Refraction of Light

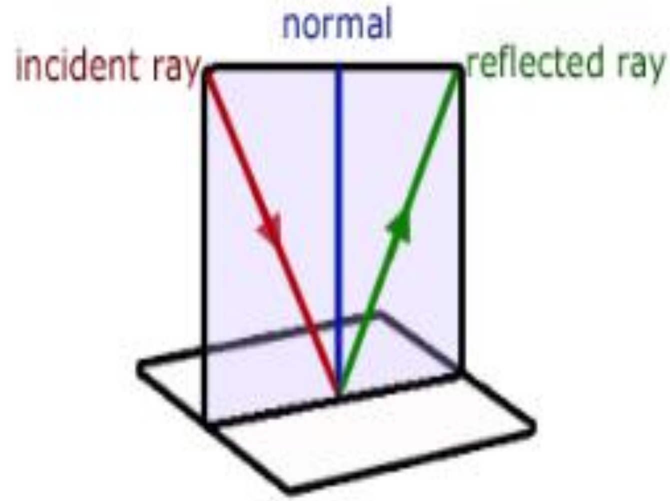
Optics

The Study of Light

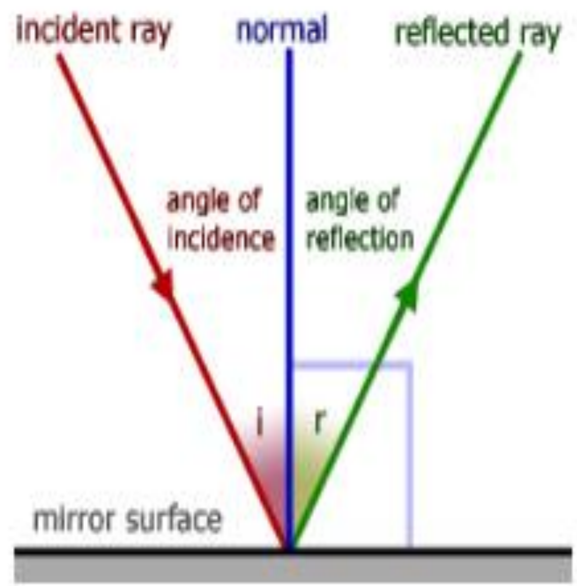
MIRRO
RS

LENSES

Laws of
Reflectio



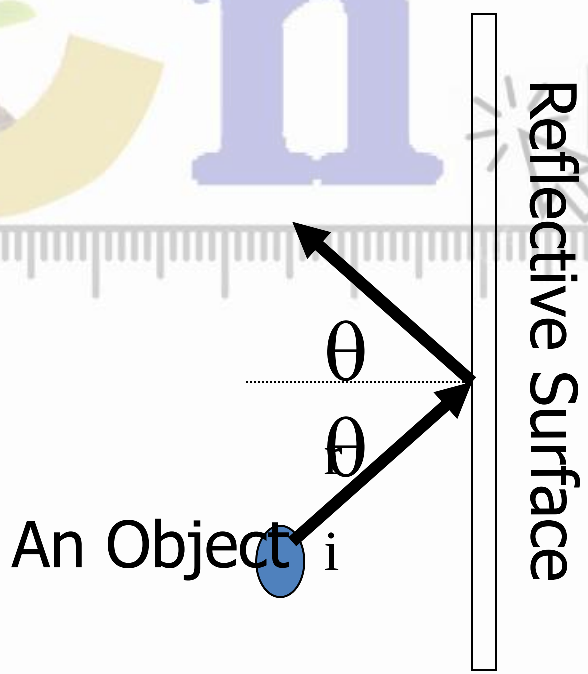
1. The incident ray, the reflected ray and the normal, at the point of incidence, all lie in the same plane.



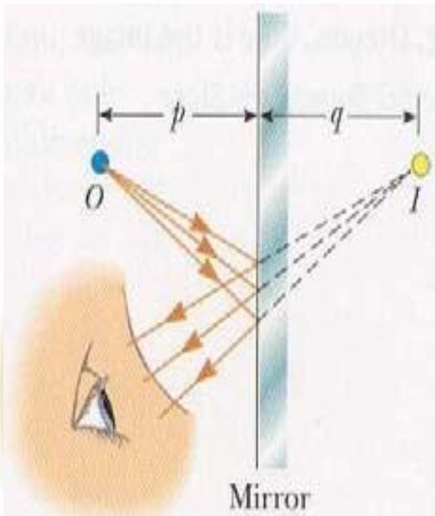
2. The angle of reflection equals the angle of incidence

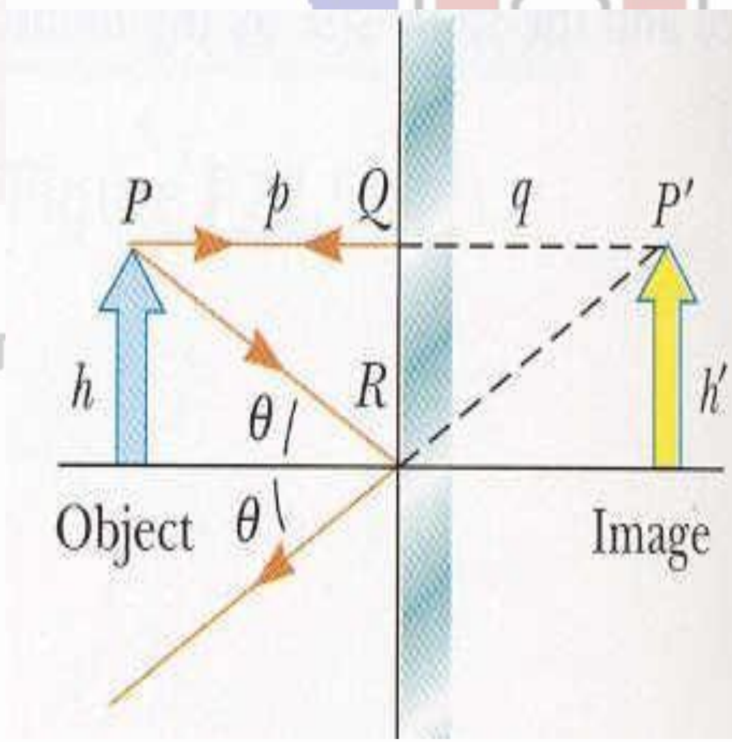
Law of Reflection

- Angle of incidence equals angle of reflection.



$$\theta_i = \theta_r$$


p
q
O
I
Mirror

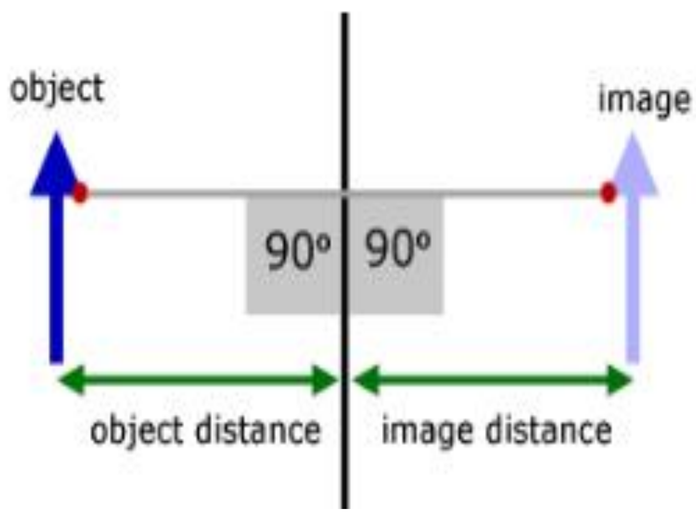

P
p
Q
q
P′
h
R
θ
θ
h′
Object
Image

Plane mirror images

1. All images are virtual. That is, they cannot be projected on to a screen.

2. The image produced in a mirror is as far behind the mirror as the object is infront.

object distance = image distance



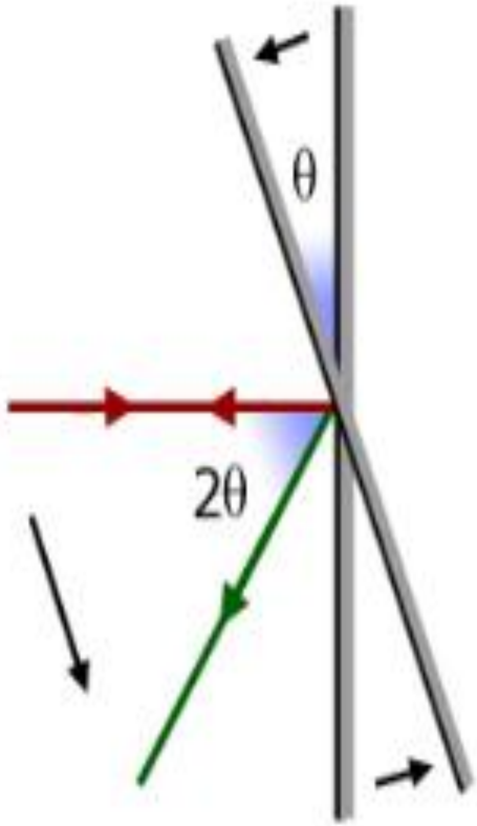
3. The image is the same size as the object.

4. A line joining a point on the image to a corresponding point on the object is perpendicular to the mirror.

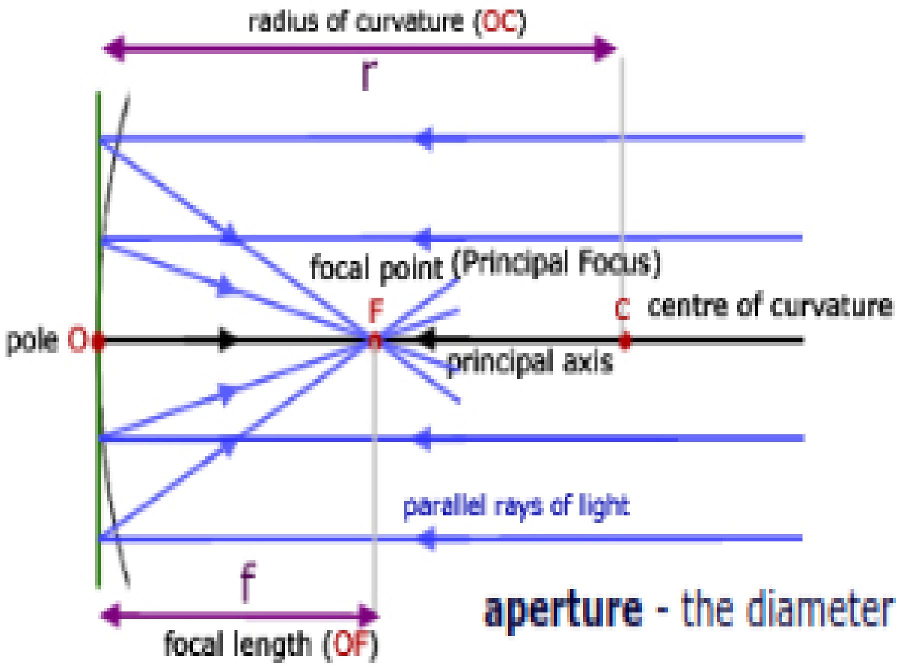
5. The image is laterally inverted (sideways upside down).

Mirror rotation

When a light ray is normal to a mirror it reflects back the way it came. However, if the mirror is tilted say, through θ °(theta) then the reflected light ray rotates through 2θ °.



Convex mirrors



aperture - the diameter of the circular mirror

pole - where the principal axis meets the mirror surface

centre of curvature - the centre of the sphere that the mirror forms part

radius of curvature (*r*) - radius of the sphere

principal axis - the line through the centre of curvature and the pole of the mirror

focal length (*f*) - equal to half the radius of curvature $f = r/2$

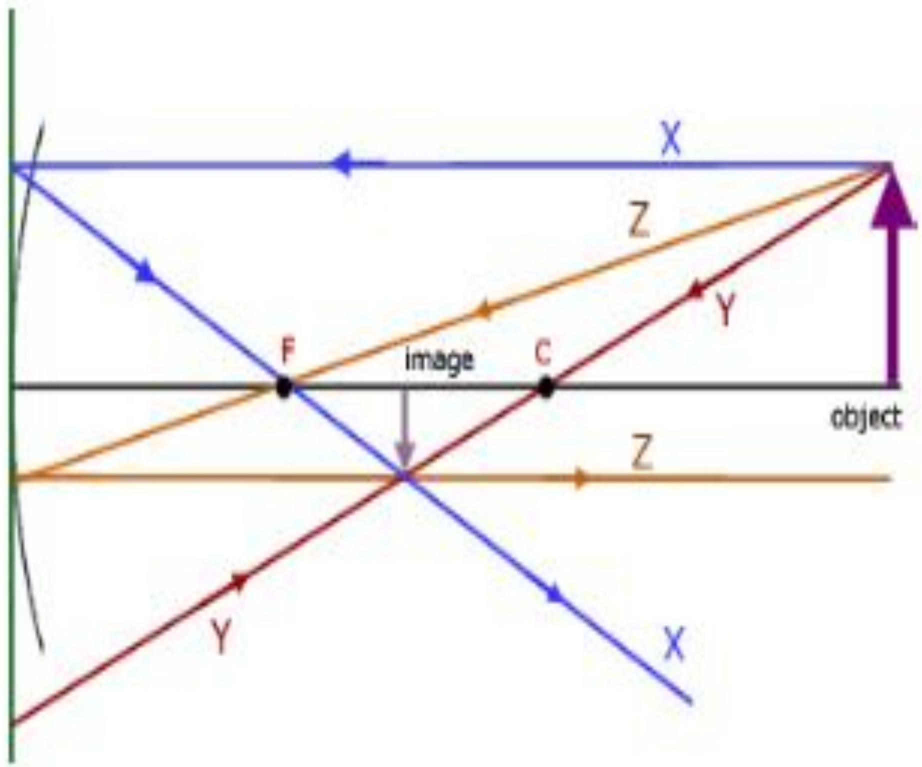
Ray diagrams

Ray diagrams are constructed by taking the path of three distinct rays from a point on the object:

X) a ray parallel to the principal axis reflected through **F** (the principal focus)

Y) a ray passing through **C** which is then reflected back along its original path

Z) a ray passing through F, which is then reflected parallel to the principal axis



Drawing Ray Diagrams for Mirrors

- 1st- Ray parallel to principal axis reflects through focal point.
- 2nd- Ray through focal point reflects parallel to principal axis.
- 3rd- Ray through center of curvature reflects back upon itself.
- Convergence of rays gives image.

The image types and positions for a concave mirror are very similar to those of a convex lens.

object between F and the lens

The image is upright, virtual and magnified.

object at F

The image is formed at infinity from parallel rays that do not converge. Therefore no image is formed.

object between F and C

The image is real, inverted and magnified.

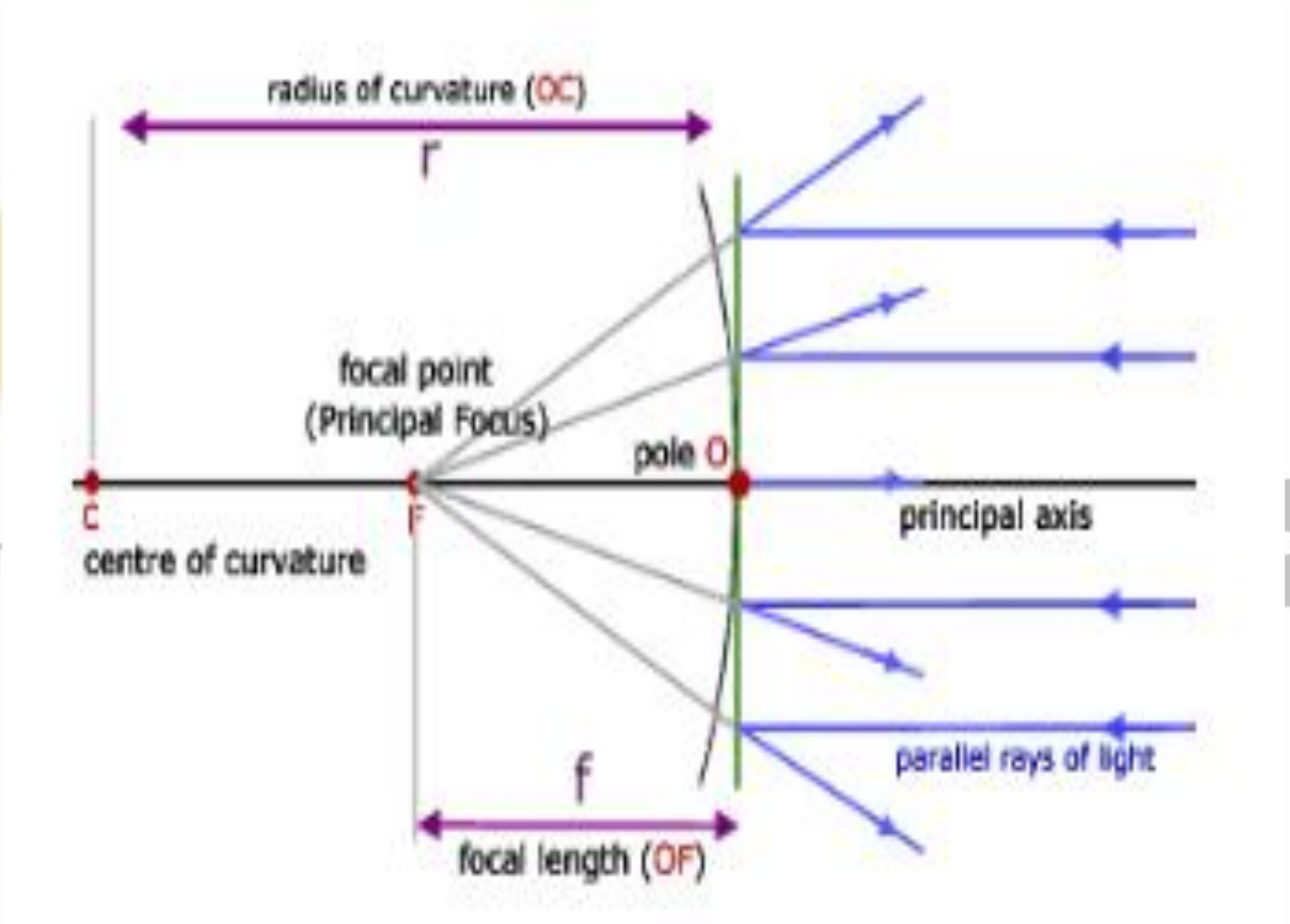
object at C

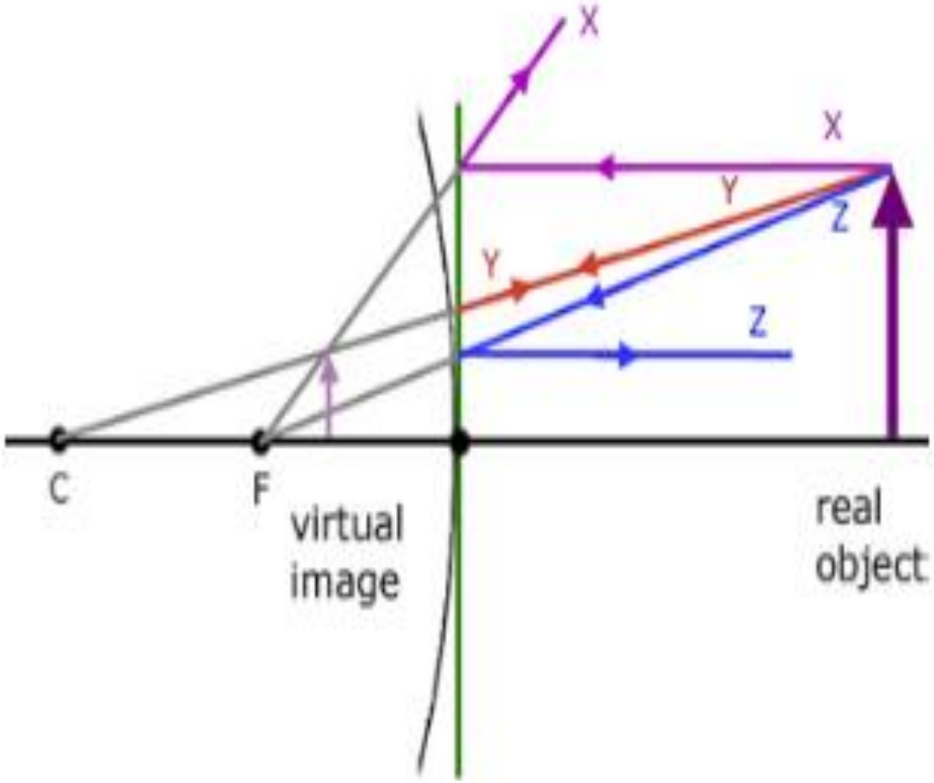
The image is formed at C.
The image is inverted, real and the same size as the object.

object at infinity

The image is formed at the focal point of the lens. It is real, inverted and diminished in size.

Concave mirrors



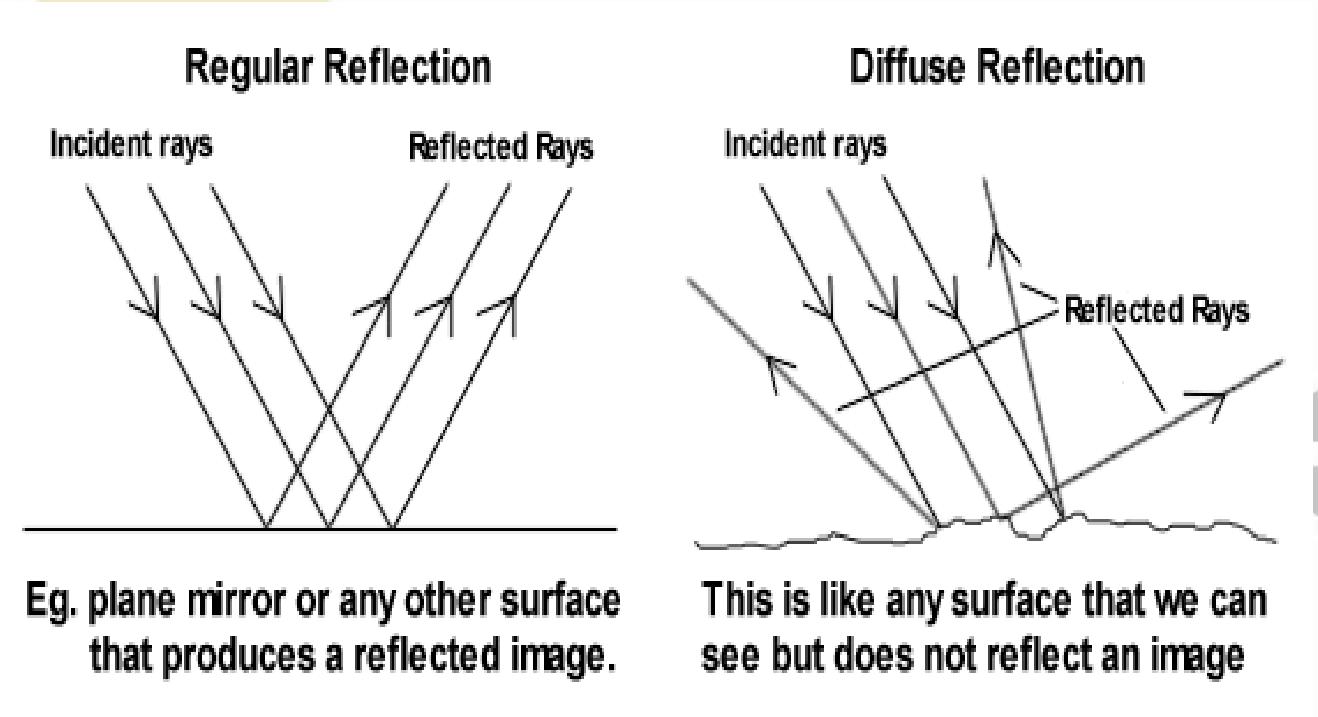


For all the object positions listed below,

object between *f* and the mirror
object at *f*
object between f and 2f
object at 2*f*
object at infinity

the ray diagrams are virtually the same as in the diagram above. Hence the result is the same. The image produced is virtual, upright and diminished.

Types of Reflections



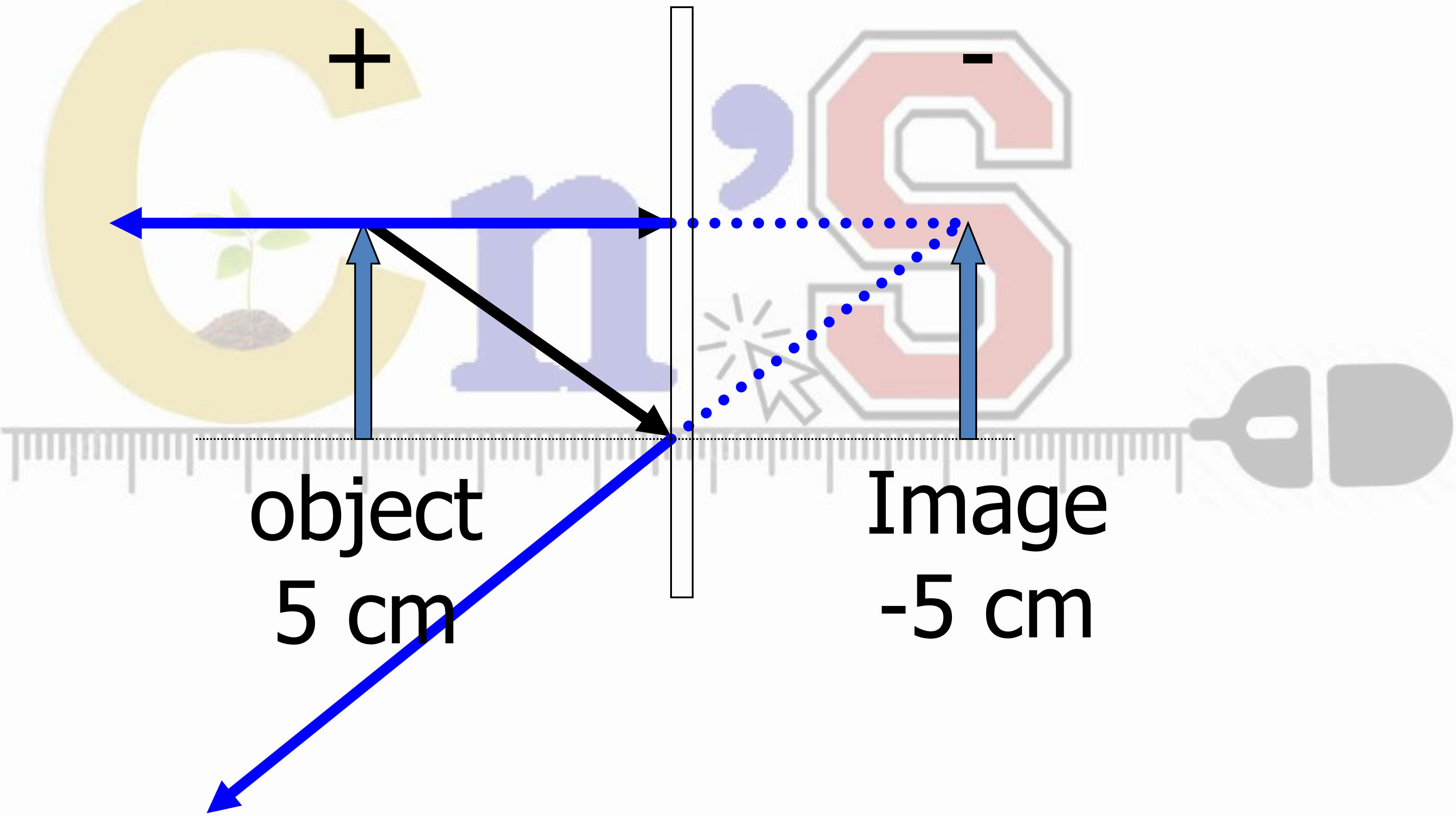
Regula
r
Reflect
ion

Diffuse
Reflection

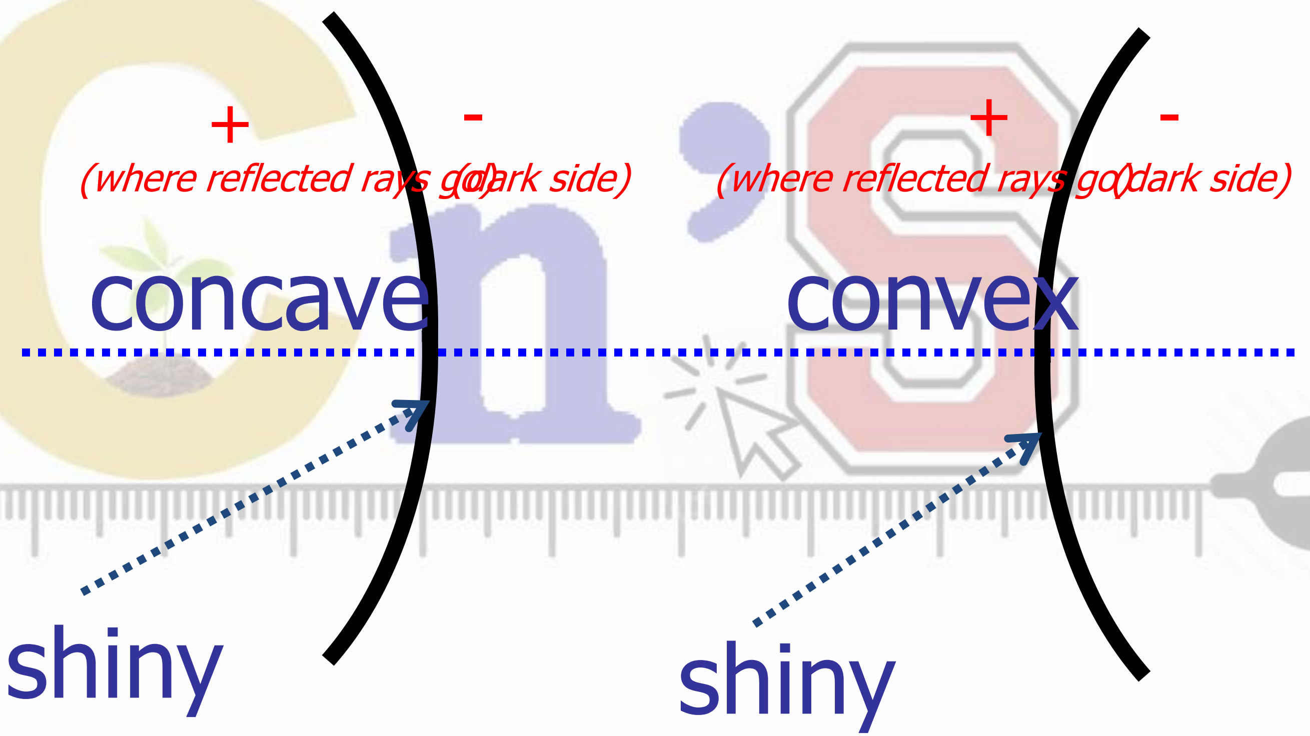
Optical Images Terminology

- *Type*
  - real (converging rays)
  - virtual (diverging rays)
- *Orientation*
  - Upright (erect)
  - inverted
- *Size*
  - True (same size)
  - Enlarged (larged)
  - Reduced (diminished)

Plane Mirror

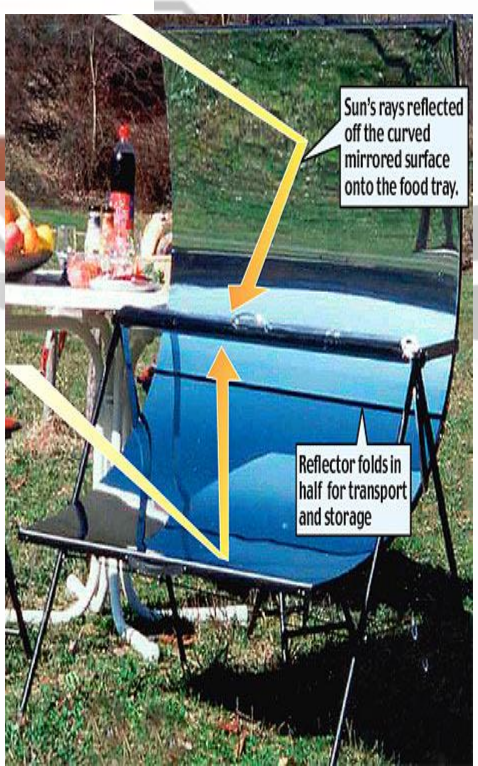


Spherical mirrors



Focal length, f, is positive

Focal length, f, is negative



Concave Mirrors

Convex Mirrors

- A distance, p, of a point light source (called **object**) in front of a flat mirror is called the **object distance**. Light rays leave the source and are reflected from the mirror. After reflection, the reys diverge (spread apart), but they appear to the viewer to come from a point behind the mirror, called the **image** of the object. Images are formed at the point at which rays of light actuylly intersect or at which they appear to originate. A distance, q, of the image is called **image distance**.
- Images are classified as real or virtual. A **real image** is one in which light actually intersects, or passes through, the image point; a **virtual image** is one in which the light does not pass through the image point but appears to come (diverge) from that point. The image formed by the flat miror in the figure is a virtual image. **Real images can be displayed on a screan, but virtual images cannot**.
- **The image formed by an object placed in front of a flat mirror is as far behind the mirror as the object is in front of the mirror**, **p=q**.

Definition: Refraction

Change in speed of light as it moves from one medium to another.

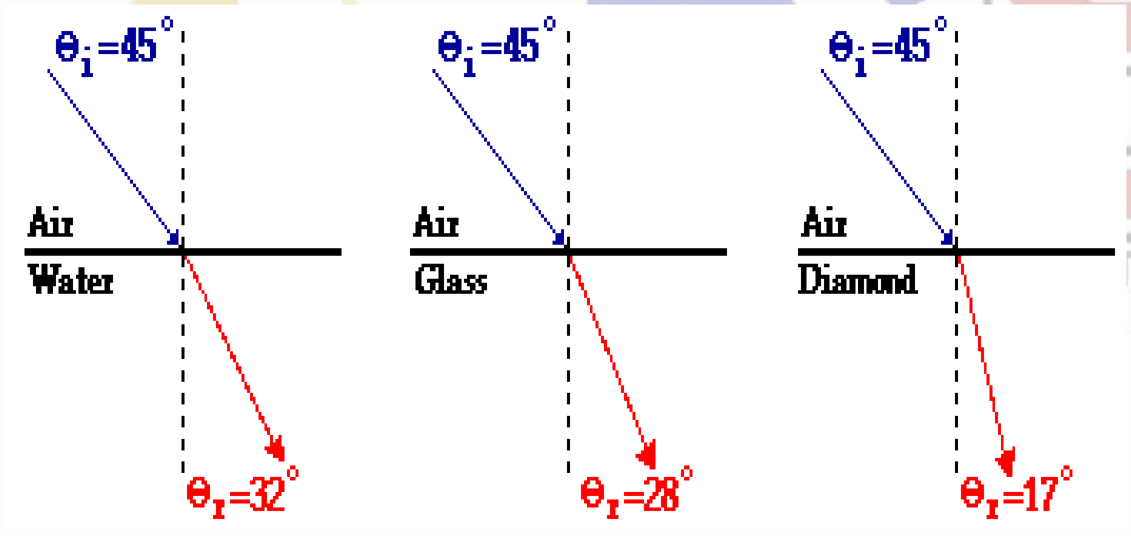
Can cause bending of the light at the interface between media.

Refr

Index of Refraction

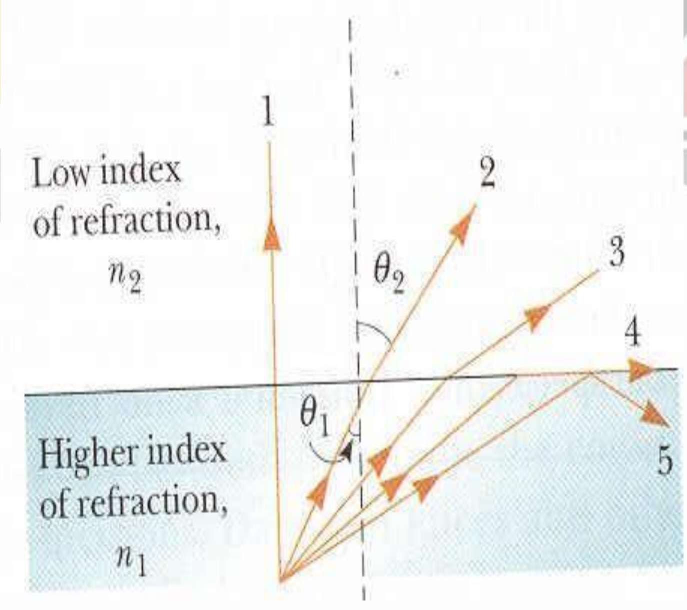
$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

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



$\theta_i=45°$
Air
Water
$\theta_r=32°$
$\theta_i=45°$
Air
Glass
$\theta_r=28°$
$\theta_i=45°$
Air
Diamond
$\theta_r=17°$

An interesting effect called **total internal reflection** can occur **when light attempts to move from a medium with a high index of refraction to one with a lower index of refraction**. At some particular angle of incidence, called the **critical angle**, the refracted light ray moves parallel to the boundary. For angles of incidence greater than the critical angle, the beam is entirely reflected at the boundary.
Interecting applications are submarine periscopes and fiber optics (in medicine and telecommunications)



Common Indices of Refraction

- Vacuum 1.00
- Air 1.00
- Water 1.33
- Ice 1.31
- Crown Glass 1.52
- Flint Glass 1.66
- Diamond 2.42

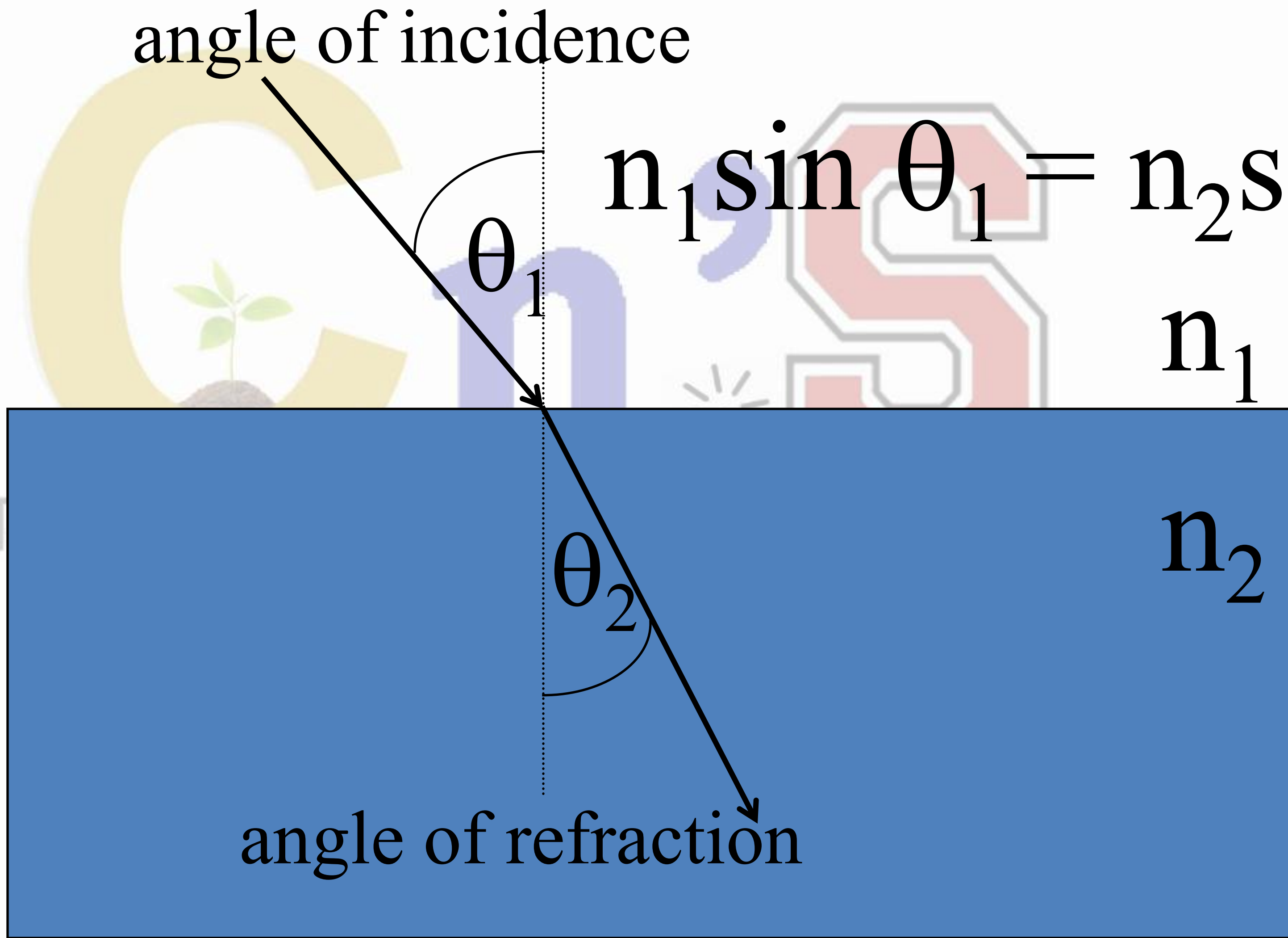
Indices of Refraction are Unitless

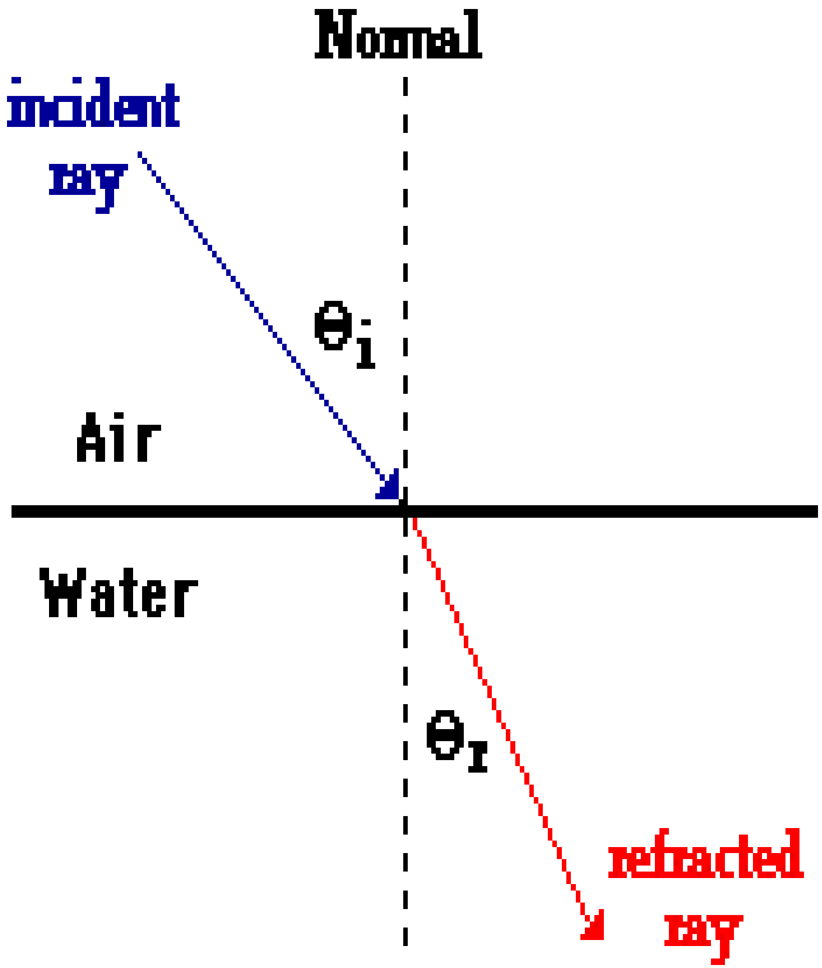
As light travels from one medium to the next, the speed changes as does the wavelength.

The frequency

Snell's Law

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




Normal
incident ray
θi
Air
Water
θr
refracted ray

- Why do astronomers looking at distant galaxies talk about looking backward in time?

  Light travels through a vacuum at a speed of 3000 000 km/s. Thus an image we see from a distant star or galaxy must have been generted some time ago.

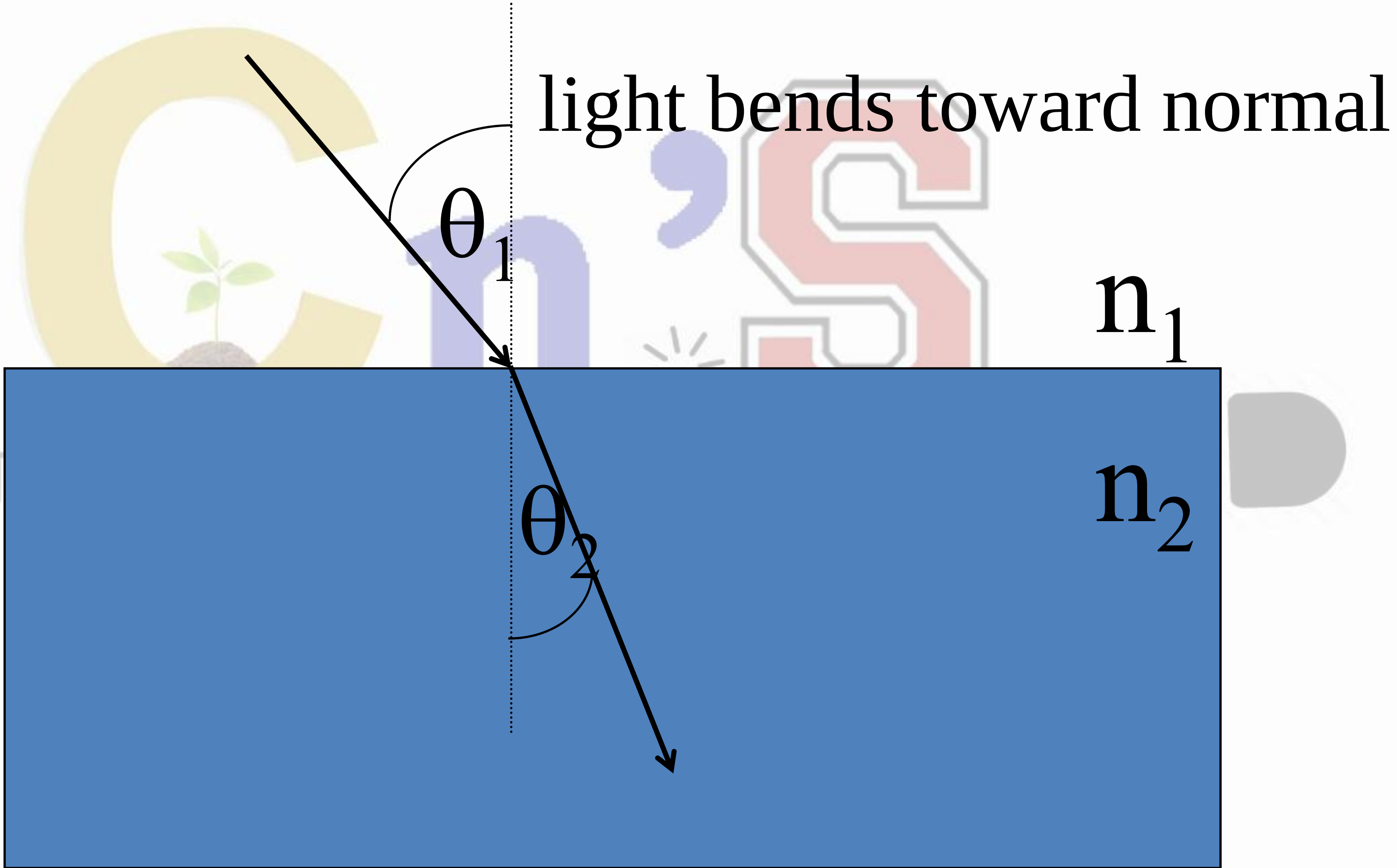
- Find the speed of light in water ($n = 1.333$).

$$\begin{aligned} n &= \frac{c}{v} \\ v &= \frac{c}{n} = \frac{3 \cdot 10^8 \text{ m/s}}{1.333} = 2.25 \cdot 10^8 \text{ m/s} \end{aligned}$$

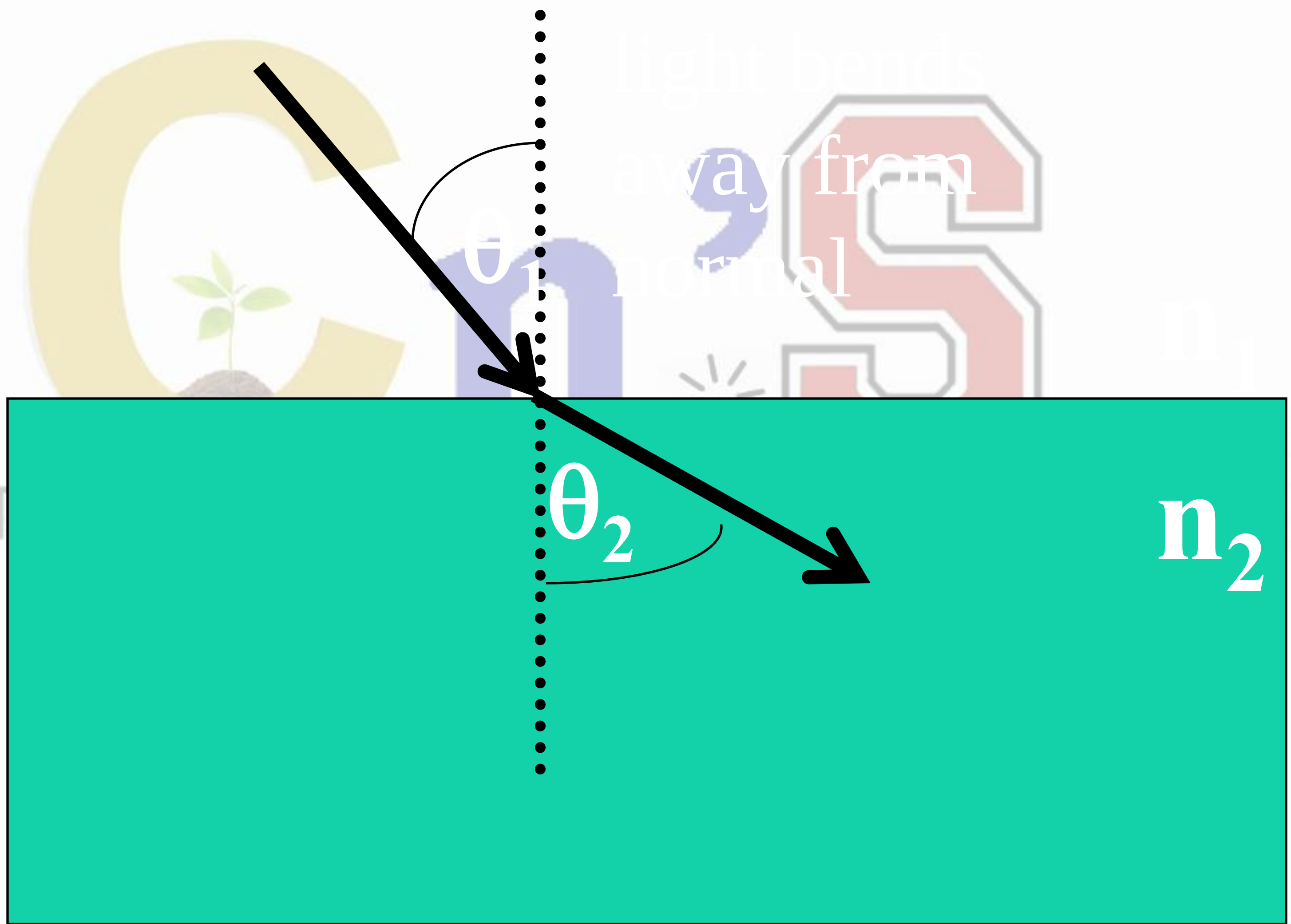
- A beam of light enters a layer of water at an angle of 36^0 with the vertical. What is the angle between the refracted ray and the vertical?

$$\begin{aligned} n_1 \sin\theta_1 &= n_2 \sin\theta_2 \\ \sin\theta_2 &= \frac{n_1}{n_2}\sin\theta_1 = \frac{1}{1.333}\sin 36^0 = 0.44095 \\ \theta_2 &= \arcsin(0.44095) = 26.2^0 \end{aligned}$$

$n_1 < n_2$



$n_1 > n_2$

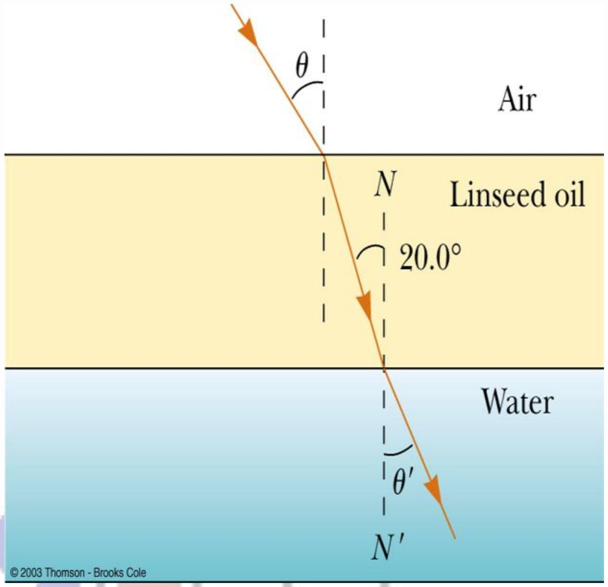


Relationships between index, speed of light, and wavelength

$$\frac{n_1}{n_2} = \frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}$$

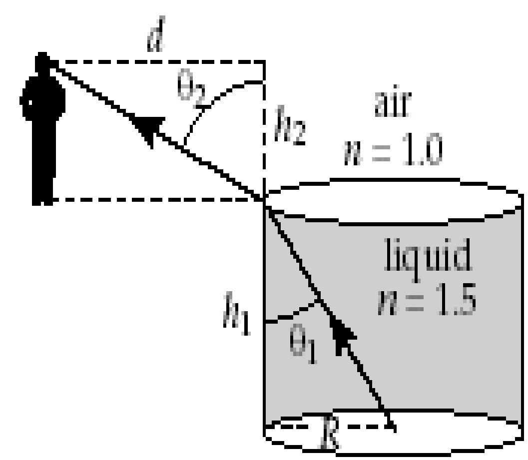
Problem 22.21

The light shown in the figure makes an angle of 20^o with the normal NN’ in the linseed oil (n=1.48). Determine angles θ and θ’.

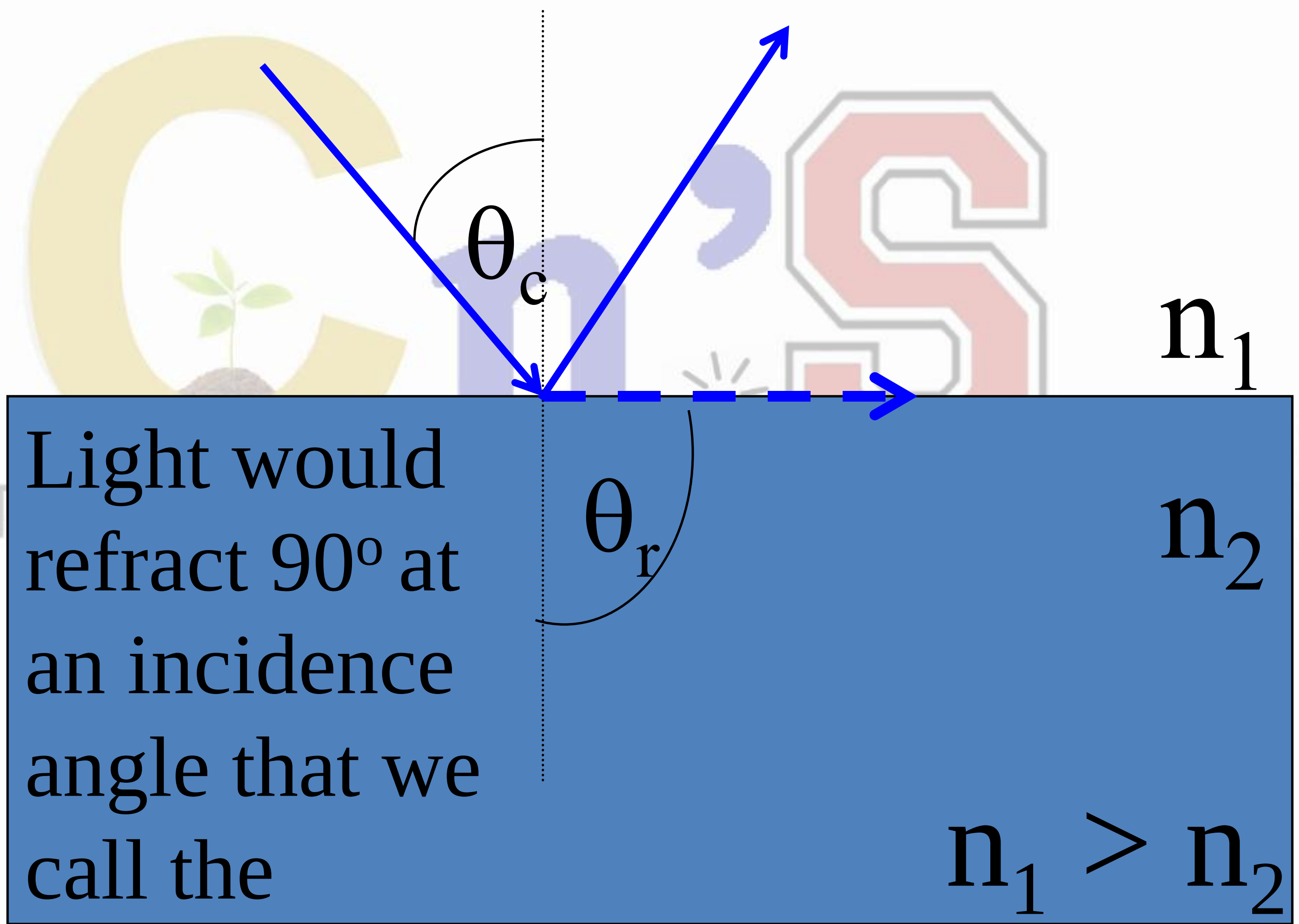


Problem 22.28

A cylindrical cistern, constructed below ground level, is 3.0 m in diameter and 2.0 m deep and is filled to the brim with a liquid whose index of refraction is 1.5. A small object rests on the bottom of the cistern at its center. How far from the edge of the cist eyes are 1.2 m from still see the object?



Critical Angle of Incidence



Calculating Critical Angle

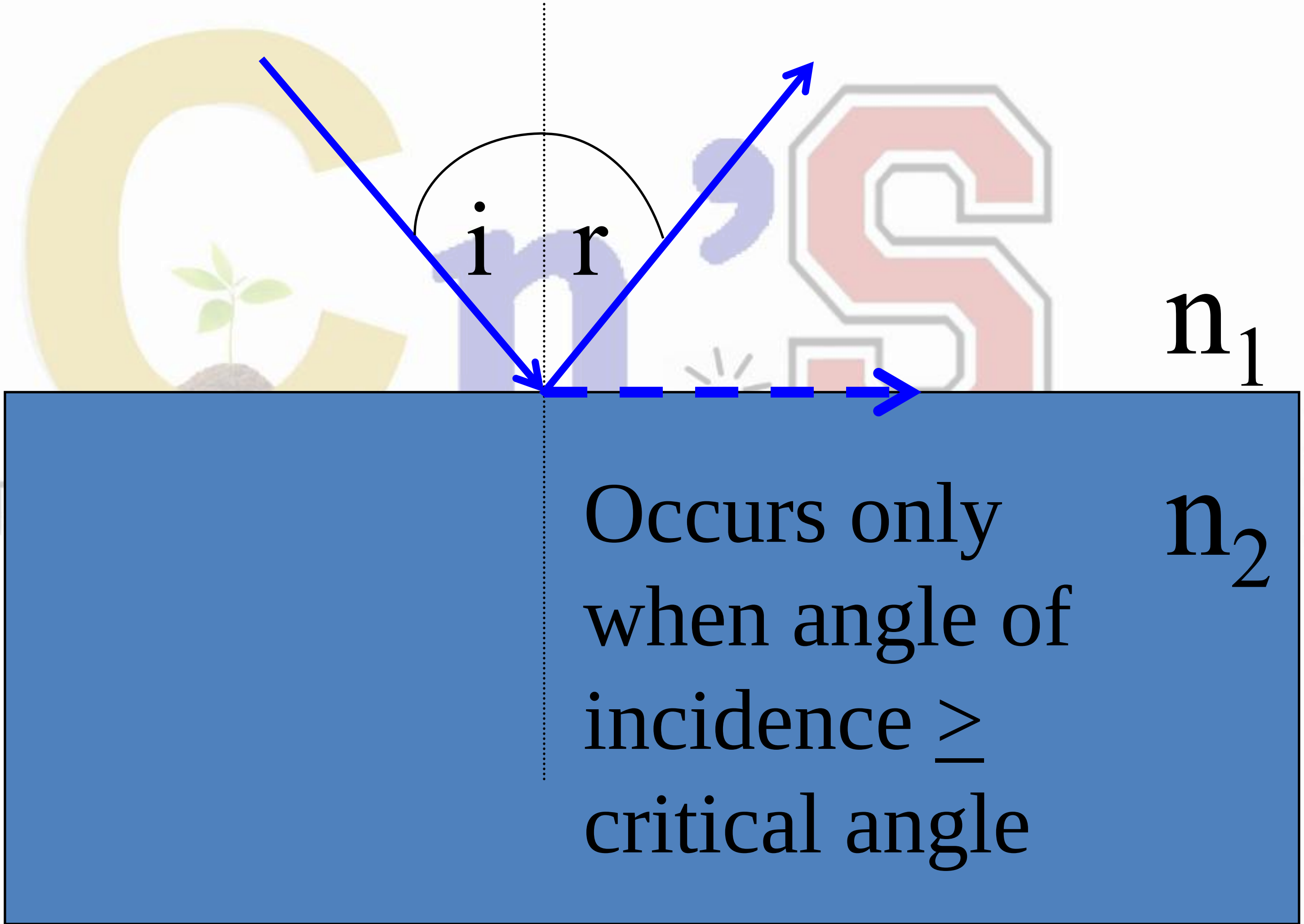
$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

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

$$n_1 \sin(\theta_c) = n_2$$

$$\sin(\theta_c) = n_2 / n_1$$

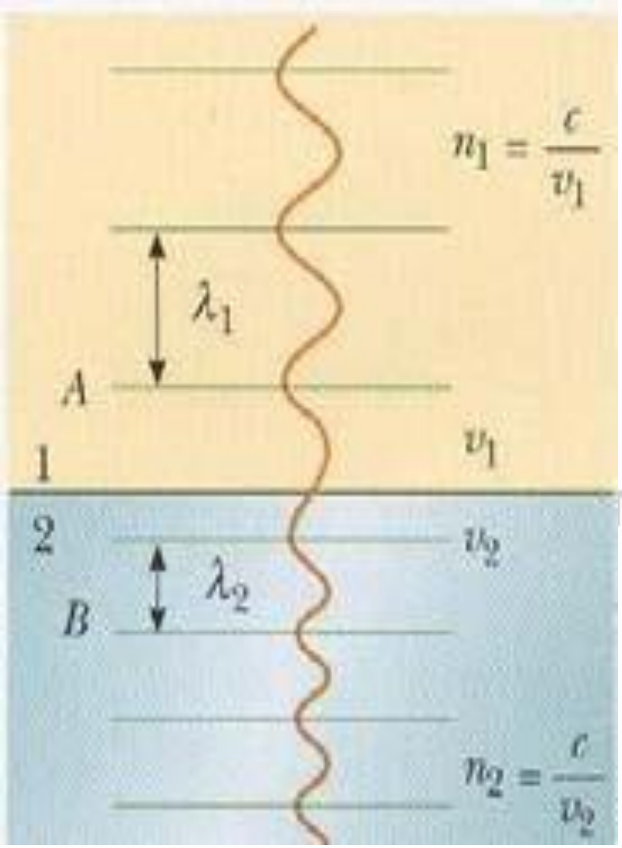
Total Internal Reflection



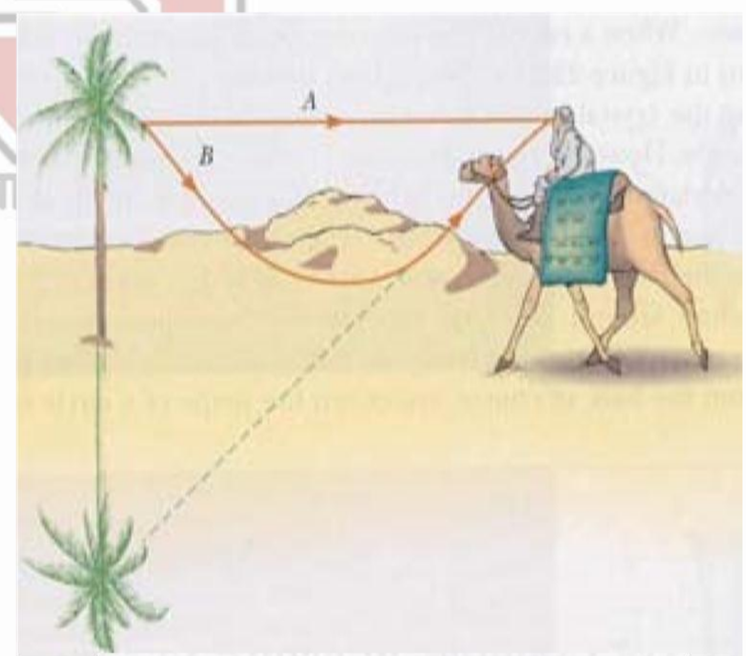
Occurs only when angle of incidence $\geq$ critical angle

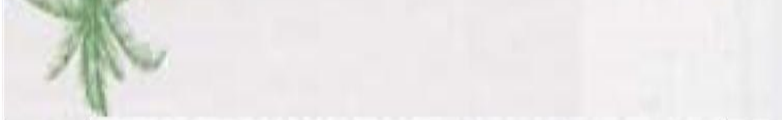
Total Internal Reflection

It is possible to show that, as light travels from one medium to another, its wavelength changes but its frequency remains constant

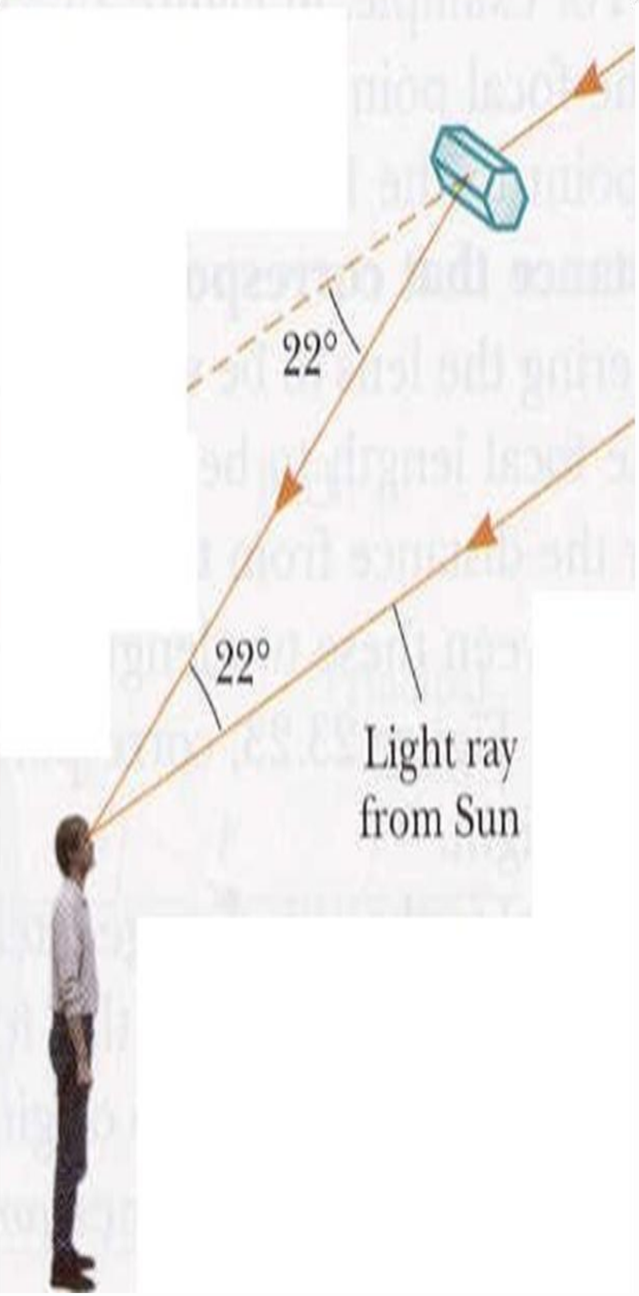


- The **mirage** is phenomenon of nature produced by refraction in the atmosphere. A mirage can be observed when the ground is so hot that the air directly above it is warmer than the air at higher elevations. The desert is a region in which such circumstances prevail, but mirages are also seen on heated roadways during the summer. The layers of air at different heights above the Earth have different densities and different refractive indicies





- A **halos** around Moon or Sun is another phenomenon of nature are caused by high, thin cirrus clouds drifting 20,000 feet or more above our heads. These clouds contain millions of tiny ice crystals, which create the halos.



super moon this is a special type of 22-degree lunar halo, called a circumscribed halo.

Robert Green of London caught this glorious solar halo on August 12, 2017, from Suðuroy, Faroe Islands. His daughter Mia is standing beneath!

Fiber Optics