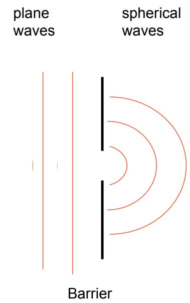
4.1 Reflection and Refraction II

- •Huygen's Principle
- •Total internal reflection
- •Dispersion

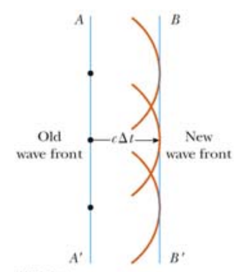
Waves



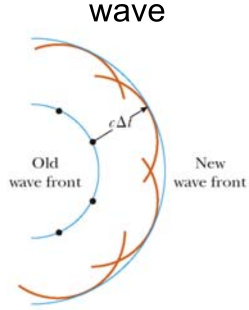
Huygen's Principle

- 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.

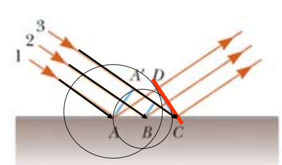
Huygen's Picture of a Plane wave



Huygen's Picture of a Spherical wave

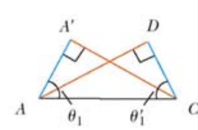


Huygen's Explanation of Reflection



therefore

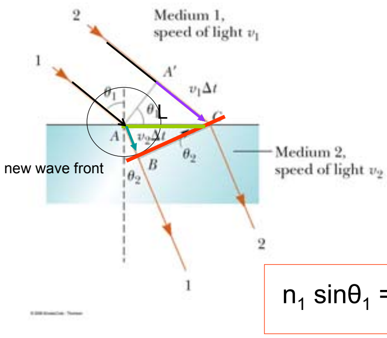
$\theta_{incidence} = \theta_{reflection}$



two sides and
an angle equal
∴ similar triangles

$\theta_1 = \theta'_1$

Huygen's explanation for Refraction



$L\sin\theta_1 = v_1 t$

$L\sin\theta_2 = v_2 t$

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

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

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

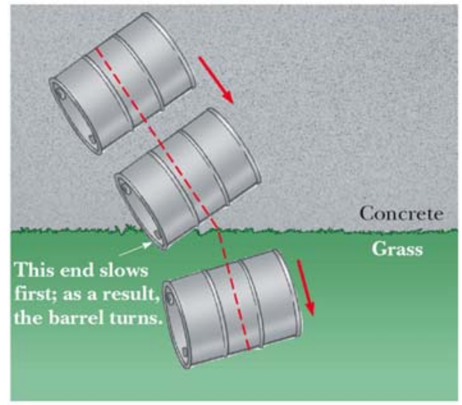
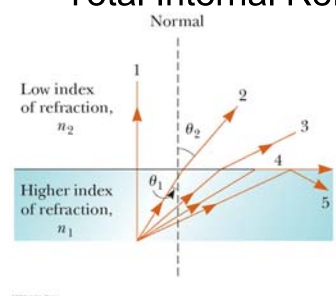


Fig. 22-24b, p.741

Total Internal Reflection

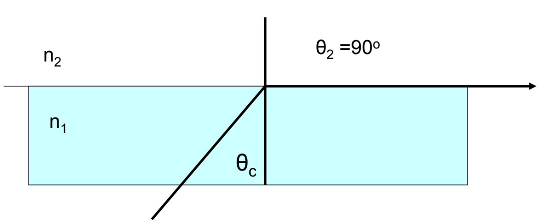
Total Internal Reflection



When the angle of refraction equals or exceeds 90°

All the light is internally reflected

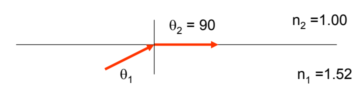
Critical Angle



At the critical angle angle of refraction is 90°

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 for total internal reflection when the light pipe is in air.



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

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

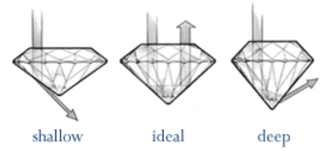
$$\theta_1 = 41^o$$

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.

Diamond cut

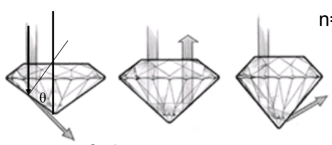


For a well cut diamond the incident light is totally internally reflected.

The high refractive index of the diamond allows total internal reflection over a wide range of angles.

Diamond cut

n=2.42



shallow $\theta<65^o$ ideal $\sim 50^o$ deep $\theta > 38^o$

What is the limiting shallow angle θ for a diamond cut?

Angle of incidence = $90-\theta$

$n\sin(90-\theta) = 1$

$\sin(90-\theta) = 1/2.42 = 0.413$

$90-\theta = 24.4^o$

$\theta = 65.5^o$ maximum

when $\theta \leq 65.5^o$ light is totally internally reflected.

Dispersion

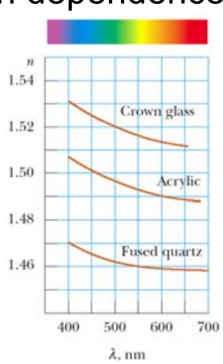
- Dispersion is the separation of light with different colors due to the wavelength dependence of the index of refraction of a prism.

Wavelength dependence of n

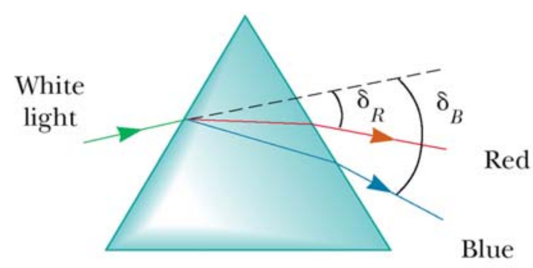
For most materials n increases with decreasing wavelength

Highest in the blue region

Lowest in the red region

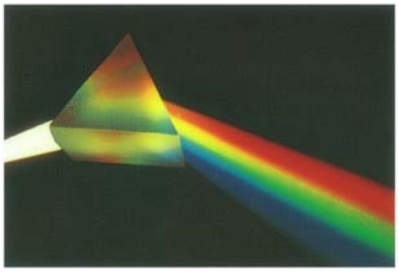


Different colors are refracted by different angles in a prism



δ is the angle of deviation

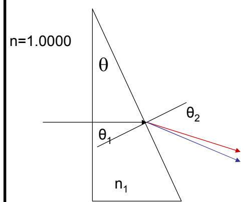
Dispersion of light by a prism



Example

A prism disperses white light into different colors.

A 90 degree prism of crown glass refracts light normally incident on the long surface. Is violet light or red light refracted more.



$\theta_1=\theta$

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

$sin\theta_2 = \frac{n_1}{n}\sin\theta$

violet n_1 = 1.538

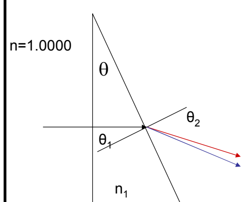
red n_1 = 1.516

Since n is greater for violet light than for red light
Violet light is refracted more

Example

A prism disperses white light into different colors.

A 90 degree prism of crown glass refracts light normally incident on the long surface. For what value of θ gives the largest dispersion Δθ



$\theta_1=\theta$

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

$sin\theta_2 = \frac{n_1}{n}\sin\theta$

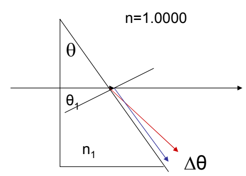
violet n_1 = 1.538

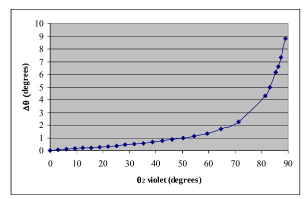
red n_1 = 1.516

$\Delta\theta = \arcsin(n_{violet}\sin\theta) - \arcsin(n_{red}\sin\theta)$

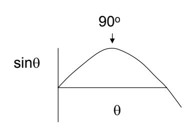
Vary θ

max difference when
θ_2 -> 90° for violet
θ=40.556





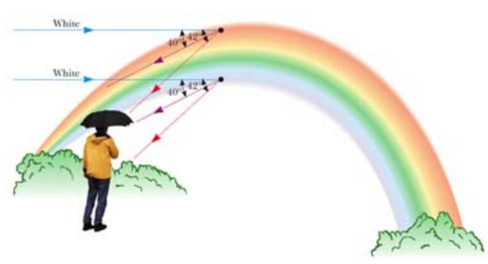
Δθ ~9.5 degrees at θ=40.556°



The large difference is because near 90° (Maximum) sin θ is quite insensitive to θ

A rainbow is seen on a rainy day when the sun is to your back, low in the horizon (less than 42° 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 40° - 42°)
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