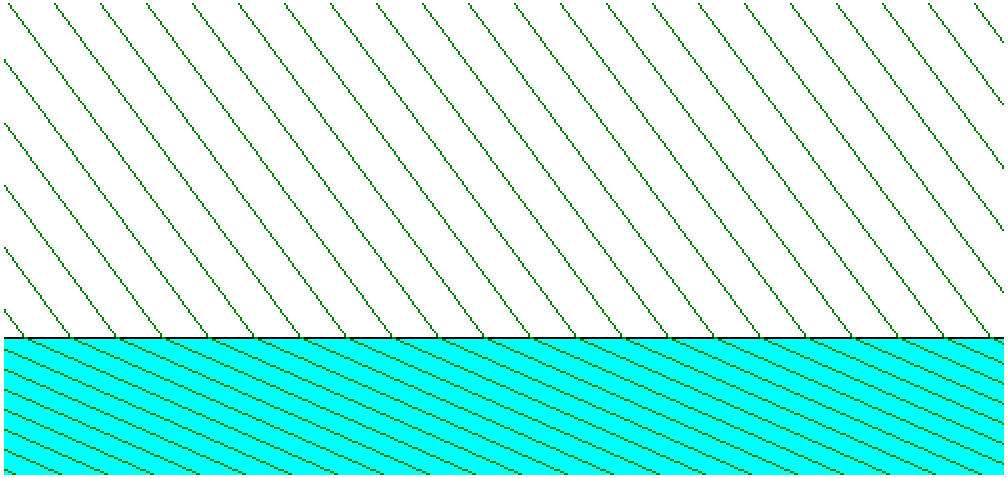
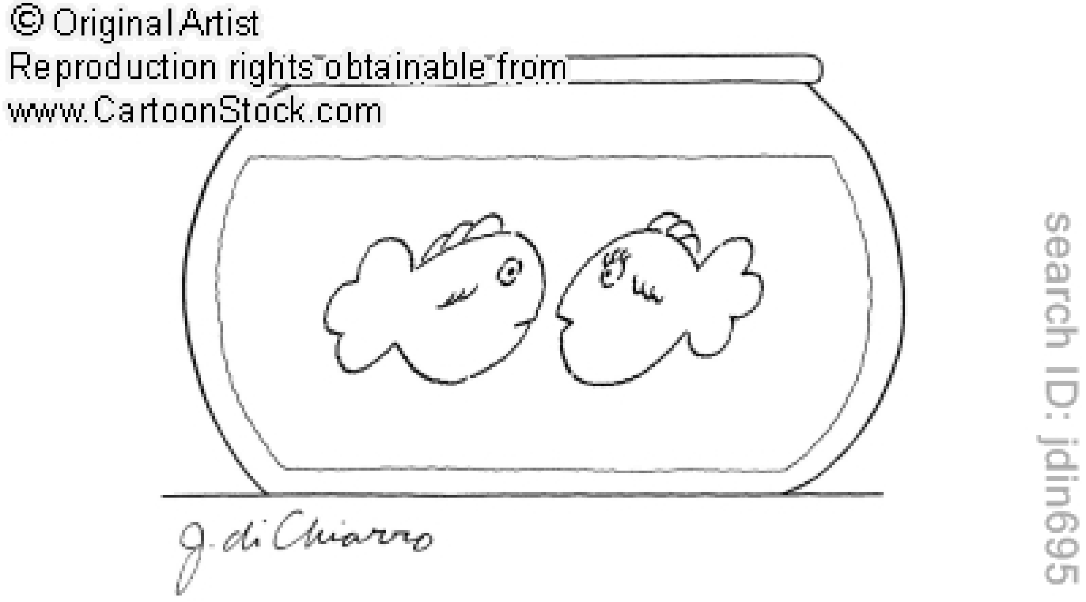


# Physics Unit 10: Refraction



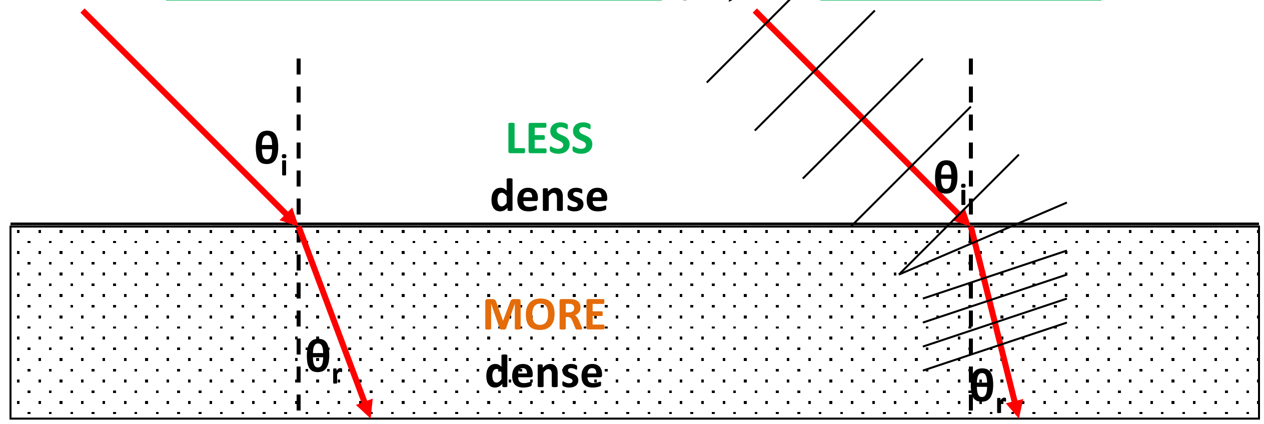

"They say the refraction adds 10 grams."

# REFRACTION

- BENDING OF LIGHT
- LIGHT SLOWS DOWN & BENDS TOWARD NORMAL (⊥) IN MORE DENSE MEDIUM

  *Like dune buggy in sand = less traction causes to turn inwards & slows*
- LIGHT SPEEDS UP & BENDS AWAY FROM NORMAL (⊥) IN LESS DENSE MEDIUM

Like Mirrors: Measure θ's with respect to ⊥




- **SNELL'S LAW:** $n_i \sin \theta_i = n_r \sin \theta_r$
- **INDEX OF REFRACTION:** Measures amount light bends through a medium

$$n = c/v_s$$

Where c = speed of light in vacuum ($3 \times 10^8$ m/s)

$v_s$ = speed of light in substance of interest

Note: $n \geq 1.0$

What is index of refraction for a vacuum? 1

Higher n value means more or less dense material?

# *REFRACTION*

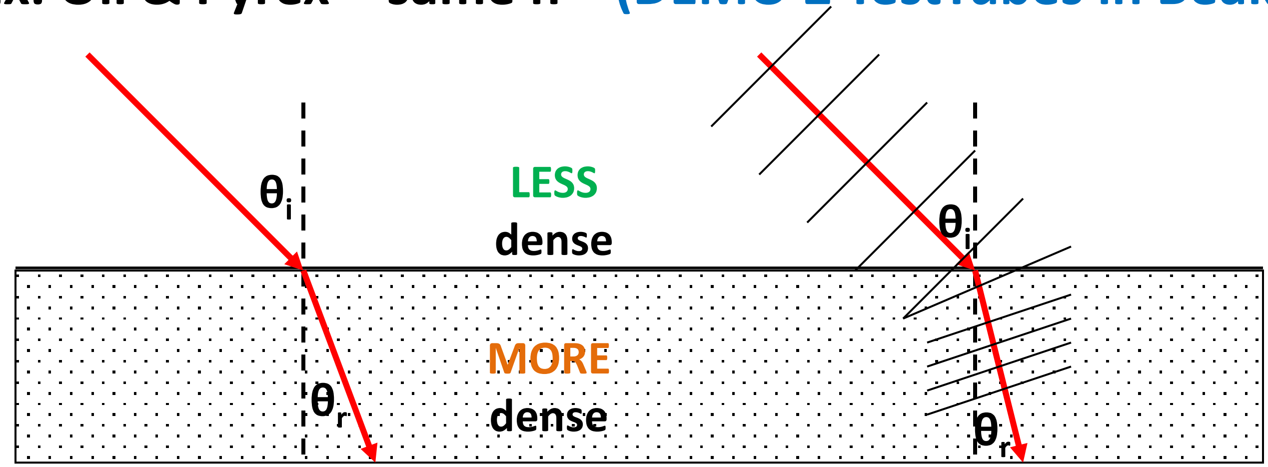
- **SNELL'S LAW:** $n_i \sin \theta_i = n_r \sin \theta_r$
- **NO REFRACTION OCCURS IF:**
  - $\theta_i = 0^\circ$, THEN $\theta_r = 0^\circ$

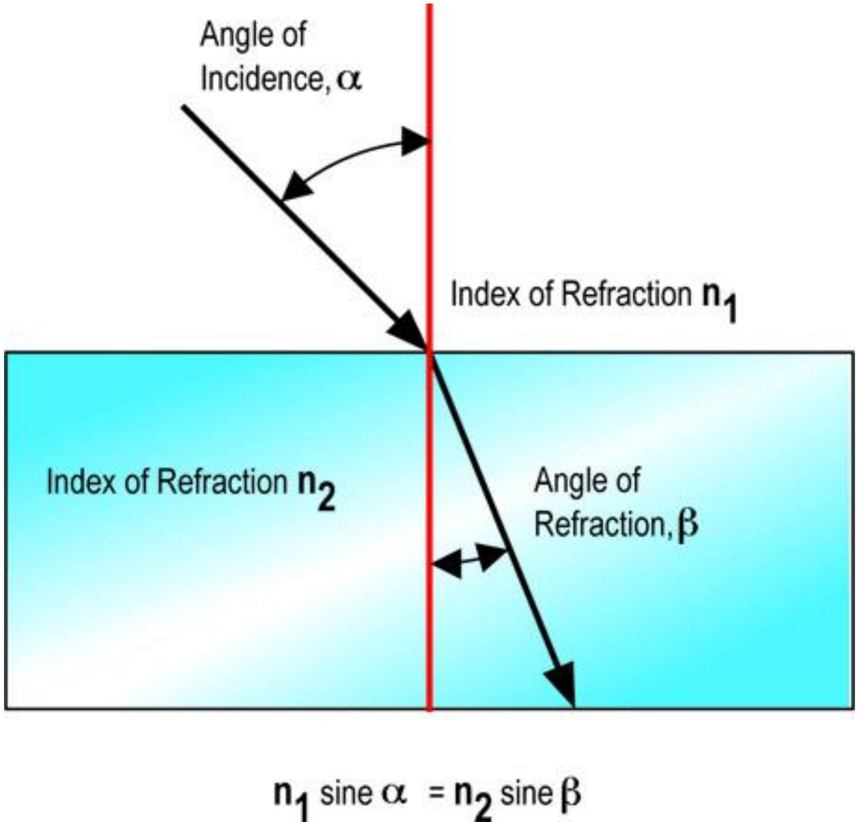
    **Straight in = ⊥ to surface = NO bending**

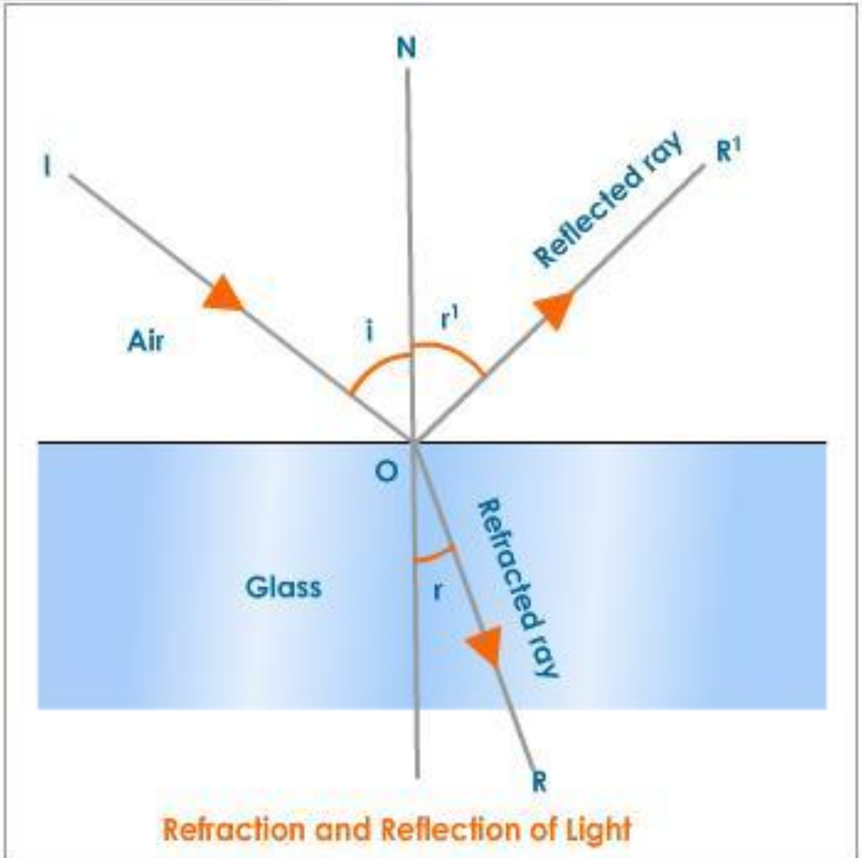
    ***OR***
  - **NO CHANGE IN INDEX OF REFRACTION**

    **Ex. Oil & Pyrex = same n (DEMO 2 TestTubes in Beaker)**

**Like Mirrors: Measure θ's with respect to ⊥**



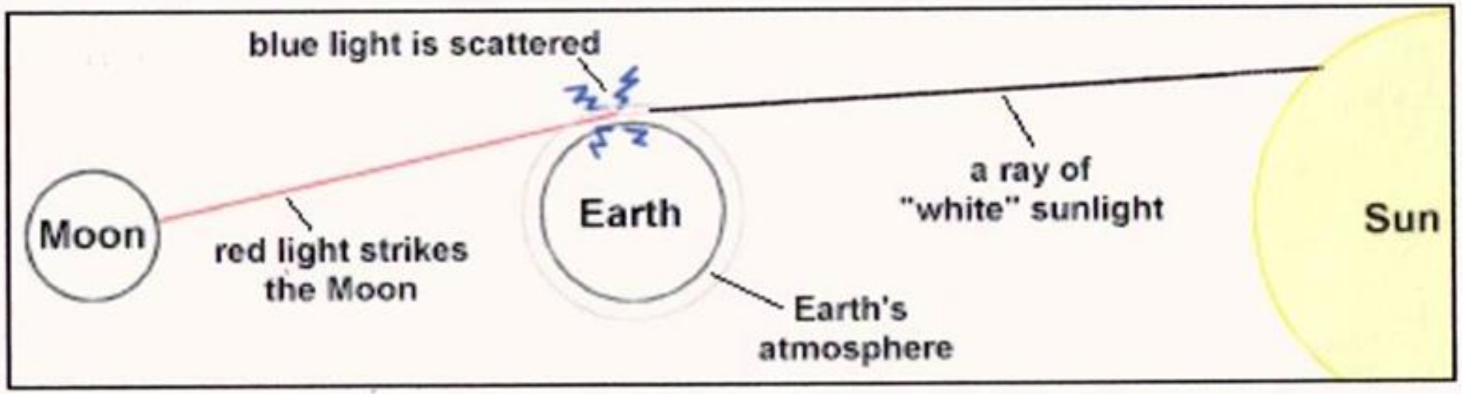

Angle of
Incidence, α
Index of Refraction $n_1$
Index of Refraction $n_2$
Angle of
Refraction, β
$n_1$ sine α = $n_2$ sine β


N
I
R¹
Reflected ray
Air
i
r¹
O
Glass
r
Refracted ray
R
Refraction and Reflection of Light

# Lunar Eclipse

Remember Scattering ≈ $1/\lambda^4$ and $N_2$ & $O_2$ molecules fit blue λ best so it is scattered more so red transmits through & REFRACTS = bends toward ⊥ of atmosphere as it enters more dense medium causing it to hitting moon = copper-Red

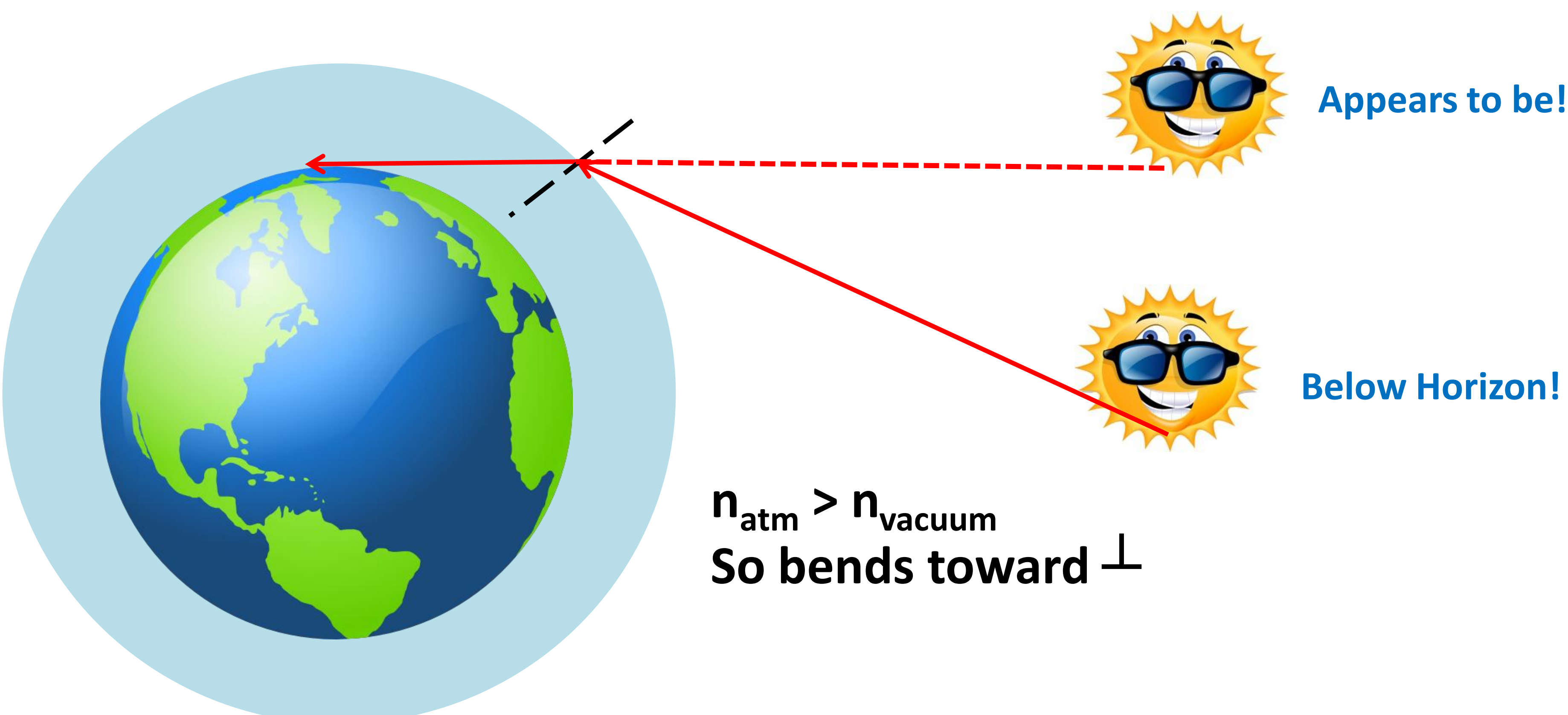
Why isn't the moon totally dark when Earth gets between it and the sun? It's because of Earth's atmosphere. (continued below)




White light from the Sun is a mixture of all the colors of the rainbow. When a ray of "white" sunlight passes at grazing incidence through Earth's atmosphere, molecules and aerosols in the air scatter blue light in all directions (this is why the sky is blue). The remaining reddish light is bent (refracted) into Earth's umbral shadow zone, giving the eclipsed Moon a coppery glow. Copyright-free image credit: Tony Phillips.

# Equinox

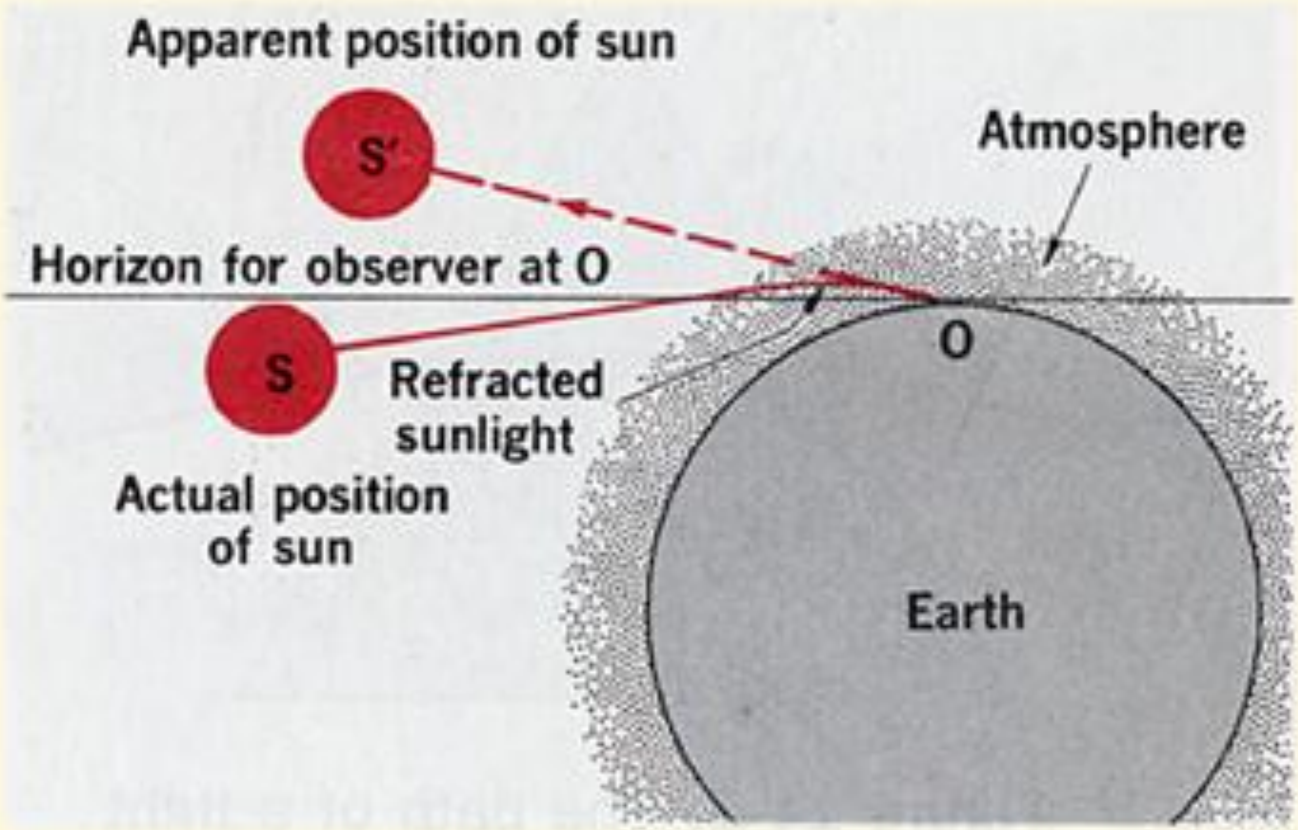
- **Equinox:** Sun is directly over equator so should have equal day & night but actually day is ≈9 min longer (4.5 min sun rise & 4.5 min sun set) due to bending of light toward curvature of earth making the sun appear to still be above horizon when it is actually physically set & below horizon



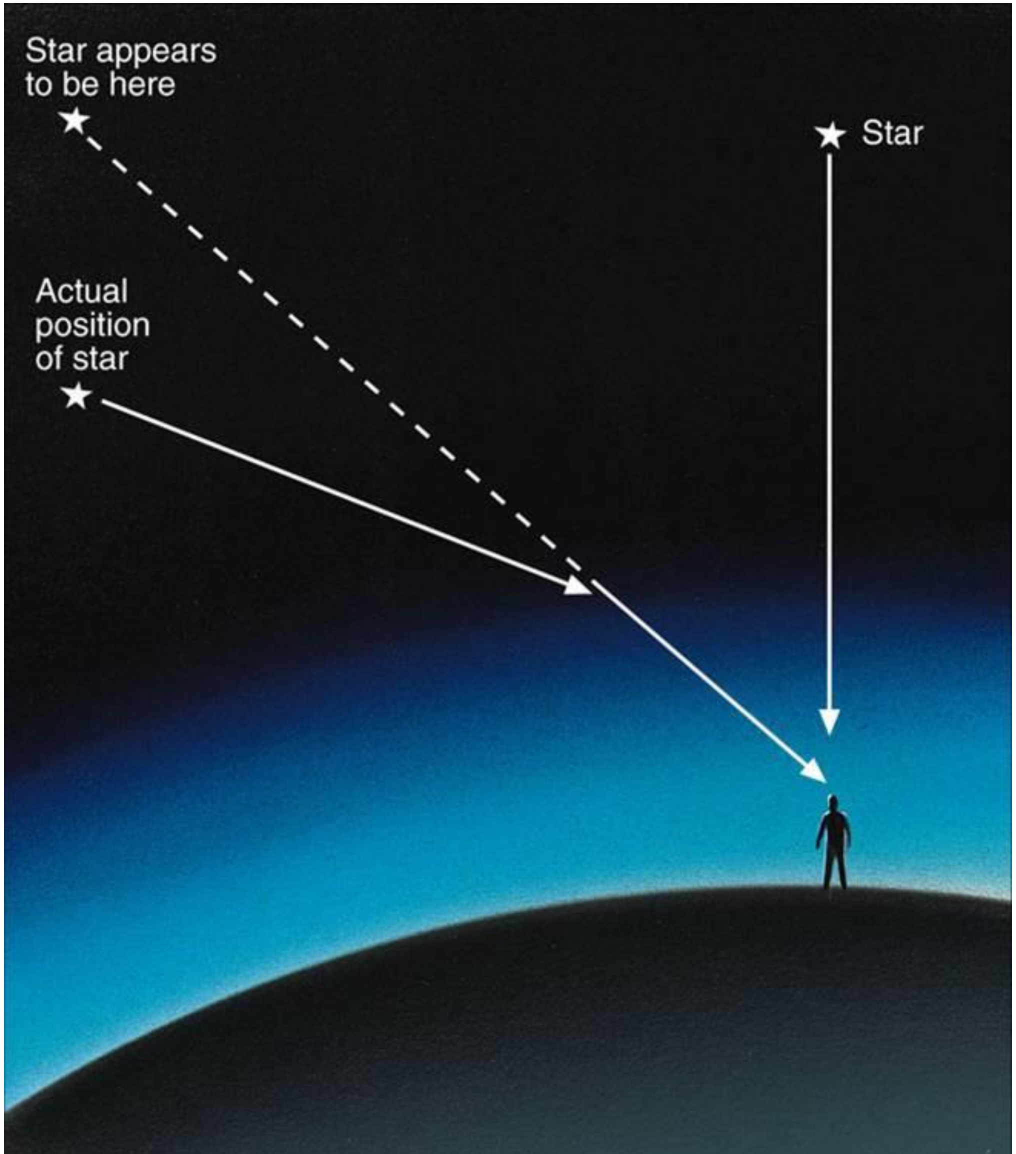

**$n_{atm} > n_{vacuum}$**

**So bends toward $\perp$**

# Sun & Moon Below Horizon

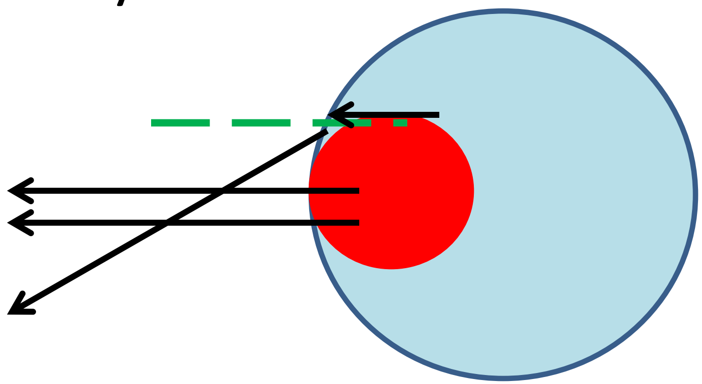



We can see the sun and moon below the horizon by the refraction of light by the atmosphere.

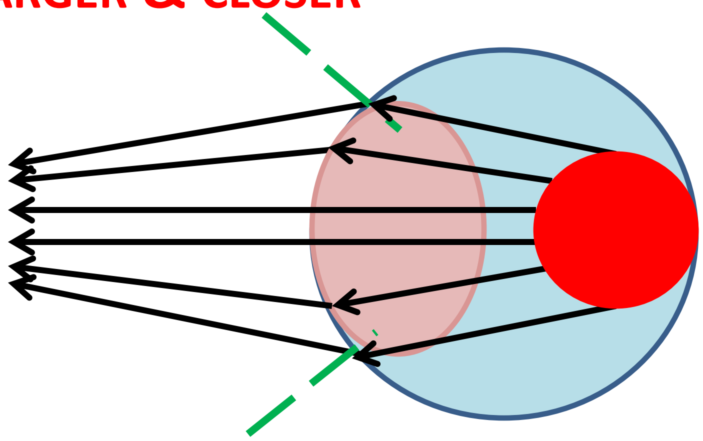

Star appears
to be here
Star
Actual
position
of star

# DEMO: colored Test Tube in $H_2O$

At FRONT of beaker: TT Appear **SAME SIZE** because only see light that is coming straight through ($\theta = 0^\circ$) so no refraction & ones that refract at an angle away from ⊥ don't reach our eyes so we see same size TT

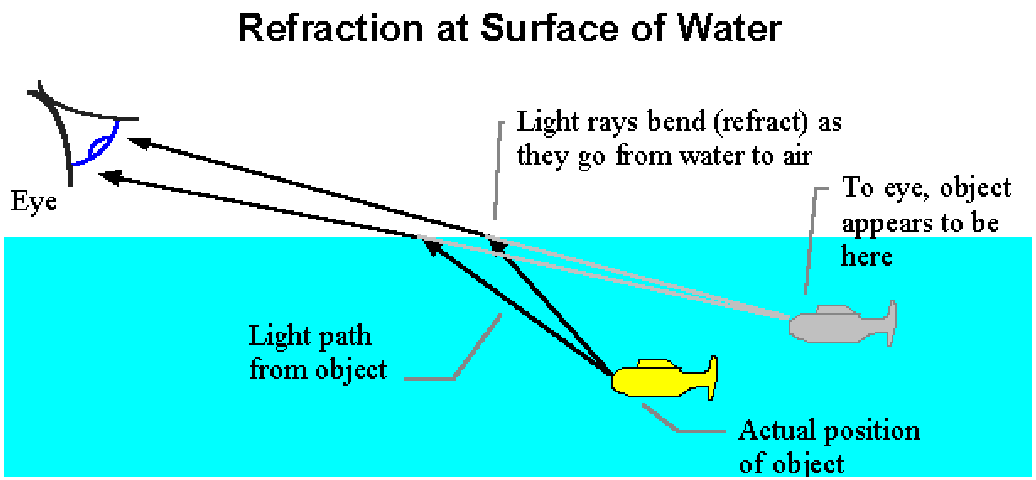


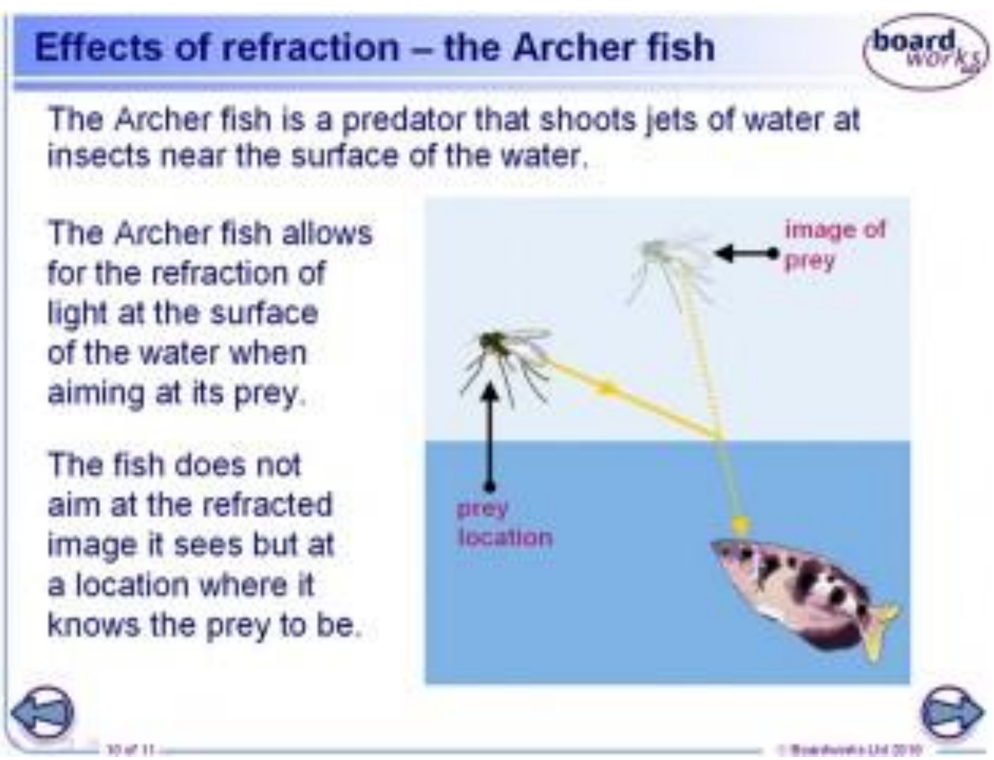
**At BACK of beaker:** light at angles refract away from ⊥ due to light traveling from more dense to less dense medium & now converge so TT appears **LARGER & CLOSER**



- **DEMO: spearing Fish**

# DEMO: spearing Fish



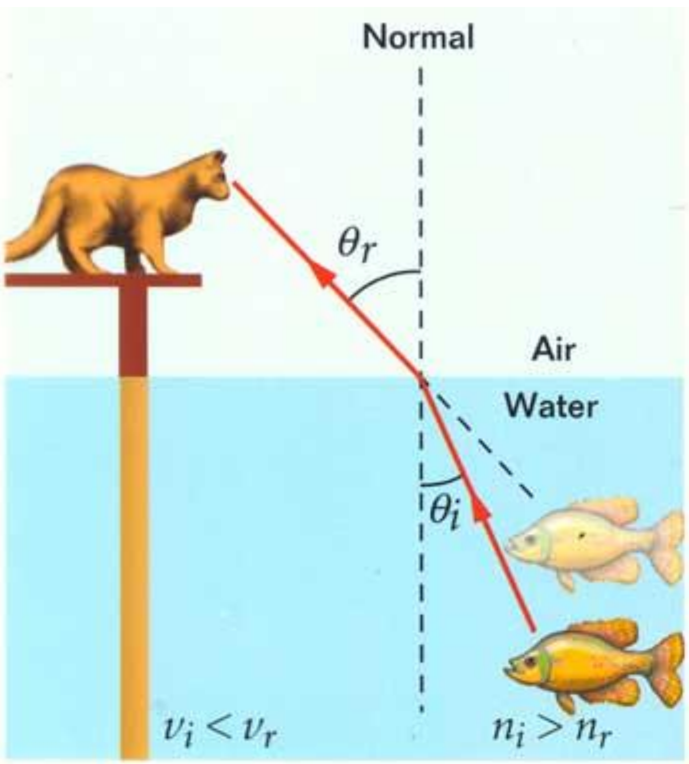



# Cat vs. Fish

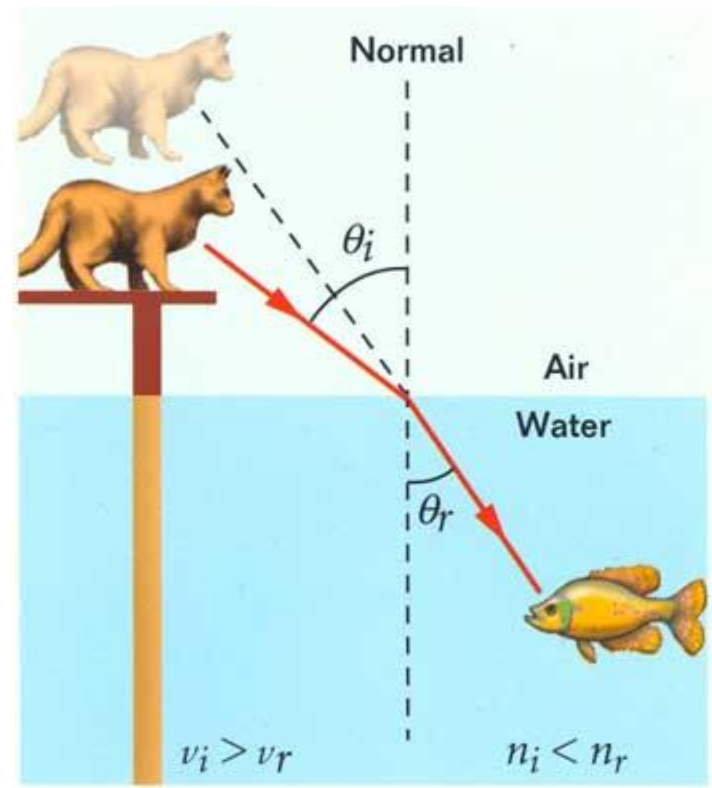
Light slows down and bends toward normal in denser material

Light speeds up and bends away from normal in less dense material

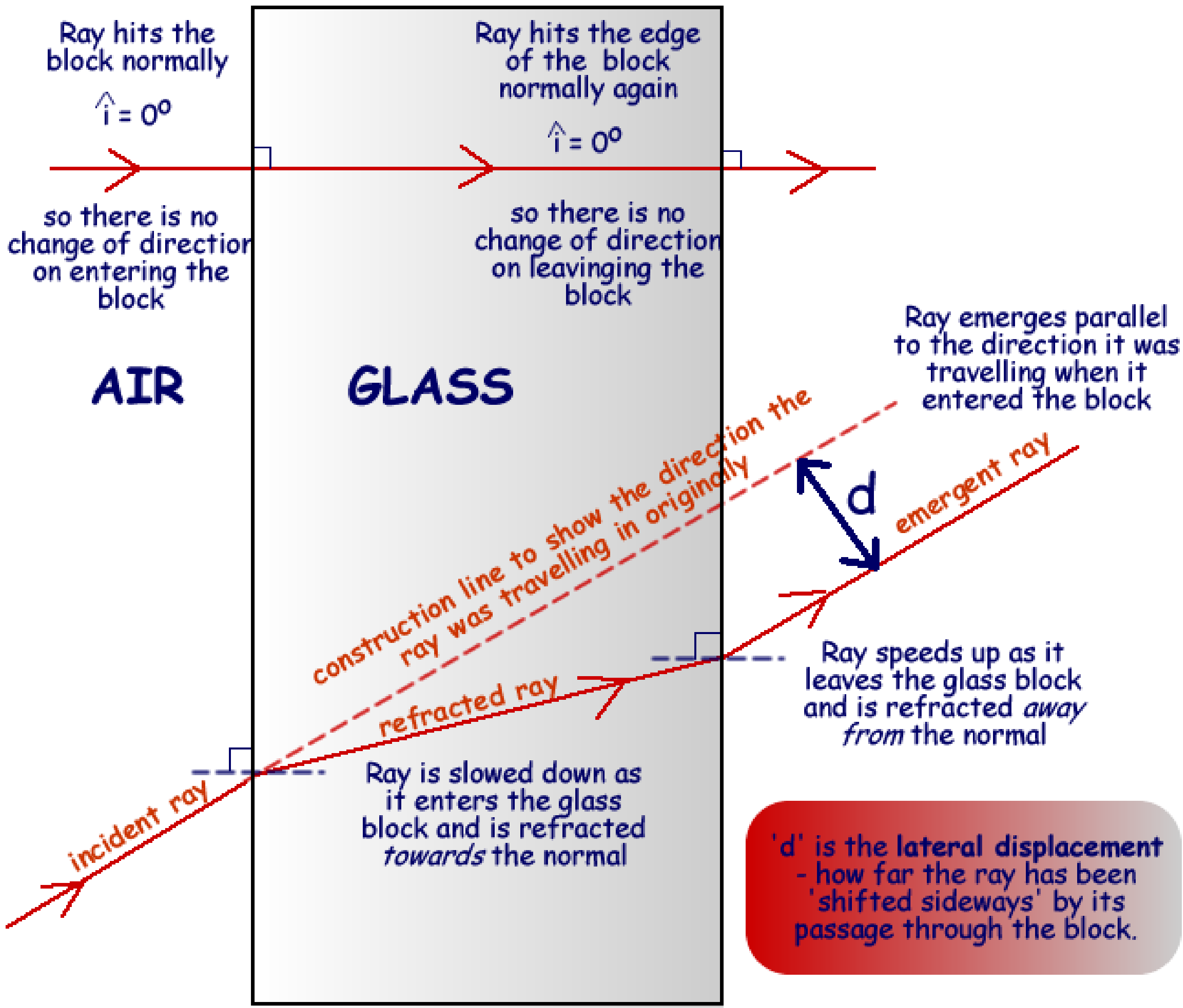
**Cat perceives fish closer to surface**




**Fish perceives cat farther from surface**



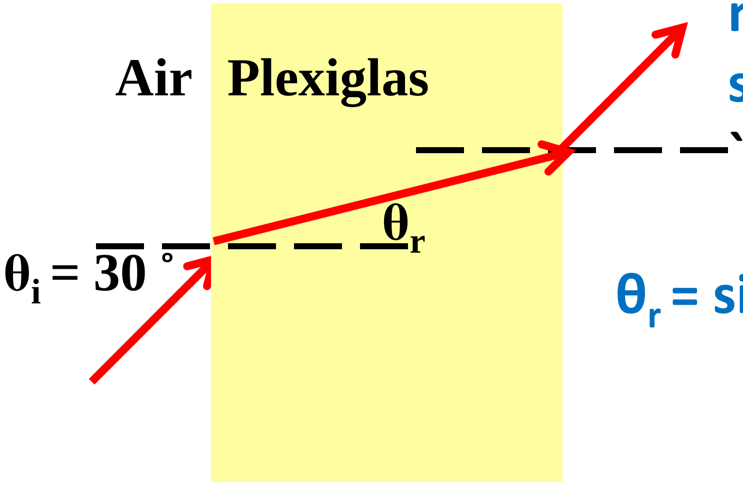
# Refraction by a rectangular glass block




'd' is the **lateral displacement** - how far the ray has been 'shifted sideways' by its passage through the block.

# Example Problems: Snell's Law

1. **Diagram the situation & Calculate the angle of refraction if light travels from air into Plexiglas and enters at a 30˚. (Hint look up n's on your homework sheet)**

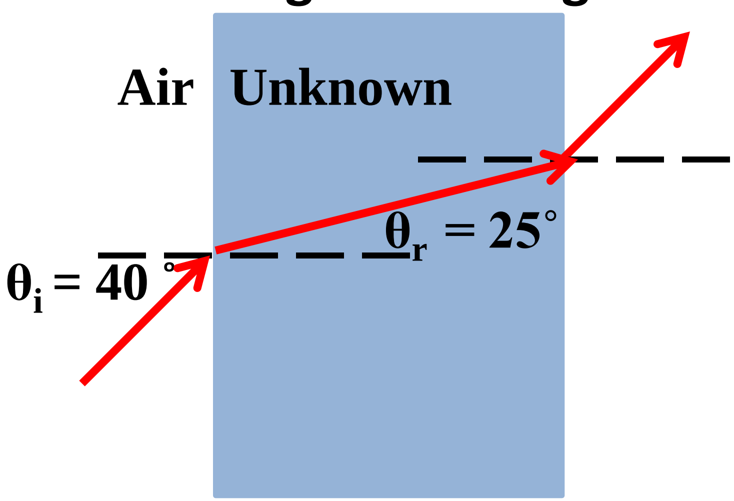



$$n_i \sin \theta_i = n_r \sin \theta_r$$

$$\sin \theta_r = \frac{n_i \sin \theta_i}{n_r}$$

$$\theta_r = \sin^{-1}\left(\frac{n_i \sin \theta_i}{n_r}\right) = \sin^{-1}\left(\frac{1.000293 \sin 30˚}{1.51}\right) = 19.3˚$$

2. **Diagram the situation & Calculate the index of refraction for an unknown material if light traveling from air enters the refraction material at a 40˚.**

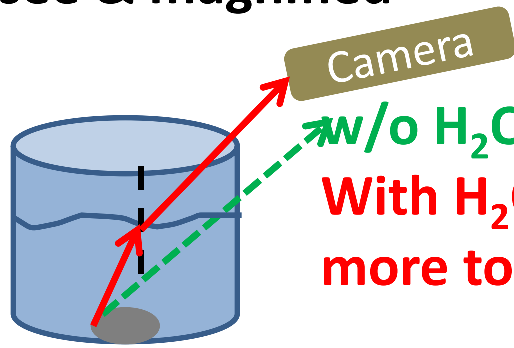



$$n_i \sin \theta_i = n_r \sin \theta_r$$

$$n_r = \frac{n_i \sin \theta_i}{\sin \theta_r} = \frac{1.000293 \sin 40˚}{\sin 25˚} = 1.52$$

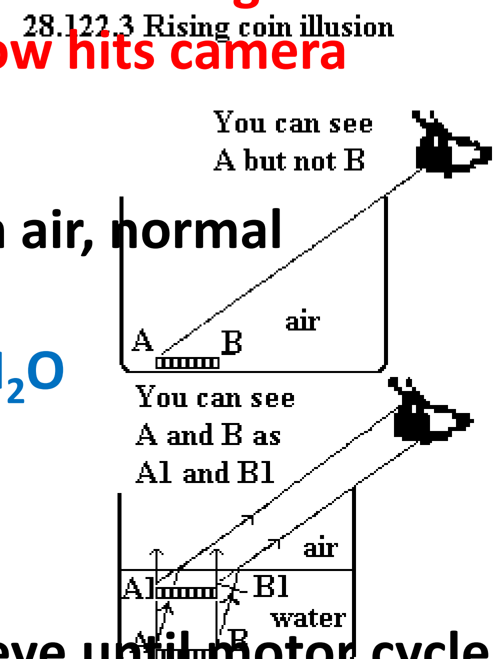
# Demo's

- Demo: Quarter in cup
  - At 1st can't see quarter but add $H_2O$ bends light away form normal so can see & magnified




w/o $H_2O$ No refraction & light misses camera

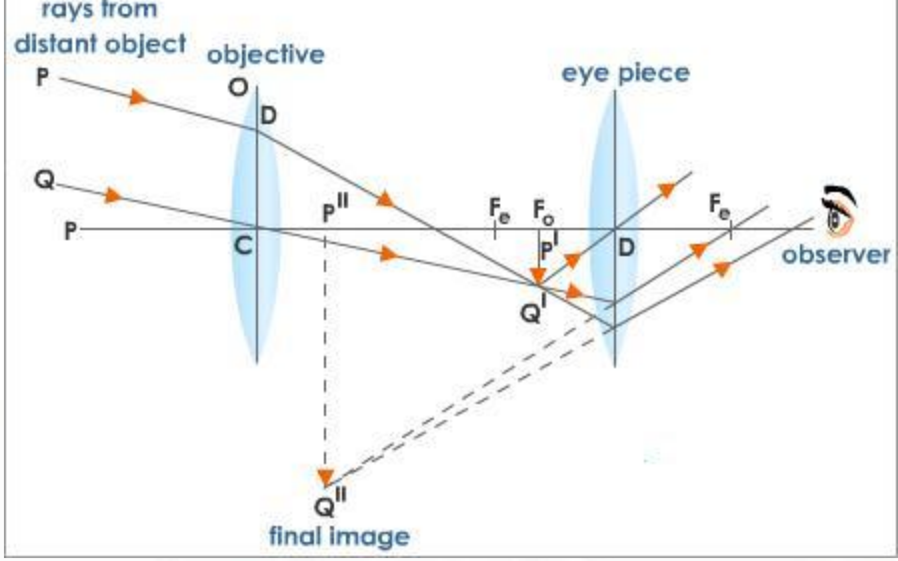
With $H_2O$ light bends away from normal as go from more to less dense mediums & now hits camera




- Demo: Aquarium & hollow lens
  - w/air under water look smaller (diverges light) & in air, normal
  - w/water under water look normal & in air bigger
- Demo: Shining spot light on magnifying glass in air & $H_2O$
  - In $H_2O$ ↓ magnifying power (diverges light)
- Demo: Eye ball model
- Demo: blind spot motor cycle ½ sheet
  - Cover right eye & but ½ sheet toward & way from eye until motor cycle disappears = optic nerve = blind spot
- Demo film canister with pin
  - Point large opening at light & look though small hole & look at pin head
  - Pin head inverted, inside focal point but brain still flips

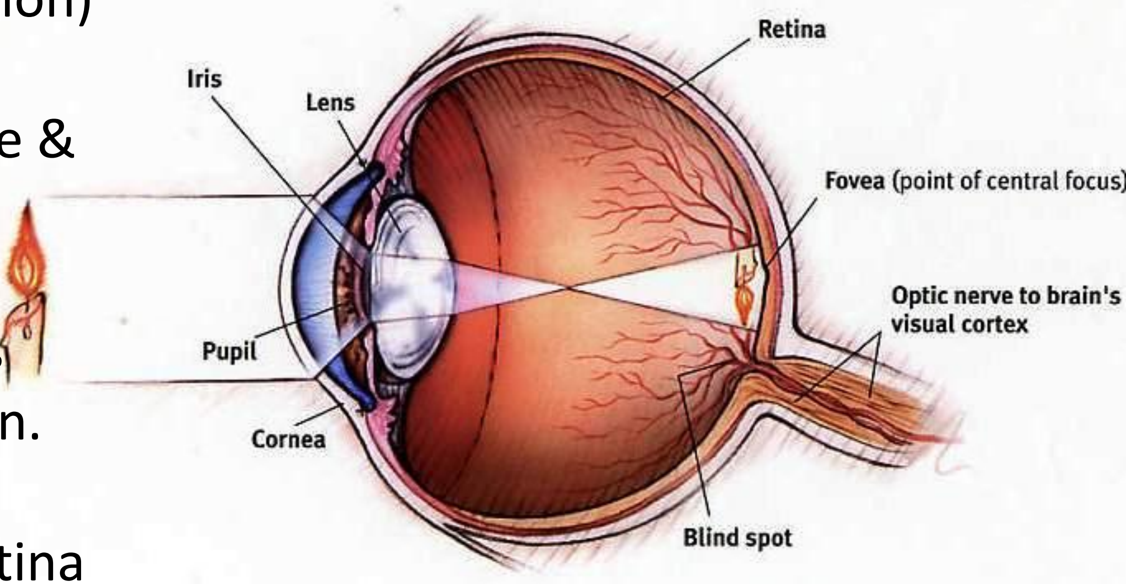
# Compound microscope

-objective lens creates real image & eyepiece creates larger virtual image




# Eyes

- **cornea** (causes 70% of refraction)
- **Pupil** (hole)
- **lens** muscles control curvature & refraction to fine tune light focused on retina.
- **Retina** = rods & cones. Cones (center of retina) = color vision. Rods (edges of retina) = dim/bright light. Image on retina is inverted
- **optic nerve** (blind spot) sends signal to brain & **brain** flips back upright




**Demo: lens Converging & diverging**

- **Converging (farsightedness, thick in middle) obj flipped far way**
- **Diverging (nearsightedness, thin in middle) = always smaller**

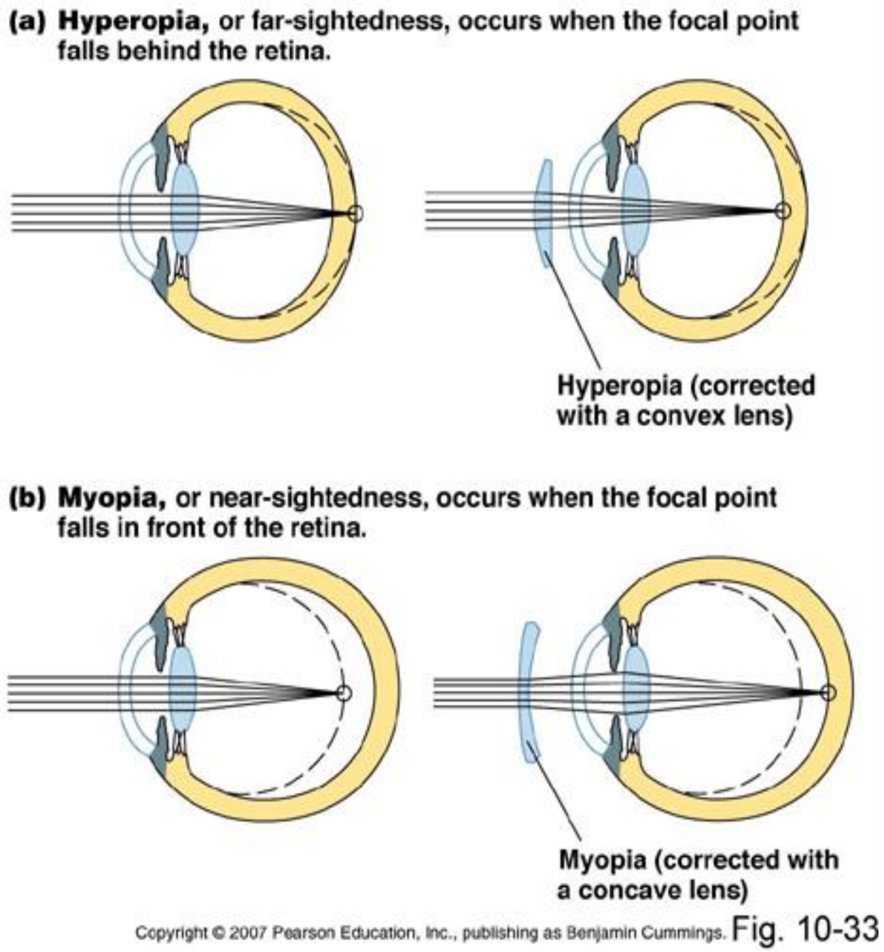
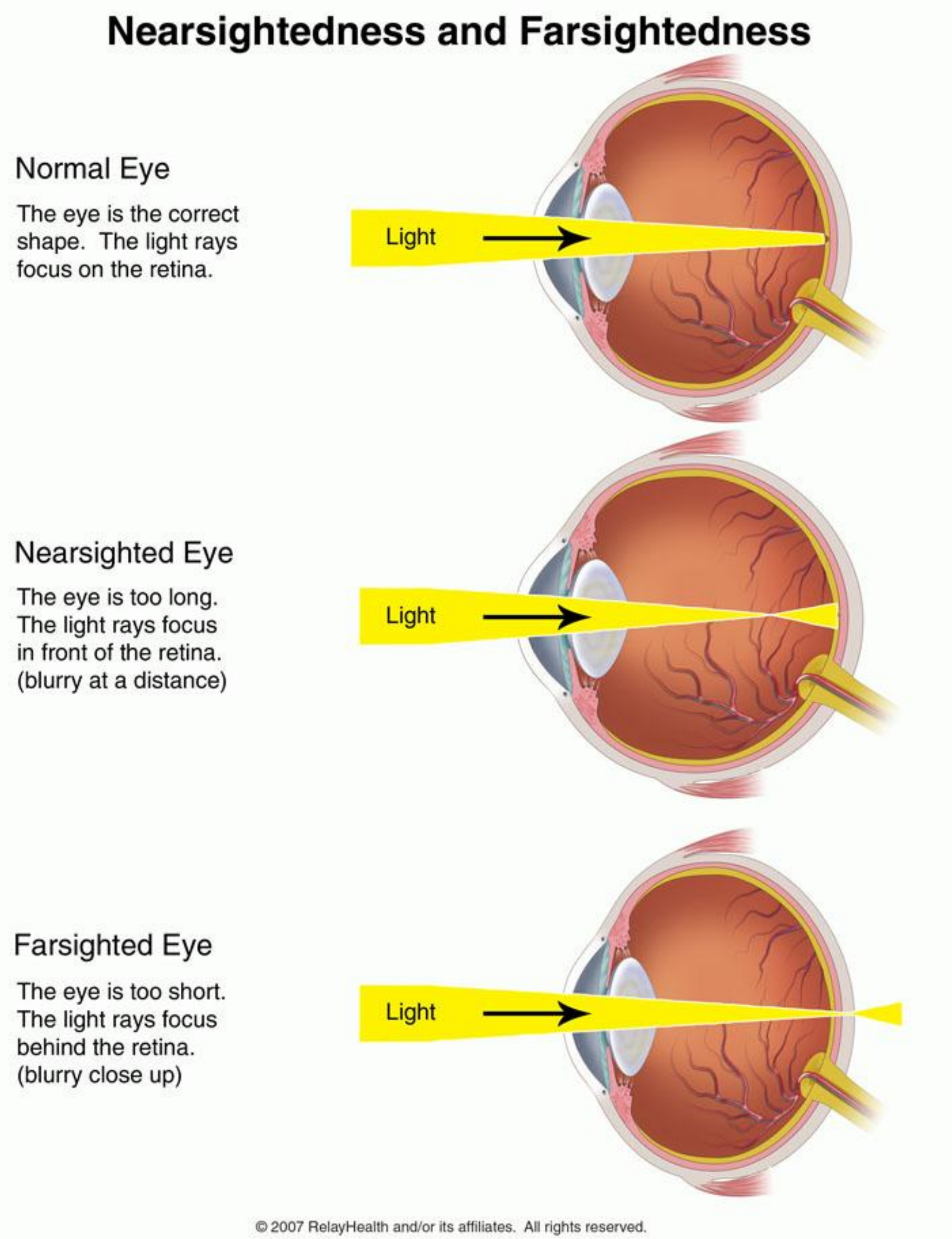
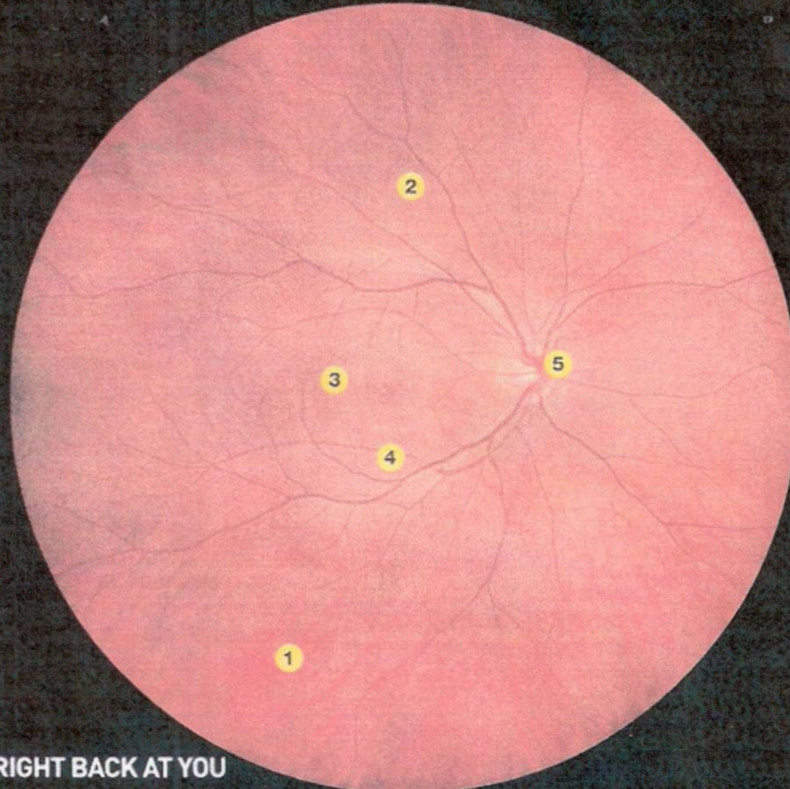



Fig. 10-33




# Demo: Nearsighted Vs Farsighted with projector




# MAP: RIGHT BACK AT YOU

The inside of your eye is one thing you're guaranteed never to get a good look at. Even if you could, the pupil is far too small an aperture to allow you to see the entire interior. University of Michigan ophthalmologic photographer Richard Hackel compares the problem to taking a picture of a room through a keyhole. To overcome this hurdle, Hackel uses a computer program to stitch together images taken from 20 different angles by a special digital camera. The result is an unusual, fully detailed map of the inside of a healthy 26-year-old's eye.

### 1 ORANGE GLOW

The inside of the eye derives its orange color from a layer of pigment cells inside the retina. This layer of pigment—just one cell thick—absorbs light coming in and prevents it from scattering. The result is a crisper view. How much pigment a person has is variable and is determined mostly by genetics. Optometrists call lightly colored retinas "blondes," but the blondest retinas belong to vision-poor albinos, who have no pigment in their retinas at all.

### 2 LIGHT MY NERVE FIRE

Sitting just above the pigment layer toward the eye's interior are light-sensitive rod cells and color-sensitive cone cells. Molecules in these cells change shape when light hits them. The change is translated into an electrochemical signal that is picked up by nerve cells, which relay it to the brain.

### 3 BULL'S-EYE

While most rods are evenly dispersed throughout the retina, all of an eye's 6 million or so color-sensitive cones are concentrated in a 1/7-inch bull's-eye of color vision—the macula. The speck in the center of the bull's-eye is the fovea, which is so cone-dense that it creates a dip in the otherwise smooth retinal surface. About 30,000 cones are clustered here, more than anywhere else in the eye.

### 4 GOOD VISION GONE BAD

Cone cells work hard, and when their waste products build up faster than the body can clear them, tiny yellow spots can form around the fovea. As a person ages, these plaques, along with leaky blood vessels, tend to interrupt normal rod and cone functioning. Known as macular degeneration, this is the leading cause of vision loss and blindness in older Americans.

### 5 BLIND SPOT

A layer of nerve cells coats the innermost surface of the retina. All nerve paths meet at the optic nerve—the large white spot—which transmits data to the brain at a rate of 10 megabits per second. That's about as fast as a computer Ethernet cable. The optic nerve, technically considered brain matter, is the only part of the central nervous system that can be photographed directly. But the lack of light-sensitive rods where it meets the retina creates a blind spot. Dave Mosher

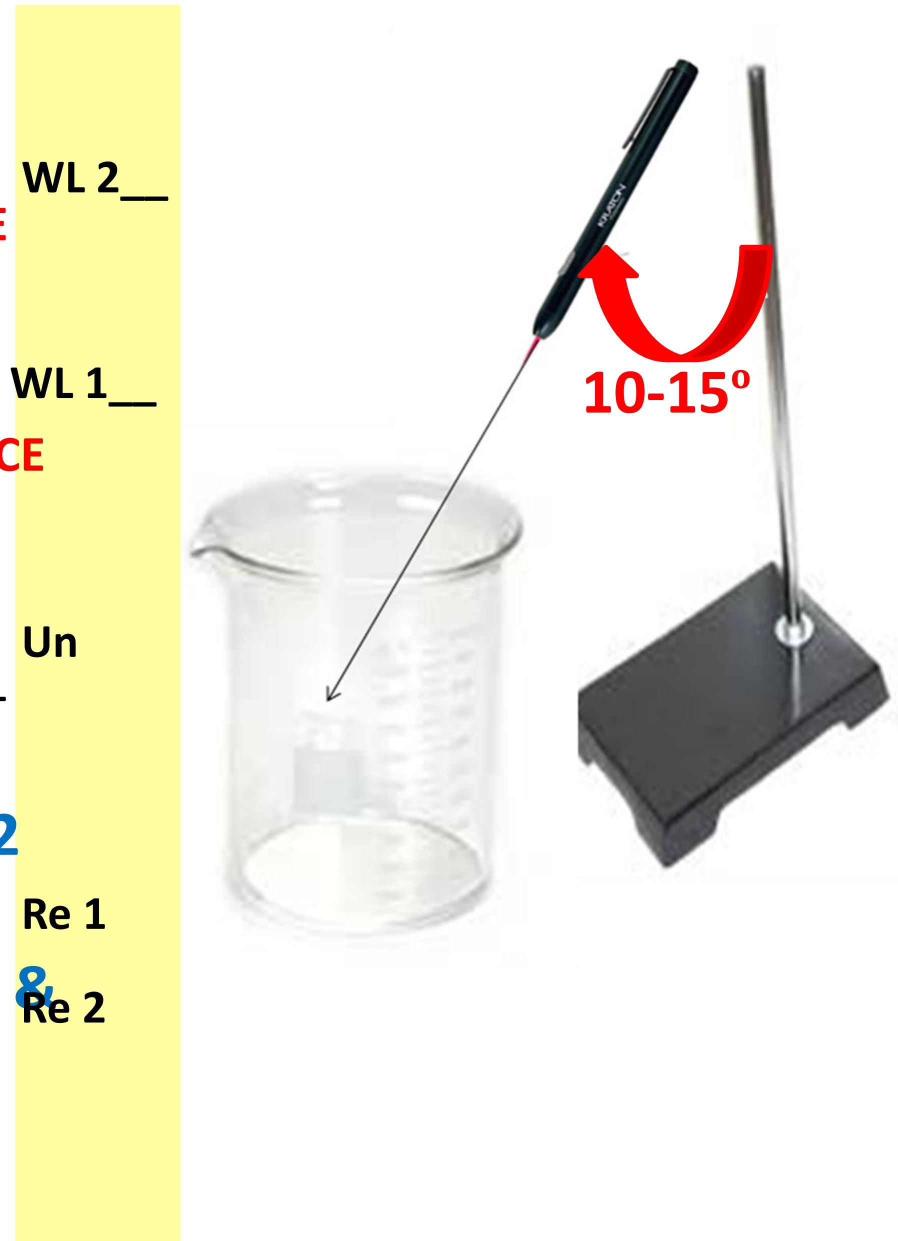
RICHARD HACKEL, CRA, FOPS

# LAB: Refraction of Light—Part 1

## *Index of Refraction for $H_2O$*

**Procedure:**

- Set laser at 10-15º & use clamp to hold down laser button (**UNCLAMP THE BUTTON WHEN FINISHED**)
- On vertical tape strip, mark un-refracted laser dot (**Un**) (**CAUTION: ONCE SET UP DON'T MOVE BEAKER!!**)
- Fill beaker 2/3 full with $H_2O$ & mark water line 1 (**WL 1**) & refracted line 1 (**Re 1**)
- Add more $H_2O$ and mark **WL 2** & **Re 2**
- **h = Re to WL    & h' = Un to WL**
- **Calculate $n_{water}$ = h/h' for both trials & % error**



# LAB: Refraction of Light—Part 2

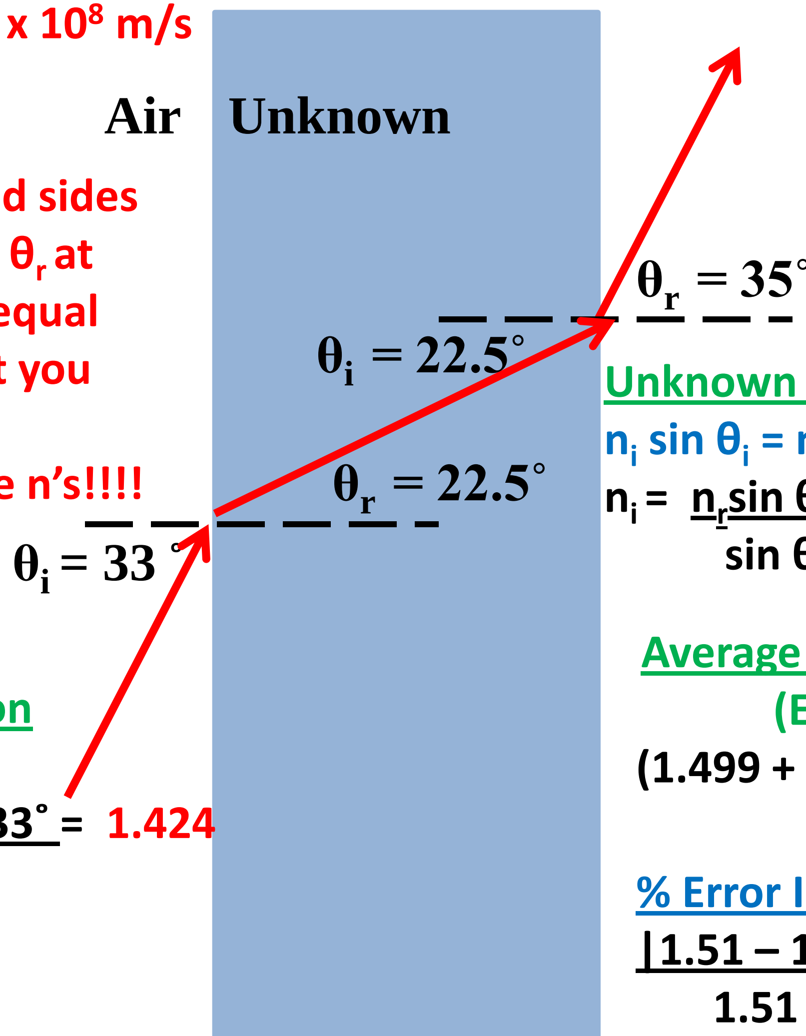
## Unknown = Plexiglas

**Speed of light in Unknown**

$n = c/v_s$

$v_s = c/n = \frac{3 \times 10^8 \text{ m/s}}{1.46} = 2.05 \times 10^8$ m/s

**NOTE: Use CLEAR not frosted sides and $\theta_i$ at the 1st interface & $\theta_r$ at the 2nd interface should be equal because both are air—If not you will need to do 2 Snell Law calculations and average the n's!!!!**

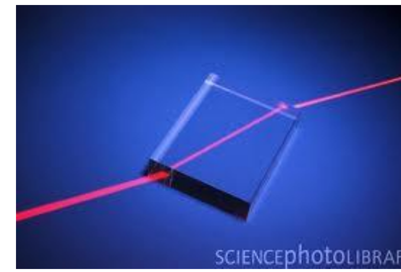



**Unknown Index of Refraction**

$n_i \sin\theta_i = n_r \sin\theta_r$

$n_r = \frac{n_i \sin\theta_i}{\sin\theta_r} = \frac{1.000293 \sin 33^\circ}{\sin 22.5^\circ} = 1.424$

**Explanation: This sketch shows…**




**Unknown Index of Refraction**

$n_i \sin\theta_i = n_r \sin\theta_r$

$n_i = \frac{n_r \sin\theta_r}{\sin\theta_i} = \frac{1.000293 \sin 32^\circ}{\sin 22.5^\circ} = 1.499$

**Average Index of Refraction (Experimental)**

$(1.499 + 1.424)/2 = 1.46$

**% Error Index of Refraction**

$\frac{|1.51 - 1.46|}{1.51} \times 100 = 3.31\%$

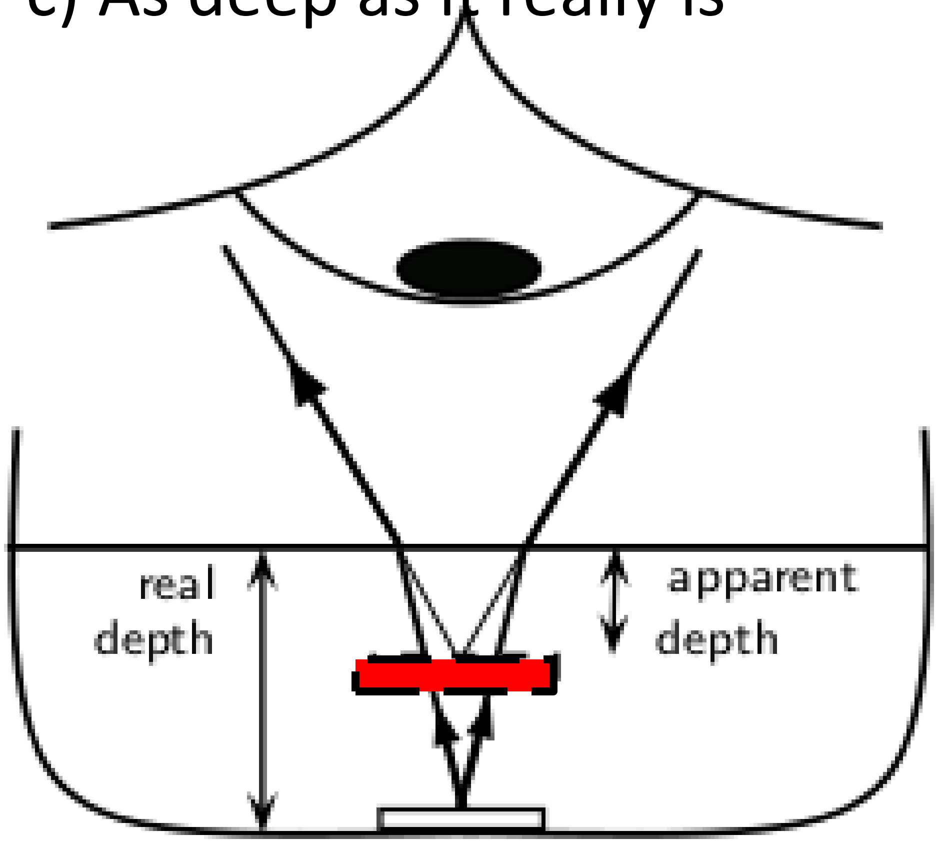
# I could Almost Touch it!

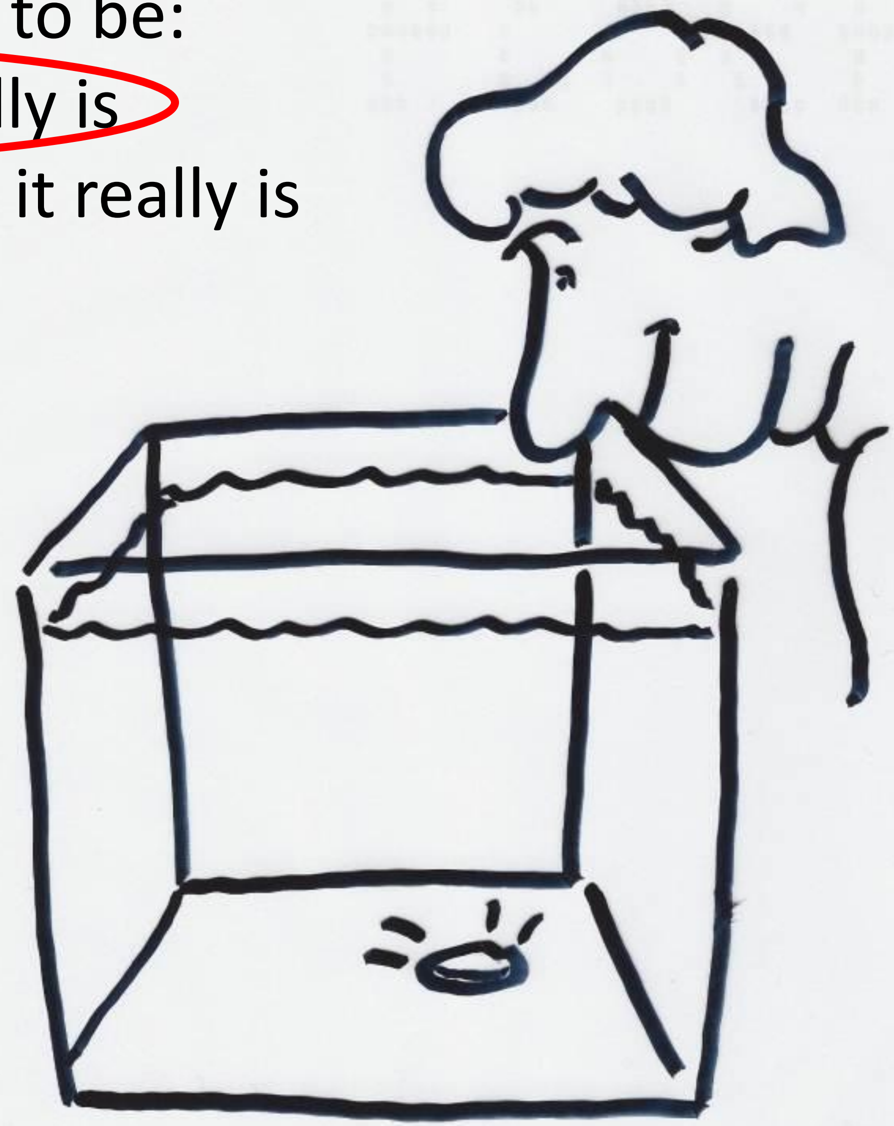
A coin is underwater. It appears to be:

a) Nearer the surface than it really is

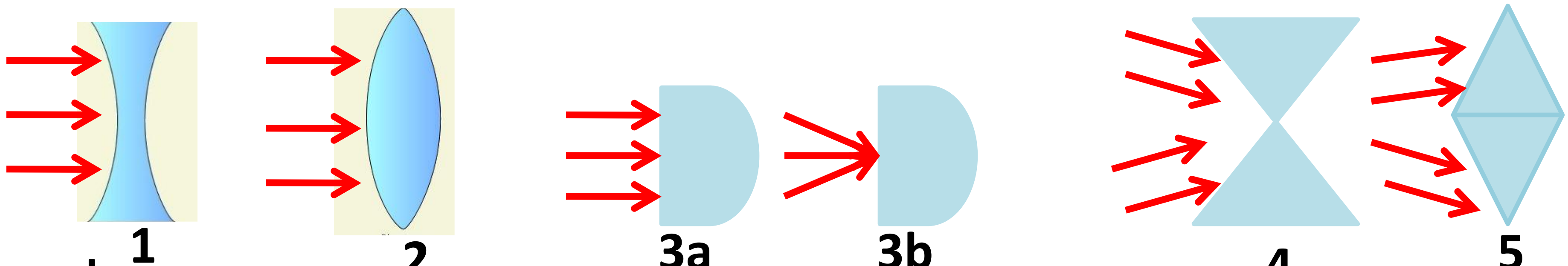
b) Further from the surface than it really is

c) As deep as it really is



# LAB: Refraction of Light—Part 3




**Procedure:**

- As a group , trace the paths of the light rays through the different shapes
- Test the shapes for reversibility (does it follow the same path back?)
- Make **summary table**: shape, converging/diverging & reversibility

## LAB REPORT REQUIREMENTS:

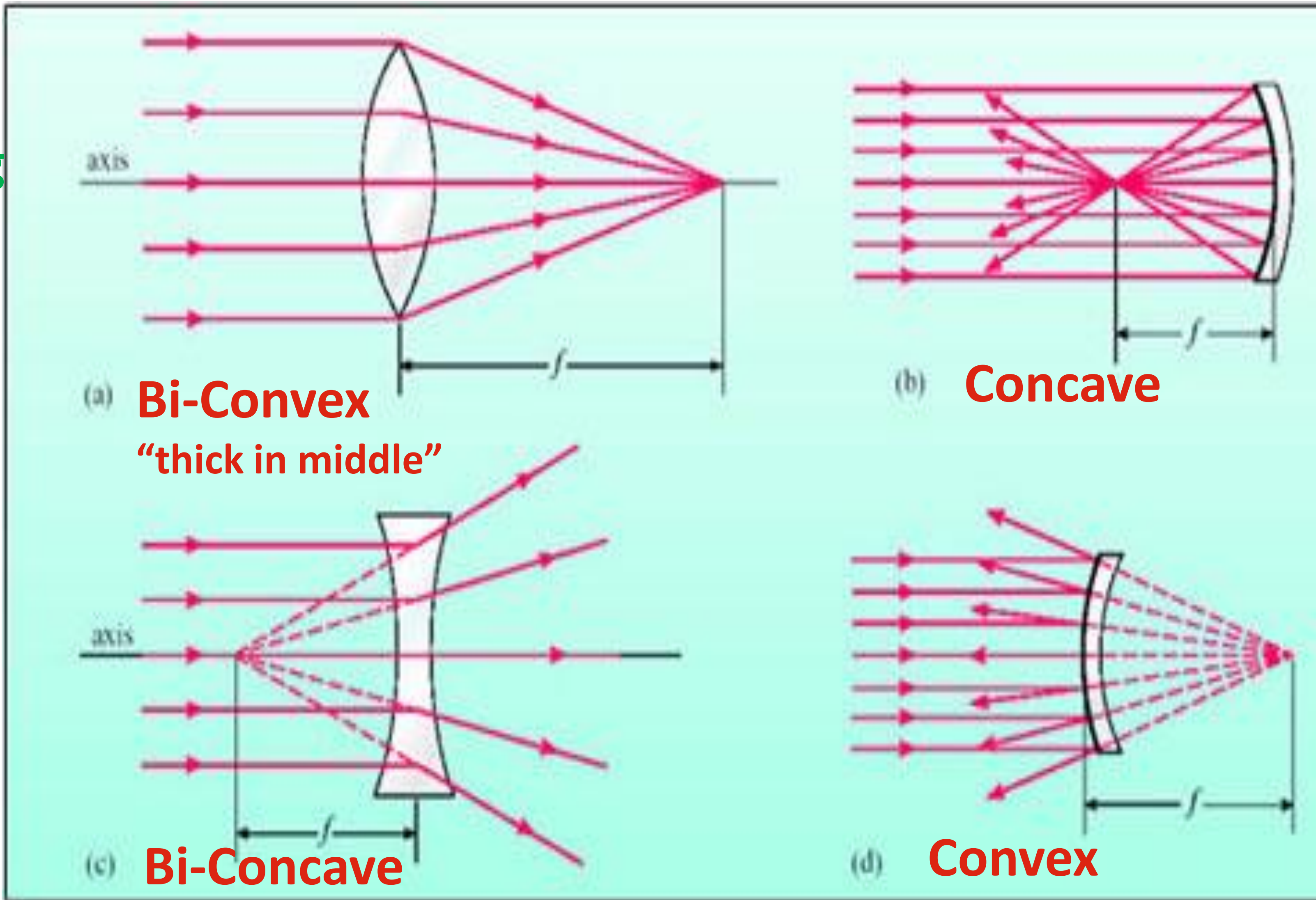
- Follow lab report handout for guidelines
- Each part should have its own data table
- Include Lab handout (**this does NOT count as your procedure & don't forget sketch of set-up**) with tape on it from Part 1
- Part 2 sketches: put your name, block material name, sketch description/ explanation, clearly labeled & diagramed & ALL calculations clearly shown: Vs, n's & $n_{ave}$ & % error
- Part 3 Sketches: clearly diagramed & labeled & summary table

# Lenses Vs Mirrors

## Light reflection/refraction Vs. Shape

Converging

Diverging




“Thin in middle”

# Lenses

Cause light rays to refract and change direction

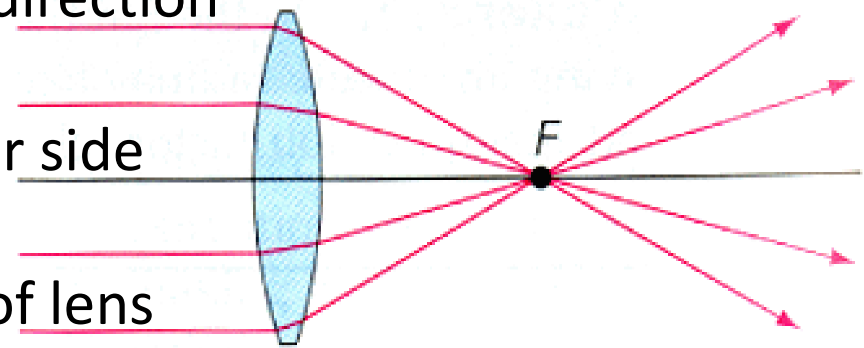
<u>**Converging Lens**</u> (Thick in middle)

-rays intersect (refract inward) on other side

-Creates real or virtual image

NOTE: Real Images = opposite side of lens

Virtual Images = same side of lens



Converging lens

-used for farsightedness

-Ex. magnifying lens (virtual image = image of bug,

real image = sun light projected on bug)

**Magnification** = change in size of image compared to size of object

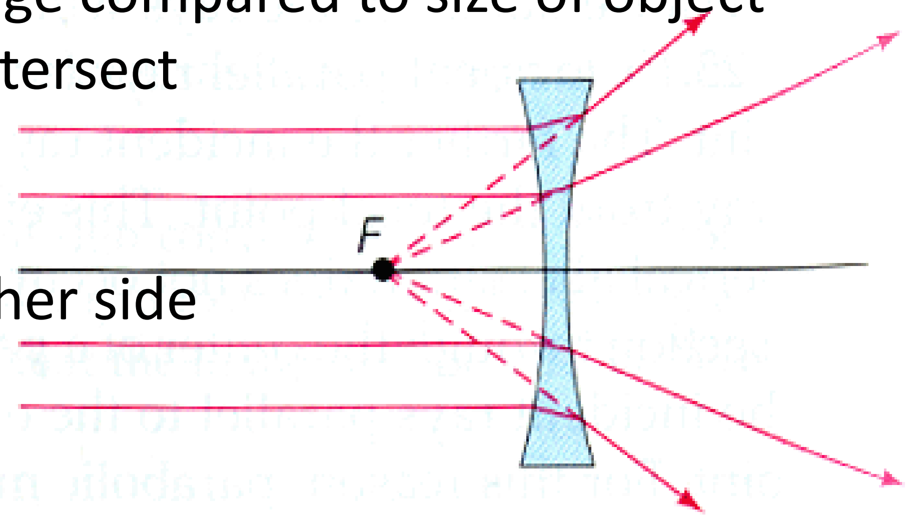
**Focal Point** = where rays appear to intersect

<u>**Diverging Lens**</u> (Thin in middle)

-Rays diverge (refract outward) on other side

-creates only virtual images

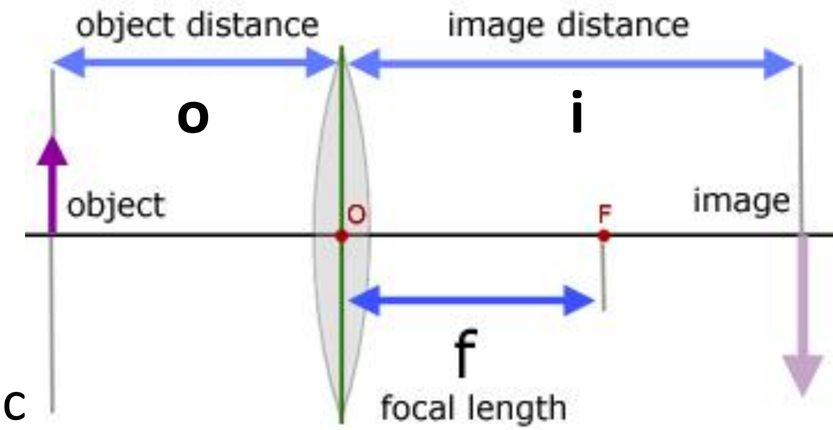
-used for nearsightedness



Diverging lens

# Mirror Equation:

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$




**<u>Note: CAUTION OPPOSITE OF MIRRORS</u>**

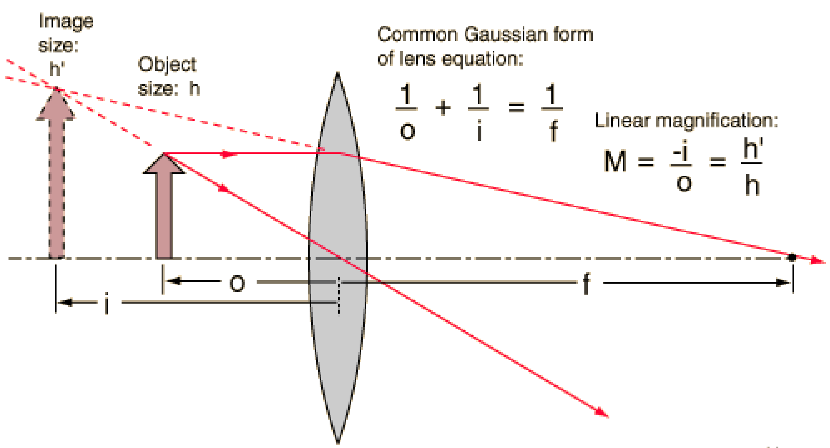
o always = + #

+ i = real image **opposite side of** lens as obj (c

- i = virtual image = appears **same side** of lens

Diverging: f = - # because rays refract through focal in front of lens

Converging: f = + #




# Magnification:

$$m = \frac{-i}{o}$$

<u>Note:</u>

+ m = upright

- m = inverted

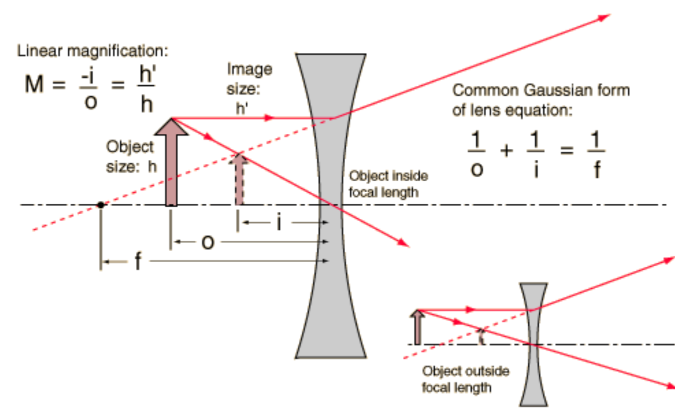
m < 1 = smaller image

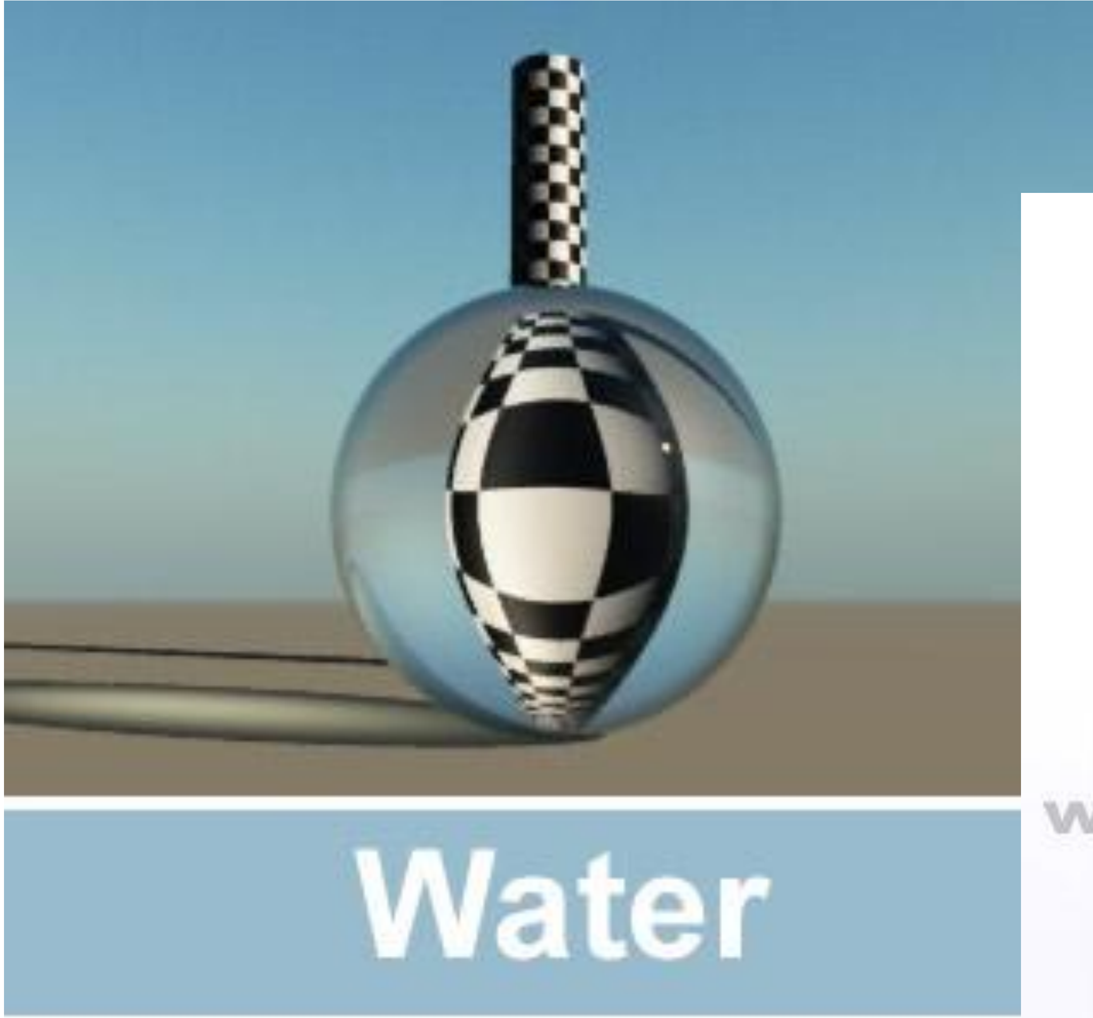
m = 1 = same size image

m > 1 = larger image

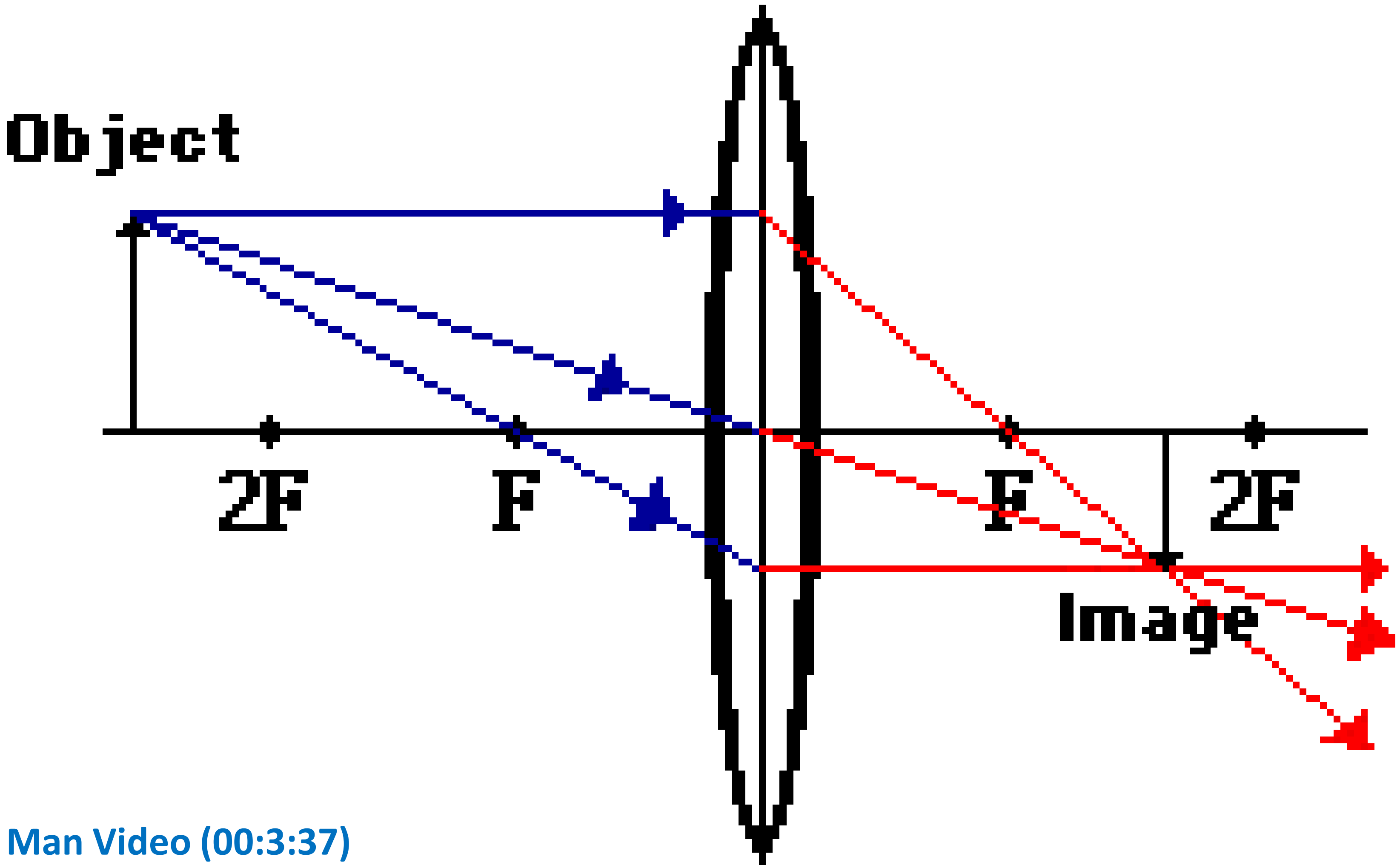
*****USE EQUATIONS WITH DIAGRAMS TO CONFIRM IMAGE LOCATION & TYPE**

**SHOW HOW TO DO # 1 & #5 ON HOCUS FOCUS SHEET0**




Water

# Converging w/Obj outside C

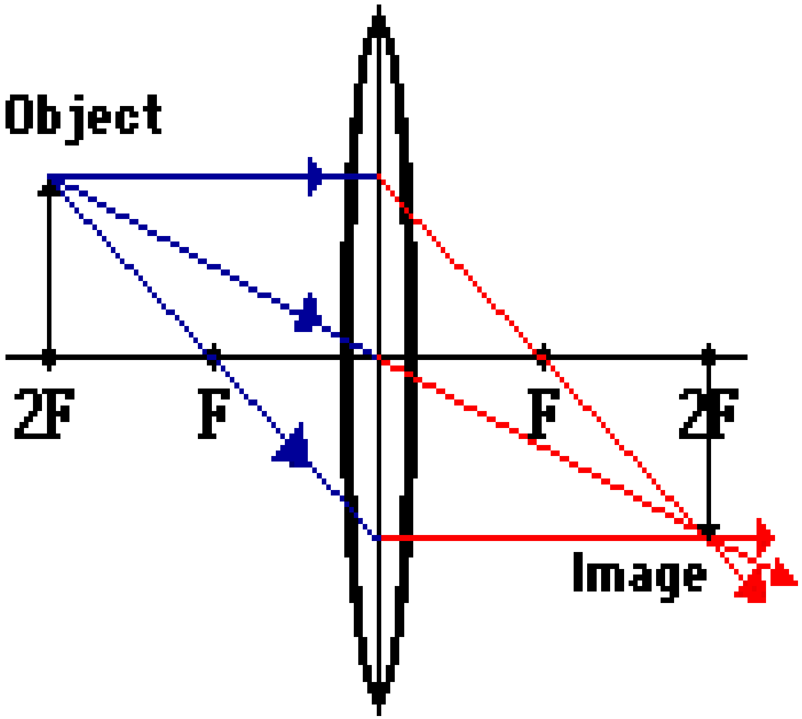



**Invisible Man Video (00:3:37)**

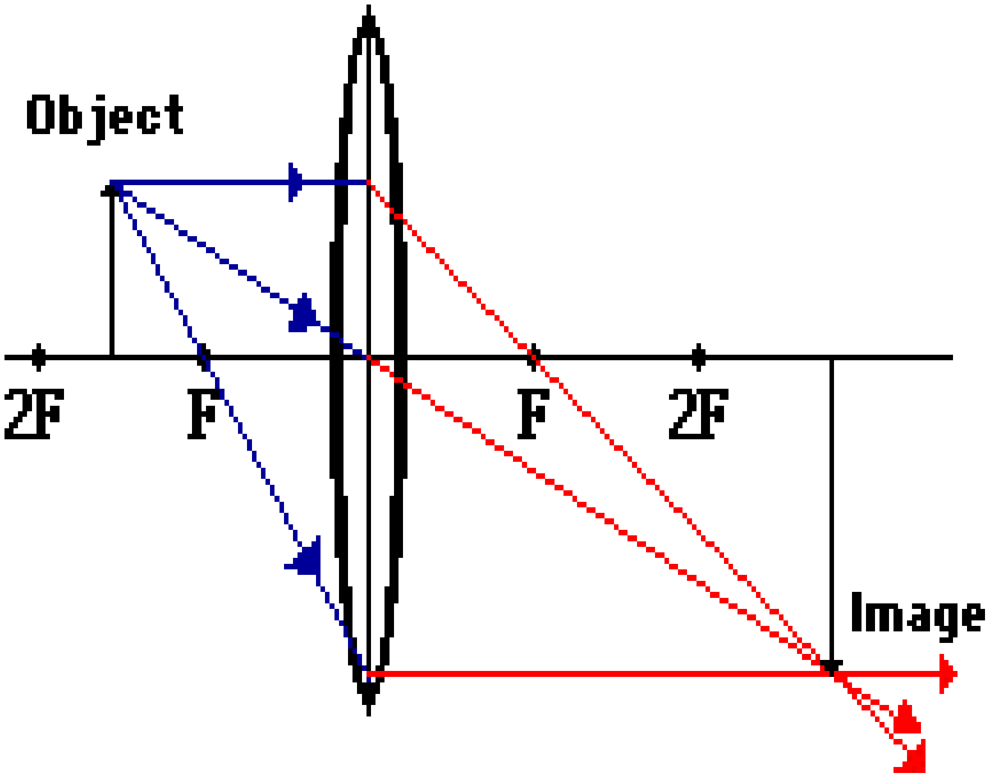
http://youtu.be/WKEBinz5bP0

OR http://www.cyberphysics.co.uk/topics/light/refraction.htm

# Converging w/obj at C & Between C & F

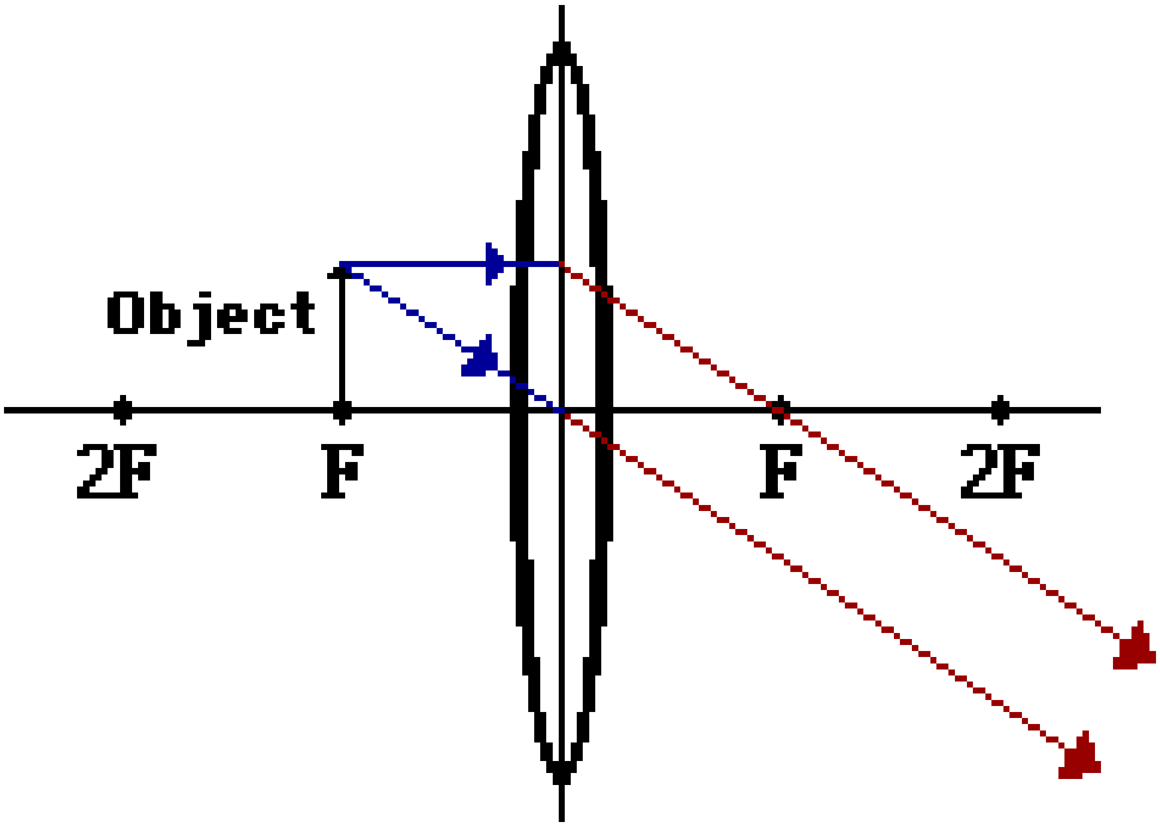



Ray Diagram for Object Located at 2F



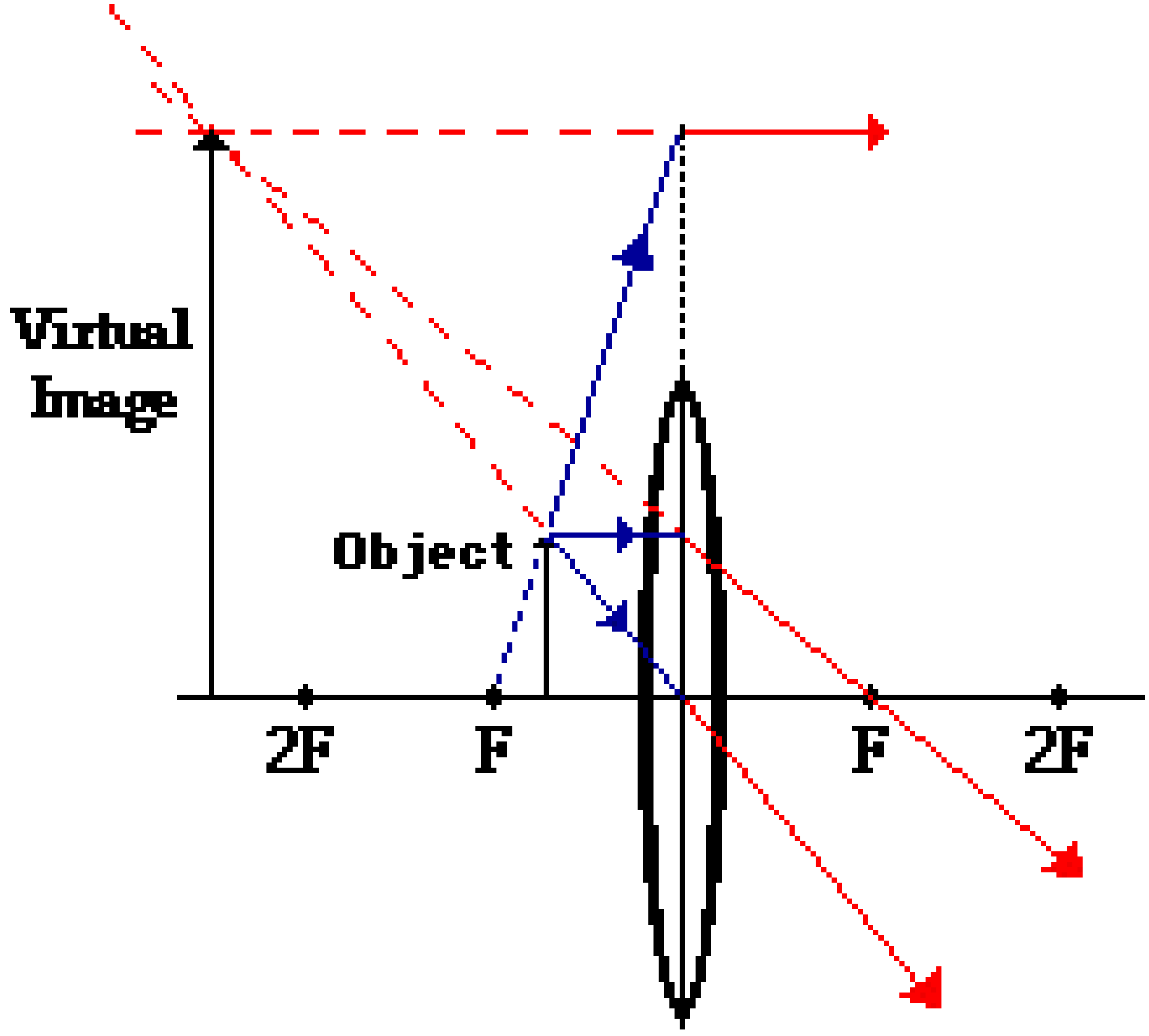

Ray Diagram for Object Located Between F and 2F

# Converging w/Obj at Focal



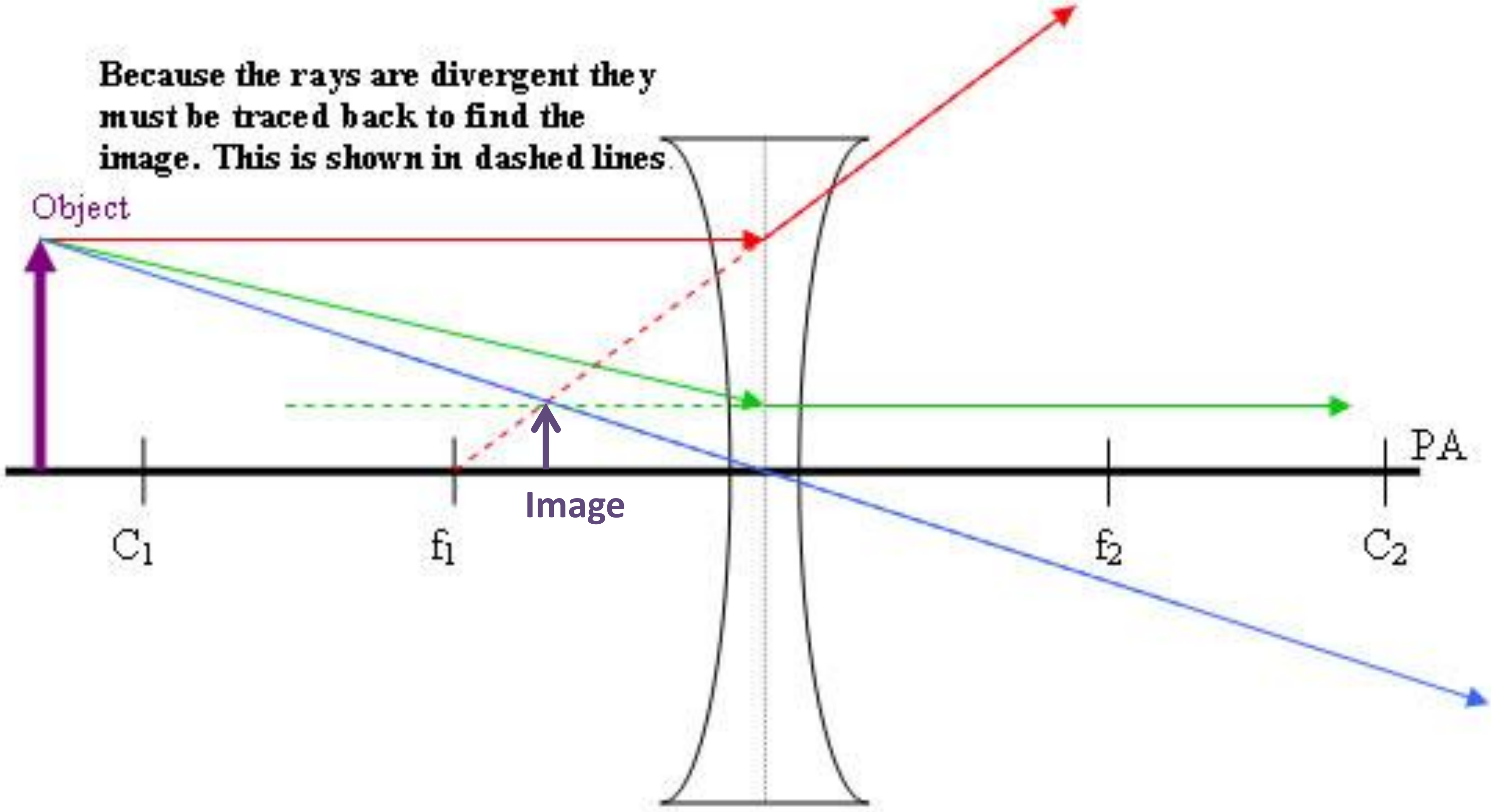

Ray Diagram for Object Located at F
(an image is not formed)

# Converging w/Obi inside Focal




Ray Diagram for Object Located in Front of F

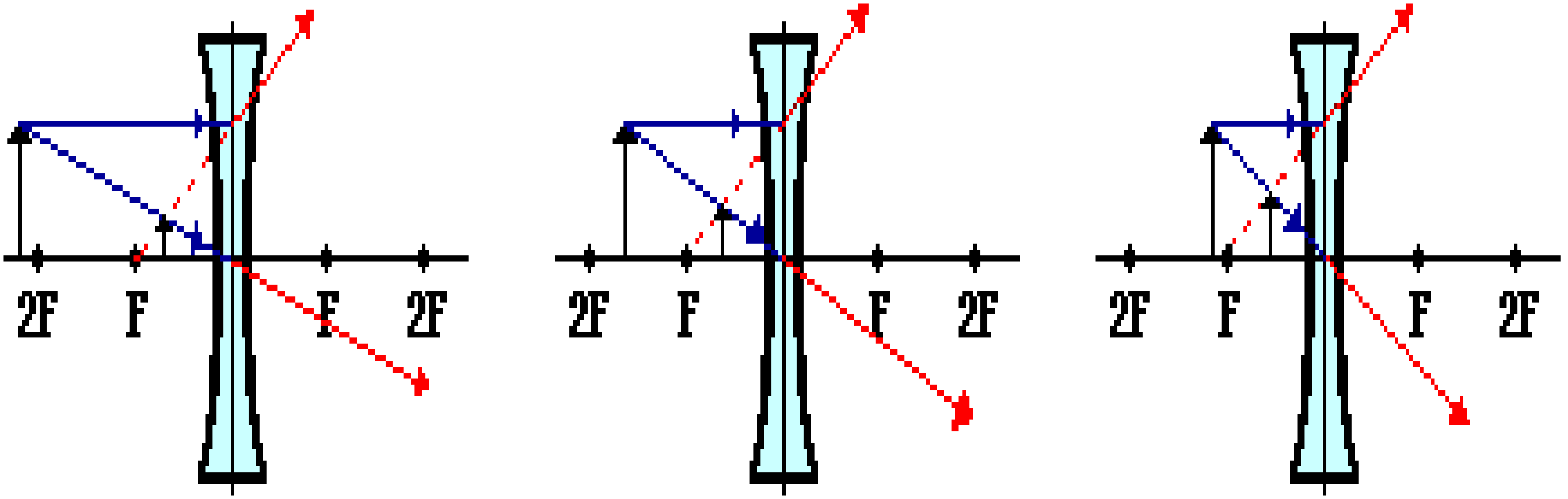
# Diverging w/Obj Outside C




## Image = Virtual, Upright & smaller

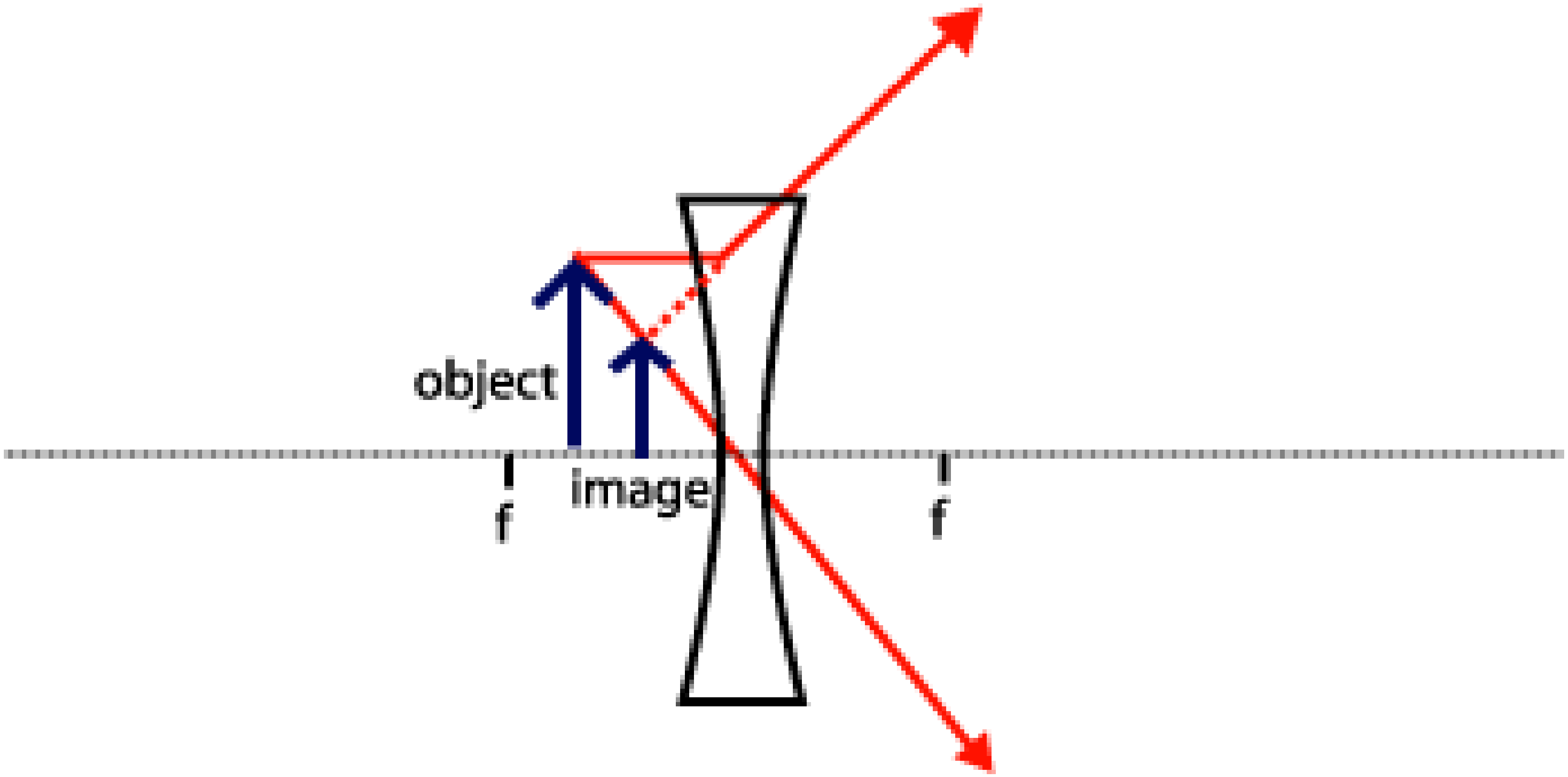
# Diverging moving closer to focal

## Image ALWAYS = virtual, upright & smaller




As Obj moves closer to focal image gets bigger & closer to lens but it is still virtual & smaller than object

# Diverging w/Obj inside F



# Sample Problem 1 : Converging Lens

An object is 30 cm from a converging lens with a focal length of 20 cm.

a) Draw a 3-ray diagram to scale
b) Identify the type of image created
c) Use the equations to determine the image location & magnification

**b) Real, Larger, Inverted**

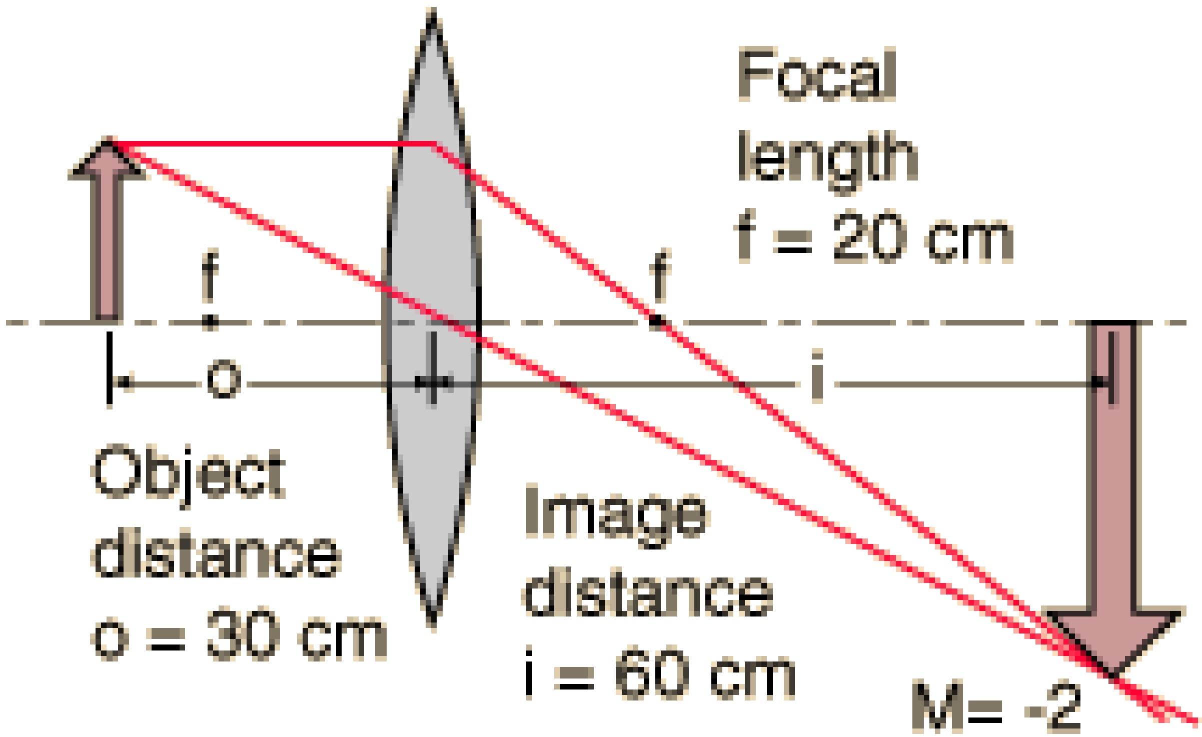
c) $\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$

$\frac{1}{20} = \frac{1}{i} + \frac{1}{30}$

$\frac{3}{60} - \frac{2}{60} = \frac{1}{i}$

**i = 60 cm**

$m = \frac{-i}{o} = \frac{-60cm}{30\ cm} =$ **-2**



# Sample Problem 2: Converging Lens

An object is 10 cm from a converging lens with a focal length of 30 cm.

a) Draw a 3-ray diagram to scale

b) Identify the type of image created

c) Use the equations to determine the image location & magnification

**b) Real, Larger, Inverted**

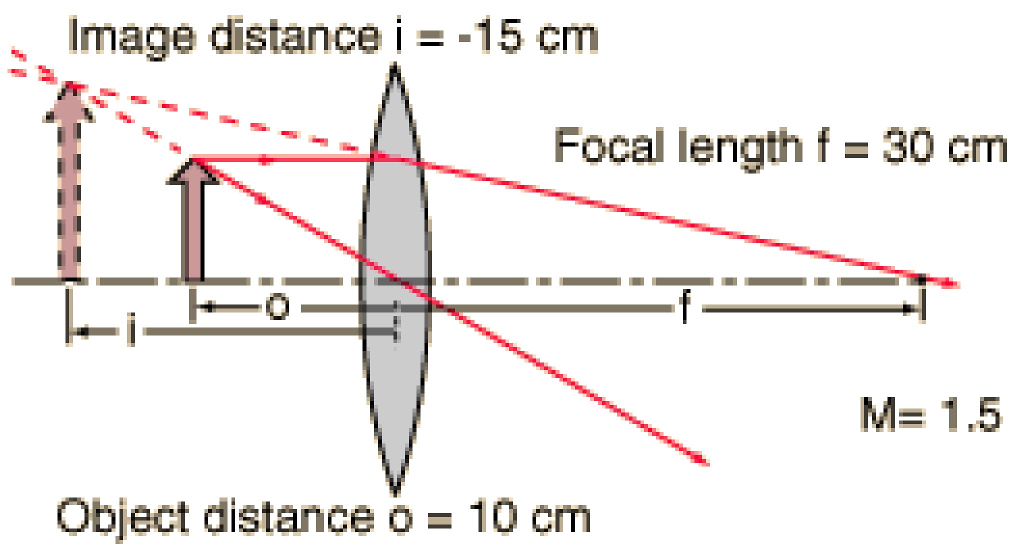
c) $\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$ so $\frac{1}{30} = \frac{1}{i} + \frac{1}{10}$

$\frac{1}{30} - \frac{3}{30} = \frac{1}{i}$ so **$i = -15$ cm**

$m = \frac{-i}{o} = \frac{- -15\text{cm}}{10\text{ cm}} =$ **+1.5**

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

$$\frac{1}{\text{object distance}} + \frac{1}{\text{image distance}} = \frac{1}{\text{focal length}}$$



# Sample Problem 3: Diverging Lens

An object is 20cm from a diverging lens with a focal length of -30 cm.

a) Draw a 3-ray diagram to scale
b) Identify the type of image created
c) Use the equations to determine the image location & magnification

**b) Real, Larger, Inverted**

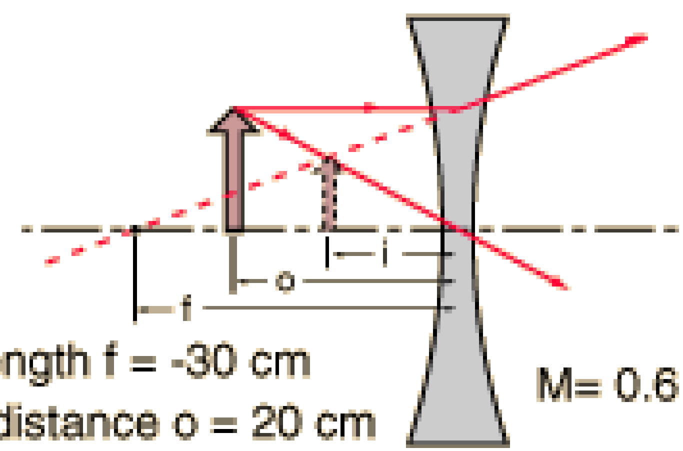
c) $\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$ so $\frac{1}{-30} = \frac{1}{i} + \frac{1}{20}$

$\frac{2}{-60} - \frac{3}{60} = \frac{1}{I}$ so **i = -12 cm**

$m = \frac{-i}{o} = \frac{- -12cm}{20cm} =$ **+ 0.6  0r  + 3/5**

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

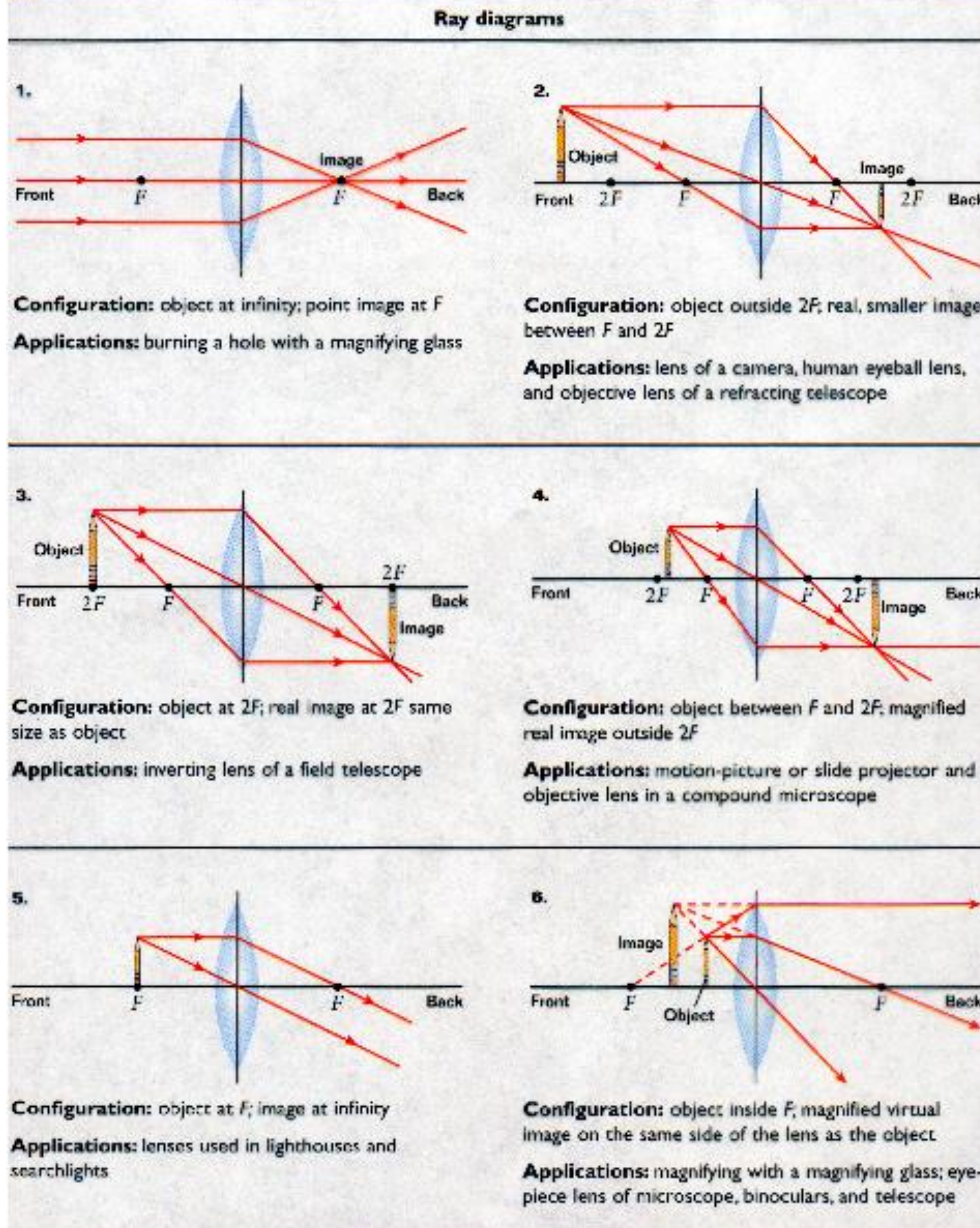
$$\frac{1}{\text{object distance}} + \frac{1}{\text{image distance}} = \frac{1}{\text{focal length}}$$




Focal length f = -30 cm
Object distance o = 20 cm
Image distance i = -12 cm

M= 0.6

# Lens Diagram Review



Ray diagrams

1.



**Configuration:** object at infinity; point image at F

**Applications:** burning a hole with a magnifying glass

2.



**Configuration:** object outside 2F; real, smaller image between F and 2F

**Applications:** lens of a camera, human eyeball lens, and objective lens of a refracting telescope

3.



**Configuration:** object at 2F; real image at 2F same size as object

**Applications:** inverting lens of a field telescope

4.



**Configuration:** object between F and 2F; magnified real image outside 2F

**Applications:** motion-picture or slide projector and objective lens in a compound microscope

5.



**Configuration:** object at F; image at infinity

**Applications:** lenses used in lighthouses and searchlights

6.



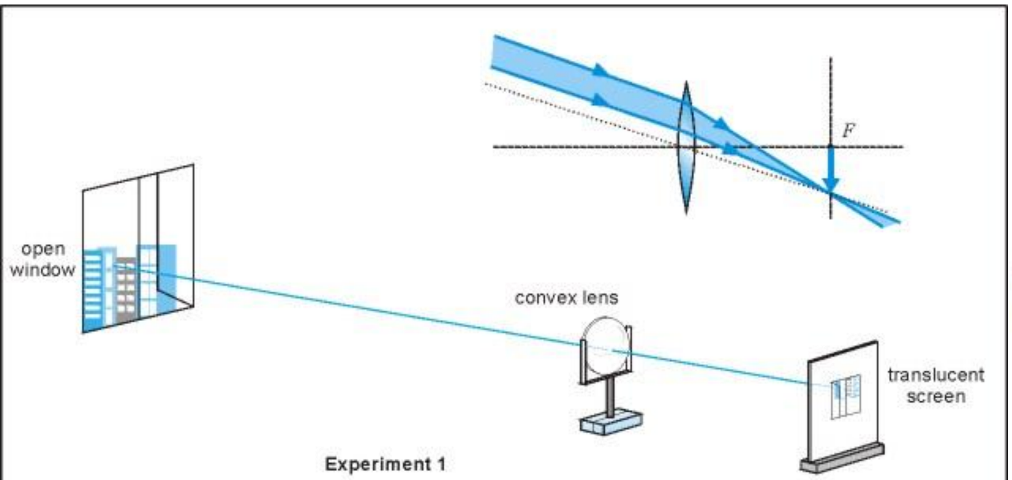
**Configuration:** object inside F; magnified virtual image on the same side of the lens as the object

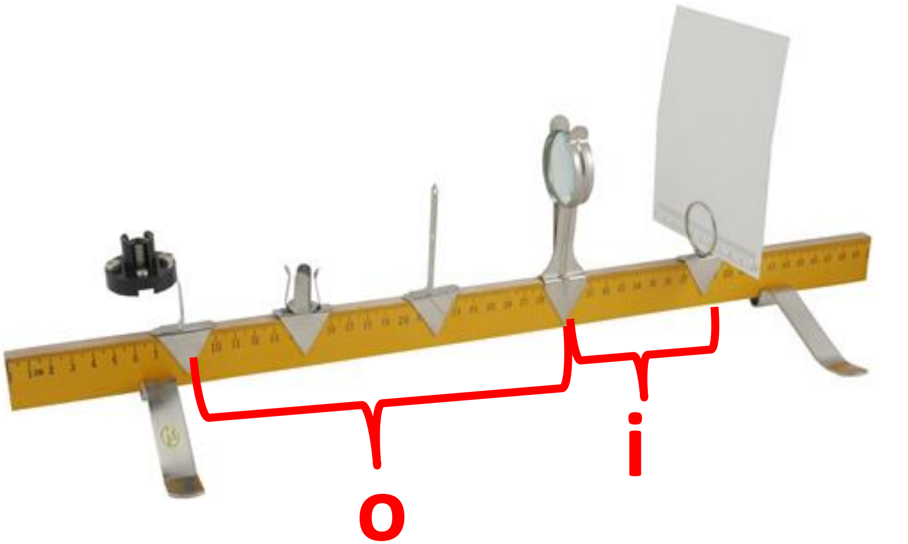
**Applications:** magnifying with a magnifying glass; eyepiece lens of microscope, binoculars, and telescope

# LAB: Lenses

## Procedure:

- Focus light on card by adjusting light, lens & card until you get a crisp bright spot on card
- For trial 2, move either light or card 10 cm & redo adjustments
- Use equations to find f for each trial & use average as experimental in % error
- Find actual f by going in hallway & project window image on post & measure with ruler (*parallel light rays from very far source = Sun will refract to the focal point*)
- Redo above steps for 2$^{nd}$ lens



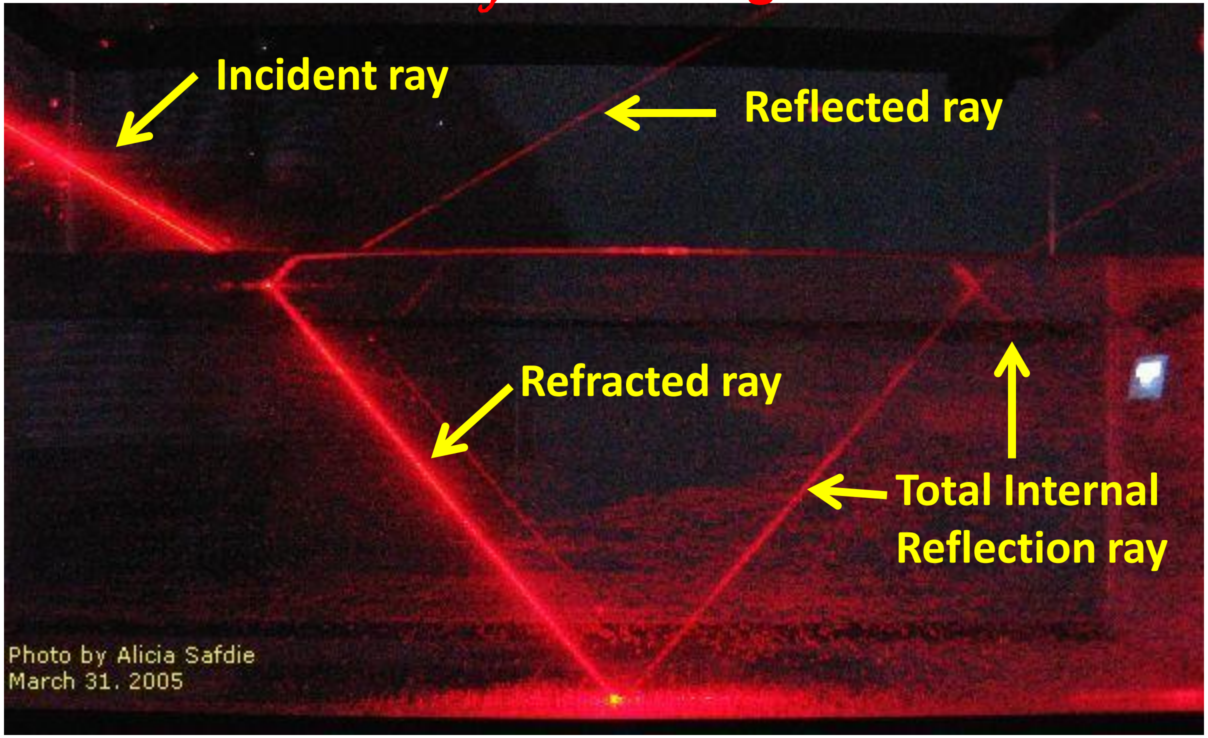

| Lens # | Trial | i (cm) | o (cm) | f (cm) | Actual f (cm) | % Error |
|---|---|---|---|---|---|---|
| | 1 | | | | | |
| | 2 | | | | | |
| | 1 | | | | | |
| | 2 | | | | | |

# Humm???

**Light rays bend as the pass from air into water at a non-0˚ angle. What doesn't change?**

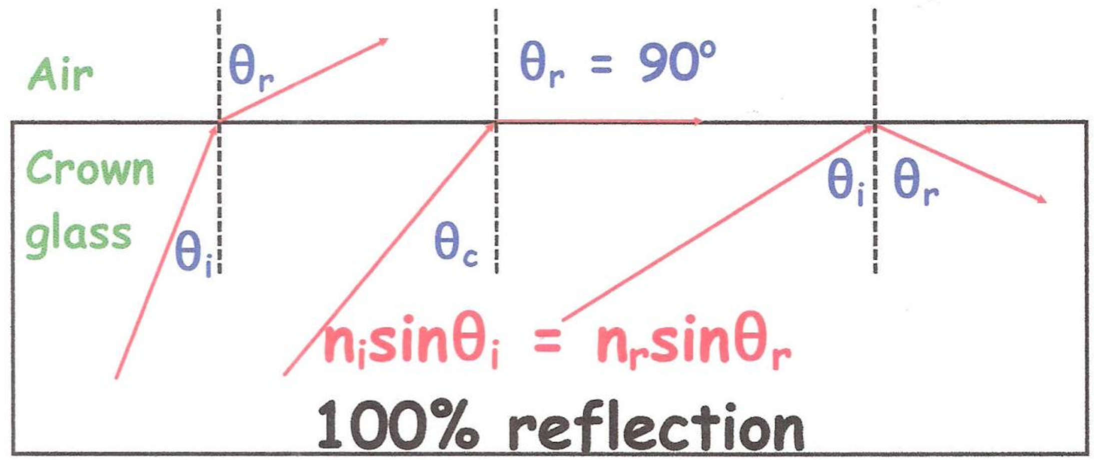
a) Average speed of light
b) Index of refraction of the material
c) Frequency of light
d) λ of light

*f* determined by source since color doesn't change. Speed of light changes in different mediums that's why it bends (inward = slower) so if *f* not change then λ must change



- **TIR:** When light going from a more dense to less dense material is not refracted but instead reflected back through incident material. This happens when $\theta_i = \theta_c$ (**critical angle**) which causes $\theta_r = 90º$
- Used in binoculars & Periscopes w/prisms
- Use Snell's Law to find $\theta_c$ for the following substances →

## TOTAL INTERNAL REFLECTION




## Critical angle problems:

**Glass to air:**

$n_i \sin\theta_c = n_r \sin\theta_r$ $\quad\quad \sin\theta_c = \dfrac{n_r \sin}{n_i}$

$\theta_c = \sin^{-1} \dfrac{n_r \sin\theta_r}{n_i} = \sin^{-1} \dfrac{1.000293 \sin 90^\circ}{1.52} = 41.15^\circ$

**Water to air:**

$n_i \sin\theta_c = n_r \sin\theta_r$

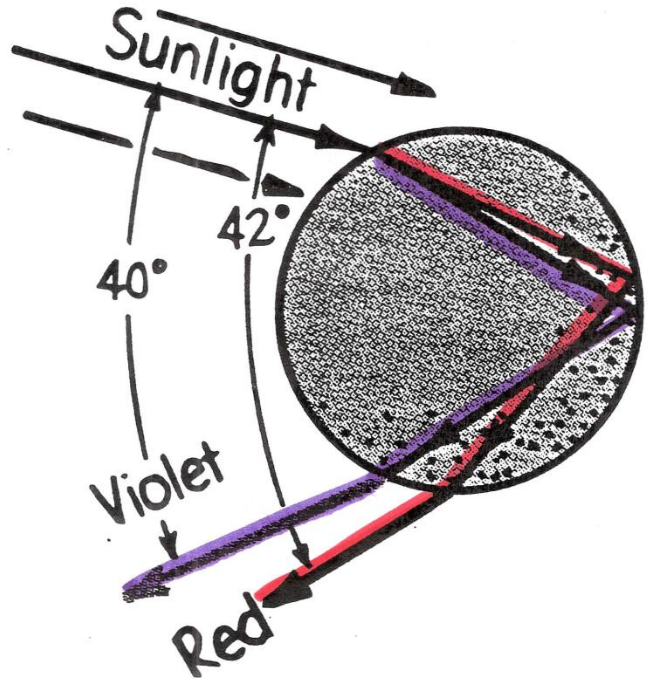
$\theta_c = \sin^{-1} \dfrac{n_r \sin\theta_r}{n_i} = \sin^{-1} \dfrac{1.000293 \sin 90^\circ}{1.333} = 48.63^\circ$

**Diamond to air:**

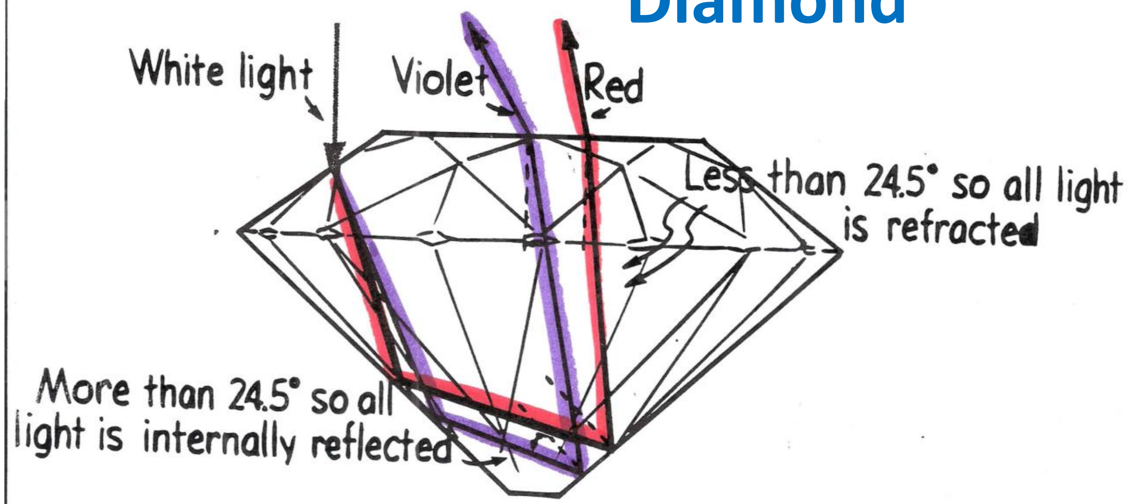
$n_i \sin\theta_c = n_r \sin\theta_r$

$\theta_c = \sin^{-1} \dfrac{n_r \sin\theta_r}{n_i} = \sin^{-1} \dfrac{1.000293 \sin 90^\circ}{2.419} = 24.43^\circ$

## $H_2O$ Drop



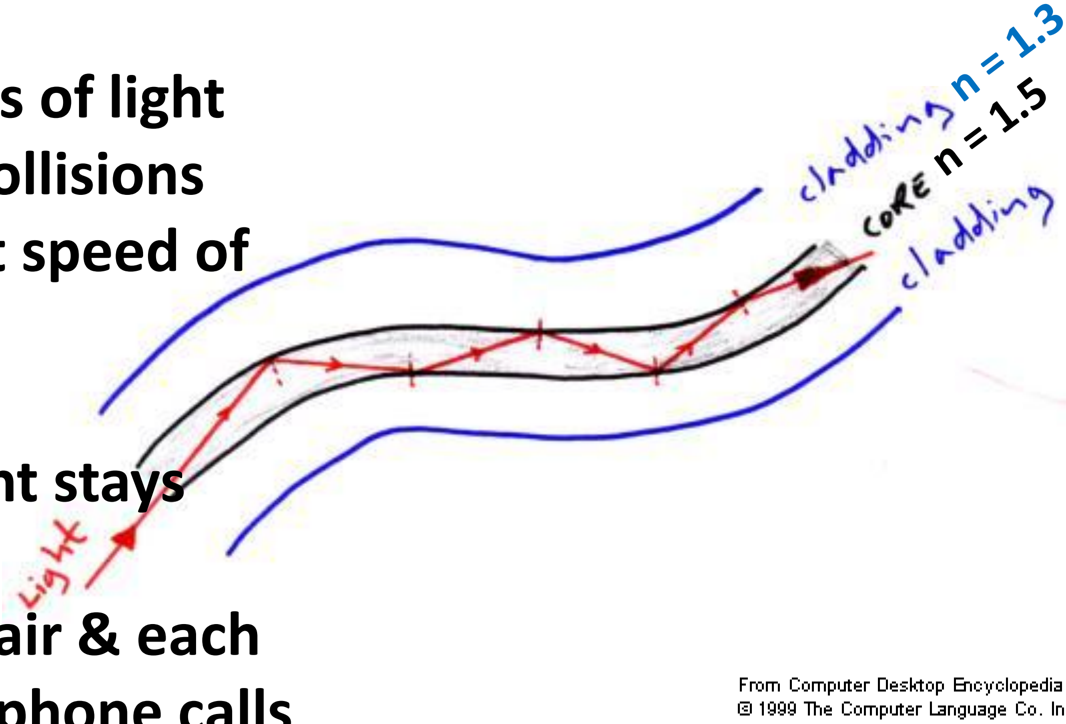

## Diamond




- **Sparkles because Light coming in at $\theta_c$ = 24º has trouble getting out due to many facets/faces but when it does it is straight at you!!**

# Fiber Optics

- Used to send info via photons of light not like telephones with e- collisions with copper so info travels at speed of light!!!
- 100% reflective
- Can bend any direction & light stays trapped in fiber
- Fiber = diameter of human hair & each send 1 million simultaneous phone calls or $10^{12}$ bits/sec or 2hr movie in ½ sec
- Amplifier every 100 km.
- Determine $\theta_c$ for the fiber

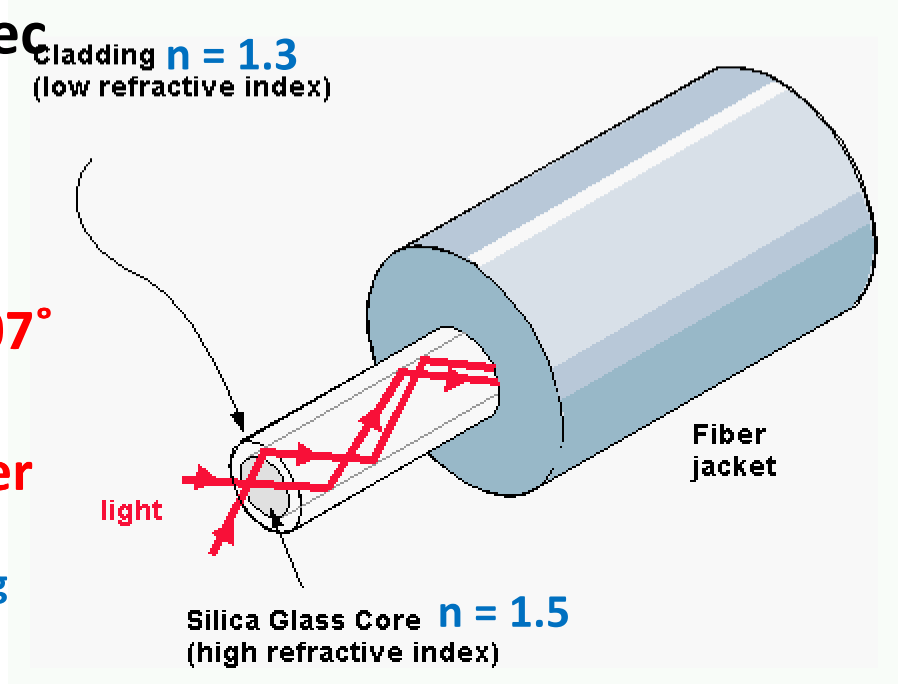



$n_i \sin \theta_c = n_r \sin \theta_r$

$\theta_c = \sin^{-1} \dfrac{n_r \sin \theta_r}{n_i} = \sin^{-1} \dfrac{1.3 \sin 90^\circ}{1.5} = 60.07^\circ$

So above 60.07˚ light stays trapped in fiber

- Demo: fiber optic cable & flashlight
- Demo: Pour $H_2O$ from soda bottle with laser shinning through bottom into a bucket



# Dispersion & Prisms

In vacuum all EM waves travels at c = 3 x $10^8$ m/s but in other mediums speed depends on λ (*f* is constant)  v = *f*λ

**Dispersion** = process of separating a wave of different frequencies into its individual component waves (Ex. white light into colors)

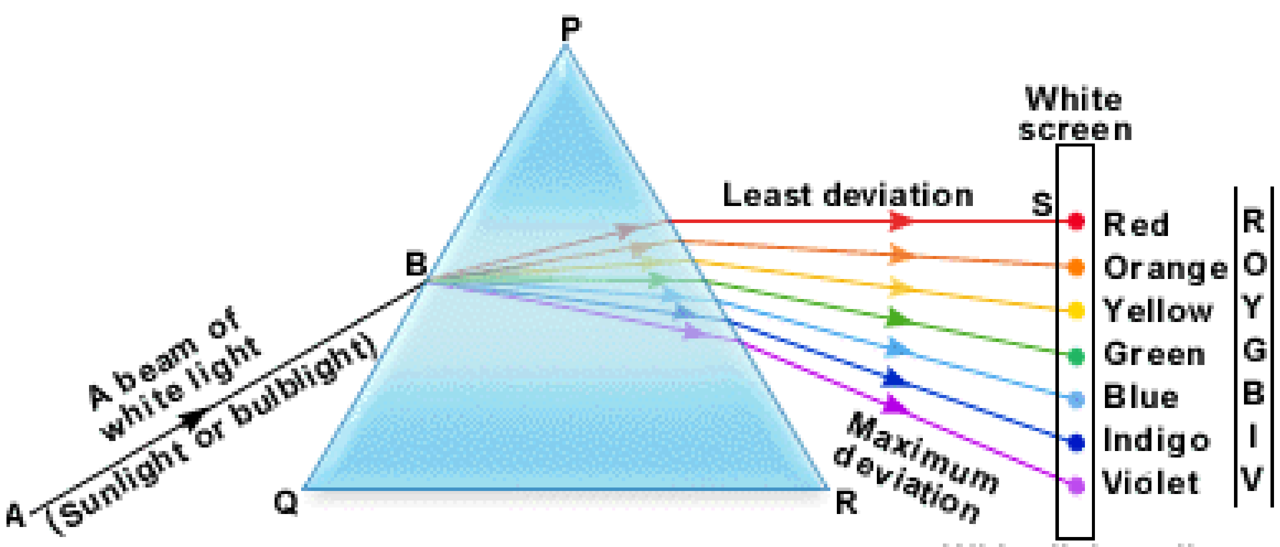
**Prisms** = a system that consists of 2 or more plane surfaces of a transparent solid at an angle with each other (Discovered by Newton)

•*Different colors refract different amounts due to differences in λ & n*

ROY G BIV

Red = ↑λ and ↑velocity so bends less

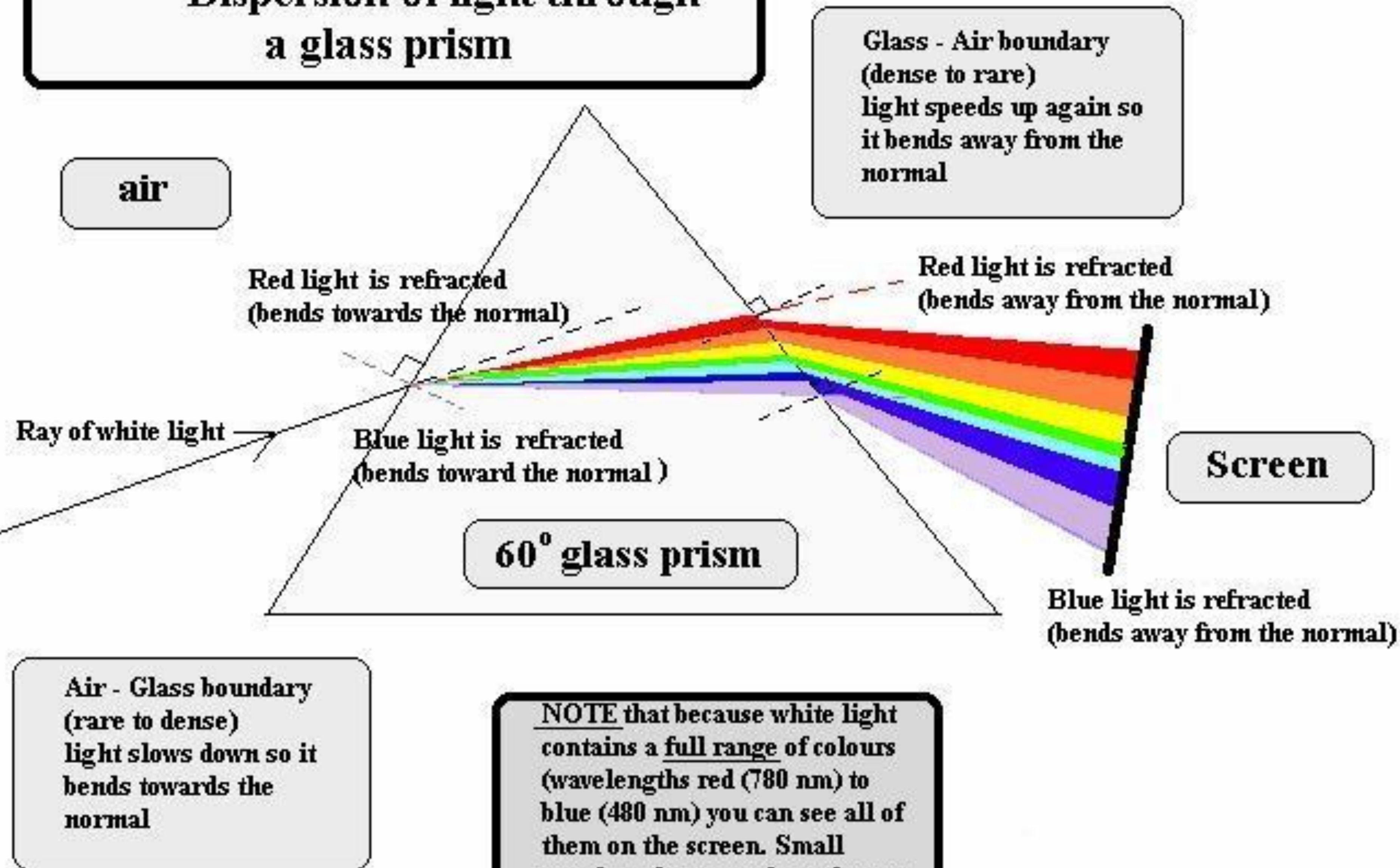
Blue = ↓ λ & ↓velocity so bends more because greater Δn's




λ = 700 nm & n = 1.61

BIV λ = 500 nm & n = 1.64

# Dispersion of light through a glass prism




NOTE that because white light contains a full range of colours (wavelengths red (780 nm) to blue (480 nm) you can see all of them on the screen. Small wavelengths are refracted more than big ones.

# Rainbows

- *Rainbows caused by dispersion and reflection*

  Light refracts upon entering water droplet causing white light to disperse into its colors. The colors then reflect off of the back of the droplet (TIR) and refract again when leaving the droplet creating a rainbow with an arc of 40-42º.

<u>Requirements for viewing Rainbow</u>

1. sun behind you
2. rain/water droplets in front of you
3. Viewing angle of 40-42º (primary)

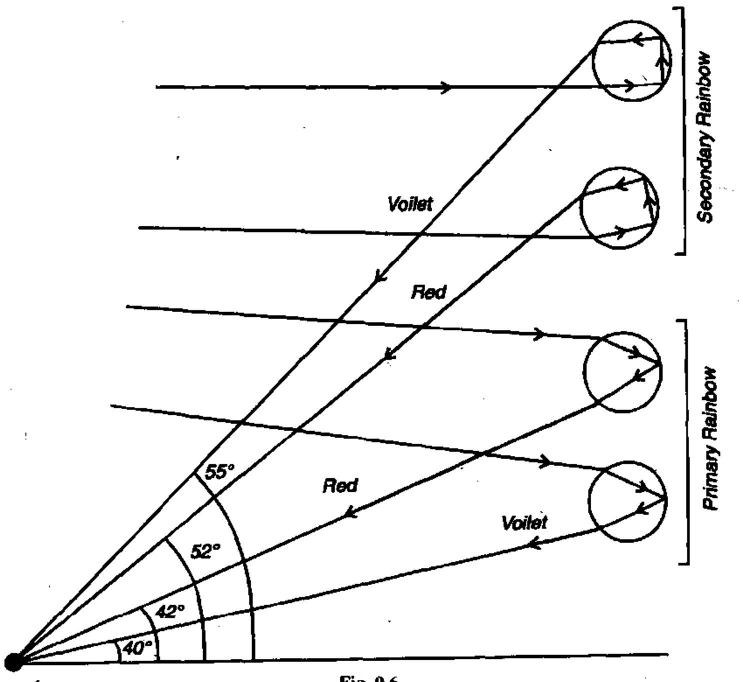


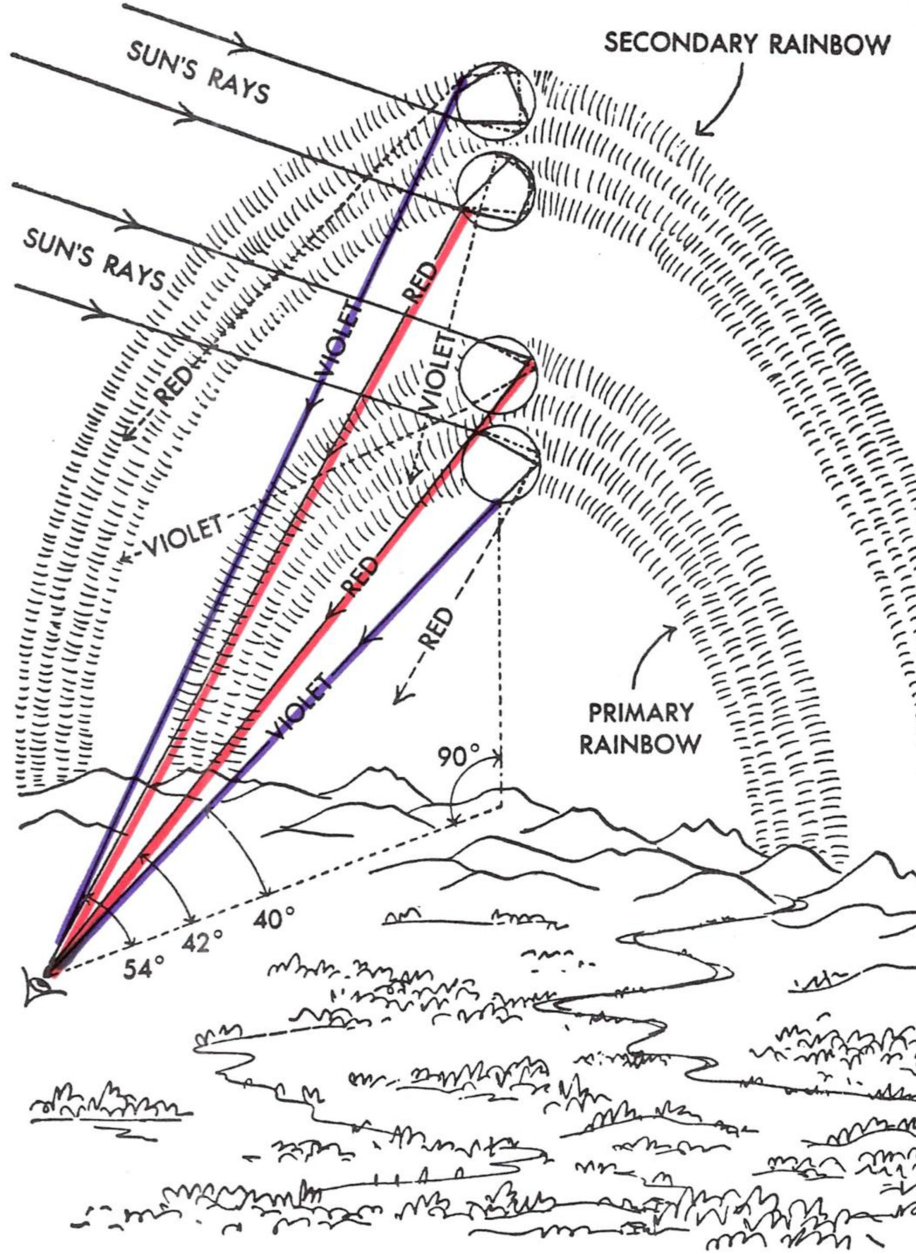

Fig. 9.6


**<u>Notice</u>** the Secondary Rainbow has the reverse order of colors compared to the Primary Rainbow

**Notice** the Secondary Rainbow has the reverse order of colors compared to the Primary Rainbow because light is reflected twice internally

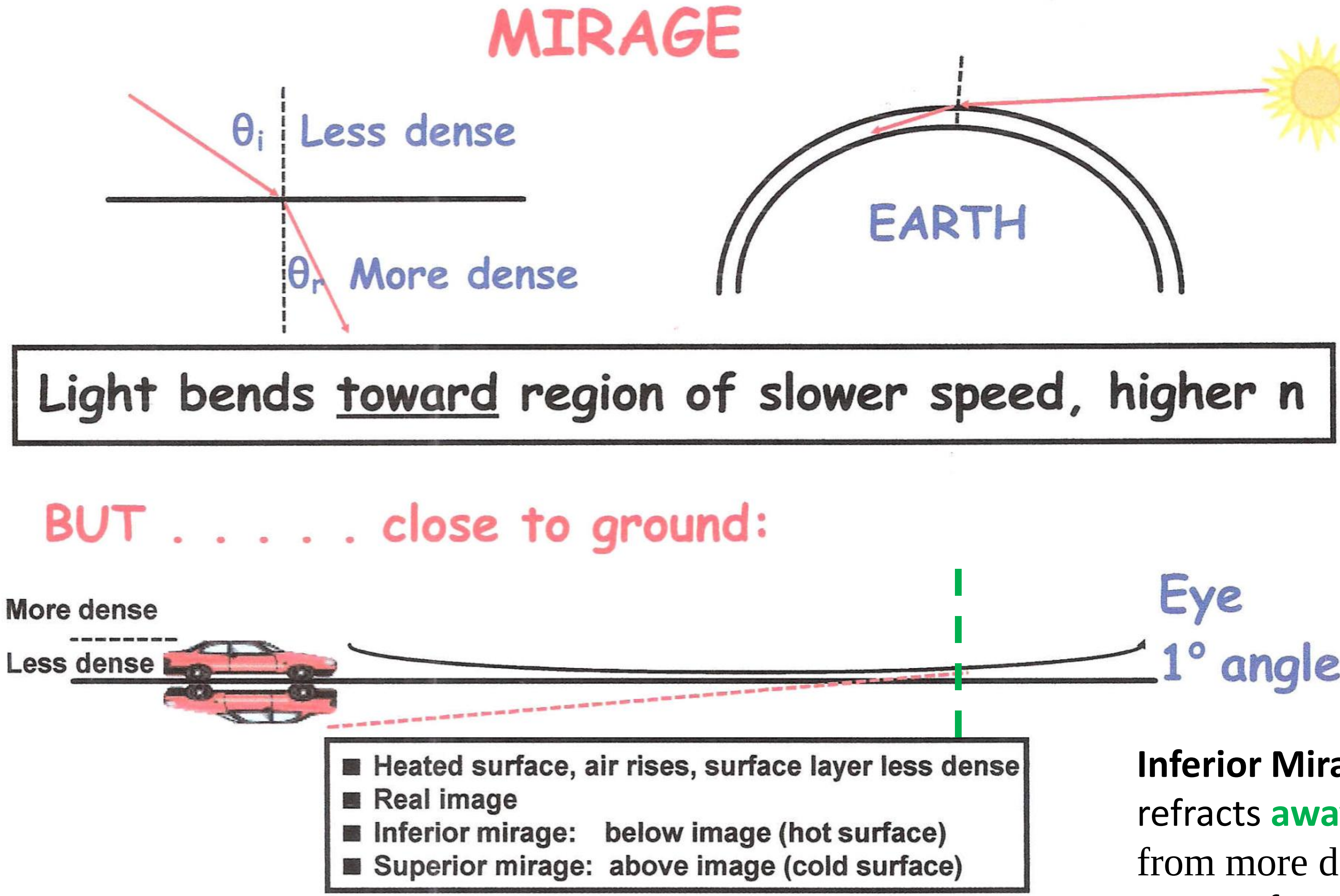
Demo: prisms & diffraction grating glasses look at white light & other color lights

Hollywood Ex: Wizard of OZ


RAINBOWS OCCUR WHEN THE OBSERVER IS BETWEE
THE SUN AND DROPLETS IN THE AIR

- **Mirage**- Real image created by refraction of light in atmosphere due to temperature differences in air molecules

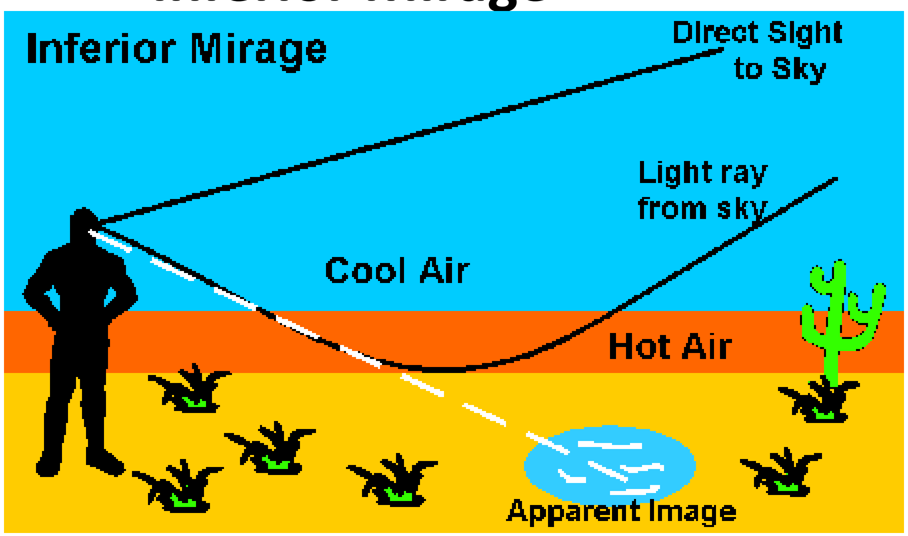


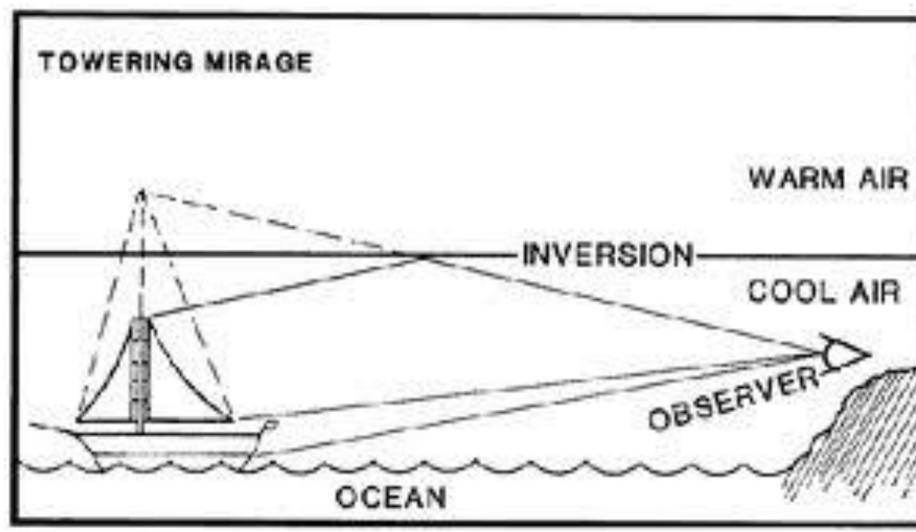

Need to be viewing inside 1$^{o}$ cone or not see mirage

**Inferior Mirage:** Light ray refracts away from ⊥ going from more dense to less dense near surface

## Superior Mirage

## Inferior Mirage

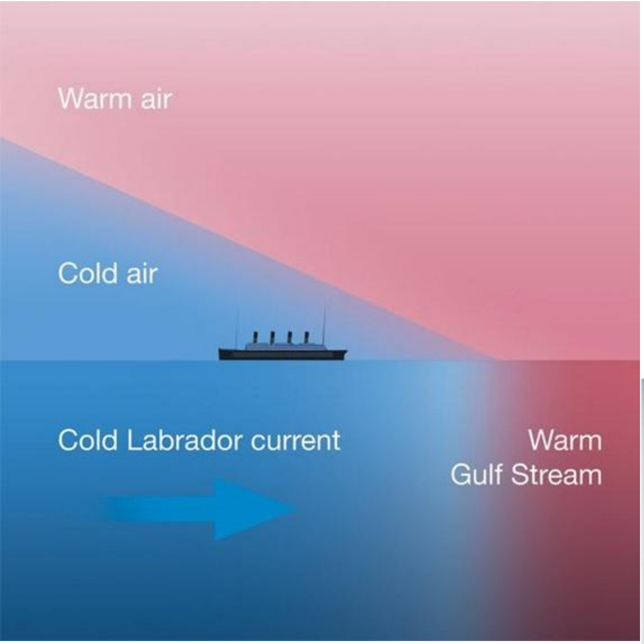



**Demo: Hot plate & laser**

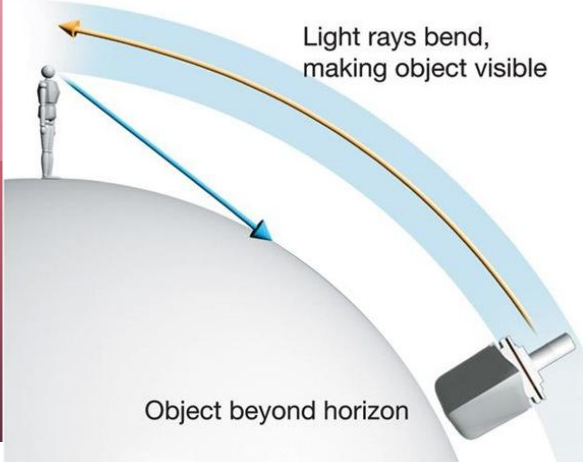
- **Reason stars twinkle due to refraction between different densities of air,**
- **Planets not twinkle because bigger spots of light**

# What caused Titanic to Sink??

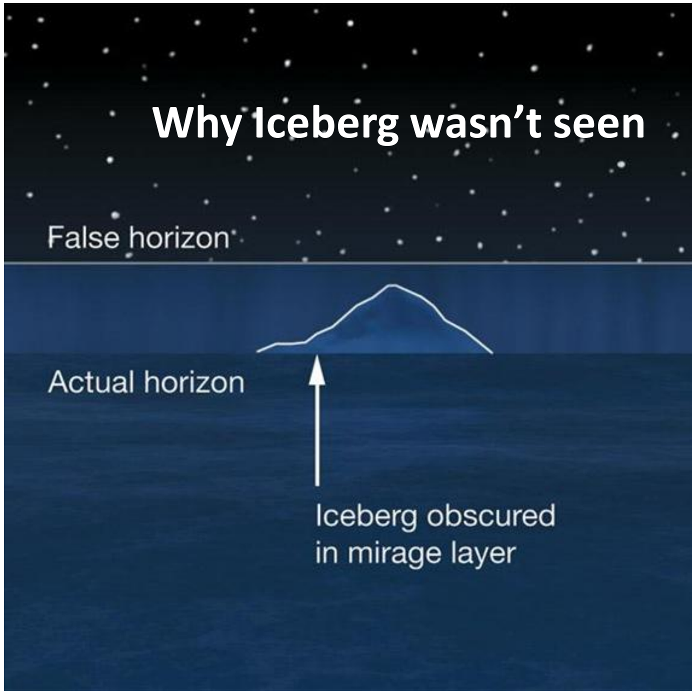



The Titanic was sailing from Gulf Stream waters into the frigid Labrador Current, where the air column was cooling from the bottom up, creating a thermal inversion: layers of cold air below layers of warmer air. Extraordinarily high air pressure kept the air free of fog.

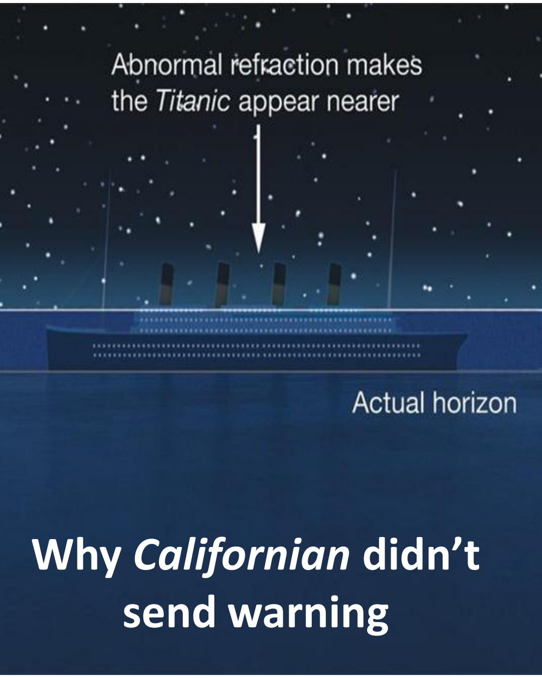
**<u>SUPERIOR MIRAGE</u> due to thermal inversion creates false horizon that hides Iceberg**




A thermal inversion refracts light abnormally and can create a **superior mirage**: Objects appear higher (and therefore nearer) than they actually are, before a false horizon. The area between the false horizon and the true one may appear as haze.

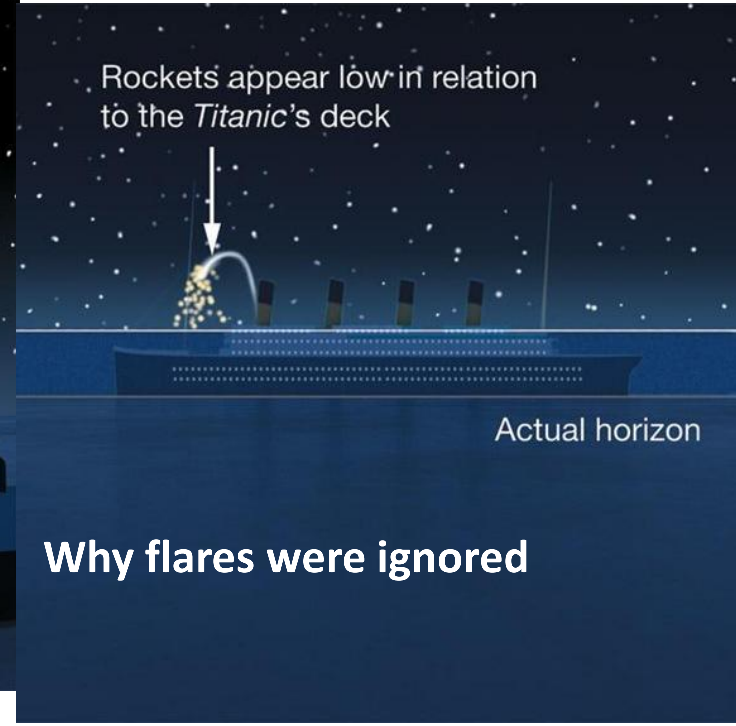



The *Californian*'s radio operator warned the *Titanic* of ice. But the moonless night provided little contrast, and a calm sea masked the line between the true and false horizons, **camouflaging the iceberg**. A *Titanic* lookout sounded the alarm when the berg was about a mile away—too late.




Shortly before the collision, the *Titanic* sailed into the *Californian*'s view—but it **appeared too near and small** to be the great ocean liner. *Californian* captain Stanley Lord knew the *Titanic* was the only other ship in the area with a radio, and so concluded this ship did not have one


Lord said he repeatedly had someone **signal the ship by Morse lamp** "and she did not take the slightest notice of it." The *Titanic*, now in trouble, signaled the *Californian* by Morse lamp, also to no avail. The abnormally stratified air was distorting and disrupting the signals.




The *Titanic* **fired distress rockets some 600 feet into the air**—but they appeared to be much lower relative to the ship. Those aboard the *Californian*, unsure of what they saw, ignored the signals. When the *Titanic* sank, at 2:20 a.m. April 15, they thought the ship might be simply sailing away.

# Pulfrich Effect

- Place 1 dark & 1 light lens over each eye
- Dark lens delays light getting to one eye compare to other so get more depth horizontally
- If swing golf ball like a pendulum appears to rotate CCW & if turn glasses around rotates CW in an elliptical orbit
- Works well for real-life situations
- In movies not much better than red & blue 3DDD & need to be in middle of screen

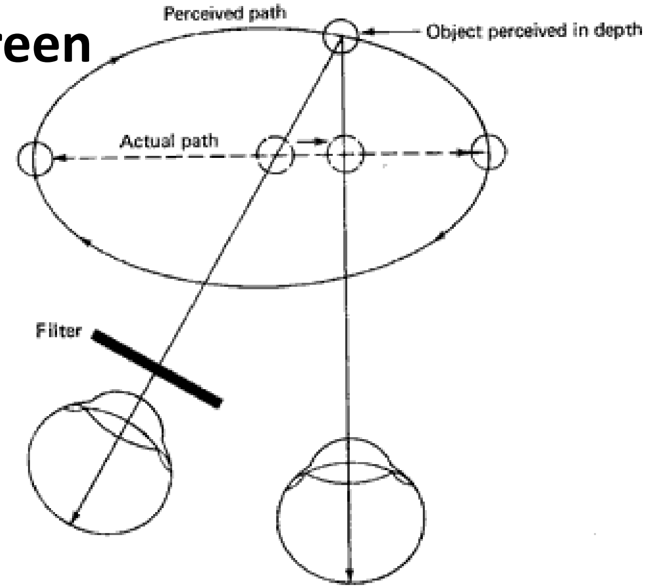
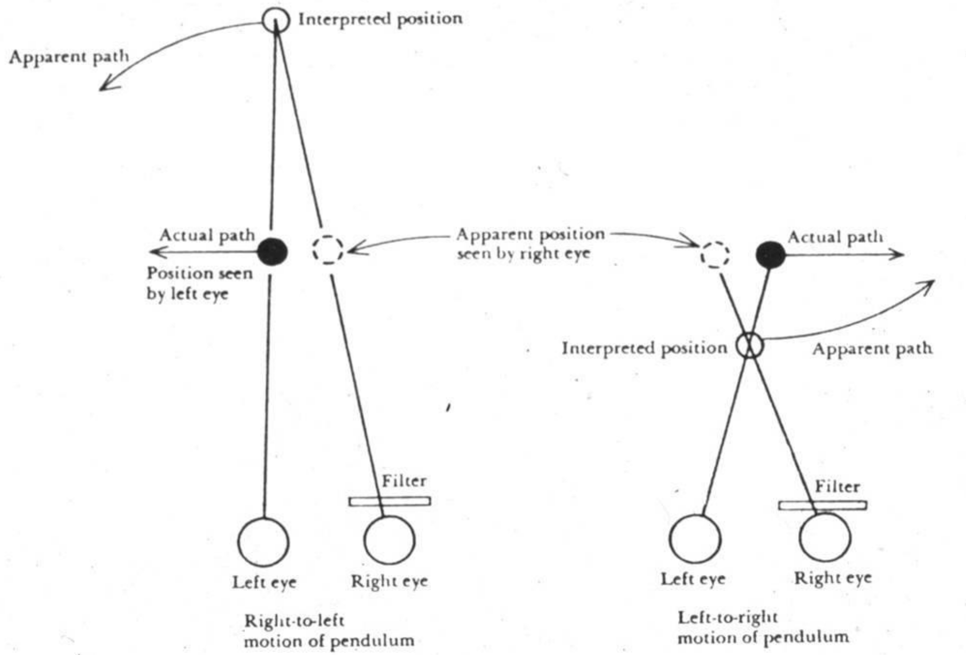



Fig. 13.7. The Pulfrich phenomenon. The attenuated eye perceives the penduli as lagging behind the position as seen by the unattenuated eye. This is consiste the ball actually traveling in an elliptical path, as shown.




**Pulfrich Carousel with glasses (00:01:46)**

http://www.youtube.com/watch?v=1mnWI_u_zBg

**Millennium Force Roller Coaster (00:02:05)**

**https://www.youtube.com/watch?v=To3jujFzwHg&feature=related**

**Hollywood Ex: 3rd Rock w/glasses (00:04:12)**