Light II

Physics 2415 Lecture 32

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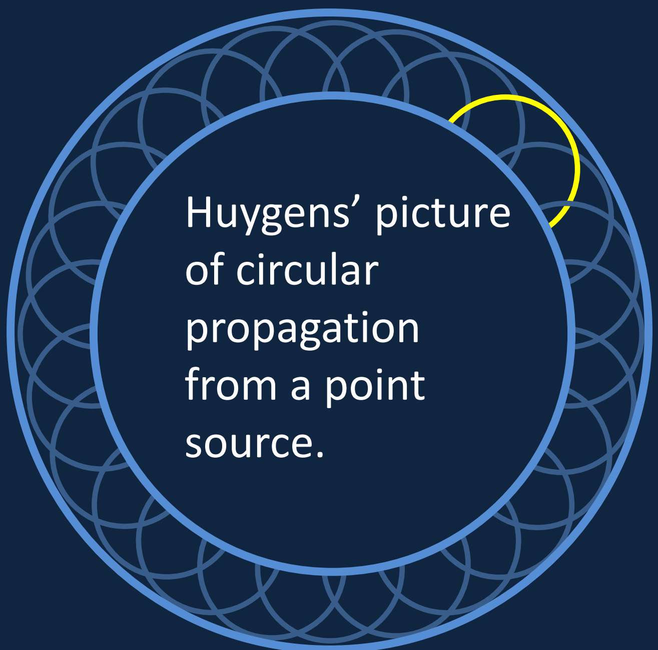
Today’s Topics

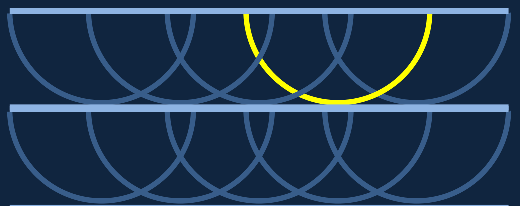
- Huygens’ principle and refraction
- Snell’s law and applications
- Dispersion
- Total internal reflection

Huygens' Principle

- Newton's contemporary Christian Huygens believed light to be a wave, and pictured its propagation as follows: at any instant, the wave front has reached a certain line or curve. From every point on this wave front, a circular wavelet goes out (we show one), the envelope of all these wavelets is the new wave front.

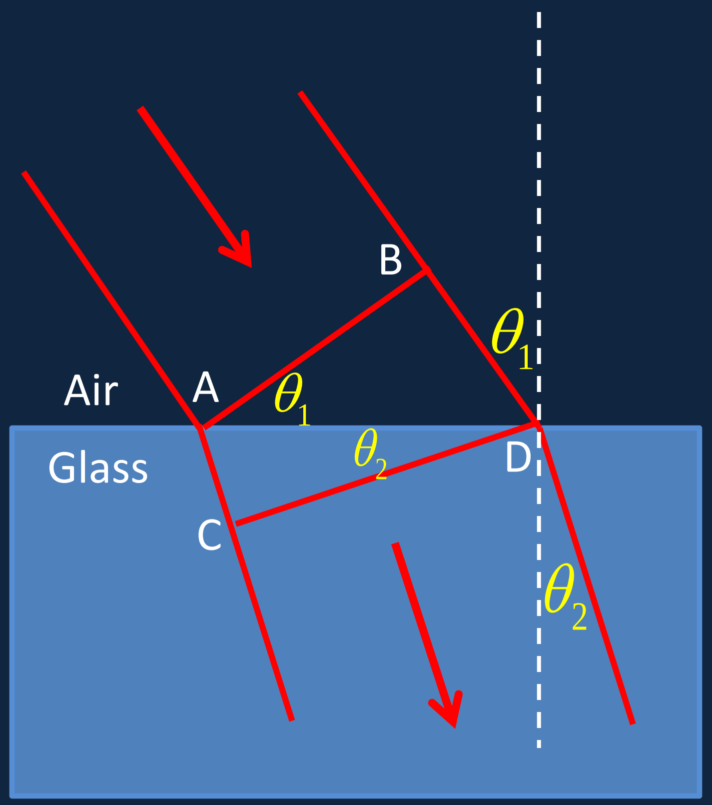


Propagation of a plane wave front.



Huygens' Principle and Refraction

- Assume a beam of light is traveling through air, and at some instant the wave front is at AB, the beam is entering the glass, corner A first.
- If the speed of light is c in air, v in the glass, by the time the wavelet centered at B has reached D, that centered at A has only reached C, the wave front has turned through an angle.

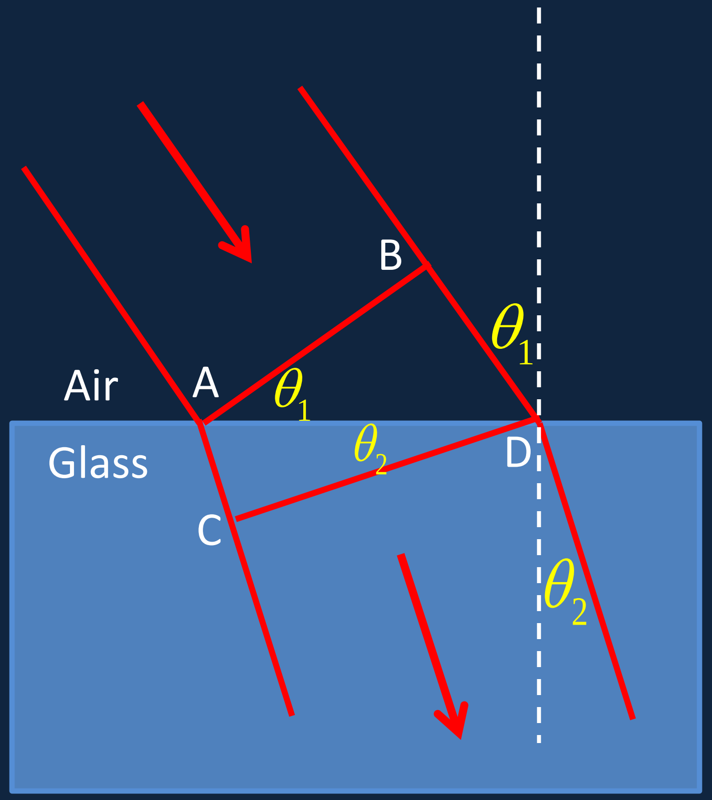


The wave front AB is perpendicular to the ray's incoming direction, CD to the outgoing—hence angle equalities.

Snell's Law

- If the speed of light is c in air, v in the glass, by the time the wavelet centered at B has reached D, that centered at A has only reached C, so AC/v = BD/c.
- From triangle ABD, BD = AD$\sin\theta_1$.
- From triangle ACD, AC = AD$\sin\theta_2$.
- Hence

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\text{BD}}{\text{AC}} = \frac{c}{v} = n$$



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The Refractive Index

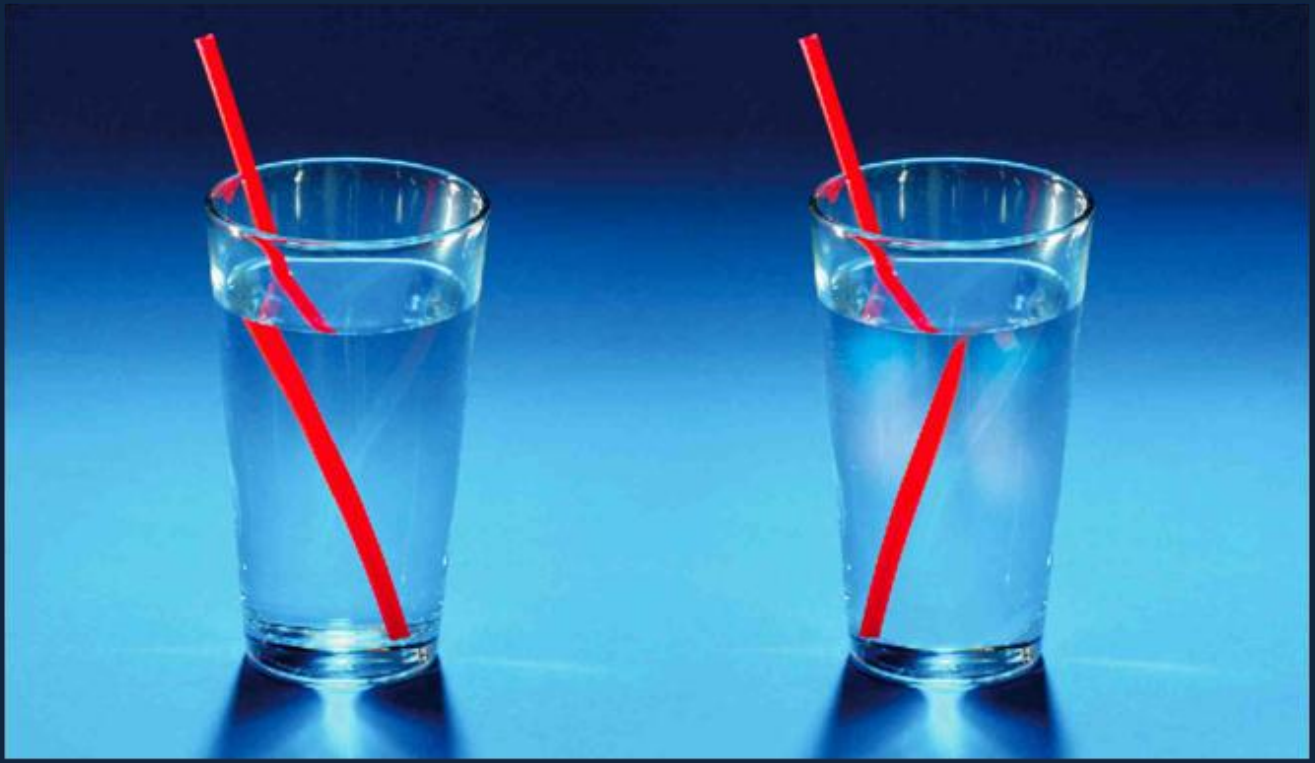
- The speed of light in a vacuum is c, very close to 3×10^8 m/sec.
- In all other media, the speed of light is less.
- The refractive index n of a material is the ratio of c and the speed v in that material:

$$n = c / v$$

- Snell's law for light going from one material to another:

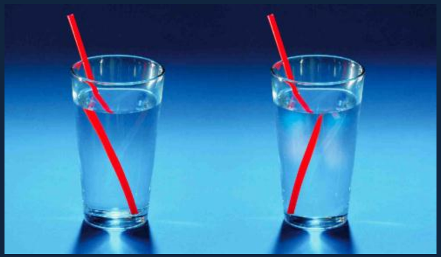
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Negative Refractive Index



Is this real or is it Photoshop?

Negative Refractive Index?

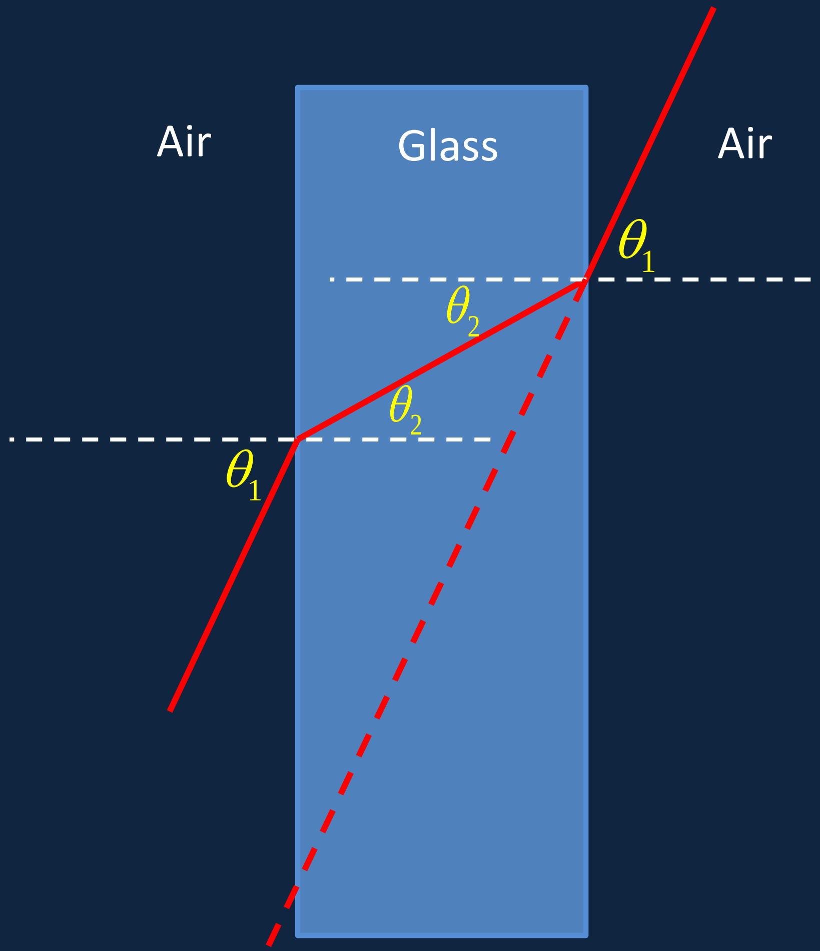


- OK, it’s Photoshop—but from a recent article in *Nature* on metamaterials (materials artificially constructed at the nanoscale) that *do* have negative refractive index, and many possible uses, from optical data storage to cloaks of invisibility…see the link for more details.

Moving Light Sideways

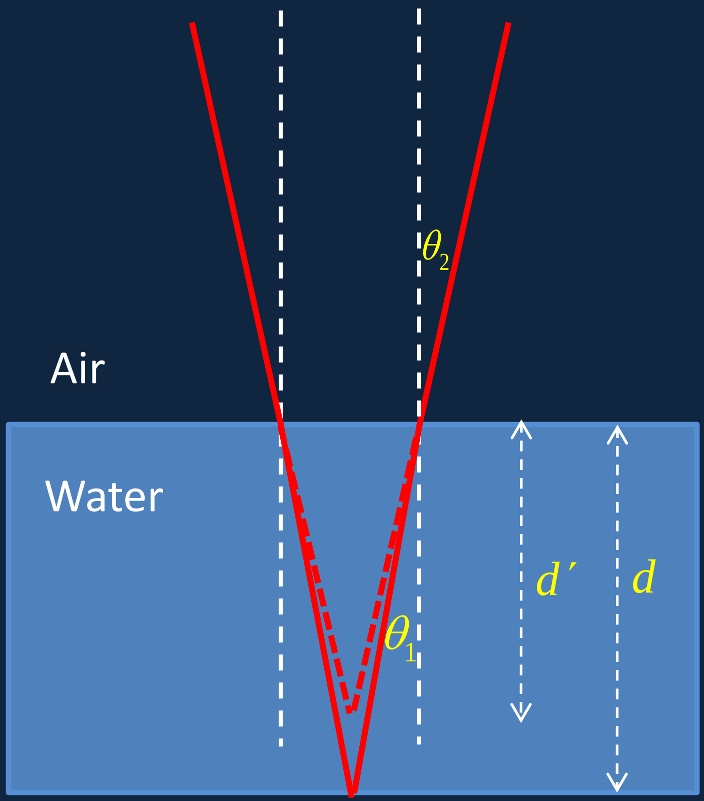
- Looking at an angle through thick glass, things appear shifted sideways.

- (If we had some negative refractive material, we could direct light around something.)



That water is deeper than it looks!

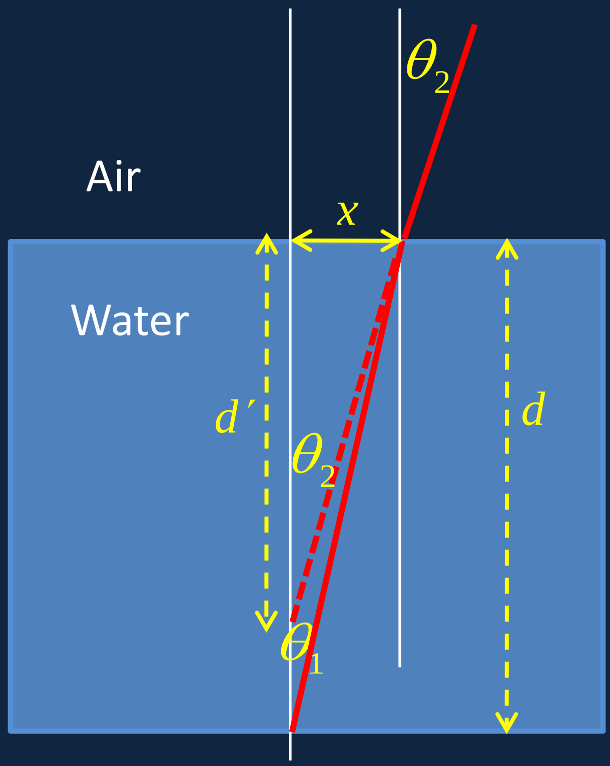
- Light rays from an object under water will appear from the air above to originate at a shallower depth.
- The dotted lines, extensions of the rays in air, locate the apparent position at depth d'.



Just how deep?

- We'll just look at half the ray diagram.
- The rays originate under water, so we use θ_1 for the ray in the water, θ_2 for the ray in air *and* its apparent extension into the water: - - - - - - - - - - - - -
- Looking straight down, both these angles are small, so, from the diagram:

$$x = d\theta_1 = d'\theta_2, \quad d'/d = \theta_1/\theta_2 = 1/n$$



Apparent depth is about 75% of true depth.

Clicker Question

- If you look towards the middle of a pool while standing on the edge does the water there look

A. Deeper

B. Shallower

C. The same

as if you were looking straight down from above the middle?

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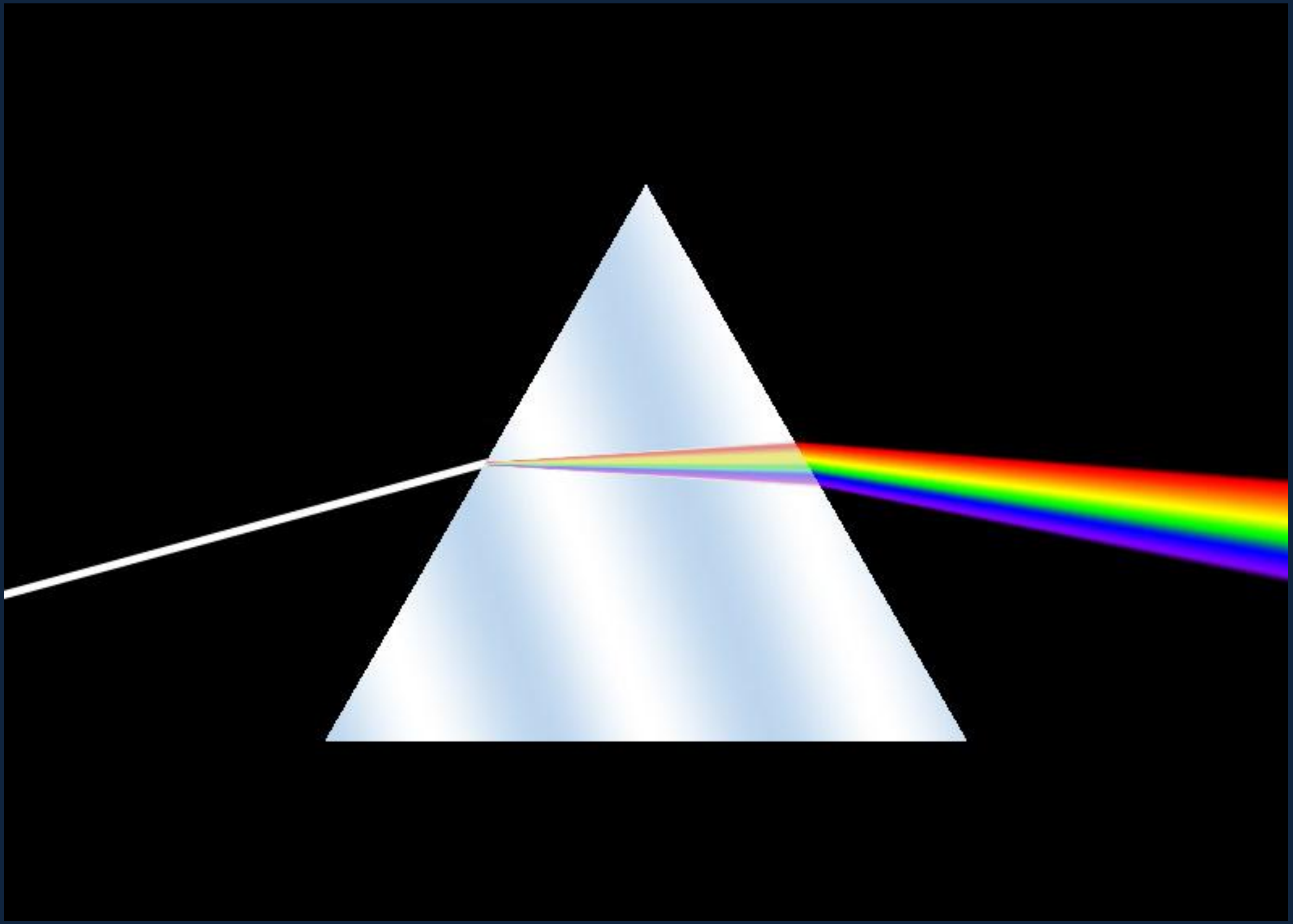
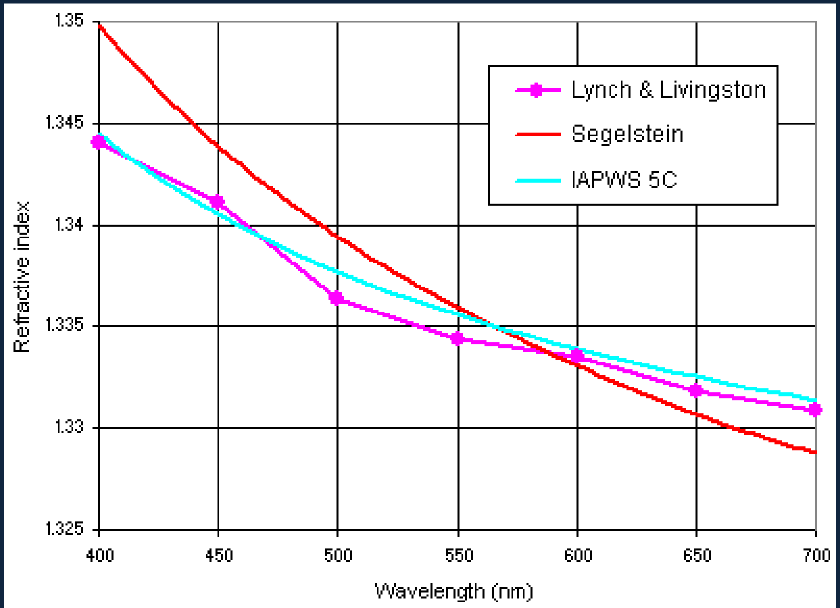
Dispersion of Light

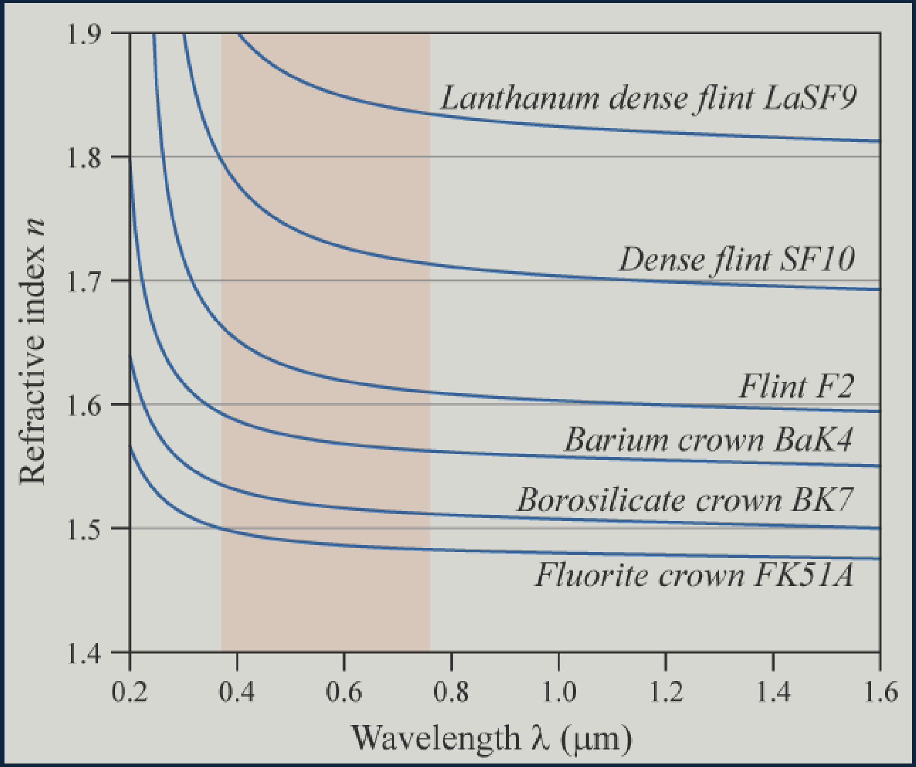
The refractive index of a material is a function of light wavelength:



Refractive Index *n* for Water and Glasses

Water



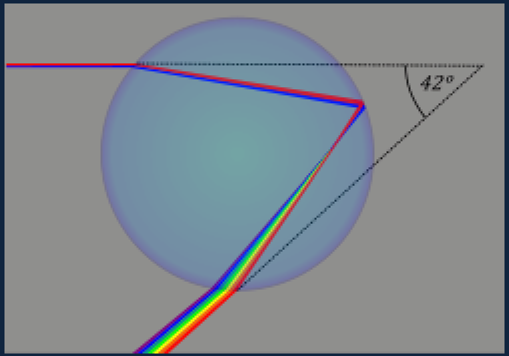


Over the visible range (400 – 700nm), the refractive index varies about 2% for water, around 5% for glasses.

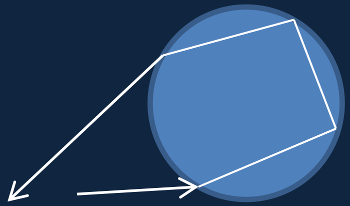
The prism also passes some infrared and ultraviolet.

Rainbows!

- Instead of a prism, the light is refracted through drops of water.

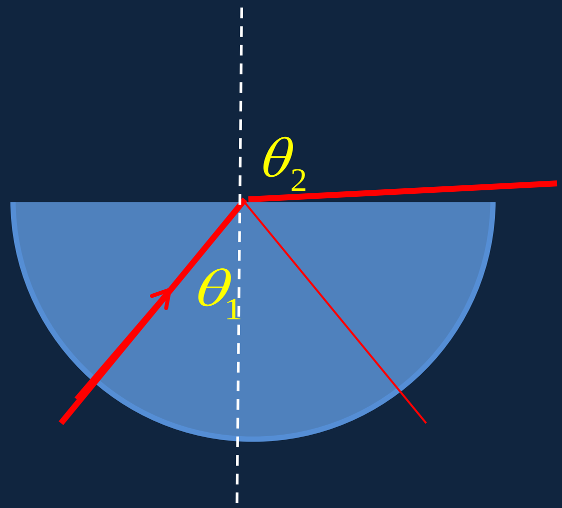


- The fainter secondary rainbow corresponds to a *double* internal reflection, which reverses the order of colors.



Total Internal Reflection

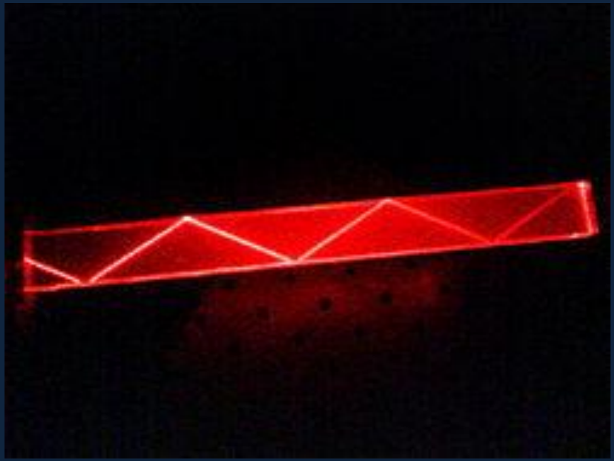
- For a ray traveling from glass (refractive index n) to air (refractive index 1), some fraction will be reflected back at the interface.
- But if the angle of incidence is increased to approach the value where $\sin\theta_1 = 1/n$, θ_2 must approach 90° from Snell's law. For θ_1 greater than that value, *no* light can escape—it's all reflected.



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

Using Total Internal Reflection

- Light shone along a solid transparent cylinder is trapped in the cylinder provided its angle of incidence is greater than the critical angle.
- This is, essentially, the principle used to transmit light in optical fibers.



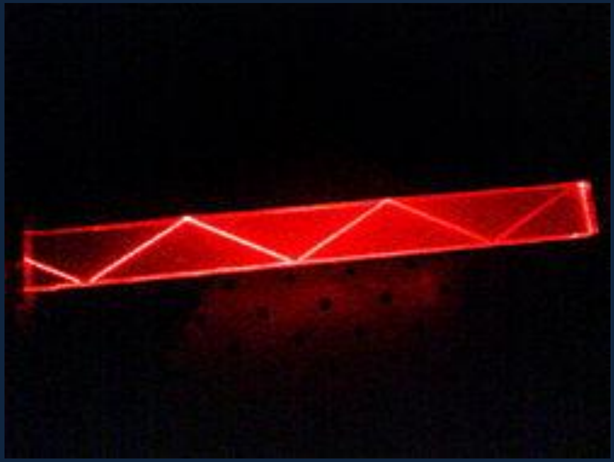
Clicker Question

- If a glass cylinder is under water, can a light signal still bounce along inside it like this?

A. No, it would always get out.

B. Yes, but the distance between reflections would have to be greater.

C. Same but smaller.



Clicker Answer

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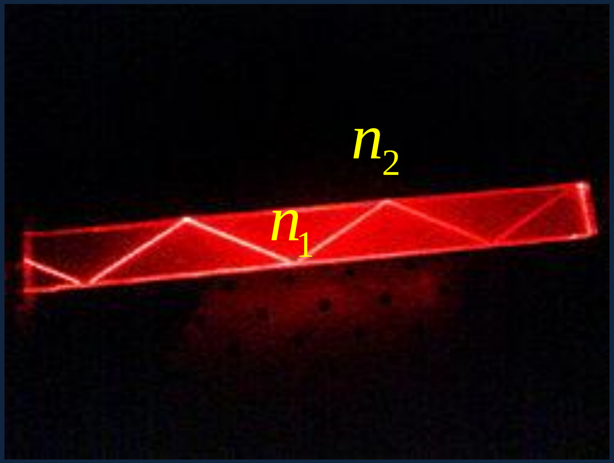

For total internal reflection, we now have $n_1 \sin\theta_1 = n_2 \sin\theta_2$ and $\theta_2 = 90°$.

Frustrated Total Internal Reflection

- A full solution of Maxwell's equations reveals that where the beam is totally internally reflected, in fact there is an electromagnetic wave in the air, but it dies away in a distance of order the wavelength on going from the surface. However, if another substance is brought close, this wave can be absorbed and/or scattered back, and detected. This is used for fingerprint reading and some touch technology.