PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 21900

General Physics II

Electricity, Magnetism and Optics

Lecture 17 – Chapter 21.3-5

Refraction of Light

Fall 2015 Semester

Prof. Matthew Jones

Announcement

Exam #2 will be on November 5th
in Phys 112 at 8:00 pm

Electric current, DC circuits, Kirchhoff's Rules
Magnetic Fields, Lorentz Force, Forces on Currents
Ampere's Law, Magnetic Induction, Lenz's Law
Induced EMF, AC Voltage, Transformers

To keep the number of questions reasonable, some will require that you combine knowledge from multiple areas. For example, you might need to know Kirchhoff's rules and how to analyze series and parallel resistors in the same problem.

Refraction

- Refraction is the change in direction of a light ray when it passes from one medium to another.

"bent" straws

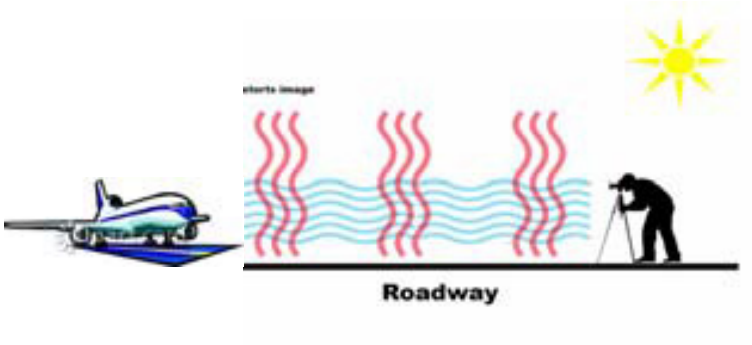
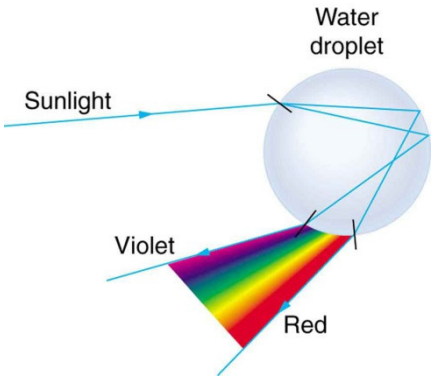


Image distortion



Rainbows

Refraction of Light

Angles of incidence and transmission are measured with respect to the normal line which is perpendicular to the interface.

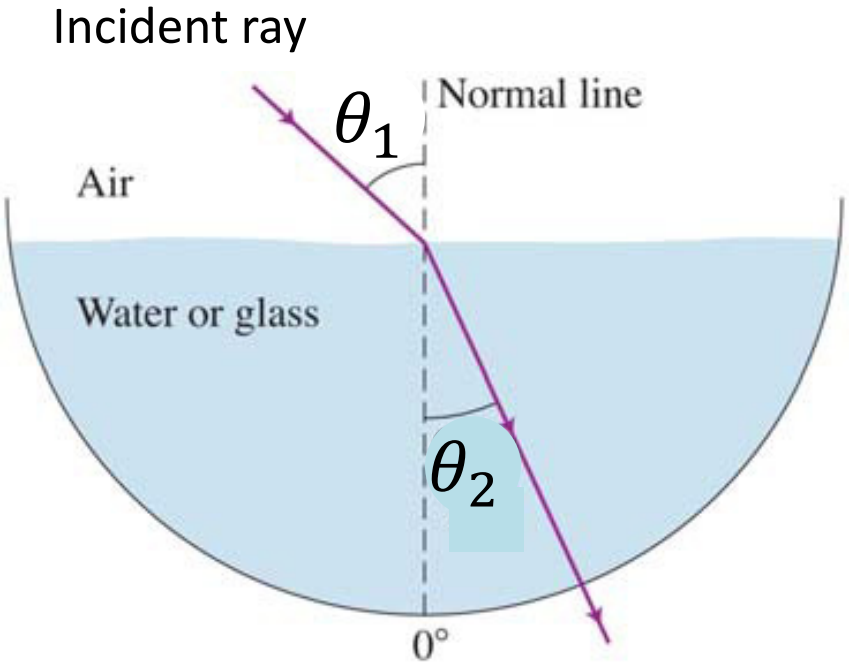


Table 21.6 Pattern found by Snell for ratio of the sines of the incident and refraction angles.

Air $\sin\theta_1$	Water $\sin\theta_2$	Glass $\sin\theta_2$	Air/water $(\sin\theta_1)/(\sin\theta_2)$	Air/glass $(\sin\theta_1)/(\sin\theta_2)$
0.000	0.000	0.000		
0.174	0.131	0.114	1.33	1.53
0.342	0.259	0.225	1.32	1.52
0.500	0.374	0.326	1.34	1.53
0.643	0.485	0.423	1.33	1.52
0.766	0.573	0.500	1.34	1.53
0.866	0.649	0.569	1.33	1.52

Index of refraction (n)

Experiment established a mathematical relationship between the angle of incidence and the angle of transmission that depends on the particular medium.

Index of Refraction

- The index of refraction is a property of a particular medium.
- Indices of refraction have been measured for many materials:

	Index of refraction
Air	1.0003
Water	1.33
Vegetable oil	1.47
Crown glass	1.51
Salt	1.54
Flint glass	1.61
Corundum (ruby, sapphire)	1.77*
Diamond	2.42

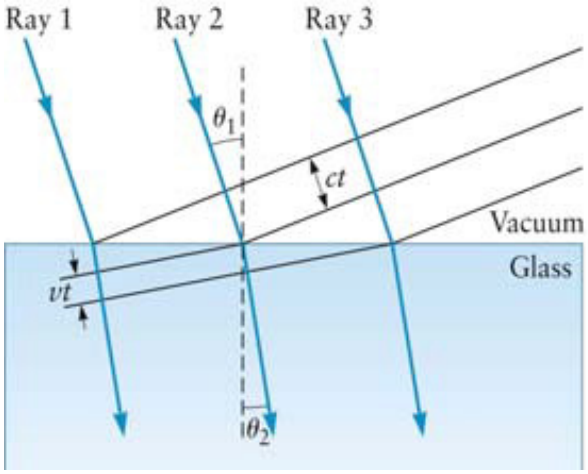
At 20° C, λ = 589 nm *Approximate value

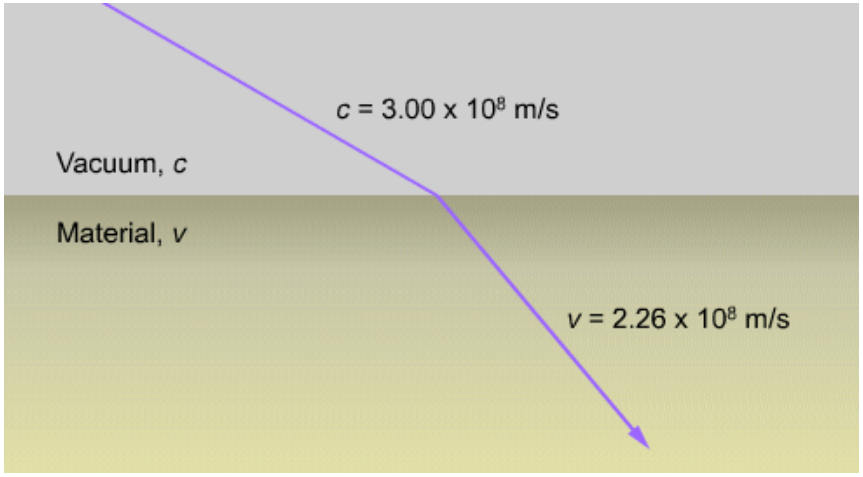
The index of refraction of vacuum is always n=1.

The index of refraction of any material is always n>1.

Origin of the Refractive Index

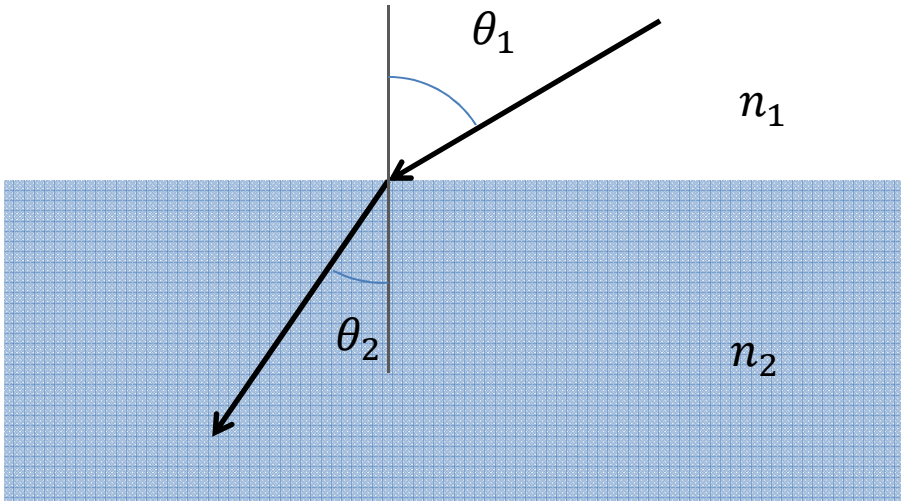
- Refraction is caused by the change in the speed at which light propagates in one material compared to the other.
- The index of refraction (n) is the ratio of the speed of light in vacuum (c) to the speed of light in the material (v).





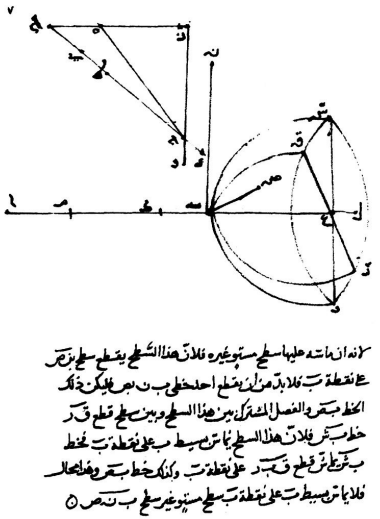
$$n = \frac{c}{v} = \frac{3.00 \times 10^8\ m/s}{2.26 \times 10^8\ m/s} = 1.33$$

Snell's Law (1621)*



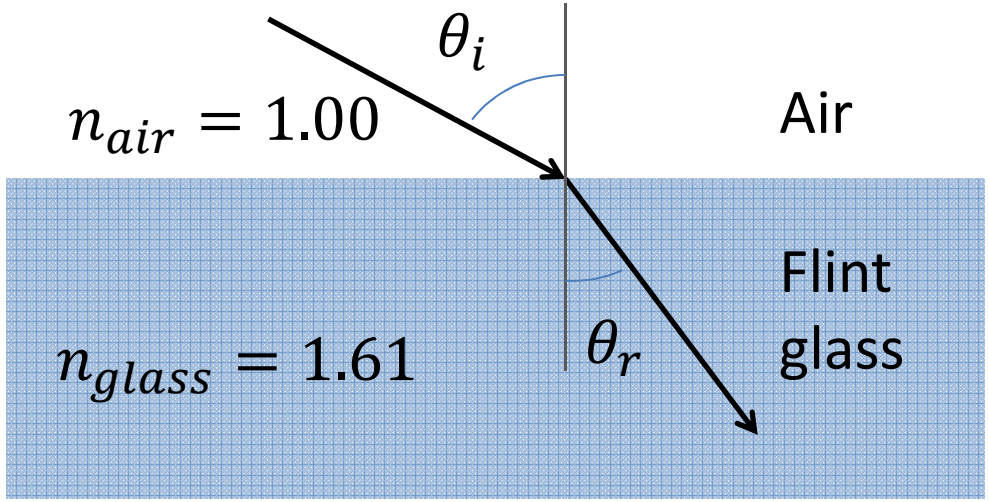
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

We use the convention where light propagates from medium 1 into medium 2.



* First reported by Ibn Sahl, Baghdad – 984 AD.

Examples



$$n_1 \sin(\theta_i) = n_2 \sin(\theta_r)$$

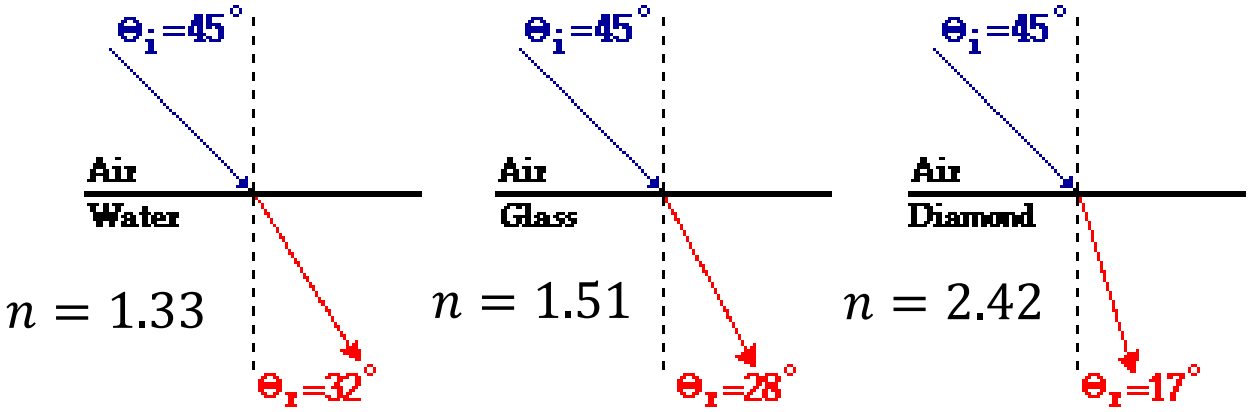
$$\sin(\theta_r) = \frac{n_1}{n_2} \sin(\theta_i)$$

$$= \frac{1.00}{1.61} \times \sin(35°)$$

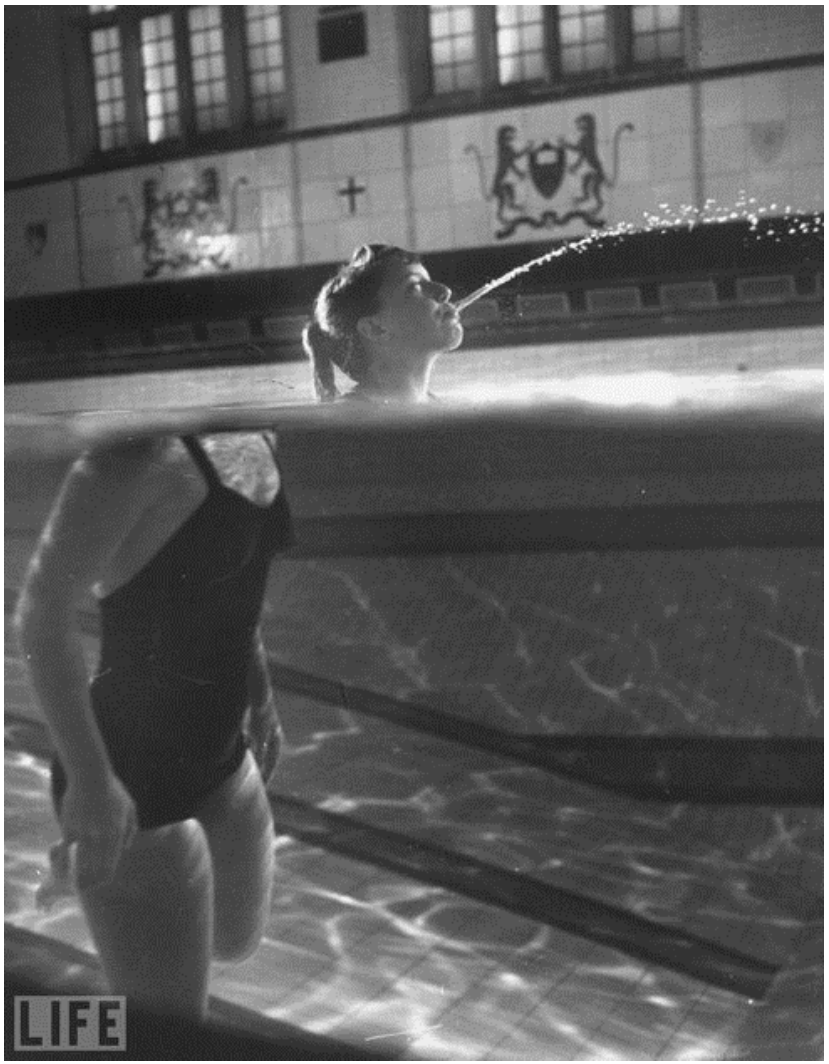
$$= 0.356$$

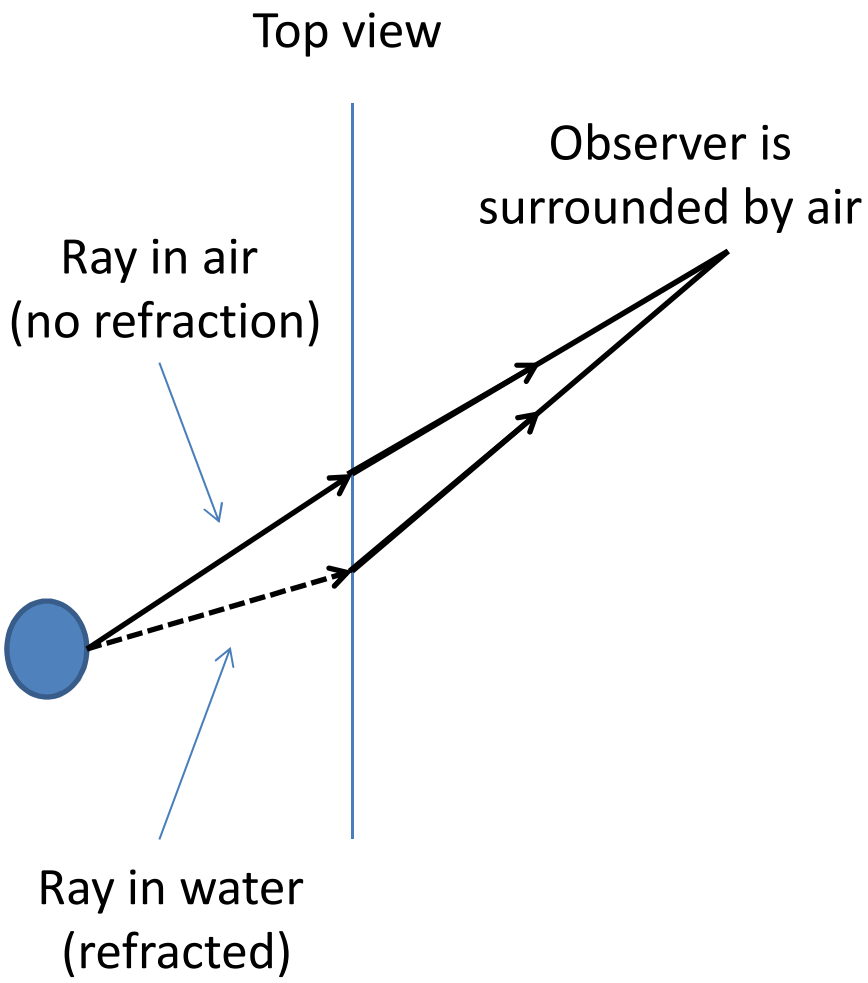
$$\theta_r = \sin^{-1}(0.356)$$

$$\theta_r = 20.9°$$

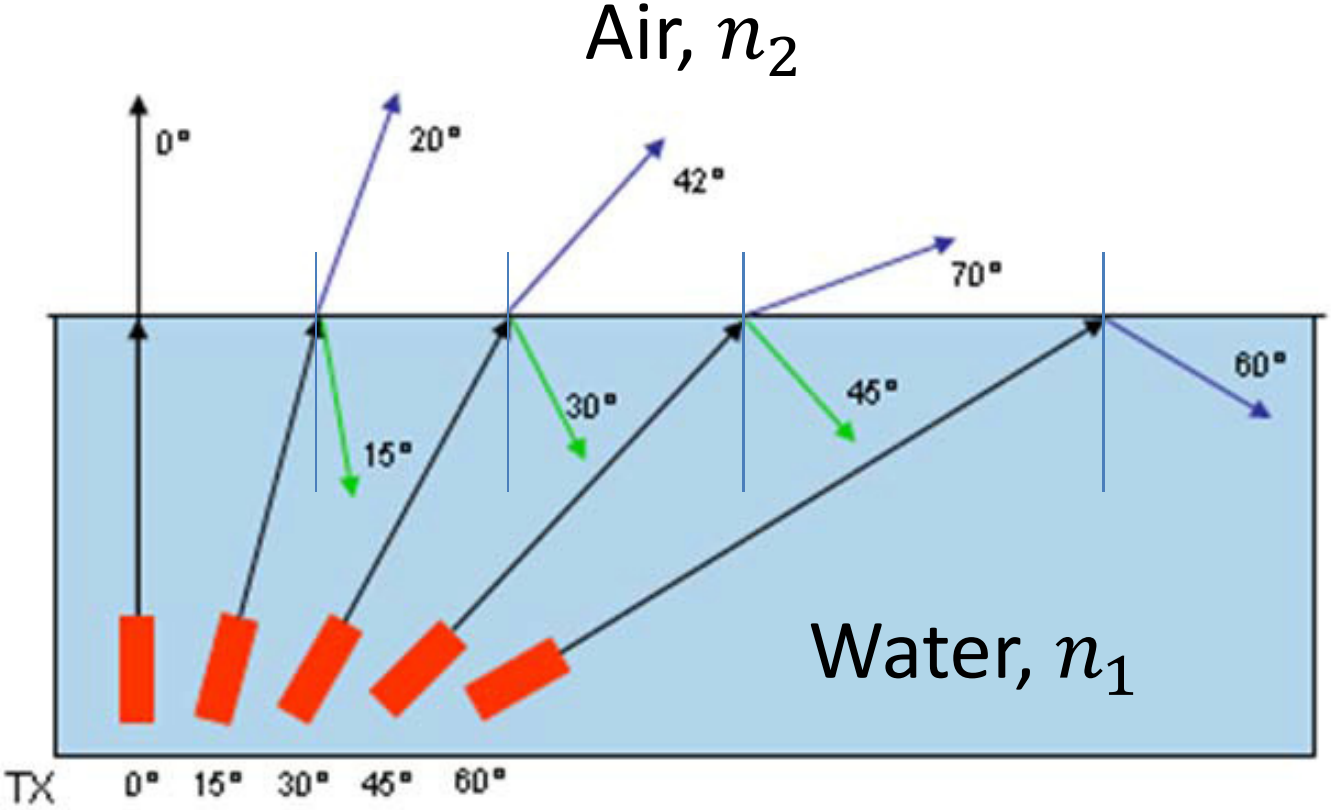


Example


LIFE


Top view
Observer is surrounded by air
Ray in air (no refraction)
Ray in water (refracted)

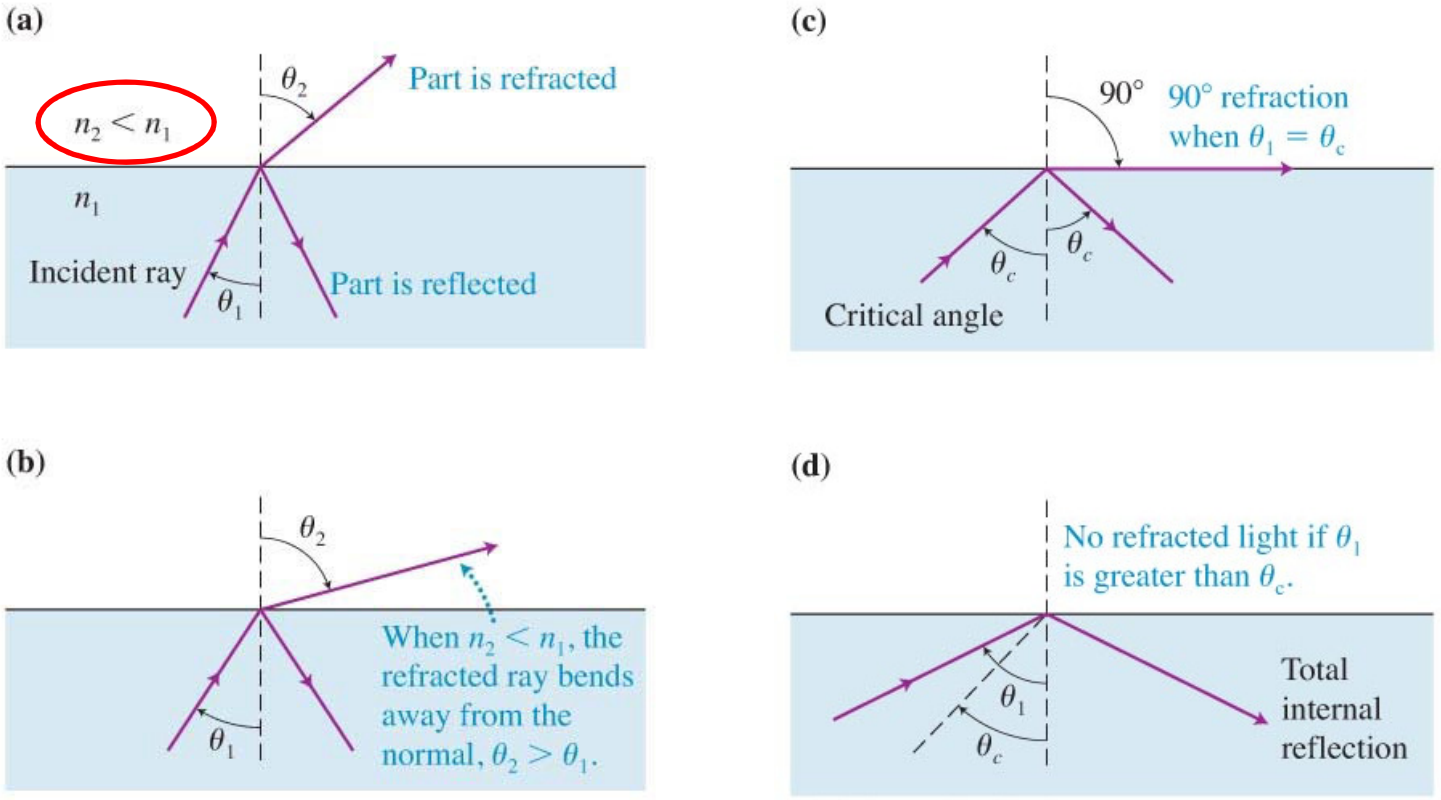
Total Internal Reflection



TIP Total internal reflection occurs only when light travels from a medium with a higher refractive index to a medium with a lower one.

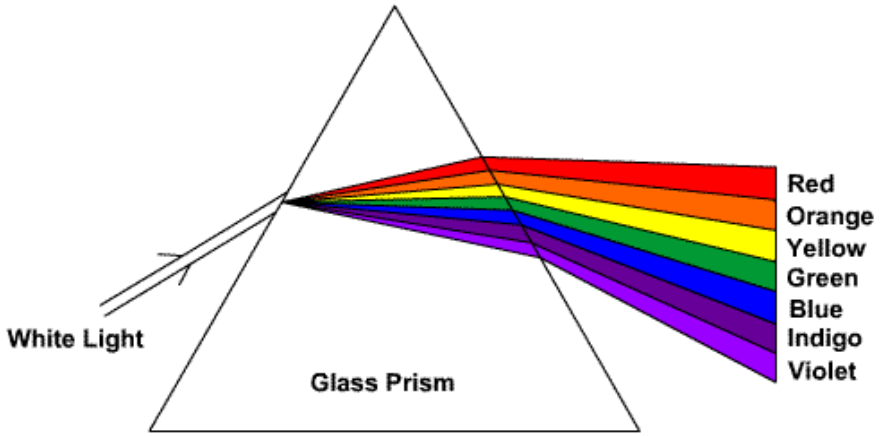
Total Internal Reflection

- At the critical angle of incidence, the angle of refraction is 90° and the refracted ray would travel along the surface of the interface.



Prisms – Dispersion of Light

- The refractive index of most materials depends on the color of light (wavelength).
- In general, n is larger for violet light and smaller for red light.

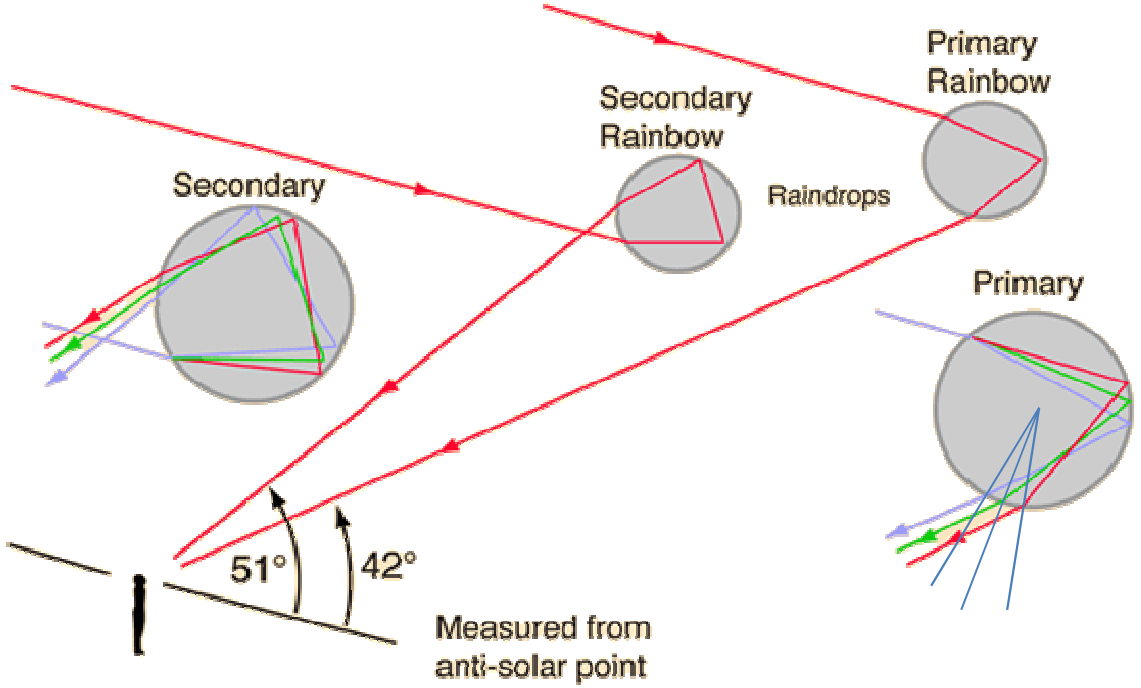


$$n_1 \sin\theta_i = n_2(\lambda) \sin\theta_r$$

Table 21.8 Refractive indexes of glass for different colors.

Color of Light	n_{glass}
Red	1.613
Yellow	1.621
Green	1.628
Blue	1.636
Violet	1.661

Rainbows



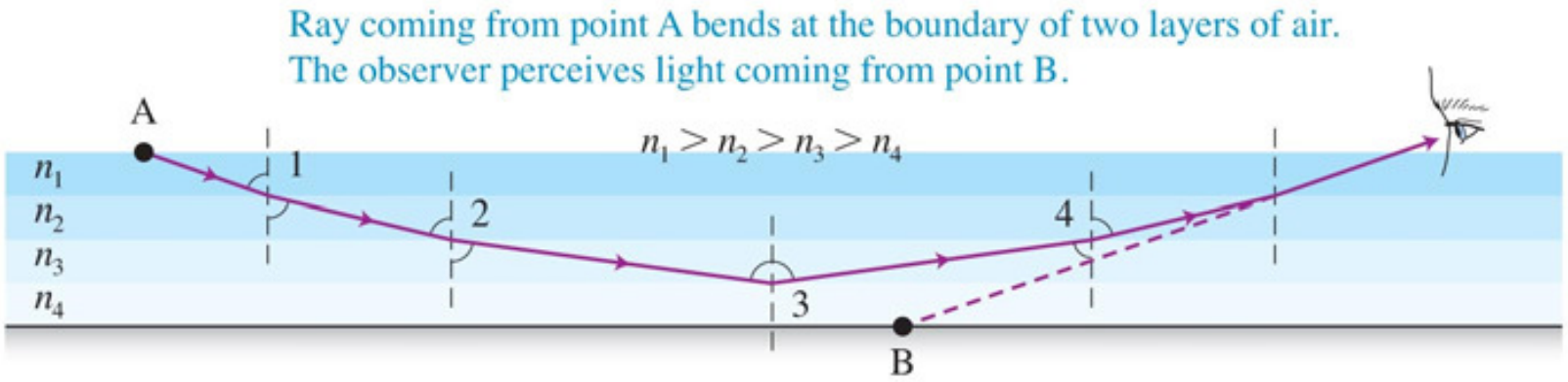
This explains why the colors are reversed on double-rainbows.

Mirages

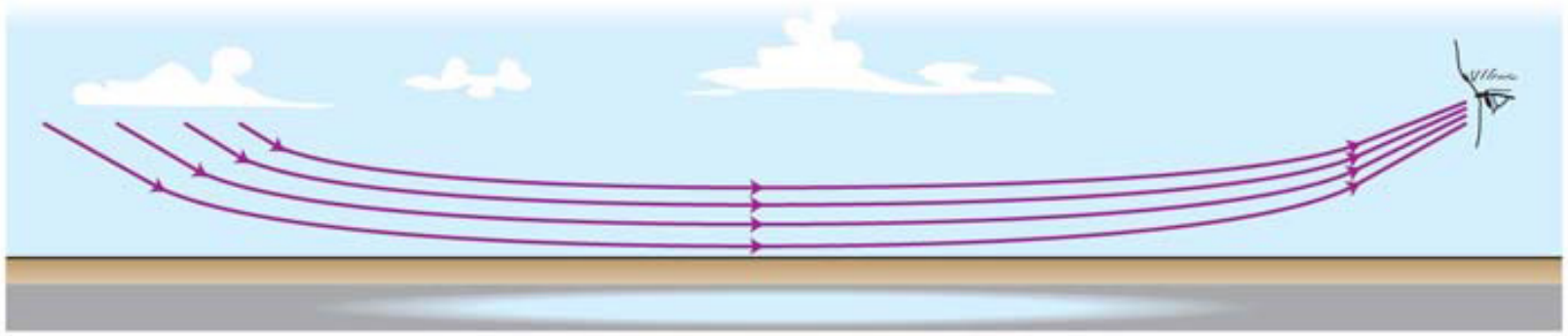
- On a hot day with little or no wind, the hot ground heats a layer of air just above the surface.
- Hot air is less dense and has a lower index of refraction than the cooler air above it.
- When light from the sky passes through air with a gradually changing index of refraction, its path gradually bends.

Mirages

(a)



(b)



Blue region is perceived as water, but is really formed by light from the sky.