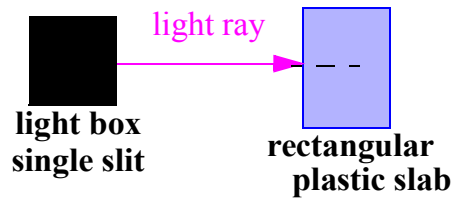
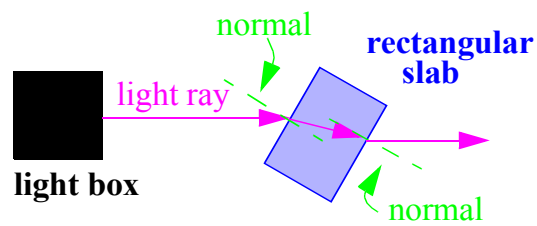


## Refraction of Light



What is the light path for a ray aligned with the normal?

What is the light path for rays not aligned with the normal?



**Normal** = imaginary line drawn perpendicular to the point where the light ray enters the second medium.

**Angle of incidence** = angle between the normal and the incoming light ray.

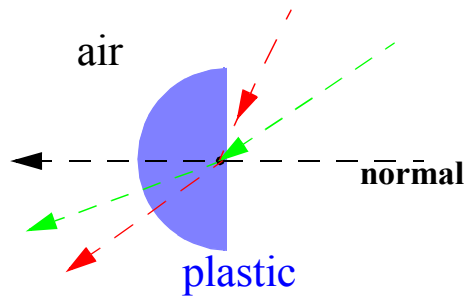
**Angle of refraction** = angle between the normal and the outgoing light ray.

## Law of Refraction

When a light ray passes from a

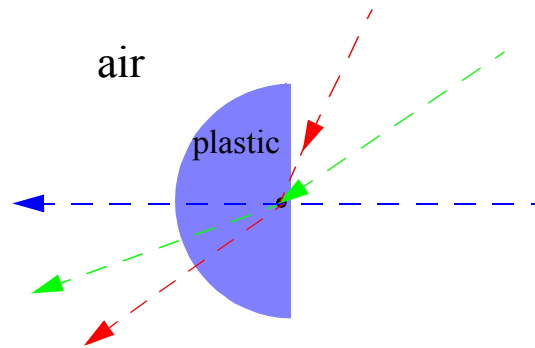
- i More dense to a less dense medium, the light wave speeds up and bends away from the normal.
- ii Less dense to a more dense medium the light wave slows down and bends toward the normal.

The greater the angle of incidence the larger the angle of refraction.



Why is there no refraction as the light rays exit the plastic slab?

## Index of Refraction



### Law of Refraction

Light is **refracted** (bent) only at the interface between two transparent materials of different density.

Light **slows down** when **entering a denser medium**.

Light **speeds up** when **entering a less dense medium**

## Index of Refraction

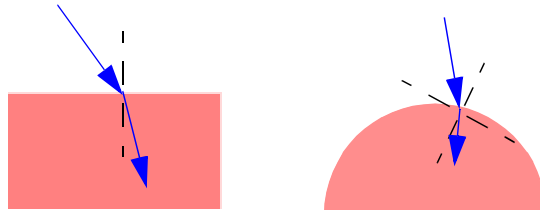
$$\text{index of refraction} = n = \frac{\text{speed of light in a vacuum}}{\text{speed of light in a medium}}$$
$$n(\text{water}) = \frac{300,000 \text{ km/s}}{225,564 \text{ km/s}}$$

Index of Refraction for different media:

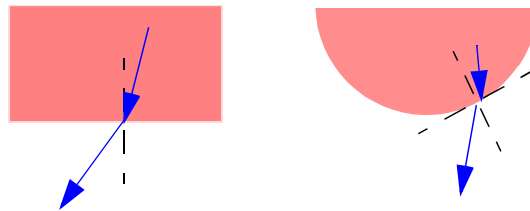
vacuum	n = 1.00000
air	n = 1.0003
water	n = 1.33
diamond	n = 2.4

## Interfaces between Two Media

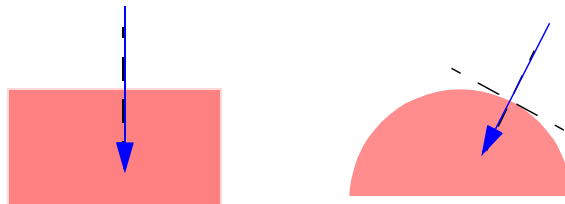
Light passing from a **less dense** to a **more dense** medium bends **toward** the normal.



Light passing from a **more dense** to a **less dense** medium bends **away** from the normal.



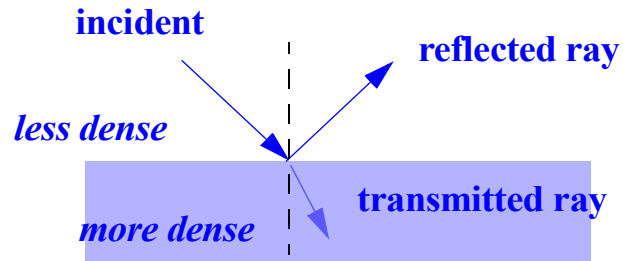
Light passing **along** the normal **does not bend** at the interface between two media of different density.



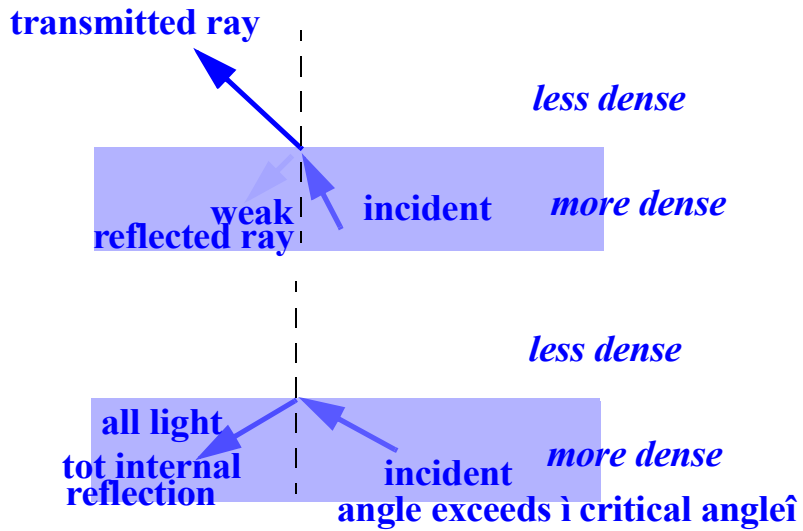
## Reflection and Refraction Usually Both Occur

Any light ray entering a transparent medium is both reflected and transmitted.

Less dense to more dense medium:

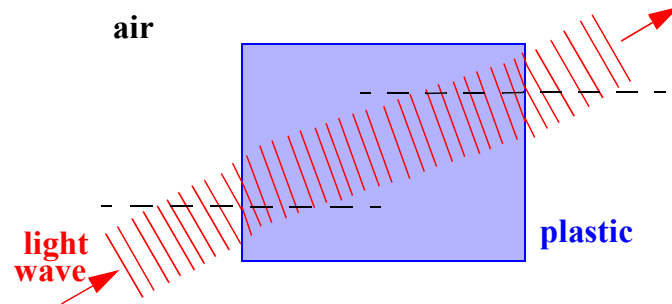


More dense to less dense medium:



## Light Changes Speed in Refraction

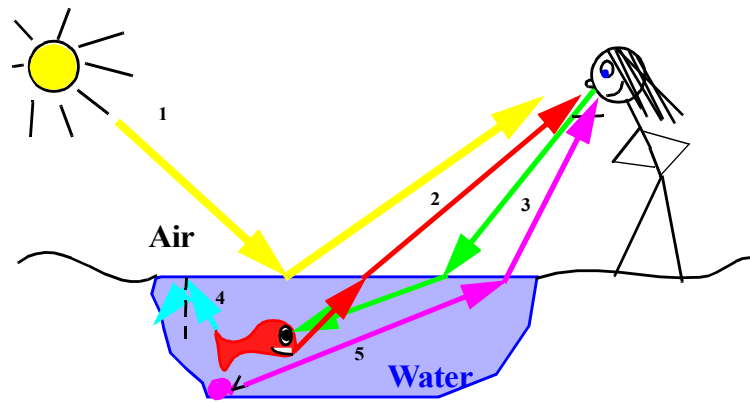
Why does light change speed and direction in media of different densities?



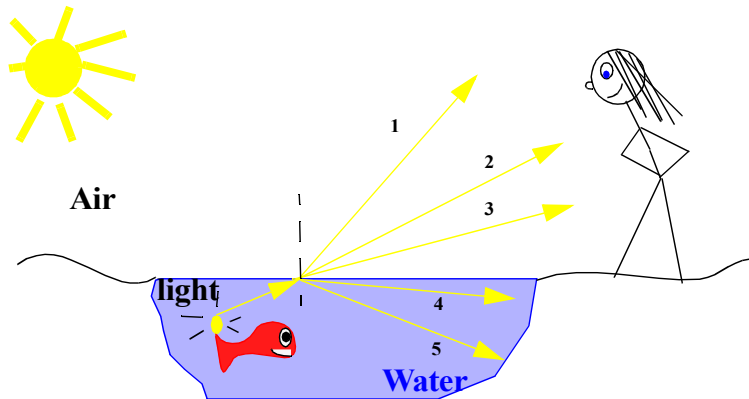
Average speed of light decreases when light passes from a less to a more dense medium.

Average speed of light increases when light passes from a more to a less dense medium.

What is wrong and what is right with this picture?



*Remember the eye always assumes that light has traveled in a straight line!  
So images of refracted objects are not where you think they are.*

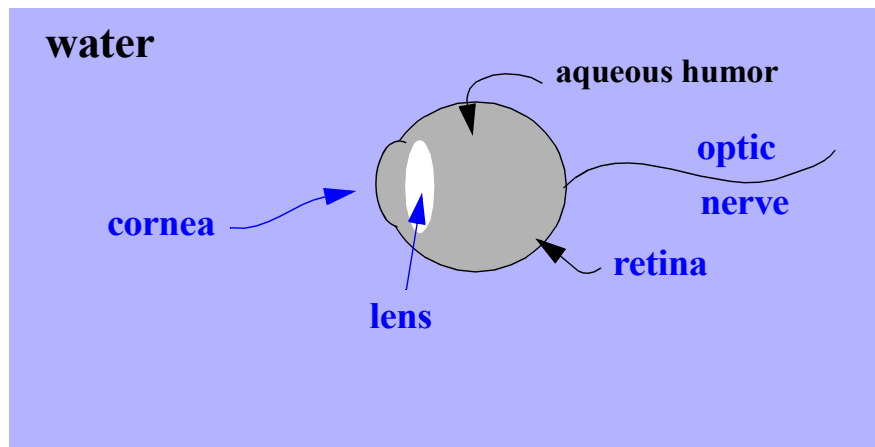


Which light ray from the light bulb is correctly drawn?

## Human Eye

- ï Cornea focuses light
- ï Lens changes shape by eye muscles to refine focus for reading or distance vision
- ï Cornea and lens form image on retina
- ï Light sensors in retina send information to optic nerve, and brain interprets image.

Can you see well under water?

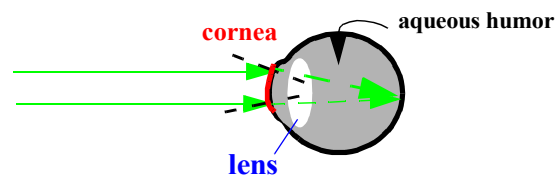


The 'aqueous humor' that fills the eye and the lens in the eye have nearly the same density as water.

Where does refraction occur and where does an image form for an eye under water?

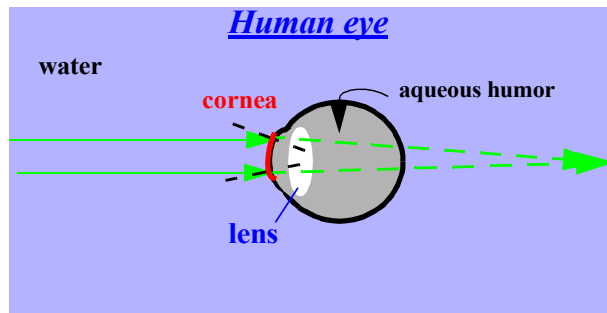
In air the human eye (cornea with help from lens) focuses light on the retina

Human eye

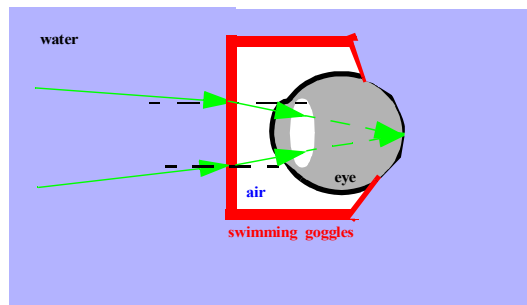


How well can you see under water?

Human eye

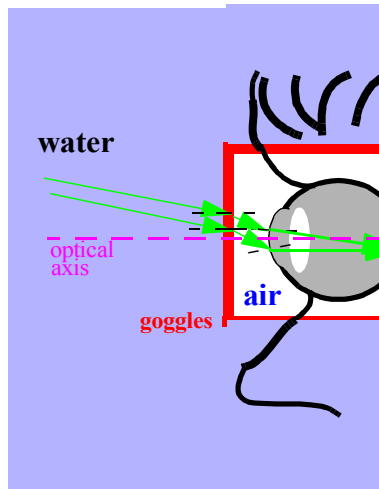


Can you see better under water with goggles?



What happens at the water/glass interface? water/air interface? air/cornea interface?

Where does the image form?

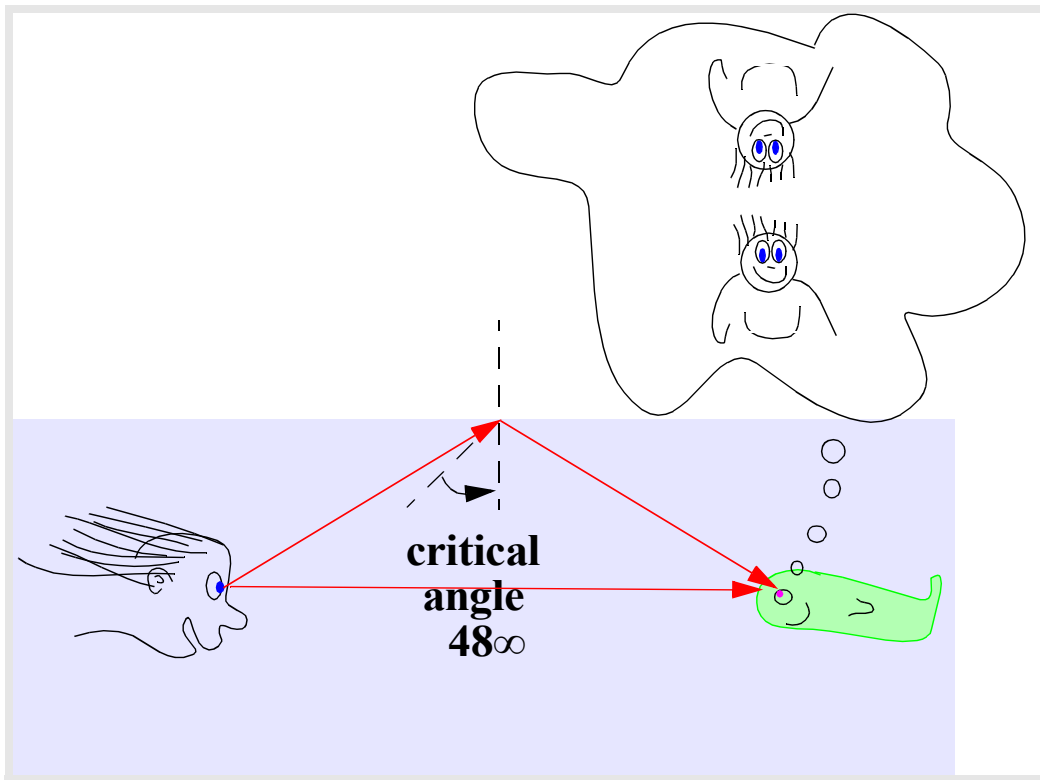


View from under water

*What does the fish see?*



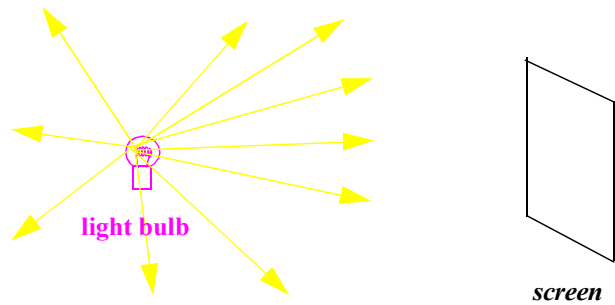
VIEW FROM UNDER WATER



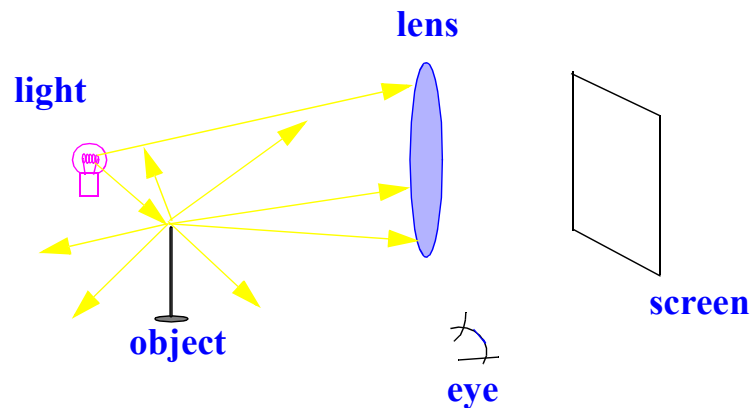
## Image Formation

### Under What Conditions Can Images Form?

Will an Image Form on this Screen?



What sends, what reflects, what refracts and what detects light?



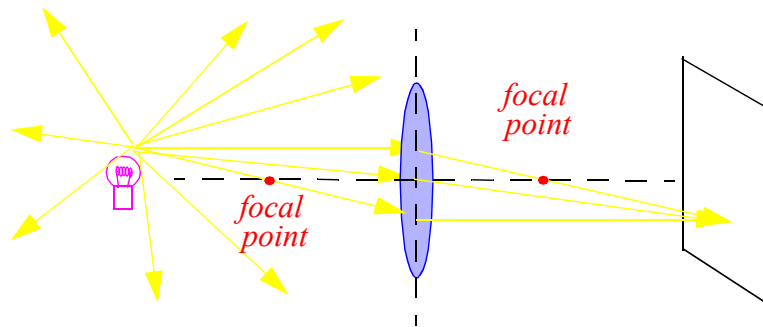
What does it mean to "see" something?

What does it mean to "see" an image of something?

What has light got to do with seeing?

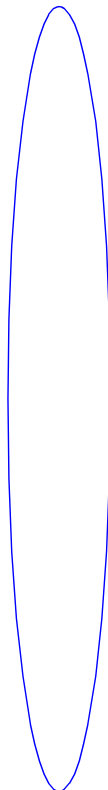
**Ray Tracing to Find Image of One Point in Bulb's Filament**

*Predicting properties of images formed by lenses.*

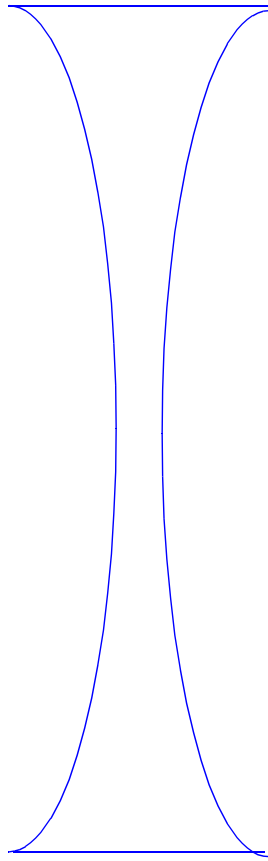


**RAY TRACING & IMAGE FORMATION LENSES**

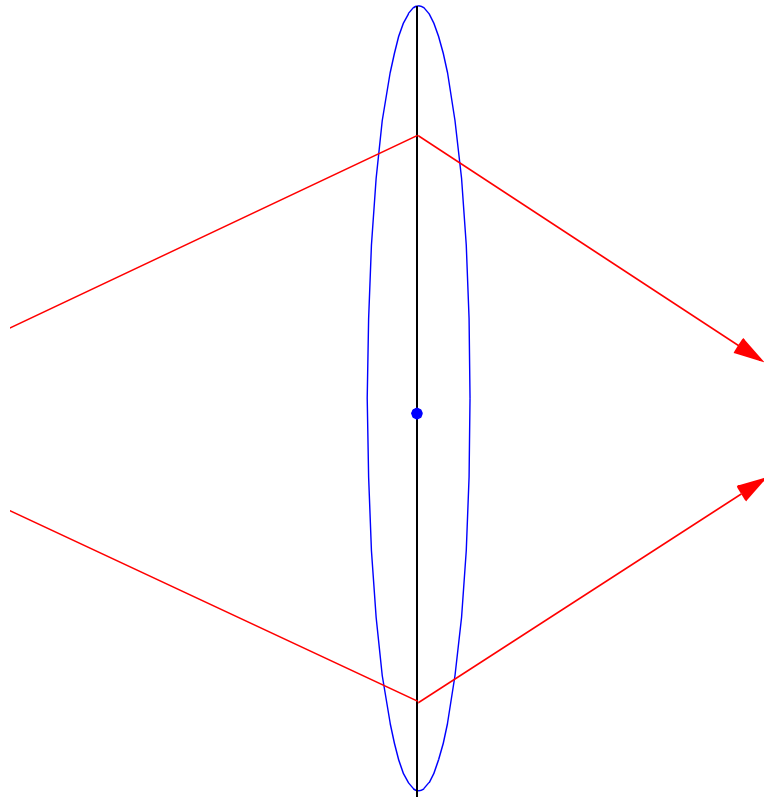
Double Convex (Converging) Lens



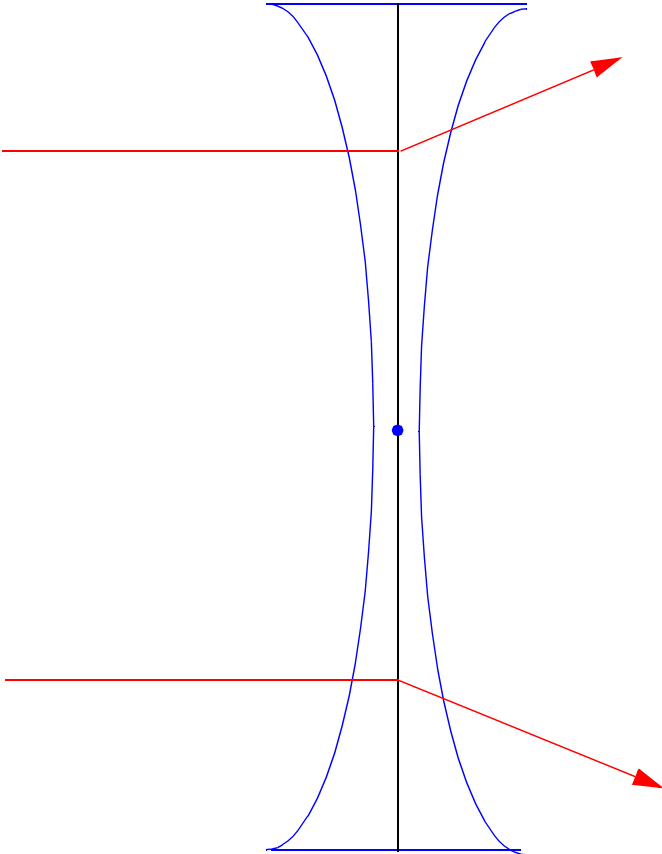
Double Concave (Diverging) Lens



Double Convex (Converging) Lens



Double Concave (Diverging) Lens



Double Convex (Converging) Lens

