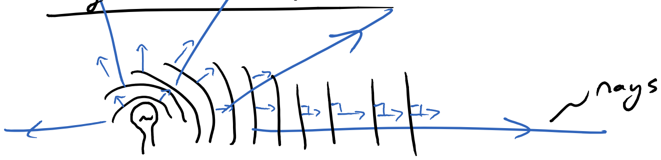
Ray Optics (completed)

Thursday, April 7, 2016 6:24 PM

Ray Model of Light (Geometrical optics)



Assumptions

- light (photons) travel in straight lines.
- two rays can cross undisturbed
- travel until interact w/ matter (reflection, refraction, absorption, scattering) — transmit
- see objects b/c light travels from object to your eye
- eye lens focuses divergent rays on the retina (rods & cones)

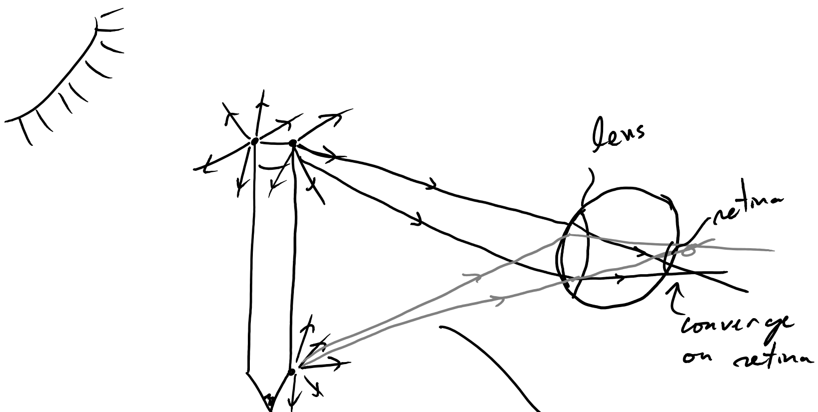
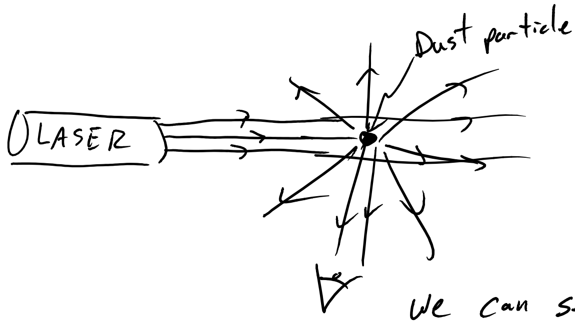


Image on retina is inverted ... but brain corrects.

Ray Diagram - follows a few specific Rays of Interest.

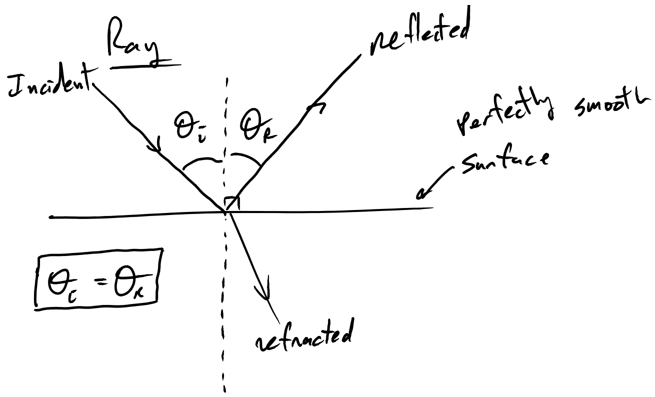
Scattering



We can see the dust (beam) b/c light scattered of it.

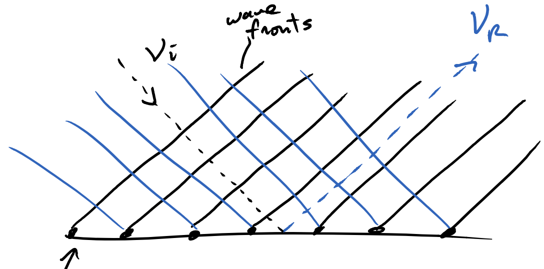
Reflections

Ray



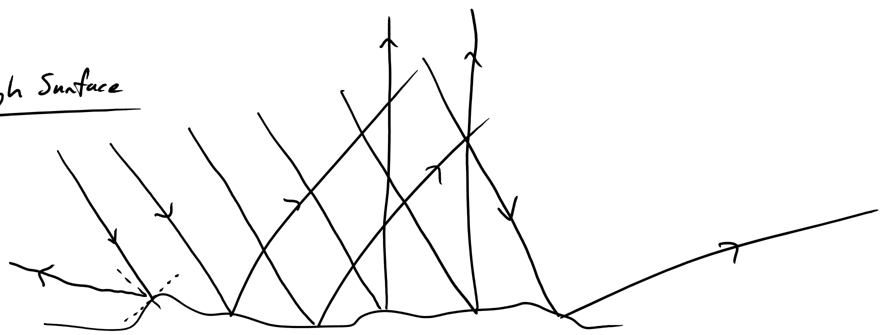
$\boxed{\theta_i = \theta_R}$

Wave model



each point becomes a scattering point

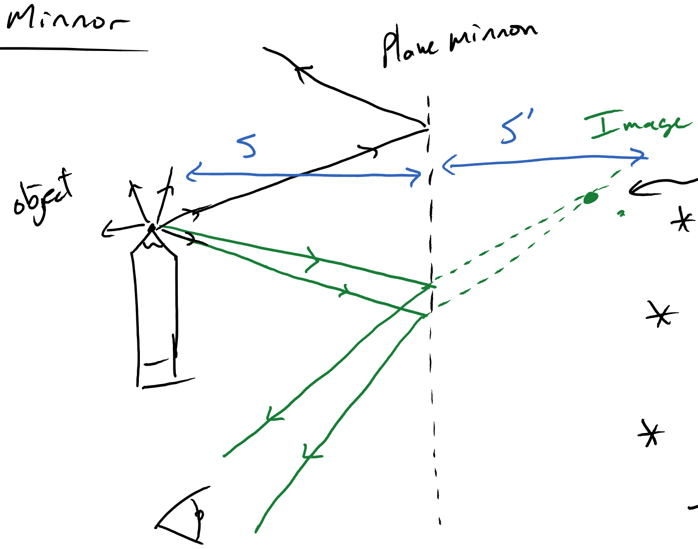
Rough Surface



$\bar{\theta}_r \approx \theta_i$

* Diffuse Reflection (it scatters over a range of directions)

Plane Mirror



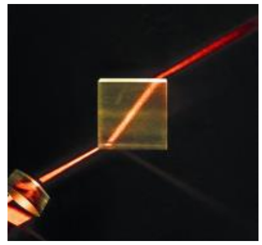
appears the rays diverge

* from this location -- Image

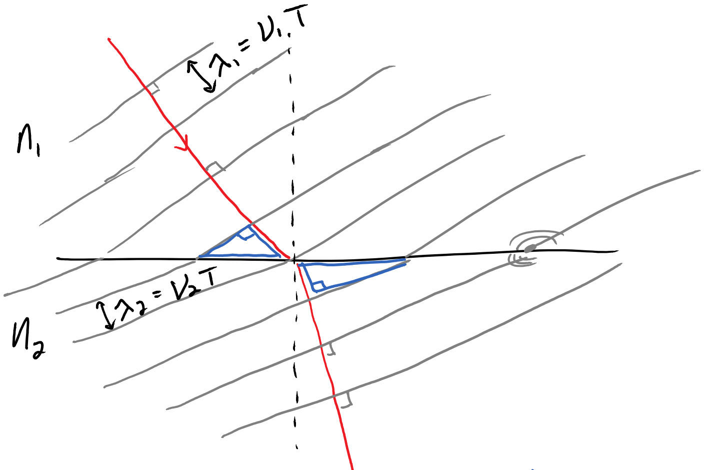
* $\boxed{S = S'}$

* Virtual Image = rays never travel through that location.

Refraction - transmitted Rays



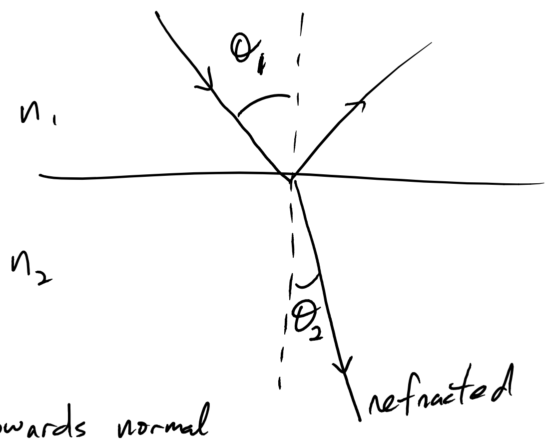
Wave model ($n_2 > n_1$)



* use Blue right triangles to derive Snell's Law

* $n_2 > n_1$ then $\lambda_1 > \lambda_2$ b/c speed changes

Ray Model



Snell's Law

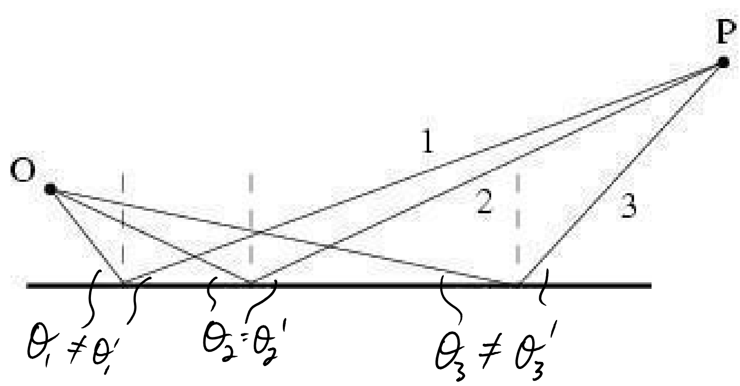
$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$

* if $n_1 < n_2$, ray defracts towards normal

* if $n_1 > n_2$, " " away " "

Rays of light travel from an object O to an observer at P via a reflecting surface. Which of the three paths provides the shortest path from O to P?

1. **Path 1**
2. **Path 2**
3. **Path 3**
4. **All three are the same**
5. **The answer depends on the roughness of the surface**



Light enters horizontally into the combination of two perpendicular mirrors as shown below. Indicate the direction of the incident light after it reflects off of both mirrors.

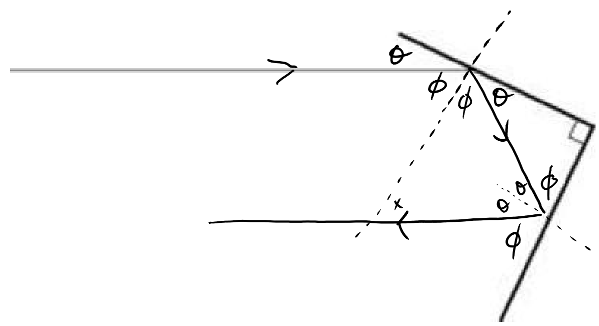
$\theta + \phi = 90^\circ$

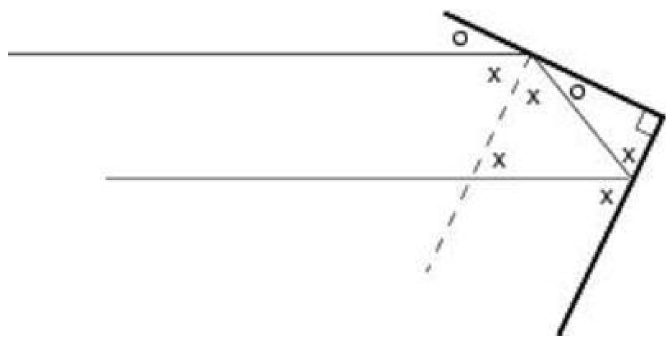
$\phi + 2\theta + x = 180$

$\phi + 2(90 - \phi) + x = 180$

$\phi + \cancel{180} - 2\phi + x\ \cancel{180}$

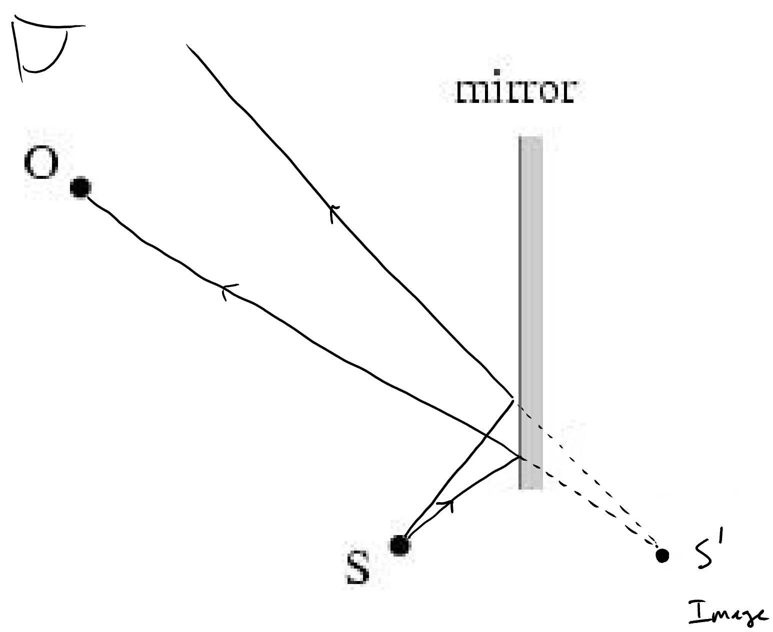
$\phi = x$





The angles marked "o" and "x" add up to 90º, the back reflected beam is parallel to the incident one. See figure.

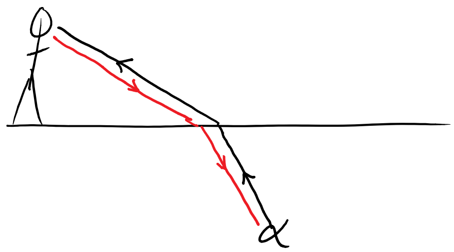
An observer O, facing a mirror, observes a light source S. Where does O perceive the mirror image of S to be located?



If you are attempting to cook the fish with a high power laser, while it's still in the water, where should you aim the laser?

1. **Directly at the fish**
2. **In front of the fish (closer to you)**
3. **Beyond the fish (further from you)**
4. **In the opposite direction of fish from you**

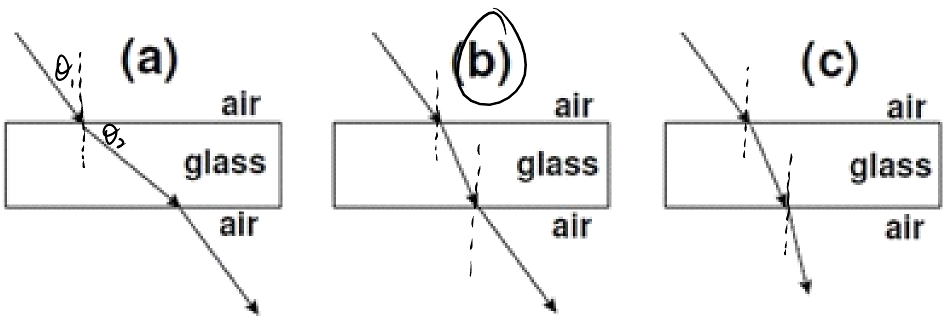
light from fish → you bends just like the laser from you → fish



If you are attempting to spear a fish with an arrow where should you aim?

Arrow does not bend ... aim in front

Which of these ray diagrams are possible?



$n_{glass} > n_{air}$

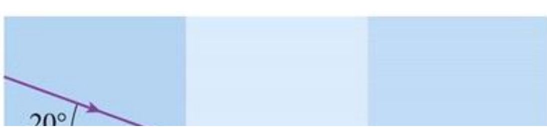
Snell's $n_1 \sin\theta_1 = n_2 \sin\theta_2$, if $n_2 > n_1$ ... bend towards Normal

b+c ok @ 1st interface

... but c bends again towards Normal @ 2nd Interface ... Not possible

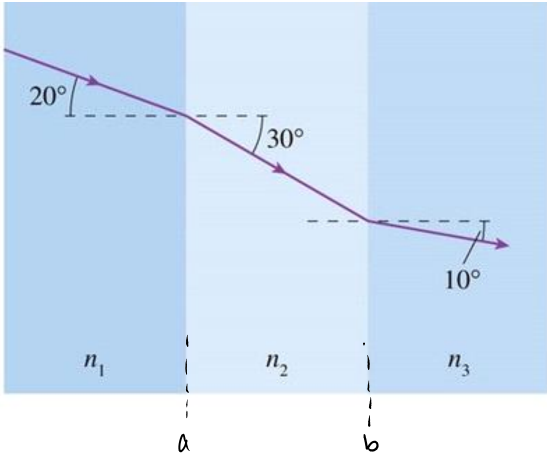
So $\boxed{\text{b possible}}$

Rank the following mediums based on index of refraction.



(0) bends away, so $n_2 < n_1$

(1) " " ...



(a) bends away, so $n_2 < n_1$

(b) " " towards, so $n_3 > n_2$

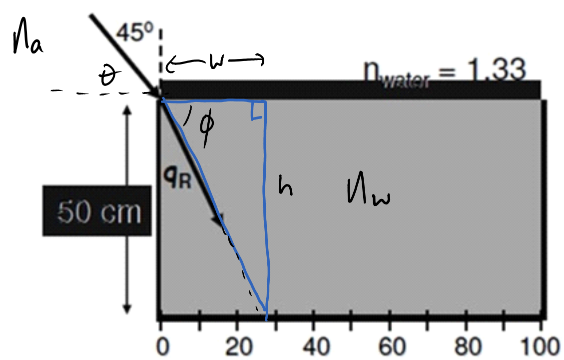
How about n_3 vs. n_1 ?

Bend is greater @ b than a

So $n_3 > n_1$

$\boxed{n_3 > n_1 > n_2}$

A meter stick lies at the bottom of a 50-cm-high water tank. If you're looking at the tank at an angle of 45°, what is the smallest length on the ruler you can see?



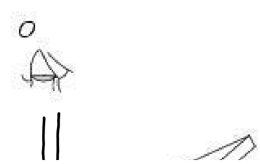
Snell $\overset{1}{\cancel{n_a}} \sin\theta = n_w \sin\phi \Rightarrow \phi = 32.12°$

Geometry $\tan\phi = \frac{h}{w} \Rightarrow w = 0.796\,m$

Incorrect picture

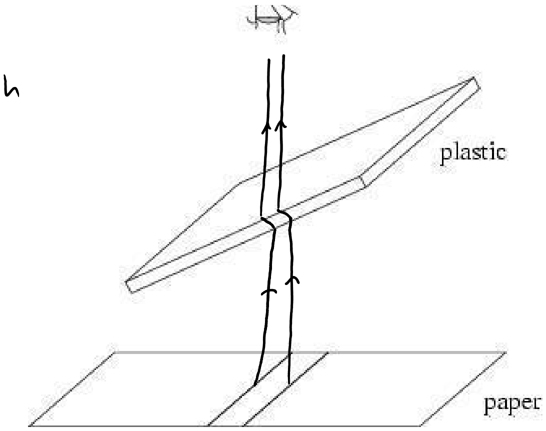
The observer at *O* views two closely spaced lines through an angled piece of plastic. To the observer, the lines appear (choose all that apply)

1. **shifted to the right.**
2. **shifted to the left.**
3. **spaced farther apart.** } same shift for both



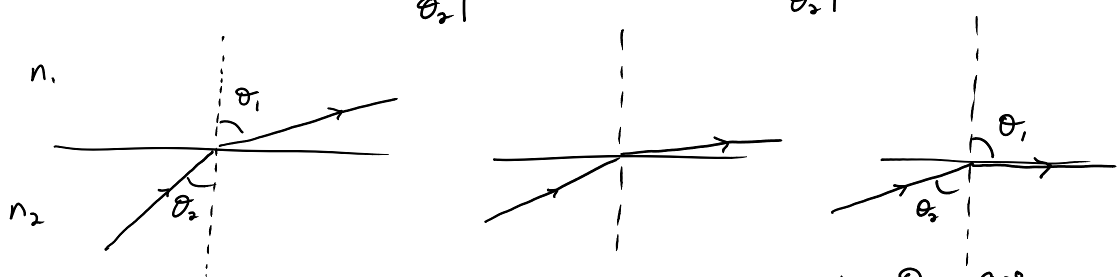
1. shifted to the right.
2. shifted to the left.
3. spaced farther apart.
4. spaced closer together.
5. exactly as they do without the piece of plastic.

} same shift for both lines



Total Internal Reflection (TIR)

$n_1 < n_2$



* when $\theta_1 \to 90°$ ...
$\theta_2 = \theta_{critical}$

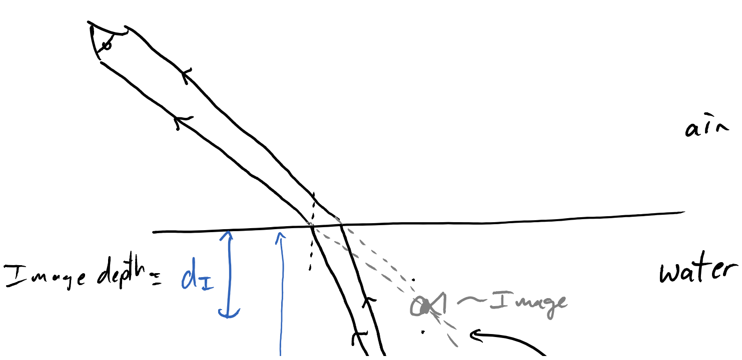
Critical Angle

$$n_1 \sin \cancel{\theta_1}^{90°} = n_2 \sin \cancel{\theta_2}^{\theta_c} \Rightarrow \boxed{\sin \theta_c = \frac{n_1}{n_2}}$$

from 2 → 1

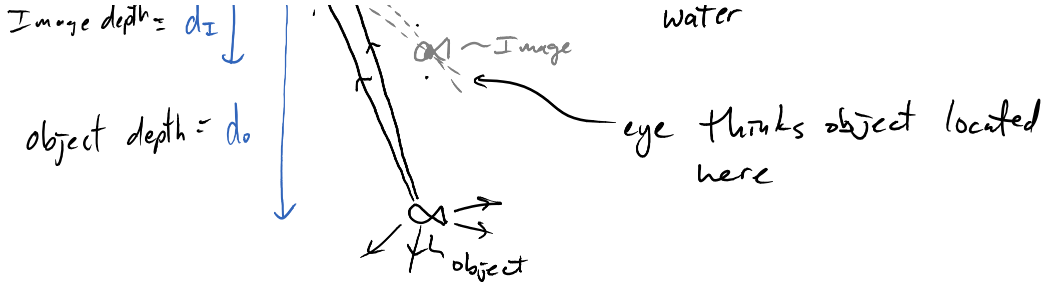
TIR

Apparent Depth



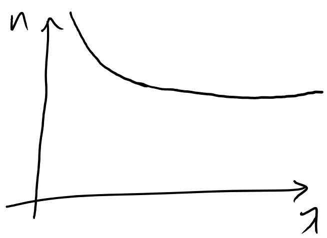
Features Image

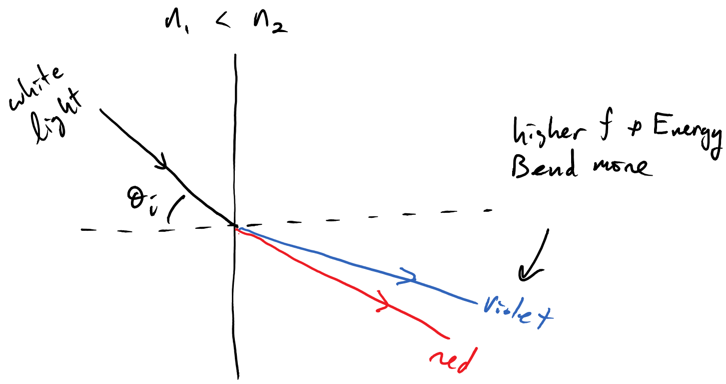
* virtual Image
* Bigger
* upright



Dispersion - spread out colors

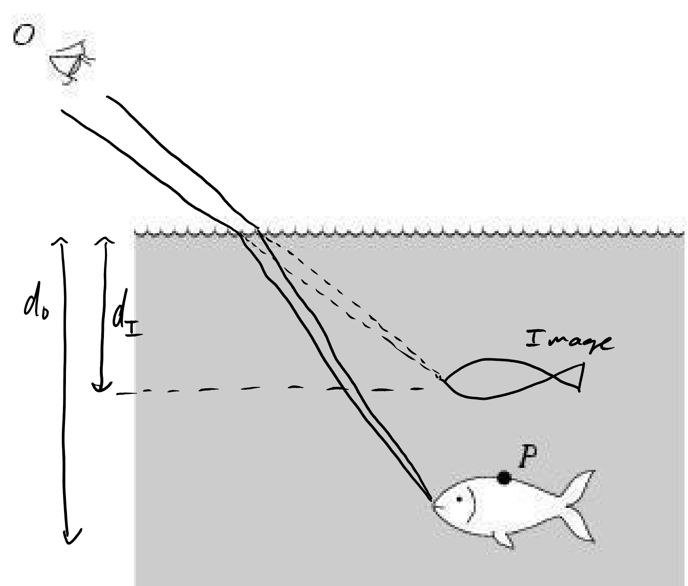
* different λ's travel w/ slightly different v_{eff} & thus n is dependent on λ





A fish swims below the surface of the water at *P*. An observer at *O* sees the fish at

1. **a greater depth than it really is.**
2. **the same depth.**
3. **a smaller depth than it really is.**



Mark the location.

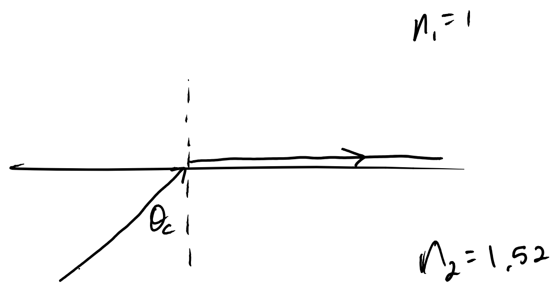
Image

* Virtual
* Upright
* Bigger (looks closer)

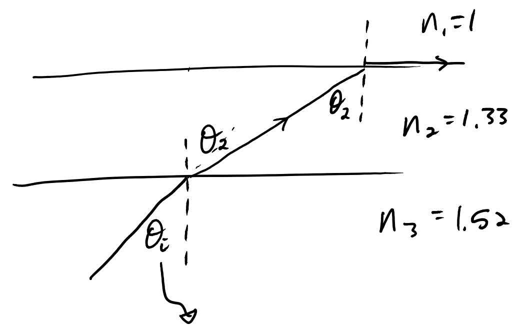
A ray directed at a glass–air interface undergoes total internal reflection at the critical angle. Suppose a layer of water is poured on top of the glass. (Water has an index of refraction between that of glass and air.) Which of the following happens?

1. **The ray is still totally internally reflected at the glass interface.**
2. **The ray is now totally internally reflected at the water–air interface.**
3. **The ray is no longer totally internally reflected anywhere.**
4. **The answer depends on the angle of incidence on the glass–water interface.**

CASE A



CASE B



ex. $\boxed{2\to1}$ $n_1 = 1$ $n_2 = 1.52$

$\sin\theta_c = \frac{n_1}{n_2} \Rightarrow \theta_c = 41.14° \equiv \theta_i$

Compare $\sin\theta_c = \frac{n_1}{n_2}$

if $\frac{n_1}{n_2}\uparrow$, $\theta_c \uparrow$

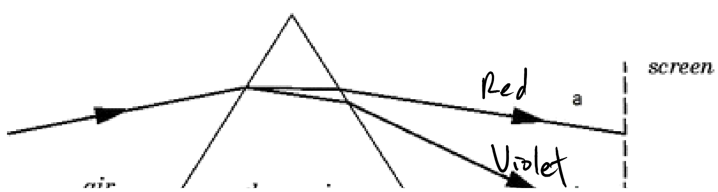
$\boxed{3\to2}$ $n_3 \sin\theta_3 = n_2 \sin\theta_2$

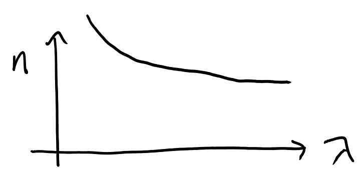
$\theta_2 = 48.75$

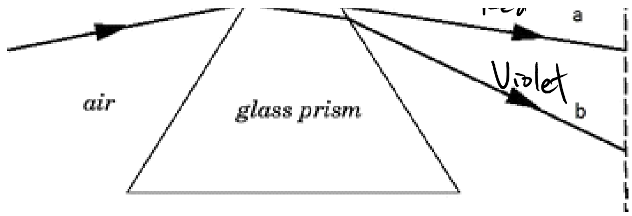
$\boxed{2\to1}$ $\underbrace{n_2 \sin\theta_2}_{1} = n_1 \sin\theta_1$

so $\theta_1 = 90°$

White light enters a glass prism. When the light leaves the prism, the colors have been separated. Match each ray with their color, red or violet.







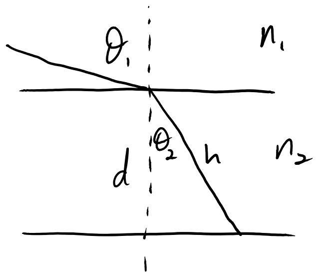
$\longrightarrow \lambda$

if $n\downarrow$, than deflection $\downarrow$

$n_{Red} < n_{Violet}$, so Red deflects less

Light with a wavelength of 569 nm in a vacuum strikes the surface of an unknown liquid at an angle of 31.2° with respect to the normal to the surface. If the light travels at an effective speed of 1.97 x 10^8 m/s through the 10-m-deep liquid, how long does it take for the light to travel from the surface to the bottom?

1. **11 ns**
2. **29 ns**
3. **32 ns**
4. **42 ns**
5. **54 ns** ✓
6. **101 ns**



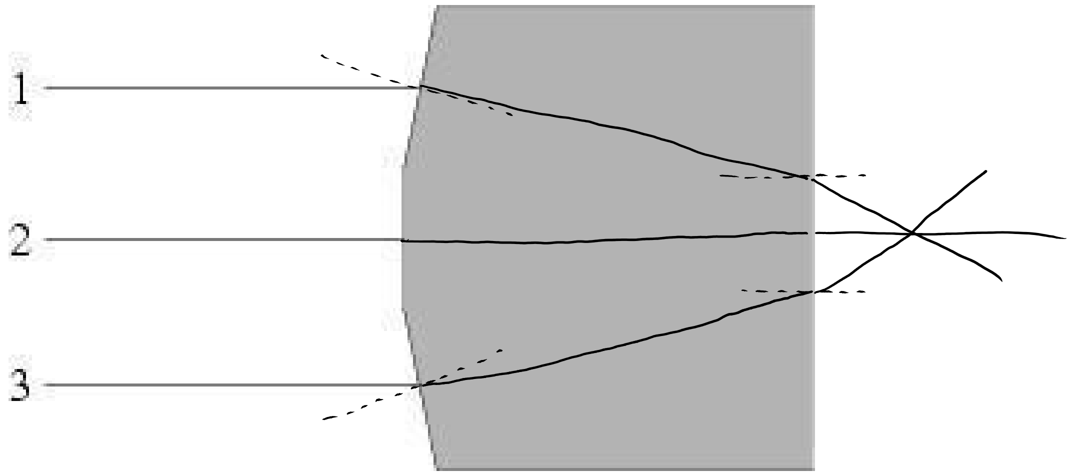
$n_2 = \frac{c}{v} = 1.523$

$n_1 \sin\theta_1 = n_2 \sin\theta_2 \Rightarrow \theta_2 = 19.9^\circ$

Now $h = \frac{d}{\cos\theta} = 10.63\,m$

$\Delta t = \frac{\Delta x}{v} = 5.4\times10^{-8}\,s$

Three parallel rays of light travel to the faceted piece of glass shown below. Sketch the path of each ray as they travel through the glass.



* form of a simple lens
  * lenses Converge / Diverge light
    * lensing effect just Snell's Law + Geometry

If the frequency of the light is decreased what happens to the point where the rays converge?

1. **moves left**
2. **moves right**
3. **stays at the same location**

if f↓ then λ↑ + n↓

if n↓ deflect less

So Converges further right

Ray Tracing for Converging Thin Lens

Three special rays used to find the location of the image

1. **Parallel to the optical axis (table) refracts through far focal point**
2. **Through near focal point, refracts parallel to the optical axis**
3. **Straight line through center of optic element**

Ray Tracing for Diverging Thin Lens

Three special rays used to find the location of the image

|| to axis refract as if near focal

1. **Parallel to the optical axis refracts through as if came from near focal point**
2. **Towards far focal point, refracts parallel to the optical axis**
3. **Straight line through center of optic element**

Thin lens Equation: Both lens + Spherical Mirrors

$$\boxed{\frac{1}{d_o} + \frac{1}{d_I} = \frac{1}{f}}$$

object distance — Image Dist — focal length

Sign Conventions

ex. focal length
~~Converg.~~ (+)
Diverg. (-)

Image dist.

* if d_I (+) then its on far side of lens ... (real)
* " " (-) " " near " " " ... (virtual)

Sign Convention for Spherical Mirrors and Thin Lenses

Applies to: Mirror and Thin Lens Equation: $1/d_o + 1/d_i = 1/f$

Magnification Equation: Image height/Object height = $h_i/h_o = -d_i/d_o$

	Spherical Mirrors	**Lenses**
Focal Length (f)	+ for concave mirrors	+ for a converging lens
	- for convex mirrors	- for a diverging lens
Object Distance (d_o)	+ if object is in front of the mirror (real object)	+ if the object is to the left of the lens (real object)
	- if object is behind the mirror (virtual object)*	- if the object is to the right of the lens (virtual object)*
Image Distance (d_i)	+ if the image is in front of the mirror (real image)	+ for an image (real) formed to the right of the lens by a real object
	- if the image is behind the mirror (virtual image)	- for an image (virtual) formed to the left of the lens by a real object
Magnification (m)	+ for an image that is upright with respect to the object	+ for an image that is upright with respect to the object
	- for an image that is inverted with respect to the object	-for an image that is inverted with respect to the object.

* Optical system that use multiple mirrors/lenses sometimes use the image formed by the first mirror/lens as the object for the second mirror/lens. When this happens, the object distance is negative and the object is said to be a virtual object.

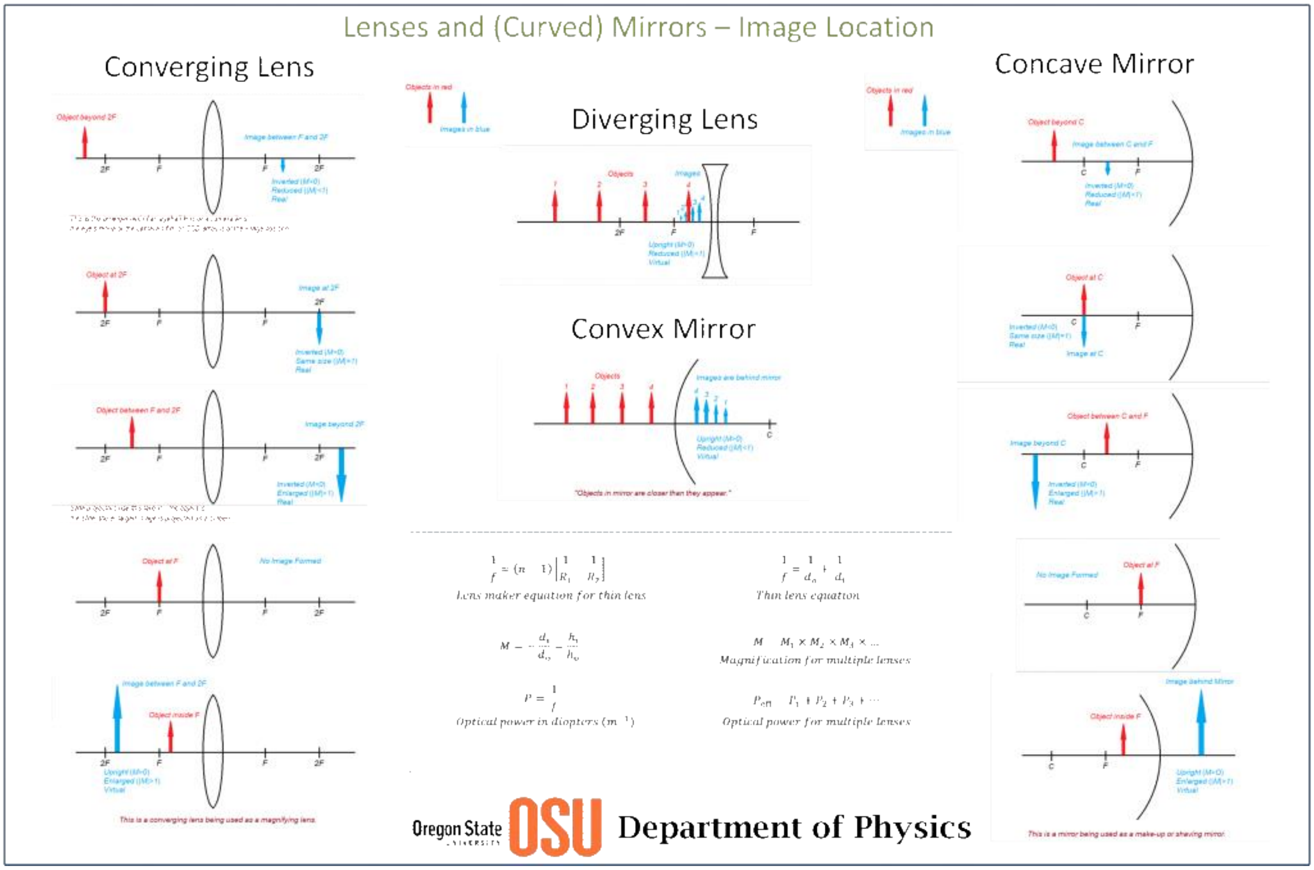
Magnification

$$\boxed{m \equiv \frac{h_I}{h_o} = -\frac{d_I}{d_o}}$$

Rules

if $|m| > 1$ Image larger
" $|m| < 1$ " " smaller

if m (+) upright
" m (-) Inverted



A light ray can change direction when going from one material into another. This phenomenon is known as

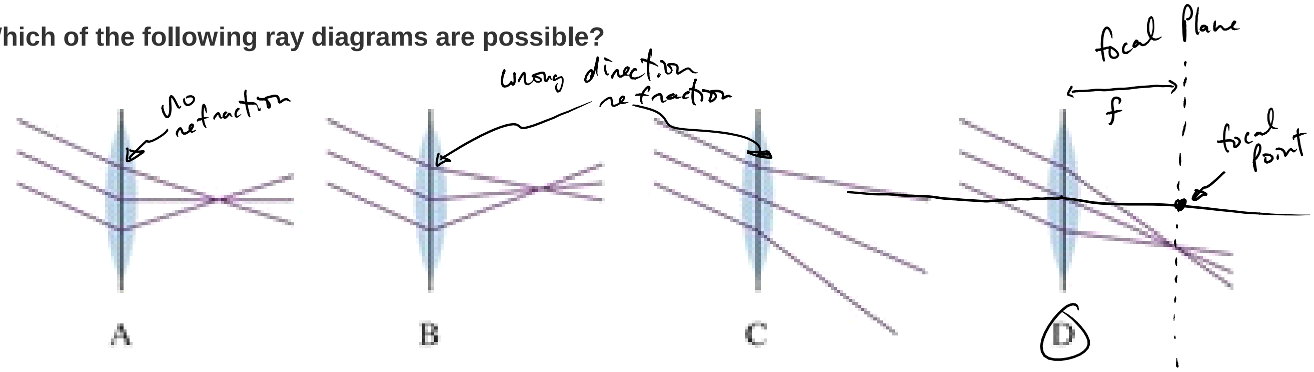
1. **reflection.**
2. **absorption.**
3. **refraction.**
4. **scattering.**
5. **transference.**
6. **diffraction.**
7. **diffusion.**

What is the focal point?

1. **The place the rays converge** → place ray // to optical axis will converge
2. **The place the rays appear to converge**
3. **The location where a screen could be placed to show a focused image**
4. **The radius of curvature of the lens**
5. **None of the above**

Which of the following ray diagrams are possible? a 0 Plane

Which of the following ray diagrams are possible?

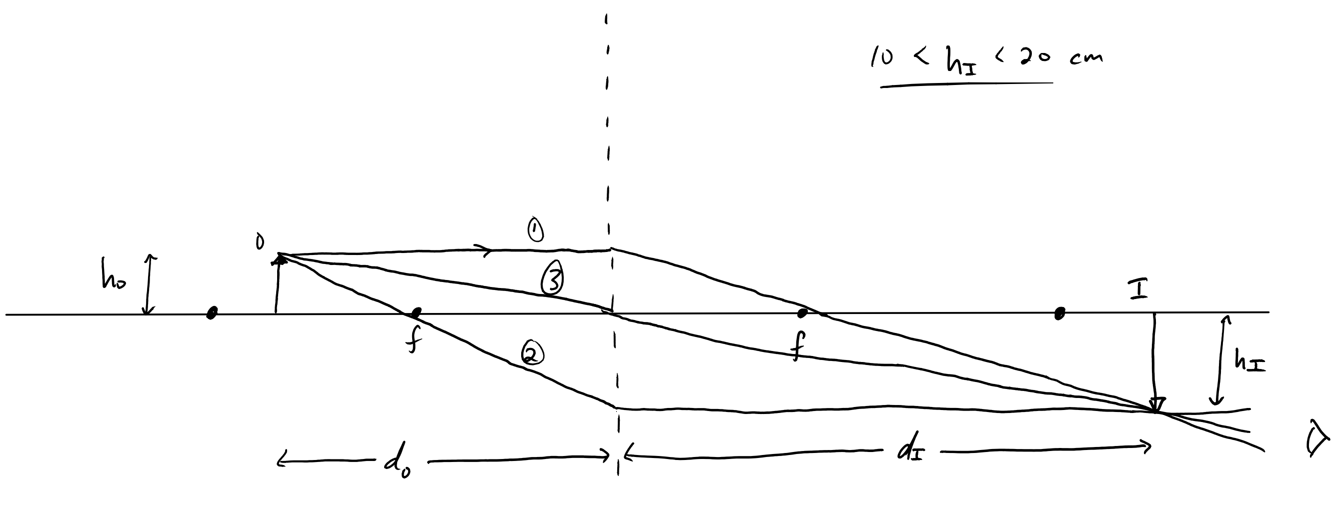


Is the image produced from an object outside the focal length of a converging lens real or virtual?

1. real
2. virtual
3. simultaneously both real and virtual
4. no way of telling
5. Swimming hole

A 10-cm-tall object is located 50.0 cm to the left of a converging lens whose focal length is 30.0 cm. Estimate the height of the image by using a carefully constructed ray diagram? Answer in centimeters.

$10 < h_I < 20$ cm



Calculate the location of the image.

Convention: Converging lens
$f(+)$, $d_o(+)$

$$\frac{1}{d_I} + \frac{1}{d_o} = \frac{1}{f}$$

So, $\frac{1}{d_I} + \frac{1}{50cm} = \frac{1}{30cm} \Rightarrow \underline{d_I = 75cm}$

since (+) Image is on opposite side & is real

$$m = -\frac{d_I}{d_o} = -\frac{75}{50} = \underline{-1.5}$$

Inverted Image

So $h_I = m h_o = \underline{-15cm}$

An object in placed a distance d_o from a converging lens of focal length f. Circle the expression that correctly solves for the distance to the image?

$$\frac{1}{d_o} + \frac{1}{d_I} = \frac{1}{f}$$

$$\frac{1}{d_I} = \frac{1}{f} - \frac{1}{d_o}$$

Invert $d_I = \left[\frac{1}{f} - \frac{1}{d_o}\right]^{-1}$

$$d_i = f - d_o$$

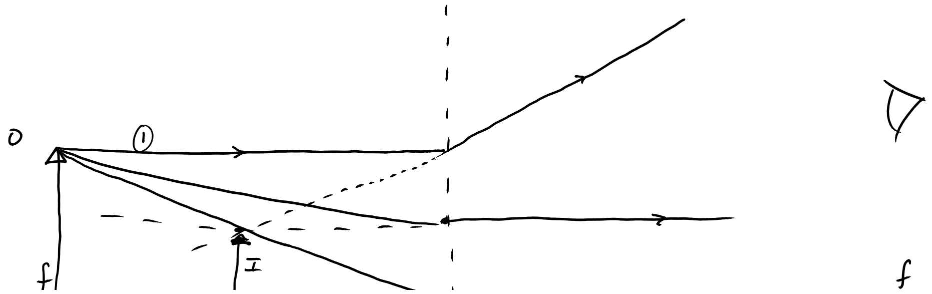
$$d_i = \frac{1-f}{d_o}$$

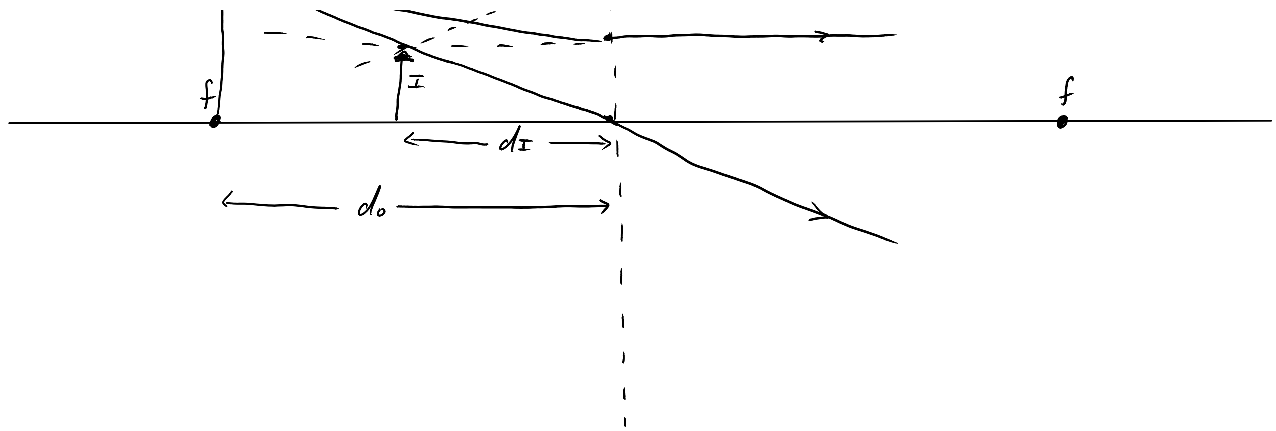
$$d_i = (f - d_o)^{-1}$$

$$d_i = \frac{1}{f} - \frac{1}{d_o}$$

$$d_i = \left(\frac{1}{f} - \frac{1}{d_o}\right)^{-1}$$

If an object is placed at the focal point of a diverging lens, estimate the magnification of the image using a carefully drawn ray diagram.





What is the image distance, in terms of *f* the focal length?

Convention: Diverging lens
$f(-)$, $d_o(+)$

$$\frac{1}{d_o} + \frac{1}{d_I} = \frac{1}{f} \Rightarrow \frac{1}{(+f)} + \frac{1}{d_I} = \frac{1}{(-f)}$$

$$\frac{1}{d_I} = -2\frac{1}{f} \Rightarrow d_I = -\frac{1}{2}f$$

same side + virtual

$$M = -\frac{d_I}{d_o} = -\frac{(-\frac{1}{2}f)}{f} = +\frac{1}{2}$$

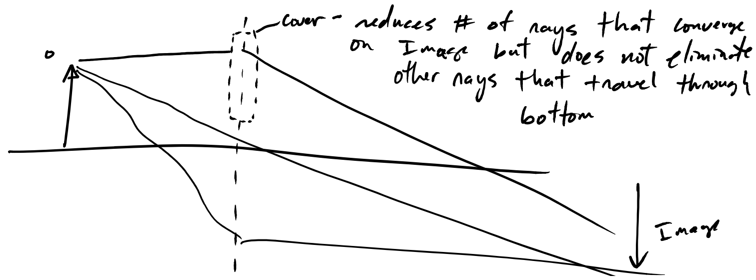
upright + smaller

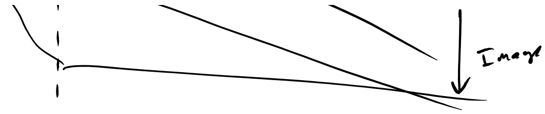
Is the image produced from an object within the focal length of diverging lens real or virtual?

1. real
2. virtual
3. simultaneously both real and virtual
4. no way of telling

A lens is used to image an object onto a screen. If the right half of the lens is covered,

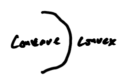
1. the left half of the image disappears.
2. the right half of the image disappears.
3. the entire image disappears.
4. the image becomes blurred.
5. the image becomes fainter.





+ reduces Intensity but preserves Image

Ray Tracing for a Concave Mirror



Three special rays used to find the location of the image

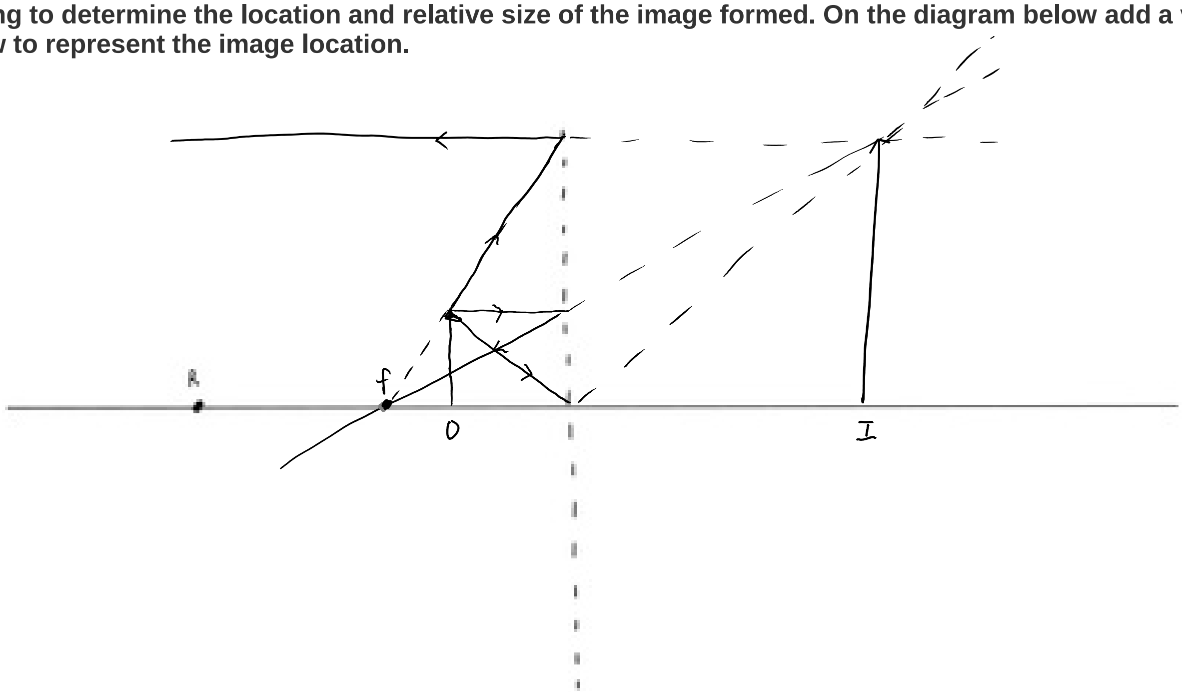
1. Parallel to the optical axis reflects through focal point
2. Ray through or from *(depending if inside or outside the focal point)* focal point, reflects parallel
3. Straight line through or from *(depending if inside or outside the focal point)* center of curvature, reflects back on itself

Ray Tracing for a Convex Mirror

Three special rays used to find the location of the image

1. Parallel to the optical axis reflects as if came from focal point
2. Heads towards the focal point, reflects parallel
3. Straight line towards center of curvature reflects back itself

A gigantic funhouse mirror has a 20 ft radius of curvature and you are standing 6 ft in front of it. Use ray tracing to determine the location and relative size of the image formed. On the diagram below add a vertical arrow to represent the image location.



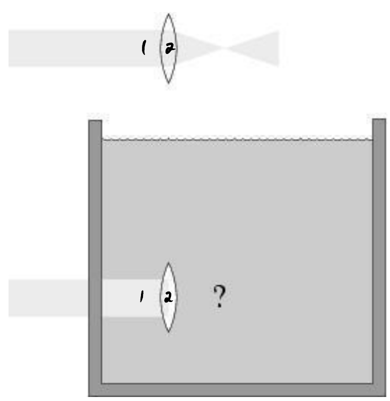
$d_I = \left(\frac{1}{f} - \frac{1}{d_o}\right)^{-1} = \left(\frac{1}{10} - \frac{1}{6}\right)^{-1} = -15$ ft , $M = -\frac{d_I}{d_o} = -\left(\frac{-15}{6}\right) = +2.5$

You are given a converging lens, a diverging lens, a converging mirror, and a diverging mirror. Neglecting combinations, using which of those four can you project an image of a pencil on a screen? Choose all that apply.

1. **A converging lens** – if $d_o > f$
2. **A diverging lens**
3. **A converging mirror** – if $d_o > f$
4. **A diverging mirror**

A parallel beam of light is sent through an aquarium. If a convex glass lens is held in the water, it focuses the beam

1. **closer to the lens than**
2. **at the same position as**
3. **farther from the lens than**



lens effect from refraction

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

air → glass

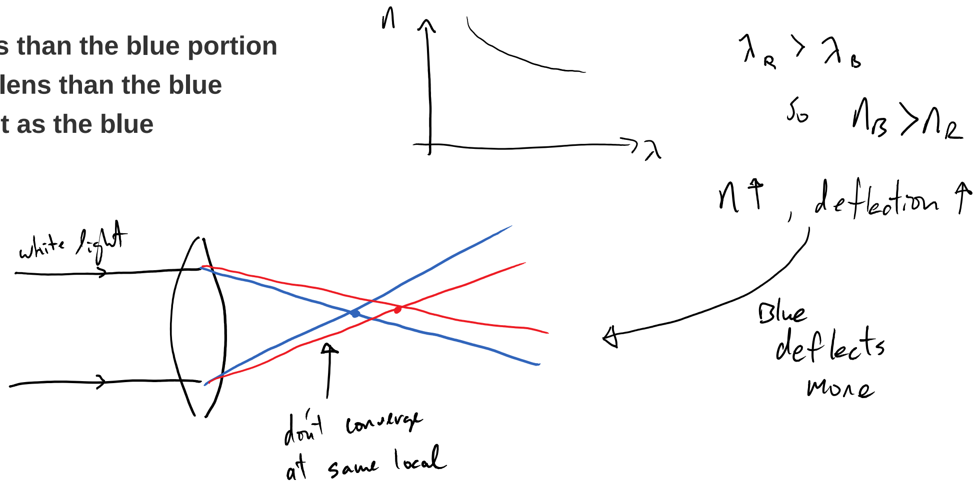
vs.

water → glass

$$\frac{n_g}{n_a} > \frac{n_g}{n_w} \quad \text{so} \quad \theta_w < \theta_a$$

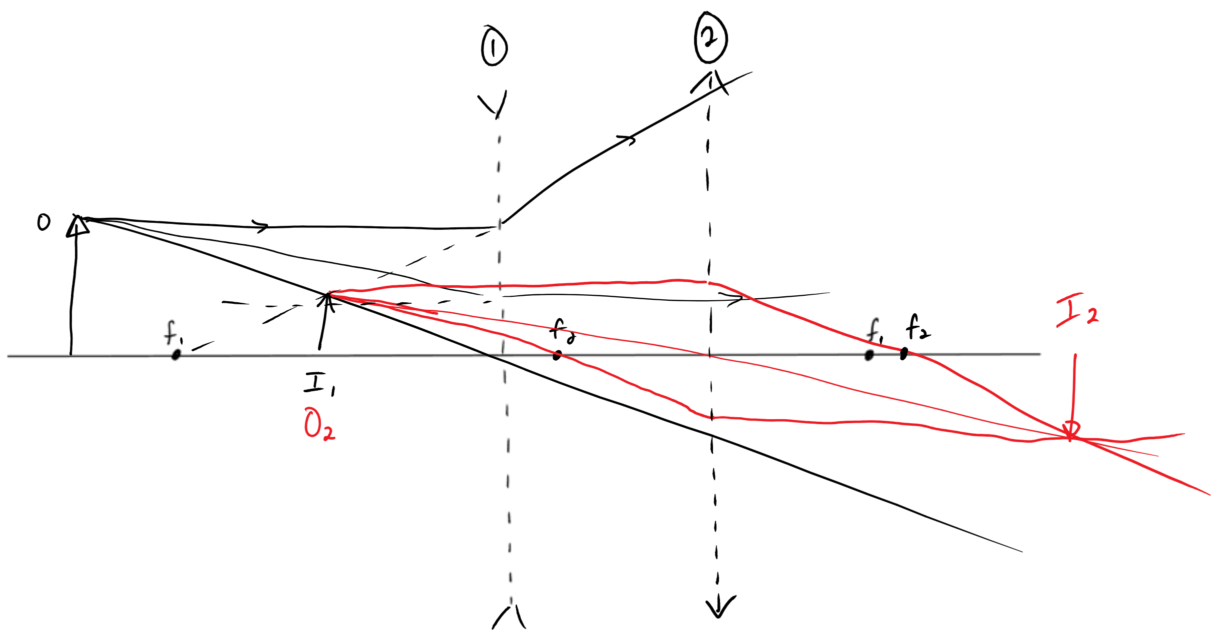
If a beam of white light falls on a converging lens made of ordinary glass, the red portion of light will be focused

1. **Closer to the lens than the blue portion**
2. **Farther from the lens than the blue**
3. **At the same point as the blue**



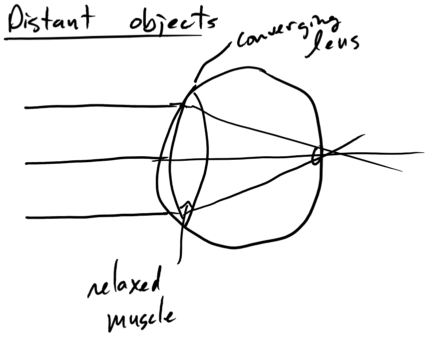
In a combination of two optics elements, would it be possible to use the second element to make a real image of a virtual image formed by the first lens?

1. **No, it is not possible.**
2. **Yes, it is possible.**

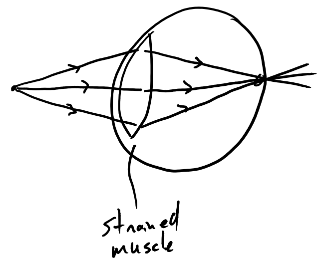


Eye is an optic element

Distant objects

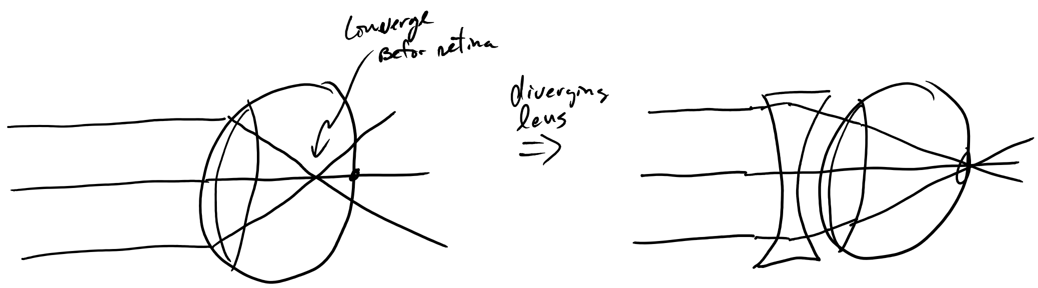


Near Objects

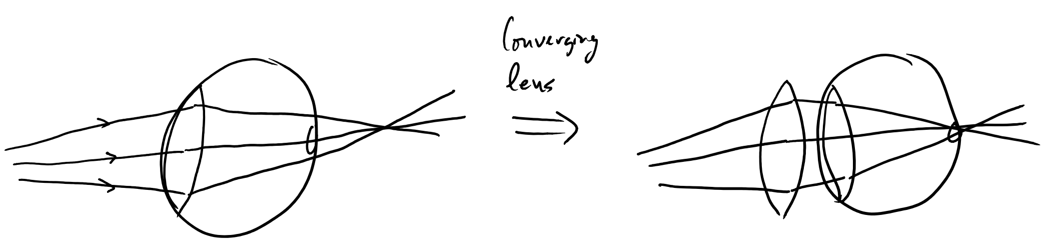


Corrective lens

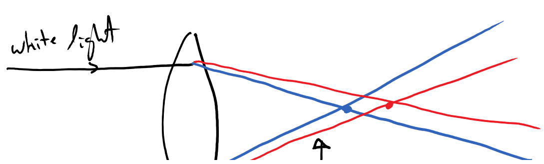
Near Sighted (Myopic)



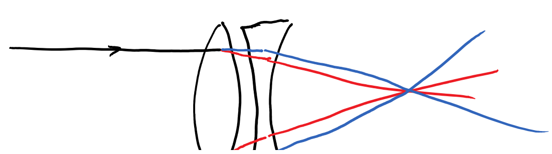
Far Sighted (hyperopic)

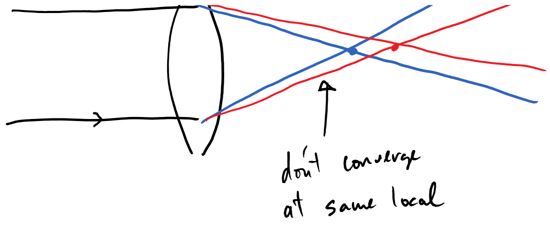


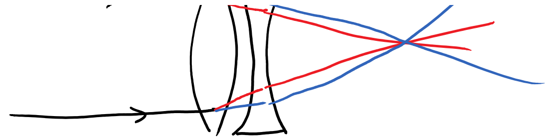
Chromatic Abboration (Dispersion)



Acromatic lens (corrective lens)





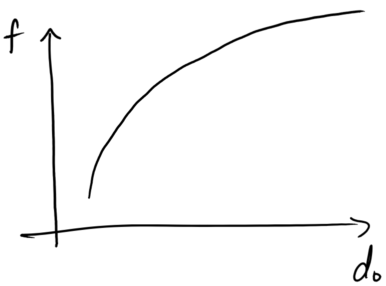


When your eye focuses on something far away, the lens in the eye has a radius of curvature *R*. What is the radius of curvature when you focus on something at your eye's near point? (The near point is the minimum distance from your eye for an object to be in focus.)

1. **It is still *R*.**
2. **It is less than *R*.**
3. **It is greater than *R*.**

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_I} \Rightarrow f = \left(\frac{1}{d_o} + \frac{1}{d_I}\right)^{-1}$$

d_I for eye needs to be const.



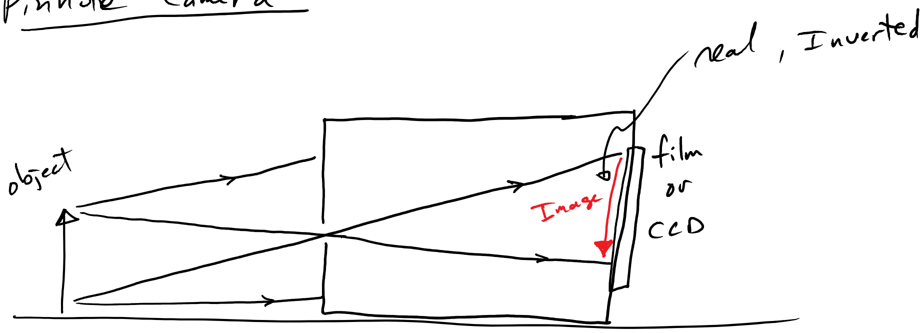
if $d_o \downarrow$, $\frac{1}{d_o} \uparrow$

+ so does $\frac{1}{d_o} + \frac{1}{d_I}$ if

if $\frac{1}{d_o} + \frac{1}{d_I} \uparrow$, $\frac{1}{\frac{1}{d_o} + \frac{1}{d_I}} \downarrow$

+ so does f ... f + $R \downarrow$

Pinhole Camera



* smaller hole, the sharper Image
* but... less intensity
* and... too small Interference effects arise