
Refraction:
The “bending” or direction change of light

Refraction in action…

Figure 3

Refraction

Water is acting like a lens, flipping the image.

Refraction: The bending of light.

- The Refraction of Light most often occurs as light moves from one medium or material, to another, such as moving from air into water. The water is more optically dense than the air – this means that in the water, the light actually travels slightly slower. This ‘drag’ on the speed of the light causes the path of the light to bend as it moves from the air to the water. (Does not bend when 90 degrees to medium surface)

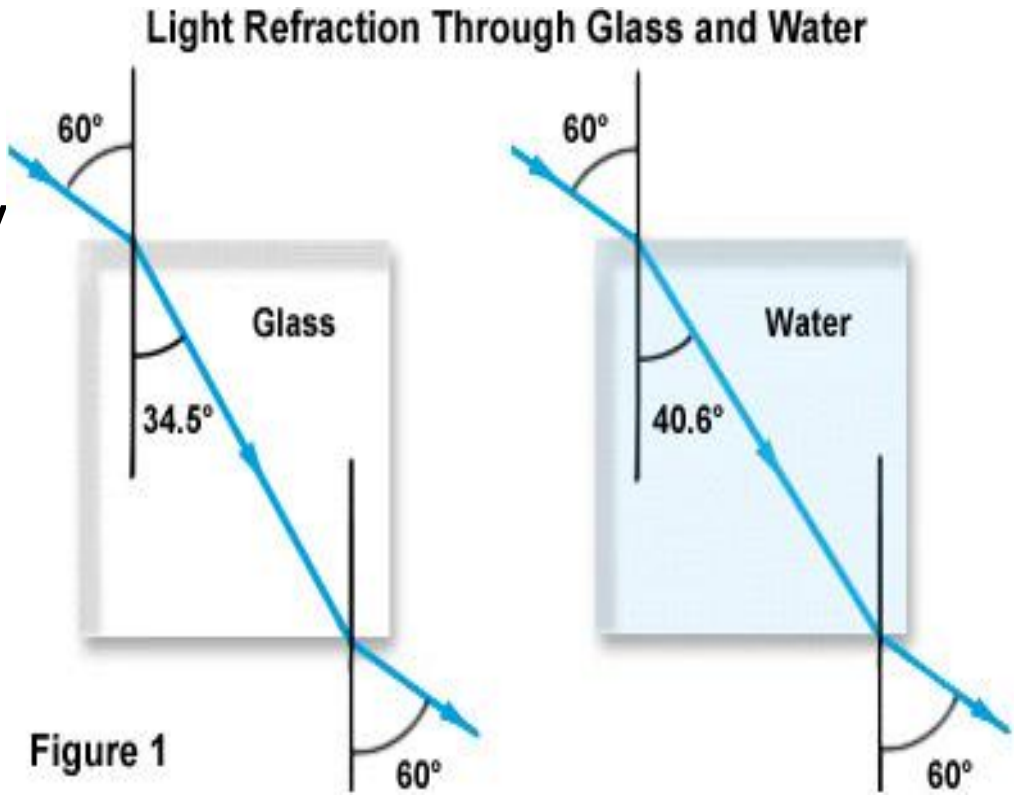
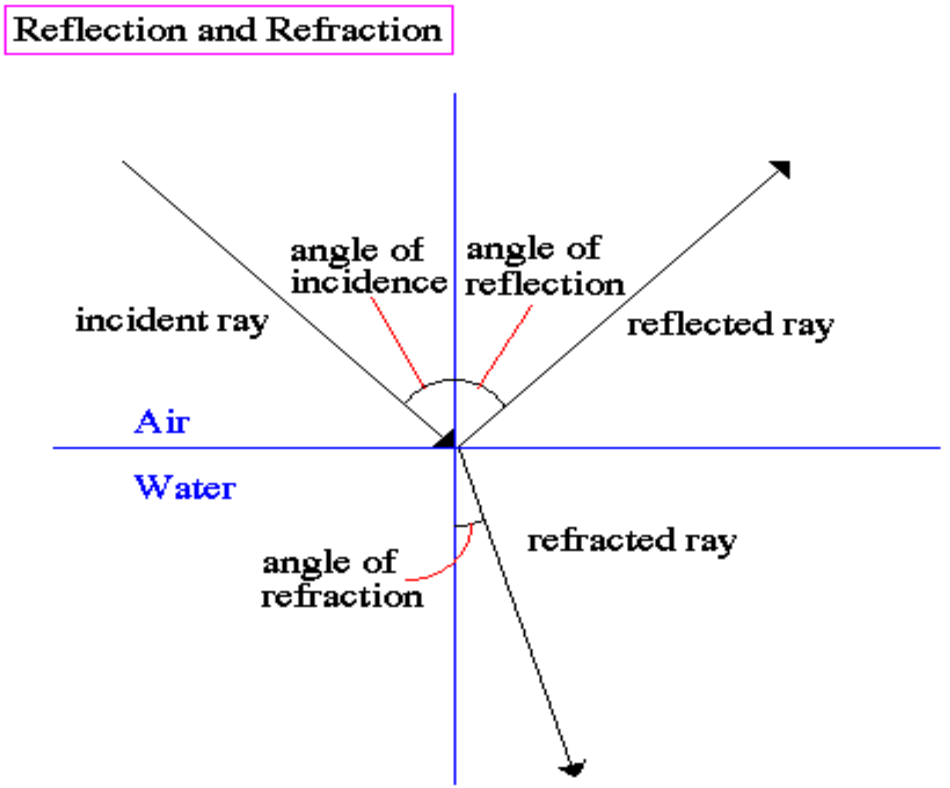
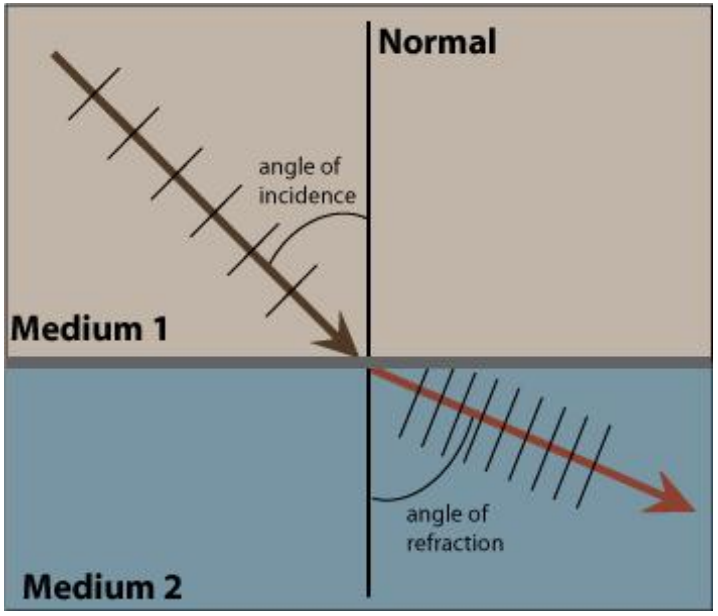


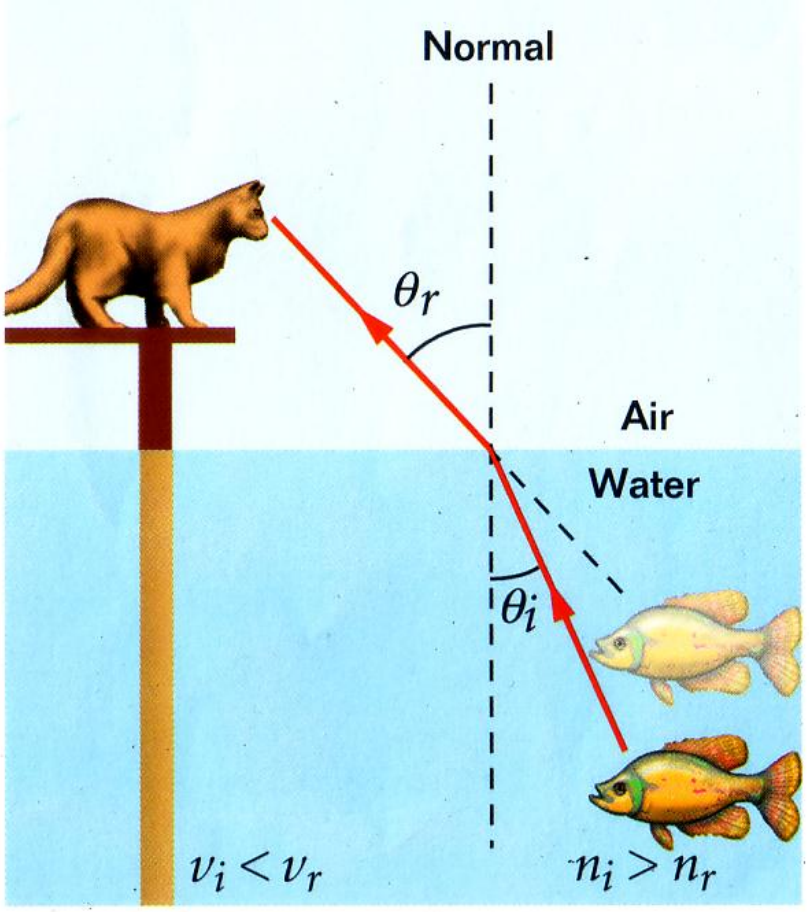
Figure 1

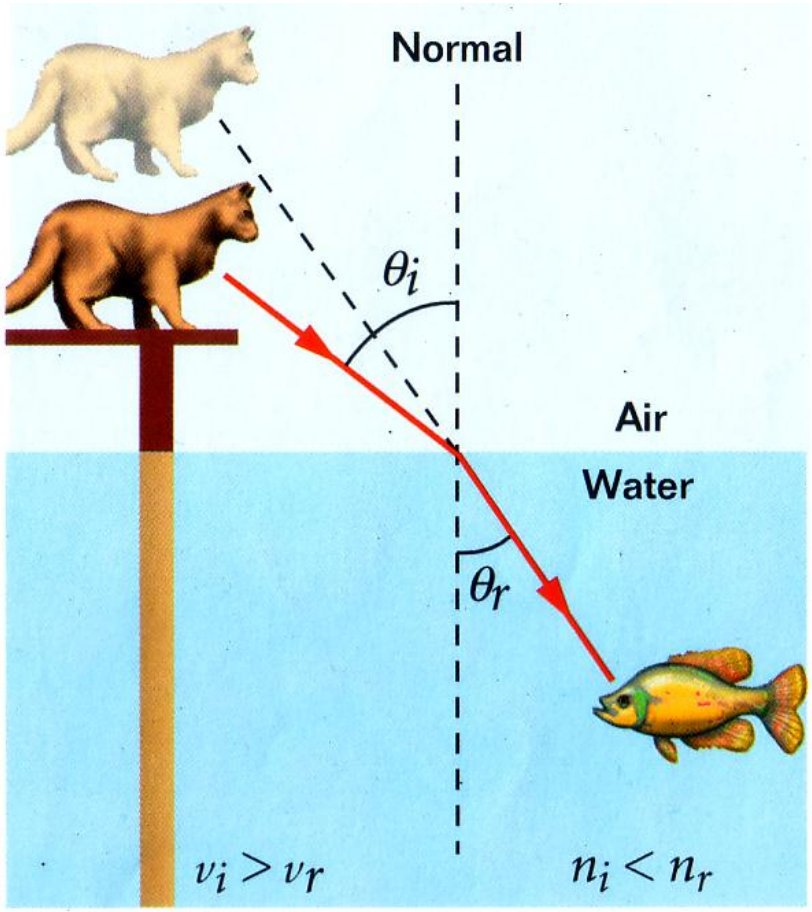
- Here we can see both reflection and refraction occurring at a medium boundary.
- When light goes from a less optically dense medium to a more dense medium it bends **toward** the normal (top). If it goes from more dense to less it bends **away** from the normal (bottom).



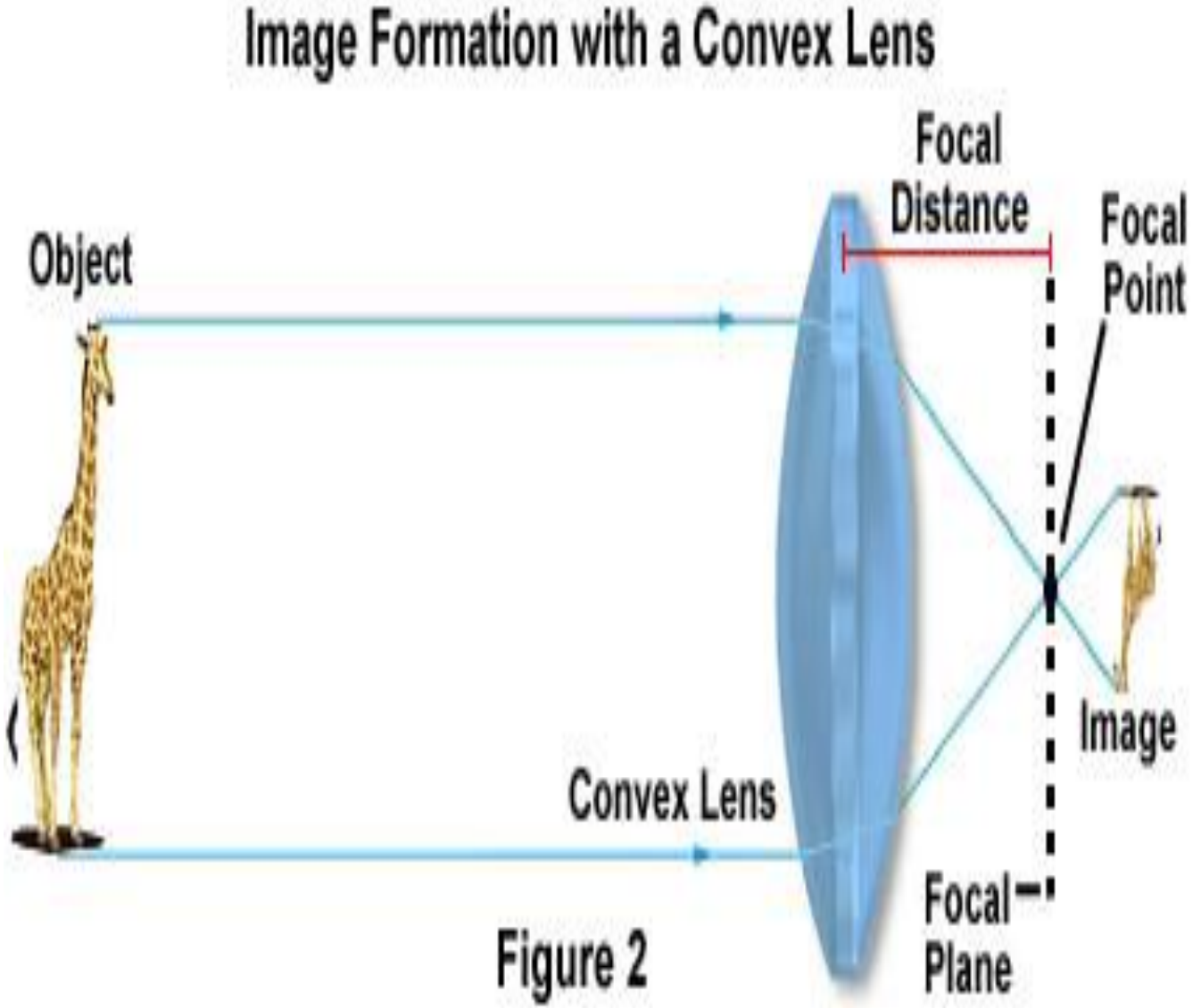


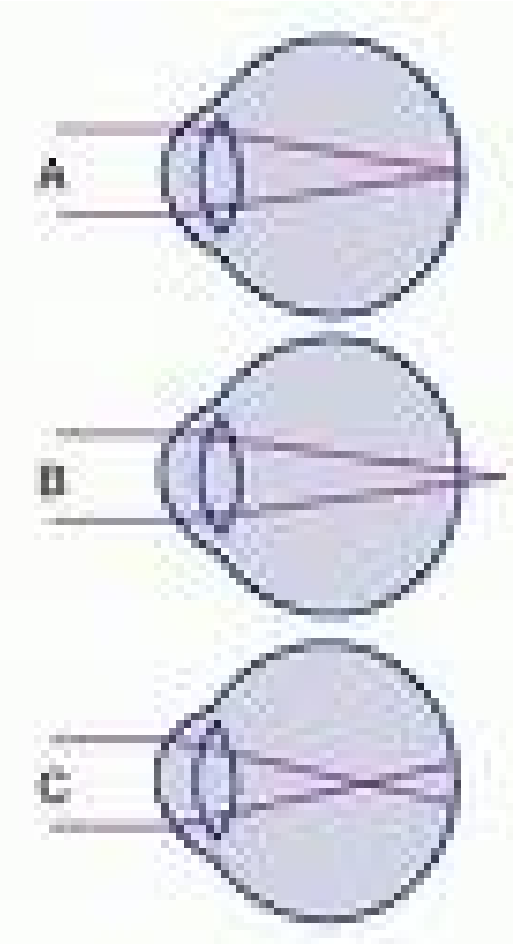
Where do you see refracted images?





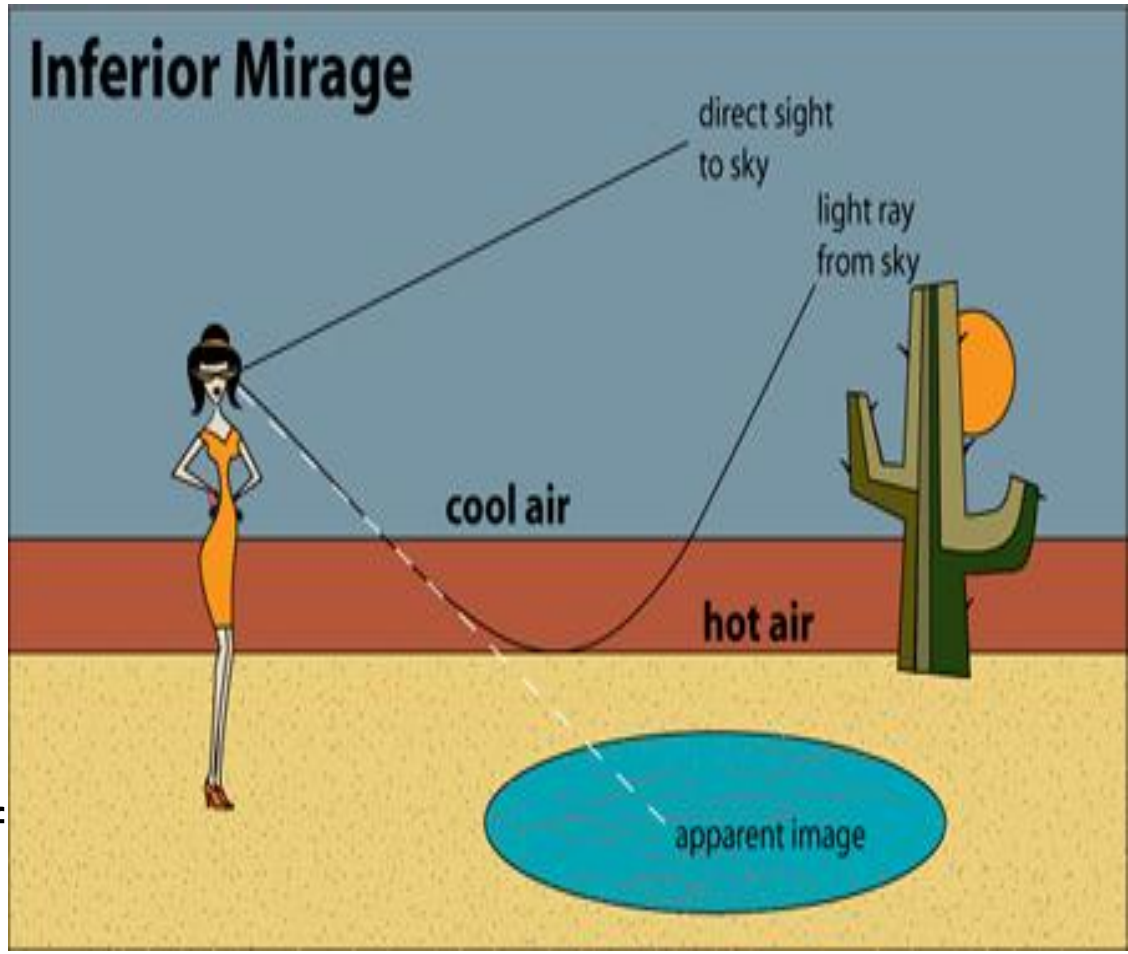
More effects…



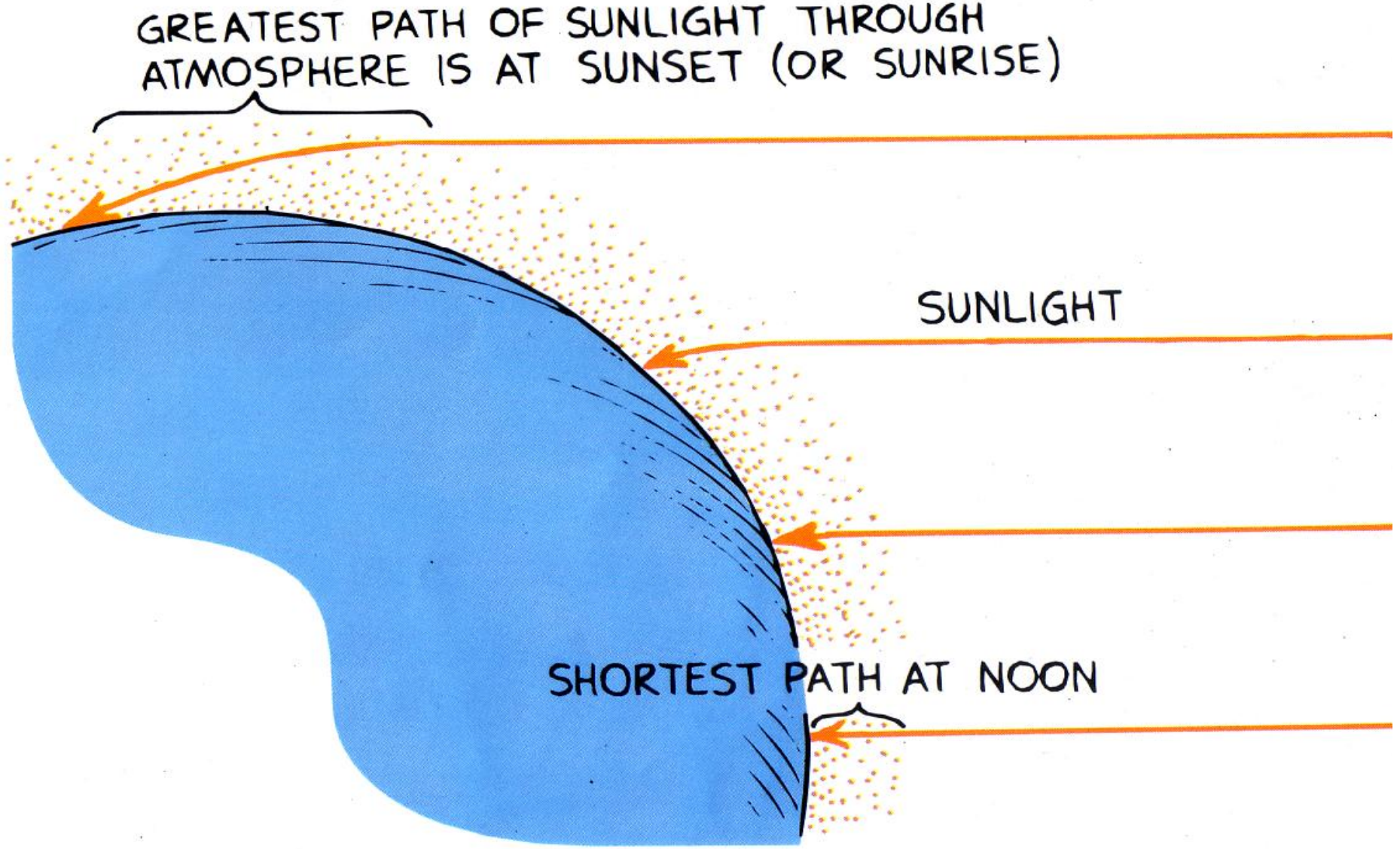


Mirage

Let's examine the situation in a desert where mysterious pools of water appear for the thirsty travelers. The light is coming down to the Earth's surface at a severe angle is actually bent by the different layers of air, curving upwards to arrive at our eyes. When this light arrives at our eyes, we see the bright blue sky, but this blue area appears on the surface of the Earth. This gives the illusion of light bouncing off water on the surface of the sand.

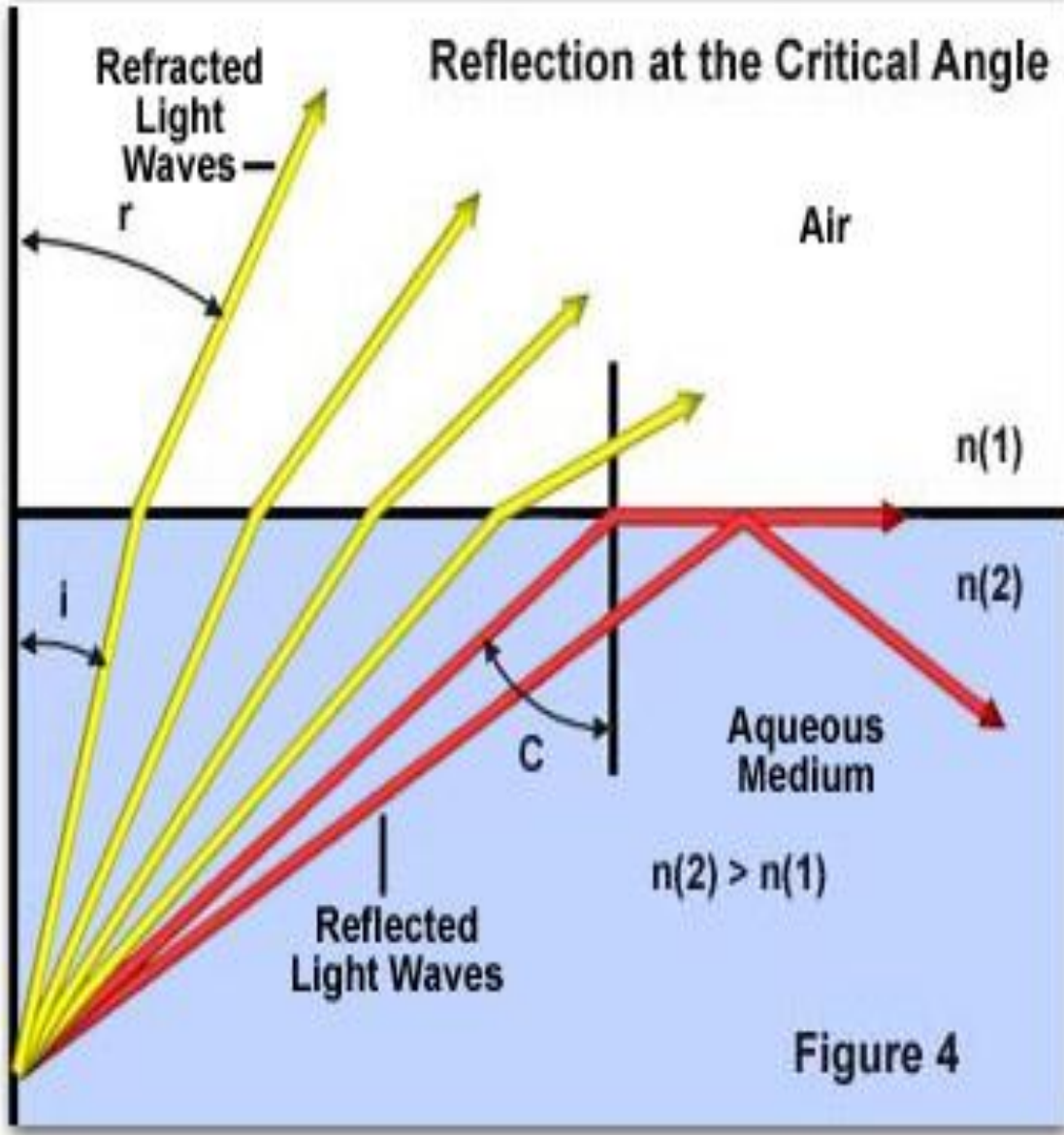


How can you see the sun after it sets?



Total internal reflection

- There is a specific angle at which light will not refract through at a medium boundary but will reflect instead. This specific angle is called **the critical angle**.
- http://www.learnerstv.com/animation/animation.php?ani=102&cat=physics



Total internal reflection

Index of refraction

- The index of refraction is a value (ratio) which represents how much slower light travels in a medium compared to light traveling through a vacuum (or air).
- The index of refraction, **n**, of other transparent materials is defined through the equation:
- where **c** is the speed of light($3x10^8 m/s$), and **v** is the velocity of light in that material.
- Because the refractive index of a vacuum is defined as 1.0 and a vacuum is devoid of any material, the refractive indices of all transparent materials are therefore greater than 1.0. For most practical purposes, the refractive index of light through air (1.0003) can be used to calculate refractive indices of unknown materials.

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

Some index values for various mediums….

Material	Refractive Index
Air	1.0003
Water	1.33
Glycerin	1.47
Immersion Oil	1.515
Glass	1.52
Flint Glass	1.66
Diamond	2.42
Zircon	1.92

- The angle of refracted light is dependent upon both the angle of incidence and the composition of the material into which it is entering.
- Light will pass into the boundary at an angle to the normal and will be refracted according to ***Snell's Law*:**
- $\mathbf{n_i \cdot \sin(\theta_i) = n_r \cdot \sin(\theta_r)}$

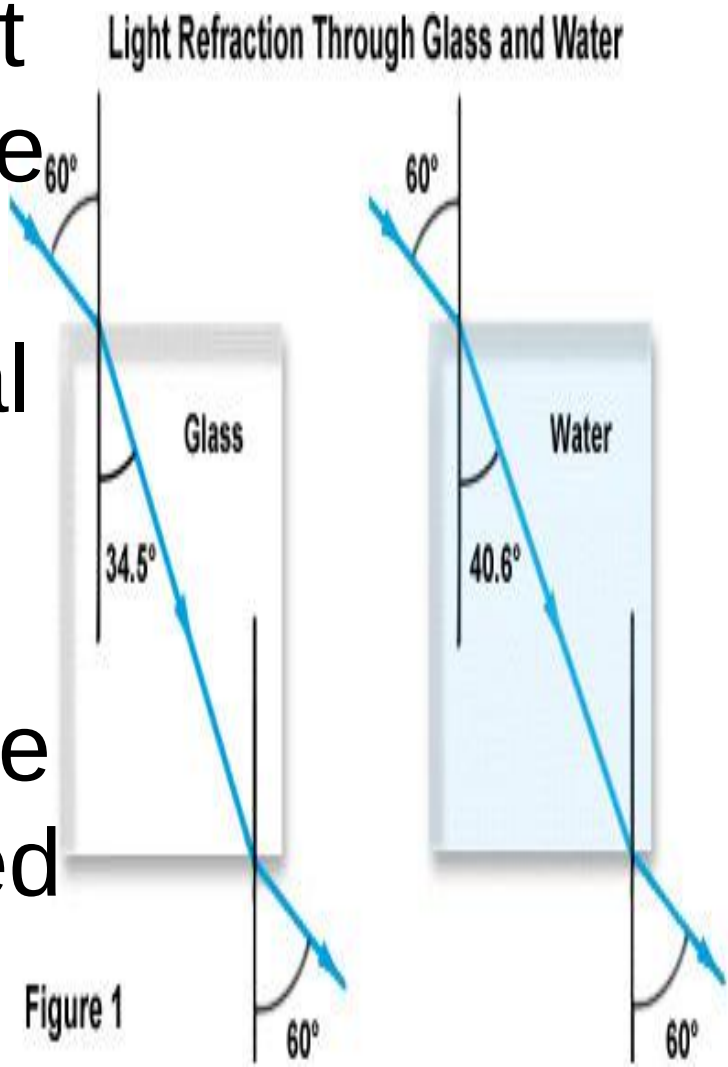


Figure 1

The Math

Putting it all together…

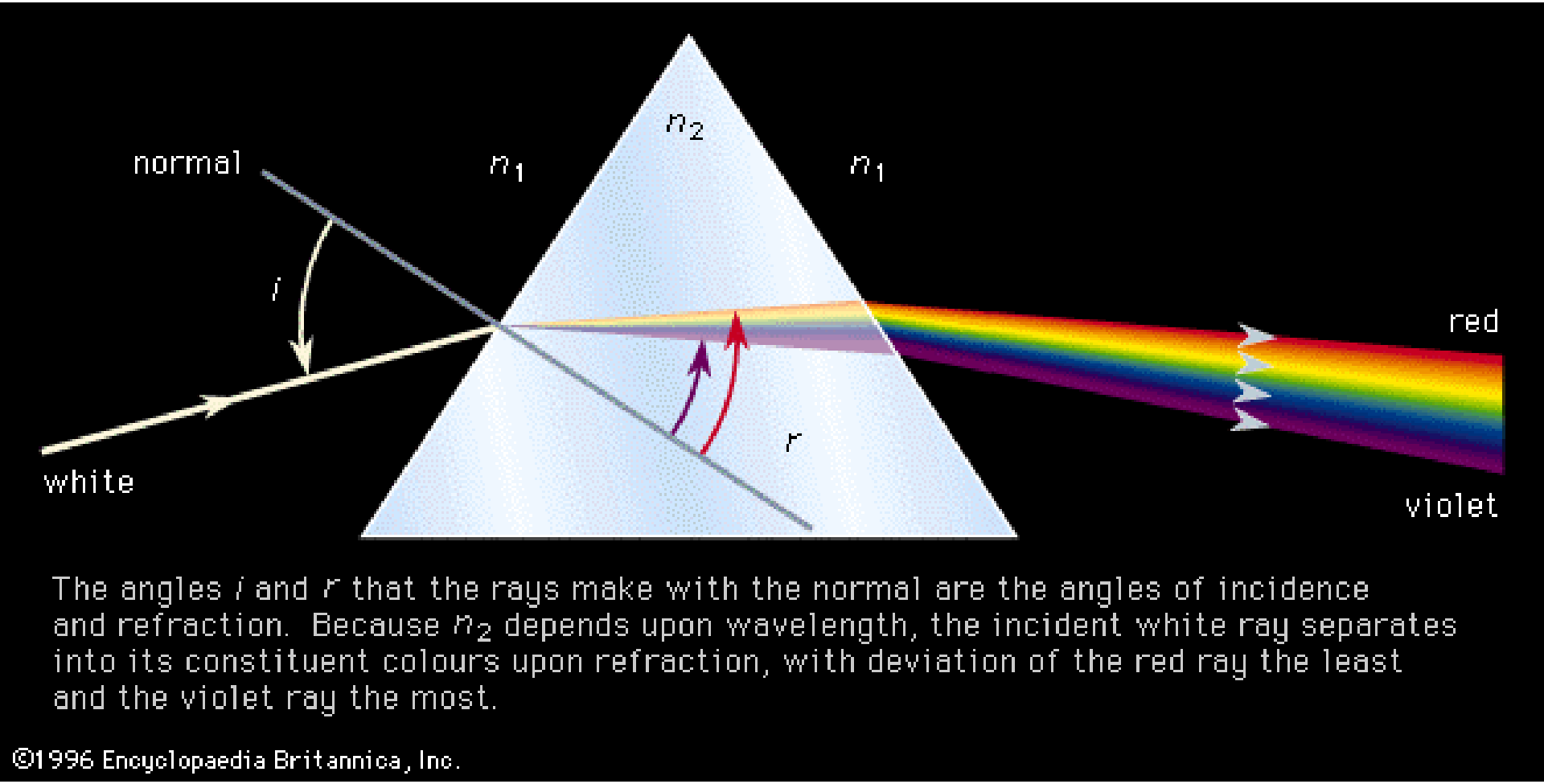
$$n_i \cdot \sin(\theta_i) = n_r \cdot \sin(\theta_r)$$

$$\frac{n_r}{n_i} = \frac{v_i}{v_r} = \frac{\sin(\theta_i)}{\sin(\theta_r)}$$

Where ***i*** = incident medium and ***r*** = refracted medium.

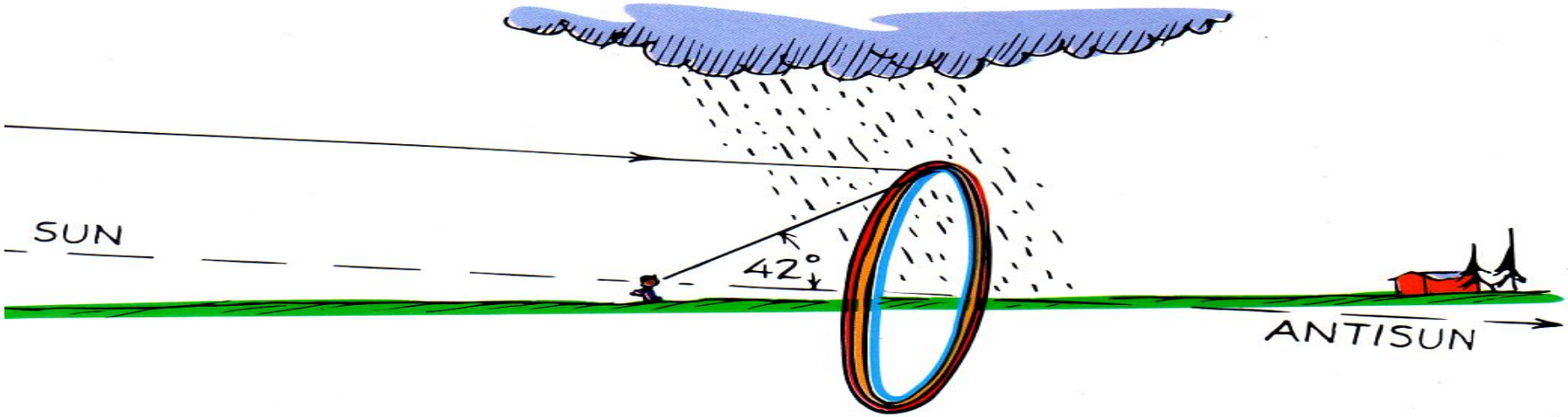
http://www.animations.physics.unsw.edu.au/jw/light/Snells_law_and_refraction.htm

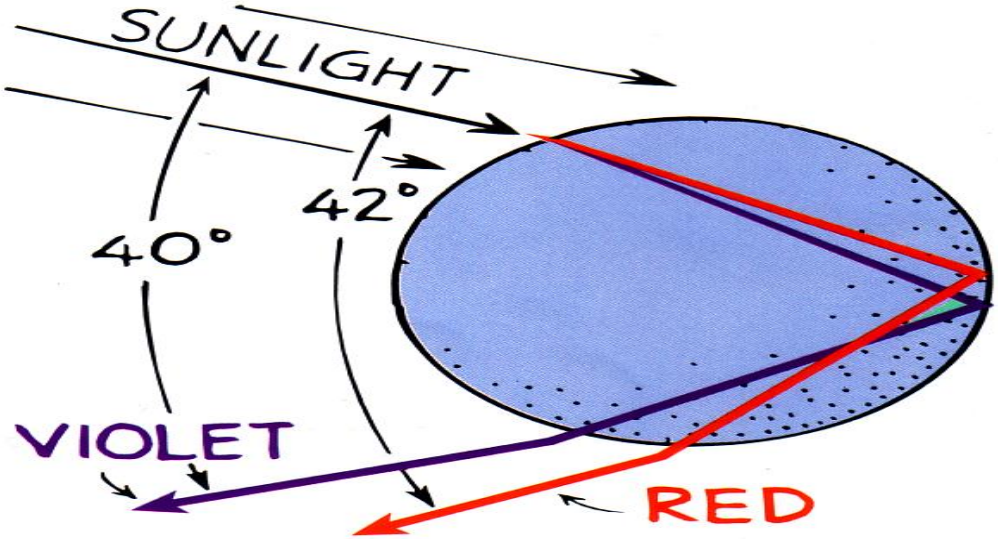
Different wavelengths of light refract different amounts



Which color of light refracts most? It has the smallest wavelength.

How a rainbow is produced.

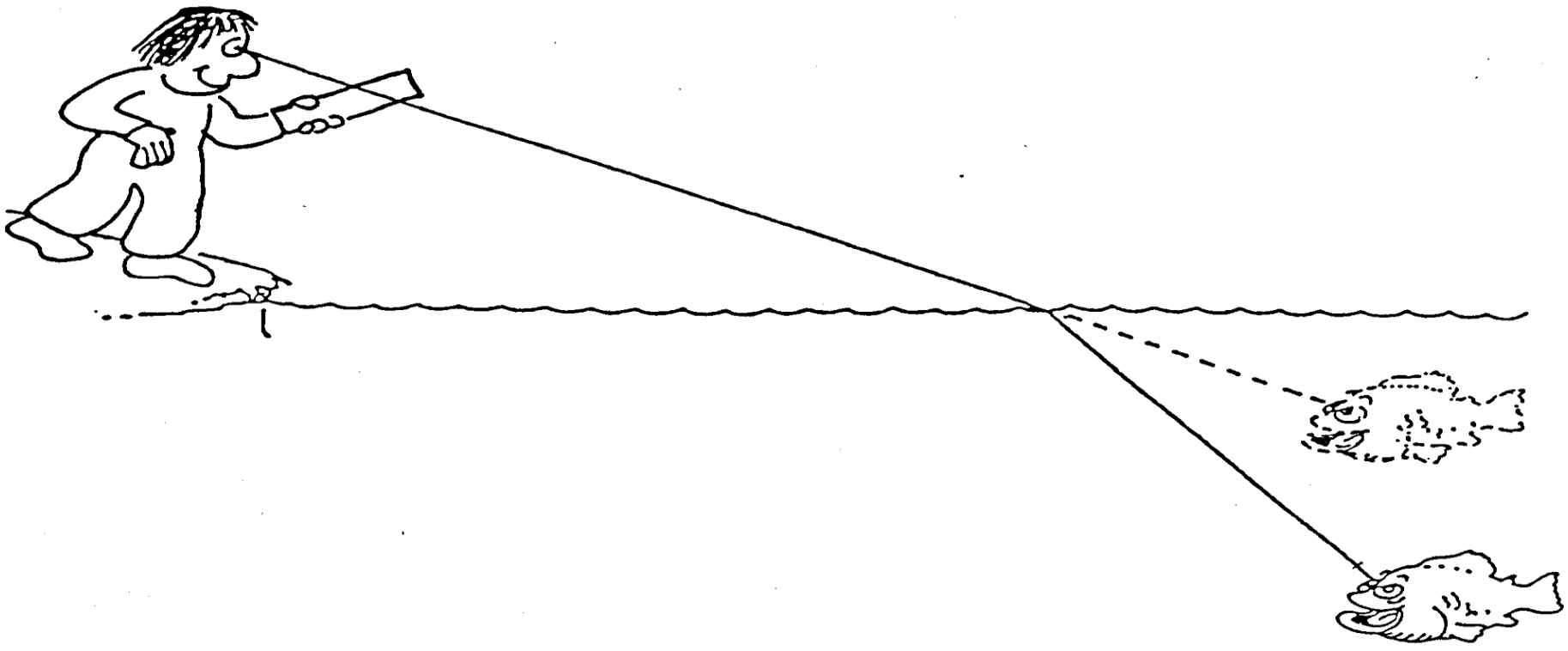




Different colors of light refract different amounts….

Material	Blue (486.1 nm)	Yellow (589.3 nm)	Red (656.3 nm)
Crown Glass	1.524	1.517	1.515
Flint Glass	1.639	1.627	1.622
Water	1.337	1.333	1.331
Cargille Oil	1.530	1.520	1.516
Carbon Disulfide	1.652	1.628	1.618

Question



BRUNO WISHES TO "SPEAR" A FISH WITH A LASER. SHOULD HE AIM THE LASER BEAM ABOVE, BELOW, OR DIRECTLY AT THE OBSERVED FISH TO MAKE A DIRECT HIT ?