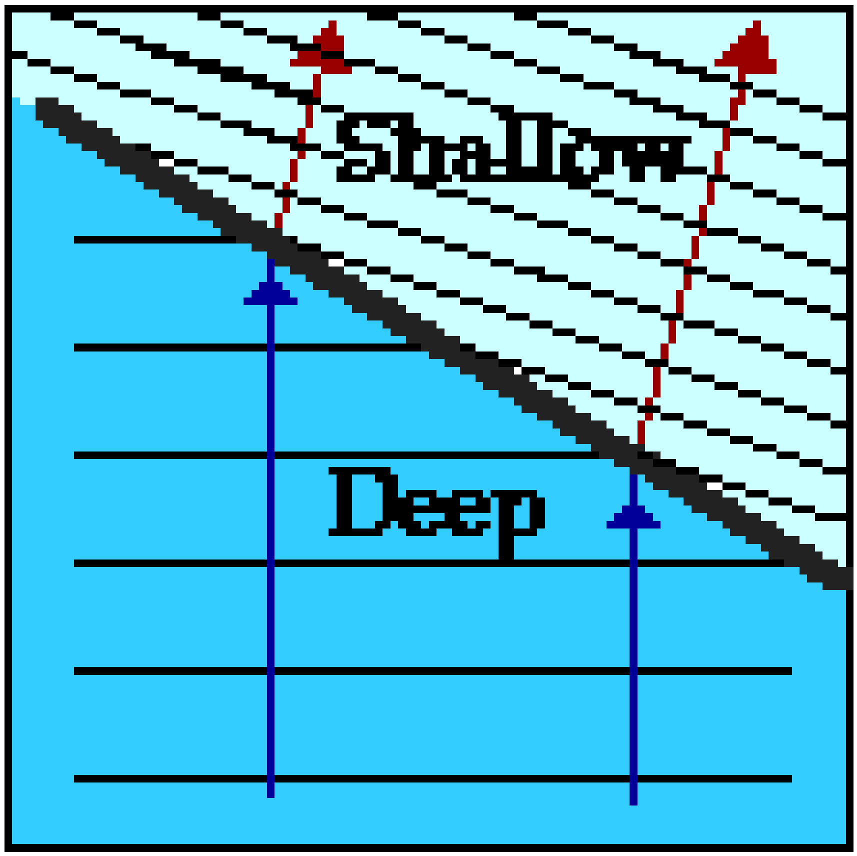
Refraction of Light

Refraction

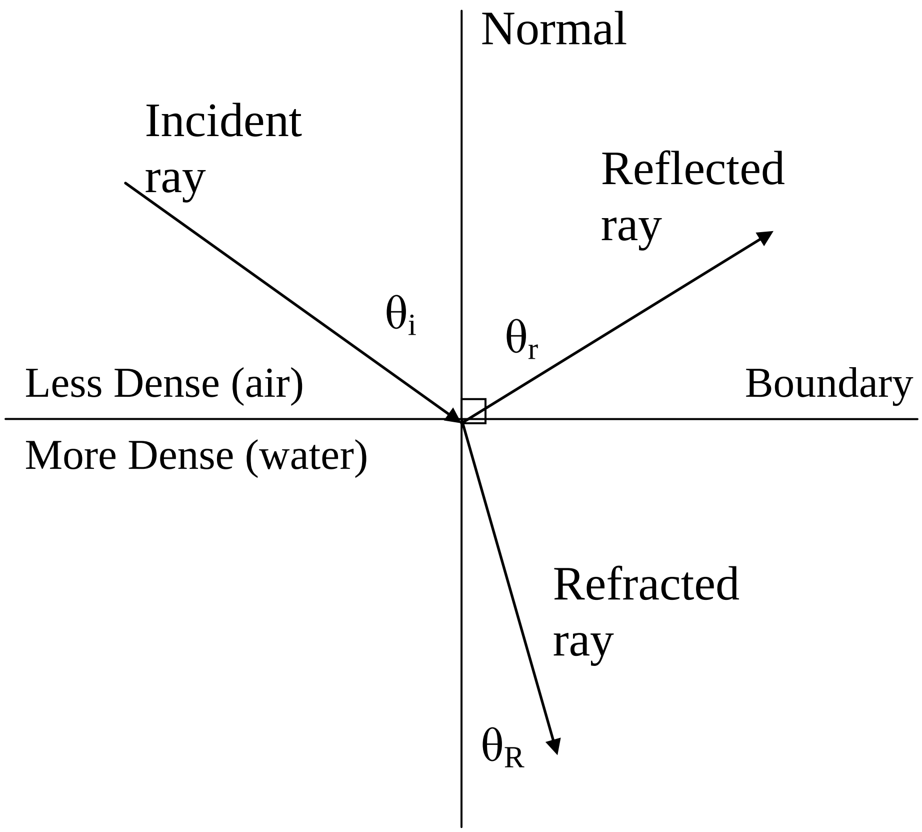
- Refraction is the change of direction of a ray of light as it travels into different media. (Different media means different densities).



www.physicsclassroom.com/Class/waves/u10l3b.html

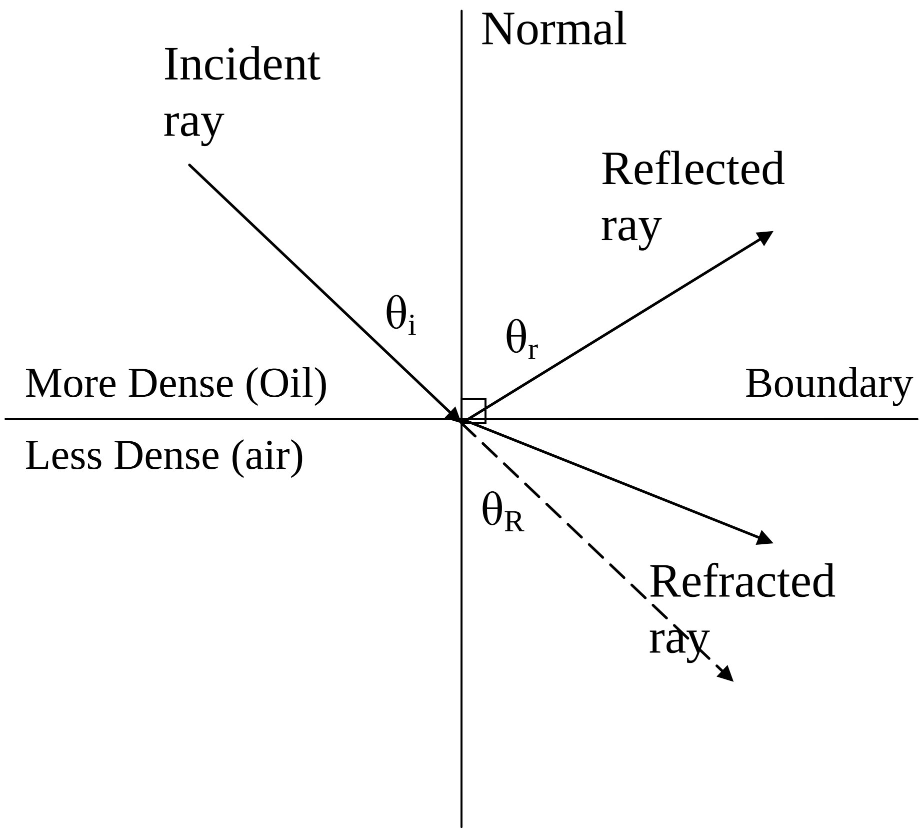
- Waves change direction as they enter shallow water.
- The same is true for light. Light changes direction as enters different media at an angle.
- How the light will bend depends on how the two media compare in density & physical structure.
- The ray diagrams below illustrate what happens to light for the two cases.

Refraction from a less dense to denser medium:



- ⇨ The angle of refraction, θ_R, is less than the incident angle, θ_i.
- ⇨ The refracted ray bends towards the normal → light slows down.
- ⇨ This will always be the case if light is coming from air and into anther medium.

Refraction from a more dense to less dense medium:



⇨ The angle of refraction, θ_R, is more than the incident angle, θ_i.

⇨ The refracted ray bends away from the normal → light speeds up.

⇨ If the angle of incidence is zero, there is no change of direction, but there is a change of speed.

⇨ Principle of Reversibility: If a light ray is reversed, it travels back along its original path.

Index of Refraction

- To understand the behavior of light in different properties, we refer to the index of refraction *n*.
- It is the ratio of the speed of light in a vacuum, c, to the speed of light in a given material, v.

- Mathematically,

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

- The higher the index of refraction, the more light is slowed down when it travels from a vacuum in to a substance.

Examples

1. The speed of light in a liquid is 2.25×10^8 m/s. What is the refractive index of the liquid?

2. Calculate the speed of light in Lucite (Plexiglas), if $n_{lucite} = 1.51$

Indices of Refraction	
Substance	Index of Refraction (*n*)
Vacuum	1.0000
Air (0°C, 101 kPa)	1.0003
Water	1.33
Ethyl alcohol	1.36
Quartz (fused)	1.46
Glycerin	1.47
Lucite or Plexiglas	1.51
Glass (crown)	1.52
Sodium chloride	1.53
Glass (crystal)	1.54
Ruby	1.54
Glass (flint)	1.65
Zircon	1.92
Diamond	2.42
Note: For yellow light, wavelength = 589 nm	

Laws of Refraction

- Willebrod Snell (1591 – 1626) was able to determine the exact relationship between the angle of incidence and the angle of refraction.
    - This enables us to predict the direction a ray of light would take in various media.

⇨ **This is called Snell's Law:**

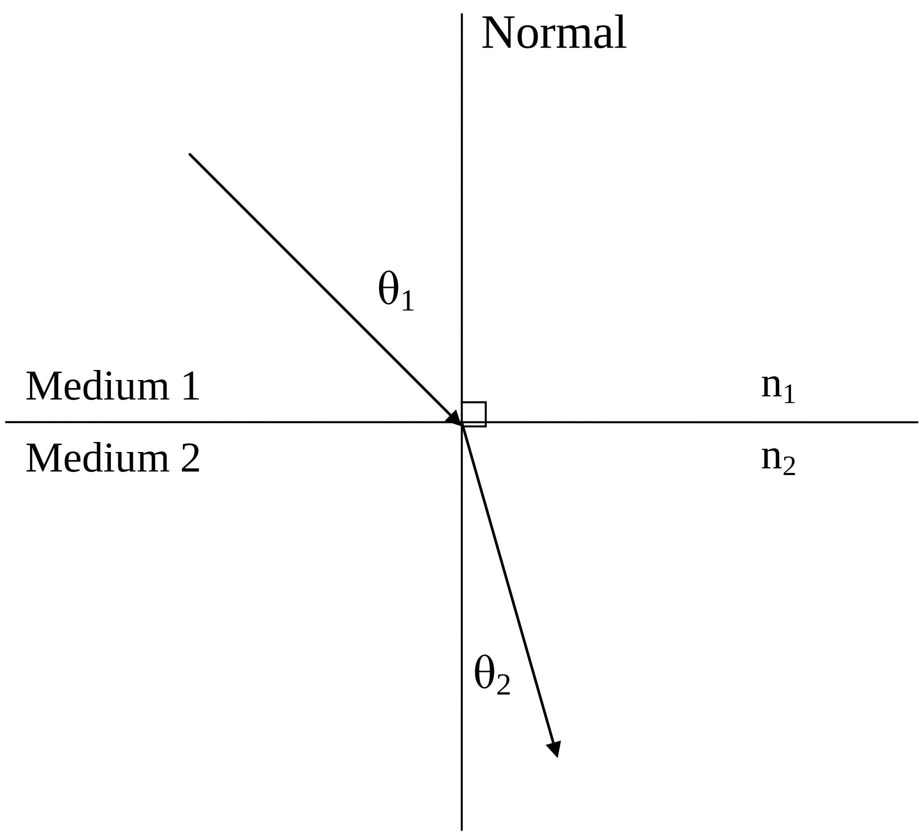
$$\frac{\sin i}{\sin R} = \text{constant}$$

- ⇨ Where i = angle of incidence and R = angle of refraction.
- ⇨ If light is traveling from a vacuum, the constant is the index of refraction of the material.

The Laws of Refraction are:

1. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant (Snell's Law).
2. The incident ray and the refracted ray are on opposite sides of the normal at the point of incidence, and all three lie in the same plane.

Snell's Law – A General Equation



Mathematically we write:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

or

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

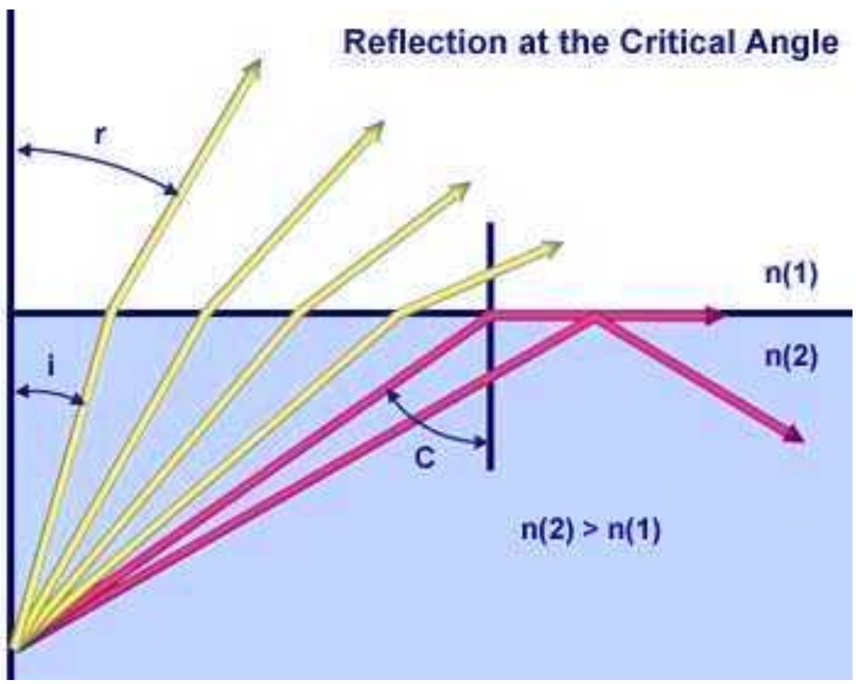
Examples

1. Light travels from crown glass into air. The angle of refraction in air is 60°. What is the angle of incidence in glass?

2. Light travels from crown glass into water. The angle of incidence in crown glass is 40°. What is the angle of refraction in water?

Total Internal Reflection and the Critical Angle

- ⇨ When light travels into a medium where its speed changes, some light is reflected, and some is refracted.
- ⇨ As the angle of incidence increases, the intensity of the reflected ray increases. The intensity of the refracted ray decreases.
- ⇨ Total internal reflection occurs when light travels into a faster medium and the angle of refraction is 90° or greater.
- ⇨ When the angle of refraction is 90°, the angle of incidence is called the critical angle, angle C.
- ⇨ Angles of incidence greater than the critical angle result in total internal reflection.



Virginia University website: galileo.phys.virginia.edu/. ../introduction.htm

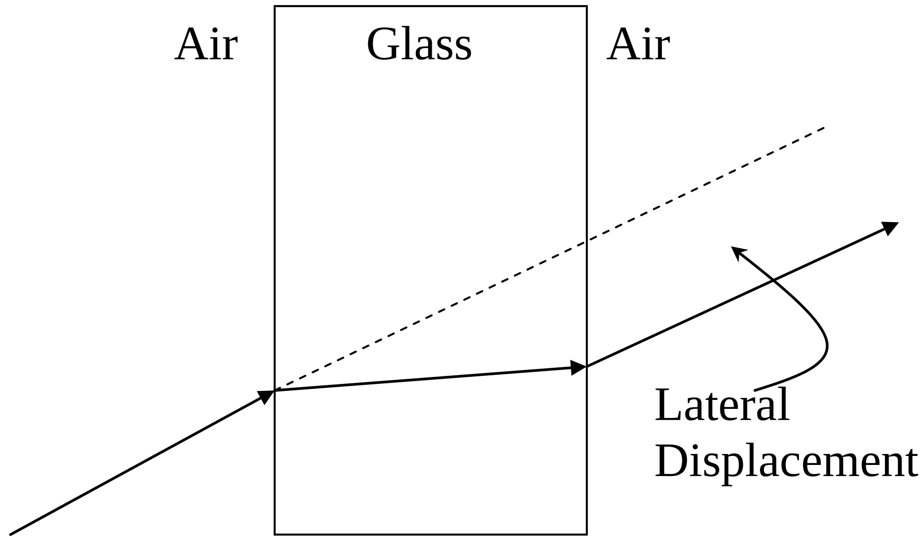
Example

1. The critical angle for light traveling from crown glass into air can be found with Snell's Law.

2. What is the critical angle of light traveling from a diamond to a ruby?

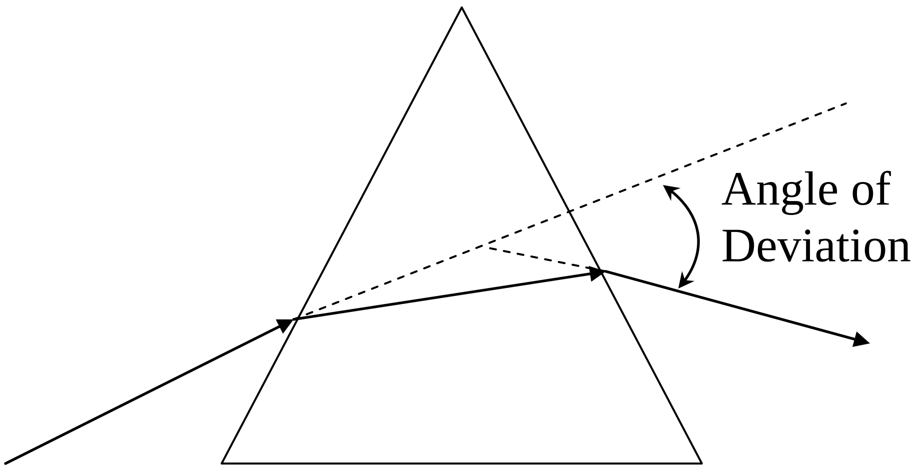
Lateral Displacement

- When light travels from air into glass and then back into air, it is refracted twice.
  - If the two refracting surfaces are parallel, the emergent ray is parallel to the incident ray, but not following the same path.
  - This is called lateral displacement.
  - The thicker the material, the greater the lateral displacement.



Angle of Deviation

- If the surfaces of the refracting material are not parallel, like with a prism, an emergent ray will take a completely different path.
  - The angle between the incident ray and the emergent ray is called the angle of deviation.



Finding Lateral Displacement

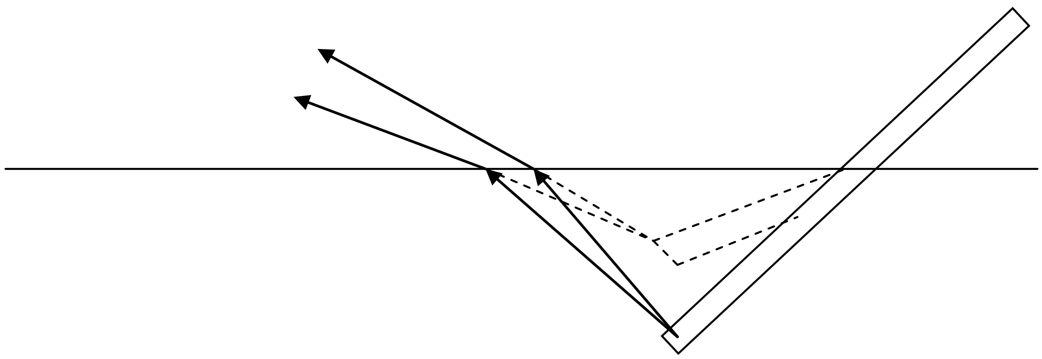
1. Draw the incident ray straight through as if it didn't refract.
2. Construct a normal at the incident side and measure angle *i*,
3. Use Snell's Law to determine the angle of refraction.
4. Measure and construct the refracted ray.
5. Construct normal #2 where the refracted ray meets the 2nd side.
6. The original incident angle will be the same as the angle made by the emerging ray back into the air.
7. Construct the emerging angle, measured from normal #2.
8. Measure the perpendicular distance between the emerging ray and the line where the incident ray would have traveled had it not refracted (step 1).

Finding Angle of Deviation

1. Draw the ray straight through as if it had not refracted.
2. Construct a normal at the incident side and measure angle *i*.
3. Use Snell's Law to determine the angle of refraction.
4. Measure angle *R* and construct the refracted ray.
5. Construct normal #2 where the refracted ray hits the opposite side of the triangle.
6. Measure the angle between normal #2 and the refracted ray in the triangle → this becomes the incident angle for the ray as it goes from the triangle into air.
7. Use Snell's Law to determine the angle of refraction when the ray passes into air.
8. Measure this angle and construct the emerging ray.
9. Project the emerging ray backwards until it meets the original ray had it not refracted (step 1).
10. Measure the angle of deviation.

Applications of Refraction

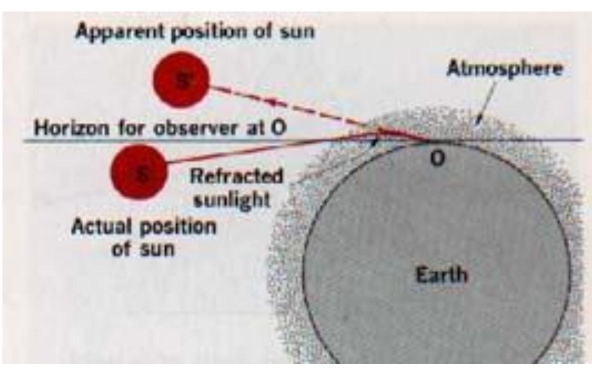
1. **Apparent bending of a straight stick in water.**



- Refraction makes it look as if the light originates closer to the surface than it actually is.

2. **Atmospheric Refraction**

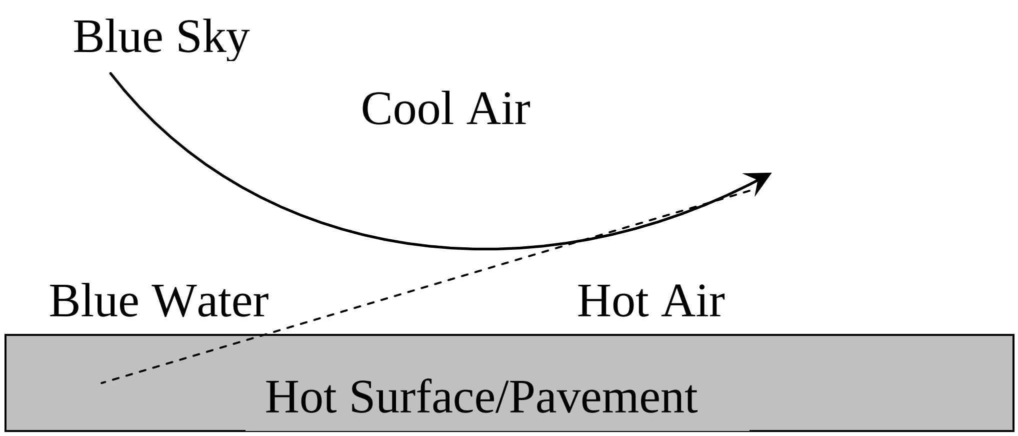
- As the Sun sets, its light is refracted as it passes from the vacuum of space into the Earth's atmosphere.
- The density of the air increases as the light gets closer to the surface of the Earth, so refraction increases, resulting in a curved path.
- An observer "sees" the Sun coming from a point higher in the sky. When we see a sunset, the sunlight is coming from below the horizon!
- This also explains the distortion of the Sun during a sunset.



cougar.slvhs.slv.k12.ca.us/.../ ch14.html www.weather-photography.com/Photos/gallery.ph.

3. Puddle Mirage on the Road

- Sometimes while driving you may see what looks like a puddle of water up ahead. Upon arriving there, the puddle disintegrates and it is in fact dry pavement.
- Light has a slightly different index of refraction in warm air than in cool air.
- As light propagates from the cool upper atmosphere towards the warmer air near the ground, it refracts and its path may take it upwards again.
- When we drive through the refracted light we see atmosphere on the road in front of us. What we see is not water but the blue of the atmosphere.



4. Red/Orange Lunar Eclipse

- During a lunar eclipse the Moon takes on a red and orange colour. This happens because of light being refracted by the Earth's atmosphere. Similar to when the Sun sets or rises when viewed from Earth.

http://www.mreclipse.com/MrEclipse.html