the focal point
– creates virtual image on object's side of lens



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Rules for Concave Lens Ray Diagrams

- Parallel rays parallel refract through the lens and travel in line with the focal point of the same side.
- Rays traveling towards the focal point after the lens will refract through the lens and travel parallel.
- Rays passing through the center of the lens will continue in the same direction that it entered the lens.
- Sight lines are drawn on the object's side of the lens for the first two cases. They intersect at the virtual image.

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Spherical Lens Defects

Spherical Aberration – inability to focus all parallel rays to a focal point
- Greatest effect is at edges
- lenses are often made aspherical

Chromatic Aberration – light can be slightly dispersed into different colors
- Greatest effect at edges
- Always present with single lenses
- Reduced by achromatic lens, a system of two or more lenses

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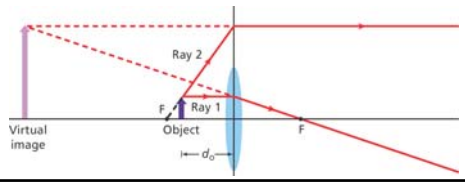
Effects of Lens Size

- A larger lens will collect more light → brighter image
- Covering part of the lens (masking) → dimmer image
- Any part of the lens can create a complete image
- The lens size drawn in a ray diagram is meaningless



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Eyeball Optics

Retina
- Image from light is focused on surface
- Absorbs light and send to brain

Cornea
- Most of focusing
- Air/cornea has greater difference in refractive indices

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Eyeball Optics

Lens
- Used for fine focus of near/far objects
- Muscles around lens contract/relax to change shape
  - Change in shape → change in f
- Contracts for short f, close objects
- Relaxes for long f, far objects

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Nearsightedness (Myopia)
- F is too short
- Image is in front of retina
- Fixed by using a concave lens

Farsightedness (Hyperopia)
- F is too long
- Image is formed past the retina
- Common in older people as lens becomes more rigid
- Fixed by using a convex lens

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Refracting Telescope

Objective Lens

- Collects light
- Focused as inverted, real image at focal point

Eyepiece

- placed so objective image is between the lens and the eyepiece focal point
- Achromatic lenses are common for eyepieces
- The final image is greatly magnified and inverted

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Binoculars

- Similar to telescope
- Uses a pair of prisms on each side

Prism Advantages

1. Uses total internal reflection to invert image
2. Extends light path inside
3. Allows each objective lens to be farther apart for a more "3-D" view, more depth

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Camera

- Light enters achromatic lens (acts as convex lens)
- When shutter closed, mirror reflects light through prism to invert and redirect light to viewfinder
- When shutter-release pressed, mirror raises, and light forms an image on the film

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Microscope

- Object between f and 2f of objective lens
- Real image from objective is inverted and larger
- The real image is located between the eyepiece lens and the eyepiece focal point
- Eyepiece makes a larger, upright, virtual image
- Viewer sees an image that is larger and inverted

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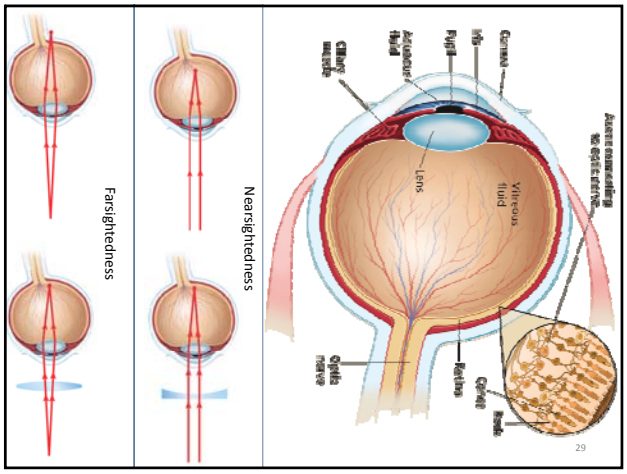

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