3.1 Reflection and Refraction

- Geometrical Optics
- Reflection
- Refraction
- Total Internal Refraction
- Dispersion

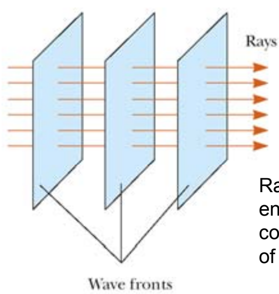
Christian Huygens

Geometrical optics

In geometrical optics light waves are considered to move in straight lines.

This is a good description as long as the waves do not pass through small openings (compared to λ)

Light waves

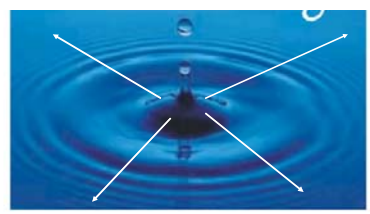


perpendicular to wave fronts

Rays are not physical entities but are a convenient representation of a light wave.

(surfaces with constant phase - e.g. maxima)

Rays are perpendicular to wave fronts



Reflection

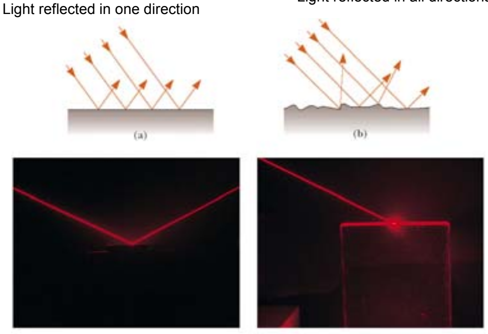
- Two general types of reflection
  - Specular reflection
  - Diffuse reflection
- Most of geometric optics deals with specular reflection.
- However, most of the time ambient lighting is due to diffuse reflection.

Specular reflection

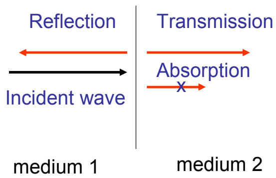
Flat surface
Light reflected in one direction

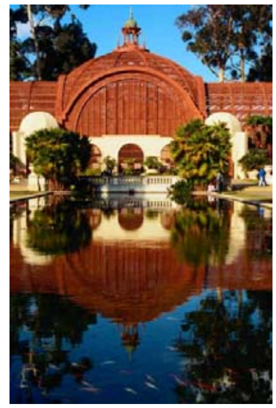
Diffuse reflection

Rough surface
Light reflected in all directions



Transmission and Reflection at an interface





What are some examples of these processes in this picture.

Specular Reflection

Diffuse reflection (scattering)

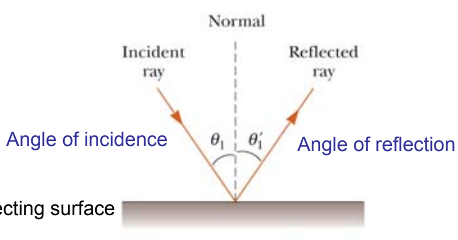
Transmission

Absorption

Law of Reflection

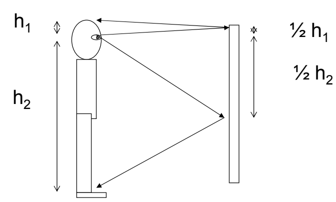
The angle of reflection equals the angle of incidence

$$\theta_1 = \theta_1'$$



Full length mirror

A 6 ft tall man wants to install a mirror tall enough to see his whole body. How tall a mirror is needed?

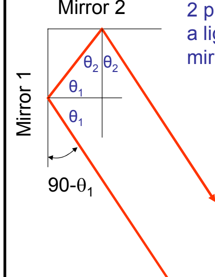


h_{mirror} = ½ (h_1 + h_2) = ½ (6) =3 ft

Multiple reflections

- For multiple reflections use the law of reflection for each reflecting surface.

2-Dimensional Corner reflector



2 perpendicular mirrors reflect a light beam in a plane perpendicular to both mirrors back along the opposite direction

we want to show that

$$\theta_2 = 90^o - \theta_1$$

$$\theta_1 + \theta_2 = 90^o$$

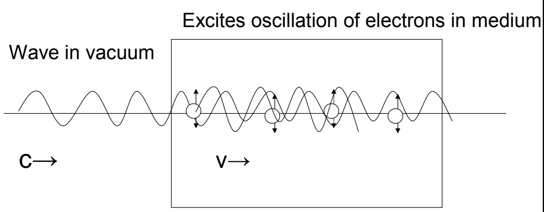
Corner reflectors on the moon

used to measure the distance to the earth by measuring the round trip time of light.

Refraction

- Refraction is the bending of light when it passes across an interface between two materials.
- Due to the differences in the speed of light in different media.

Speed of light in a medium



Superposition of waves leads to slower speed in the medium v , compared to the speed of light in vacuum. c.

Index of refraction $n = \frac{c}{v}$

Transmission across an interface

The speed of the wave changes.
The frequency remains the same.
The wavelength changes

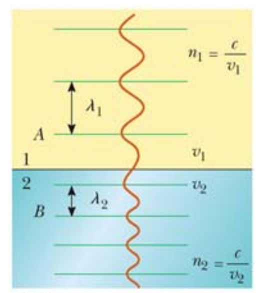
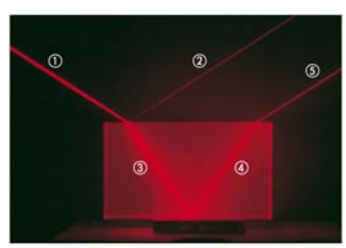


TABLE 22.1

Indices of Refraction for Various Substances, Measured with Light of Vacuum Wavelength λ_0 = 589 mn

Substance	Index of Refraction	Substance	Index of Refractio
Solids at 20°C		**Liquids at 20°C**	
Diamond (C)	2.419	Benzene	1.501
Fluorite (CaF_2)	1.434	Carbon disulfide	1.628
Fused quartz (SiO_2)	1.458	Carbon tetrachloride	1.461
Glass, crown	1.52	Ethyl alcohol	1.361
Glass, flint	1.66	Glycerine	1.473
Ice (H_2O) (at 0°C)	1.309	Water	1.333
Polystyrene	1.49		
Sodium chloride (NaCl)	1.544	**Gases at 0°C, 1 atm**	
Zircon	1.923	Air	1.000 29
		Carbon dioxide	1.000 45

Refraction and Reflection

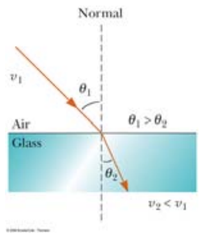


The light beam (3) is refracted at the interface.

Snell's Law of Refraction

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

Going from air to glass



$n_2 > n_1$

$\theta_2 < \theta_1$

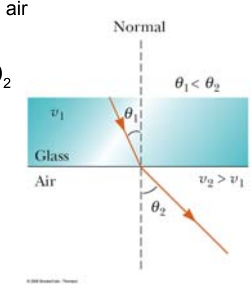
($\sin\theta$ increases with θ)

Going from glass to air

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

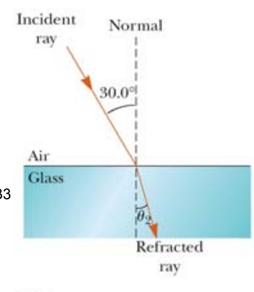
$n_2 < n_1$

$\theta_2 > \theta_1$



Example 22.2

Find the angle of refraction for an angle of incidence of 30° in going from air to glass (n_{glass} =1.52)



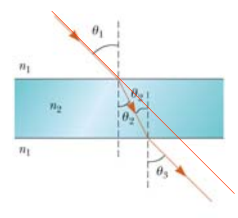
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2} = \frac{1.00(\sin 30)}{1.52} = 0.33$$

$$\theta_2 = \arcsin(0.33) = 19.3°$$

Example 22.4

Show that light going through a flat slab is not deviated in angle.



First interface

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

Second interface

angle of incidence = θ_2

$$n_2 \sin\theta_2 = n_3 \sin\theta_3$$

then $n_1 \sin\theta_1 = n_3 \sin\theta_3$

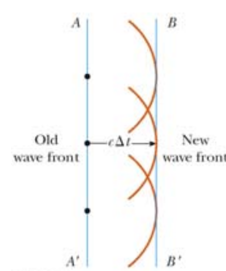
since $n_1 = n_3$ $\theta_1 = \theta_3$

Angle is the same but beam displaced

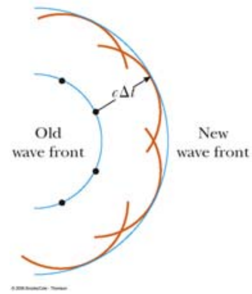
Huygen's Principle

- All points in a given wave front are taken as point sources for the production of spherical secondary wavelets which propagate in space. After some time the new wave front is the tangent to the wavelets.

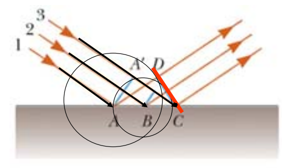
Huygen's Picture of a Plane wave



Huygen's Picture of a Spherical wave

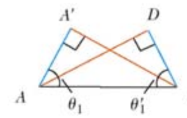


Huygen's Explanation of Reflection



therefore

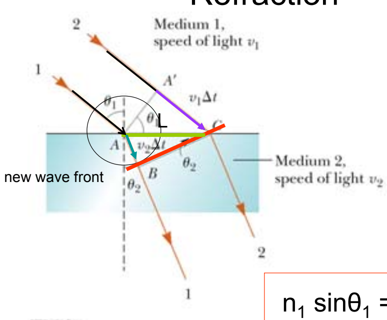
$\theta_{incidence} = \theta_{reflection}$



two sides and
an angle equal
∴ similar triangles

$\theta_1 = \theta'_1$

Huygen's explanation for Refraction



$L\sin\theta_1 = v_1 t$

$L\sin\theta_2 = v_2 t$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$$

$$\frac{1}{v_1}\sin\theta_1 = \frac{1}{v_2}\sin\theta_2$$

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

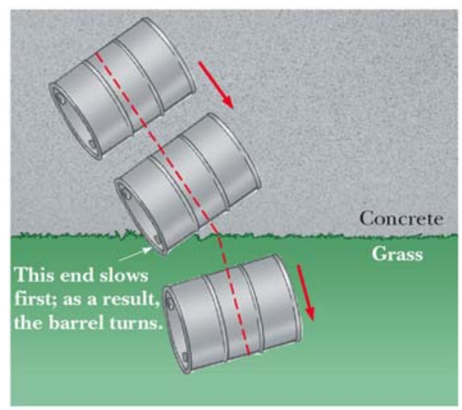
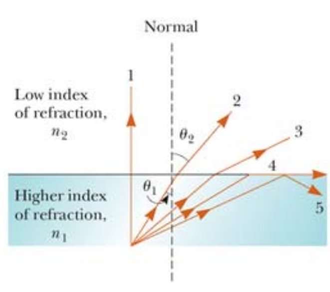


Fig. 22-24b, p.741

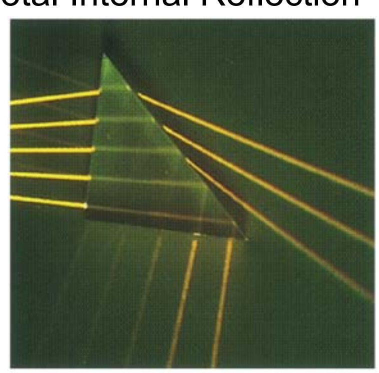
Total Internal Reflection



When the angle of refraction equals or exceeds 90°

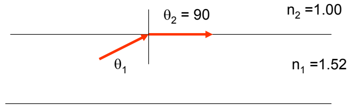
All the light is internally reflected

Total Internal Reflection



Optical Fiber -Light Pipe

An optical fiber (light pipe) confines the light inside the material by total internal reflection. If the refractive index of the fiber is 1.52 what is the smallest angle of incidence possible when the light pipe is in air.



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

$$\sin\theta_1 = \frac{n_2 \sin 90}{n_1} = \frac{(1.0)(1.0)}{1.52} = 0.66$$

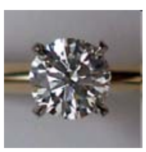
$\theta_1 = \arcsin(0.66) = 41^o$ θ_1 must be > 41°

Fiber Optics

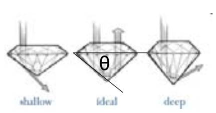
Fiber optics are used extensively in communications. Telephone, Internet,

The high frequency of light (compared to microwaves) allows it to be switched rapidly and carry more information.

A diamond sparkles due to total internal reflection



Diamond has a high refractive index n = 2.42 allowing total internal reflection occurs more readily



The diamond must be cut properly

θ = 41°

Dispersion

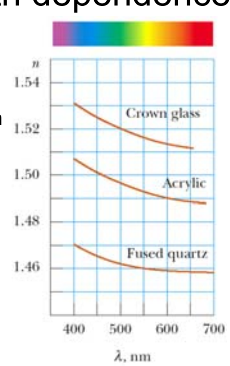
- Dispersion is the separation of light with different colors due to the wavelength dependence of the index of refraction of a prism.

Wavelength dependence of n

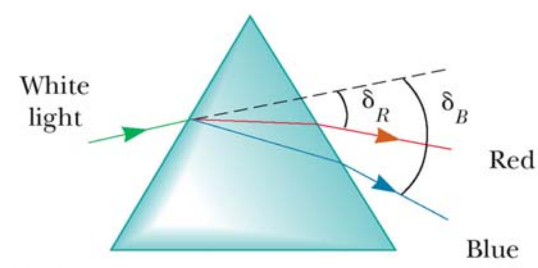
For most materials n increases with decreasing wavelength

Highest in the blue region

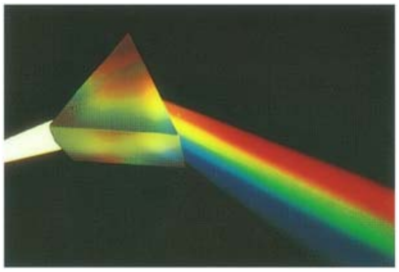
Lowest in the red region



Different colors are refracted by different angles in a prism

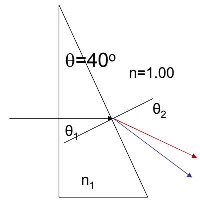


Dispersion of light by a prism



Example

A prism of crown glass refracts light normally incident on one surface. For $\theta = 40^o$ find the angle $\Delta\theta$ between the refracted red and violet light.



violet $n_1 = 1.538$

red $n_1 = 1.516$

$\theta_1 = 40^o$

$$n_1 \sin\theta_1 = n \sin\theta_2$$

$$\sin\theta_2 = n_1 \sin\theta$$

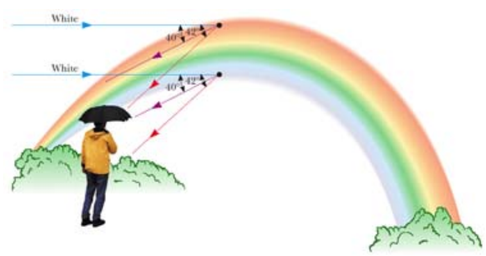
$$\theta_{2red} = \arcsin(n_{1red} \sin\theta) = \arcsin(1.516 \sin 40) = 77.0^o$$

$$\theta_{2violet} = \arcsin(n_{1violet} \sin\theta) = \arcsin(1.538 \sin 40) = 81.3^o$$

$\Delta\theta = 4.3^0$

A rainbow is seen on a rainy day when the sun is to your back, low in the horizon (less than 42º above the horizon)
A second rainbow is often seen with the order of colors reversed.

The shape of the rainbow is due to parallel beam of sunlight light reflected and refracted from raindrops at a special angle (rainbow angle of 40º - 42º)
The colors of the rainbow are due to dispersion of the light.



Dispersion of light by a rain drop

Three interfaces
A) Refraction
B) Reflection
C) Refraction

Violet light is refracted more but gives a smaller rainbow angle