Reflection and Refraction 4.2

Total internal reflection

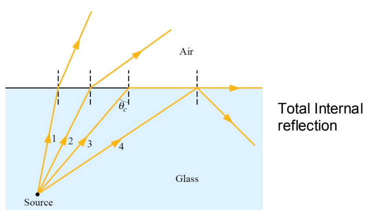
Dispersion

Rainbows

Total internal reflection

- In total internal reflection all of the light is reflected at the interface between two media.
- Total internal reflection occurs when the angle of refraction is equal to or greater than 90^o
- Total internal reflection is important for optical communications. (light pipe)

Total internal reflection

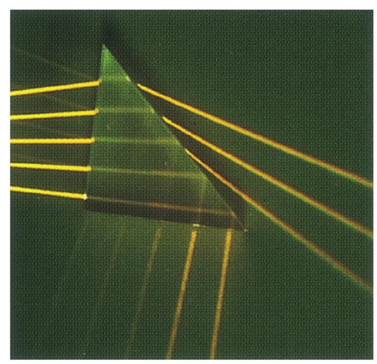


Critical Angle θ_c

$$n_1 \sin\theta_c = n_2 \sin(90^o) = n_2$$

n_2 must be less than n_1

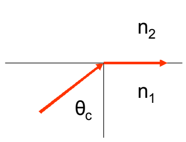
Total Internal Reflection



Critical Angle

At the critical angle

$$\sin\theta_c = \frac{n_2}{n_1}$$

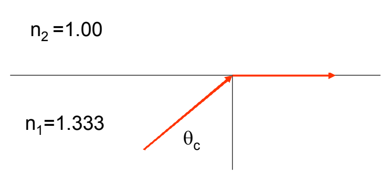


$n_2 < n_1$

When $\theta > \theta_c$, light is totally internally reflected

Question

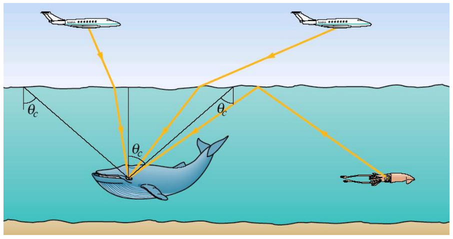
What is the critical angle at the air water interface?



$$\sin\theta_c = \frac{n_2}{n_1} = \frac{1.00}{1.333} = 0.750$$

$$\theta_c = 48.6^o$$

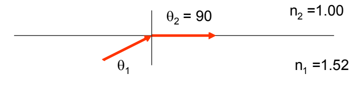
The fishes' eye view of the outside world is limited by total internal reflection



At angles greater than the critical angle the whale sees only reflected light
This illustrates the point that the path of light rays is the same in the forward and reverse directions.

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.



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

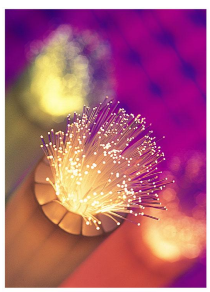
$$\sin\theta_1 = \frac{n_2 \sin 90}{n_1} = \frac{(1.0)(1.0)}{1.52} = 0.66$$

$$\theta_1 = 41^o$$

Fiber Optics

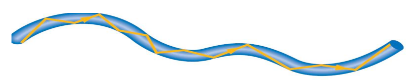
Fiber optics are used extensively in communications. Telephone, Internet,

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

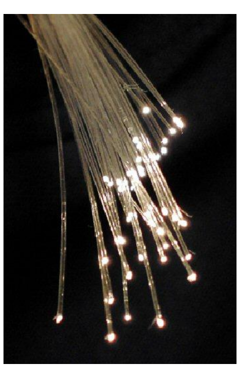


Light Pipe

A light pipe is a flexible fiber that confines a beam of light by total internal reflection

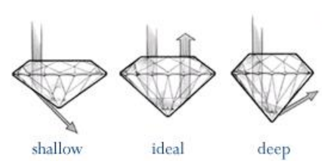


Fiber Optic are used in optical communication networks



The advantage of optical communication systems is due to the higher frequency of light
$f \sim 10^{15}$ Hz
compared to radio or microwaves
$f \sim 10^8 - 10^{10}$ Hz

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.

Dispersion

- The index of refraction generally is different for different wavelengths of light.
- This dispersion can be used to separate light into different wavelengths using a prism.
- Dispersion is a problem in fabricating lenses for imaging – causing chromatic aberration, different images for different wavelengths of light
- Dispersion is responsible for rainbows.

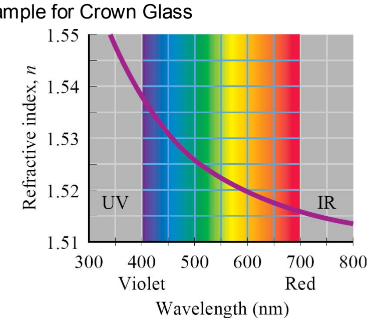
Dispersion of white light by a prism

Separation of different wavelengths by refraction through a Prism

Incident White Light

The index of refraction varies with wavelength

example for Crown Glass



violet	400	1.538
green	500	1.526
red	700	1.516

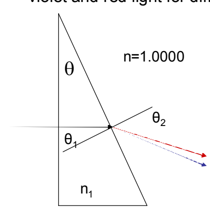
maximum change violet-red

$$\frac{\Delta n}{n} \approx 1.4\%$$

Example 35.6

A prism disperses white light into different colors.

A 90 degree prism of crown glass refracts light normally incident on the long surface.. Find the largest difference in angles of refraction of violet and red light for different values of θ.



$\theta_1=\theta$

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

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

violet n_1 = 1.538

red n_1 = 1.516

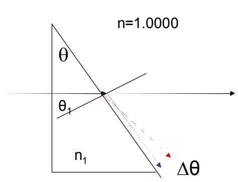
violet light is refracted more than red

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

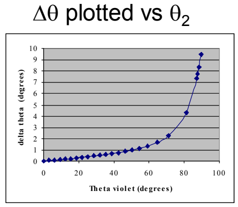
Prism

max difference when θ_2 -> 90° for violet

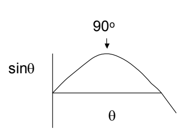
θ=40.556



Δθ plotted vs θ_2



Δθ ~9.5 degrees at θ=40.556°



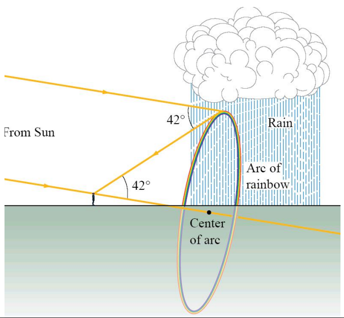
The large difference is because near 90° (Maximum) sin θ is quite insensitive to θ

Rainbow

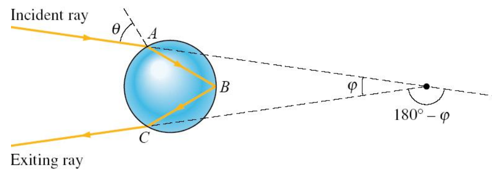
A rainbow is seen on a rainy day when the sun is to your back, low in the horizon (less than 42° above the horizon)

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 42°)
The colors of the rainbow are due to dispersion of the light.



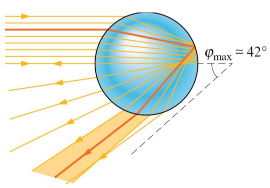
The raindrop reflects and refracts the incident sunlight.



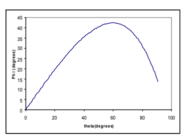
Incident beam is refracted twice and internally reflected by the raindrop

Deflection angle = 180-φ

Rainbow angle

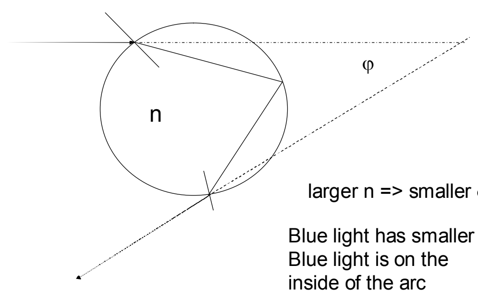


Incident light is reflected at many different angles However much of the light is reflected near the rainbow angle 42° because φ vs θ goes through a maximum



Near the maximum there are a large number of values of θ with the values close to φ_{max}

Effect of dispersion



larger n => smaller φ

Blue light has smaller φ
Blue light is on the inside of the arc
Red light is on the outside

Colors of the rainbow

The primary rainbow has blue on the inside and red on the outside
The secondary rainbow is due to light that is internally reflected twice the effect of refraction is to increase φ and the colors are reversed (see problem 60).