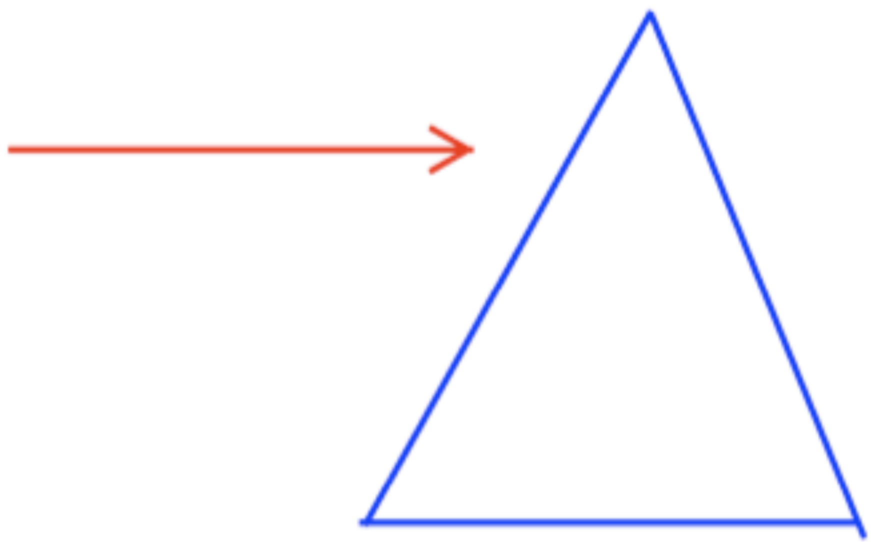
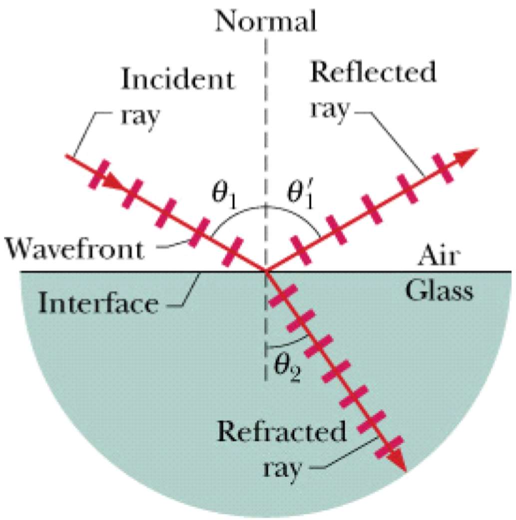
What will happen to the ray when it travels through the prism?



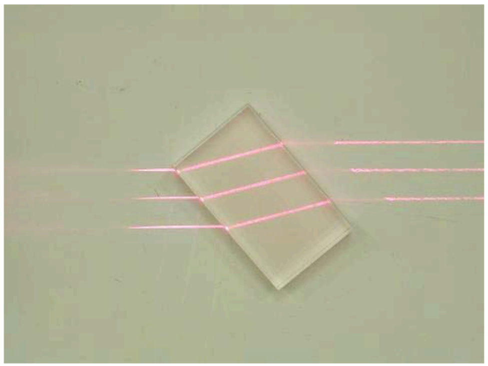
1. It does not bend
2. It bends away from the base
3. It bends toward the base
4. Could be any of the three above answers

Reflection: **Bouncing back of light that is incident on a surface.**

Refraction: **The bending light as it travels between two different media.**



(b)



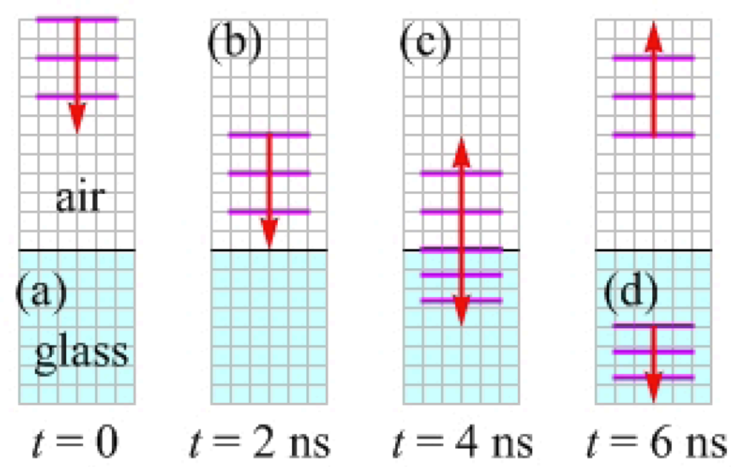
Index of refraction

When light travels from one medium to another, the speed and wavelength change, but the frequency remains the same. The index of refraction can be stated in terms of wavelength.

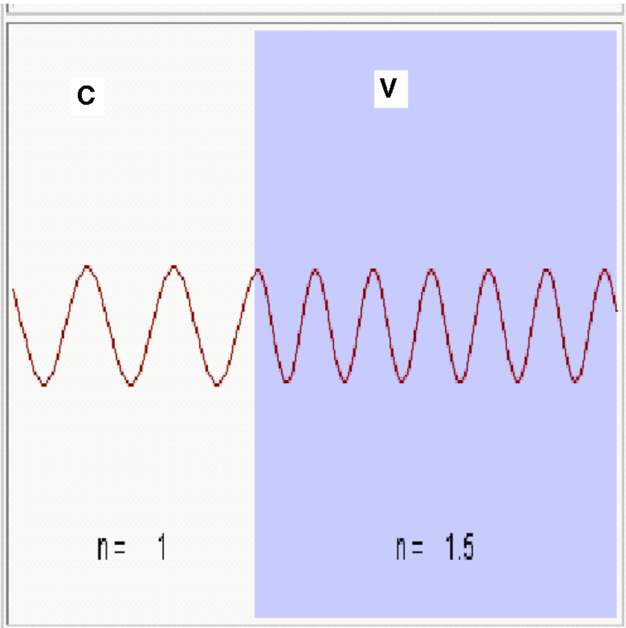
$$\text{index of refraction: } n = \frac{c}{v} = \frac{f\lambda}{f\lambda'} = \frac{\lambda}{\lambda'}$$

λ = wavelength in vacuum,

λ' = wavelength in the medium.



Light in a medium



In vacuum	In medium
c – speed of light	v – speed of light; $v < c$
λ – wavelength	λ_n – wavelength; $\lambda_n < \lambda$
f – frequency	f – frequency (<u>the same</u>!)
$c = \lambda f$	$v = \lambda_n f$
	n – index of refraction
	$n = c/v$
	$\lambda_n = \lambda/n$

Sample values of *n*

Medium	Index of refraction	Speed of light ($\times 10^8$ m/s)
Vacuum	1.000	3.00
Water	1.33	2.25
Glass	1.5	2.0
Diamond	2.4	1.25

n is ...

1. Always = or > 1
2. Could be > 1 or < 1
3. Always < 1

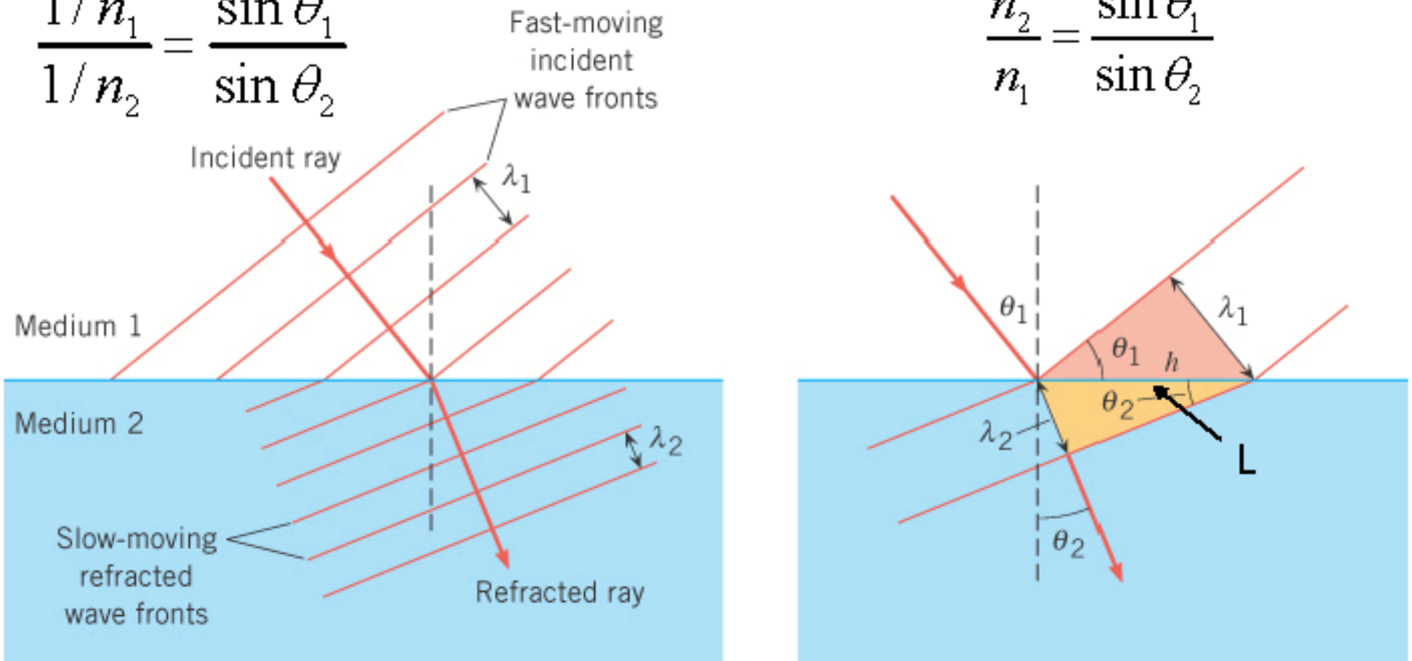
$$\text{index of refraction: } n = \frac{c}{v}$$

THE DERIVATIN OF SNELL'S LAW

$$v_1 = \frac{\lambda_1}{T} \quad v_2 = \frac{\lambda_2}{T} \quad \Rightarrow \quad \frac{\lambda_1}{v_1} = T = \frac{\lambda_2}{v_2} \quad \Rightarrow \quad \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{L\sin\theta_1}{L\sin\theta_2} \quad \Rightarrow \quad \frac{v_1/c}{v_2/c} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{1/n_1}{1/n_2} = \frac{\sin\theta_1}{\sin\theta_2}$$

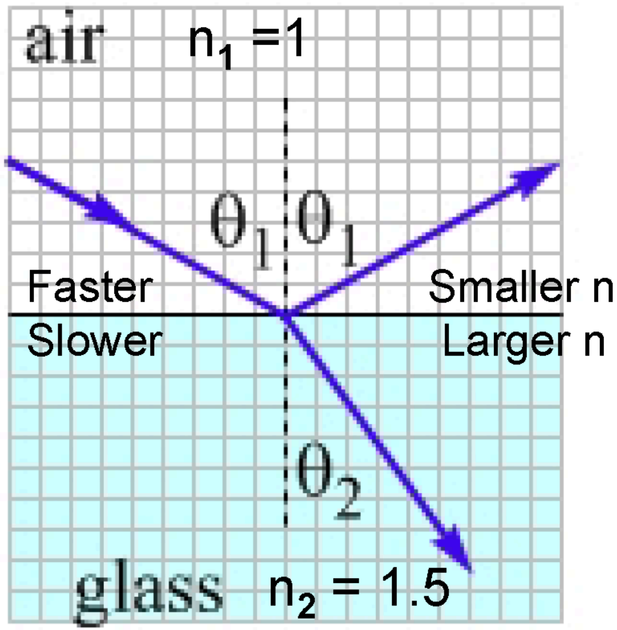
$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$



(a) (b)

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

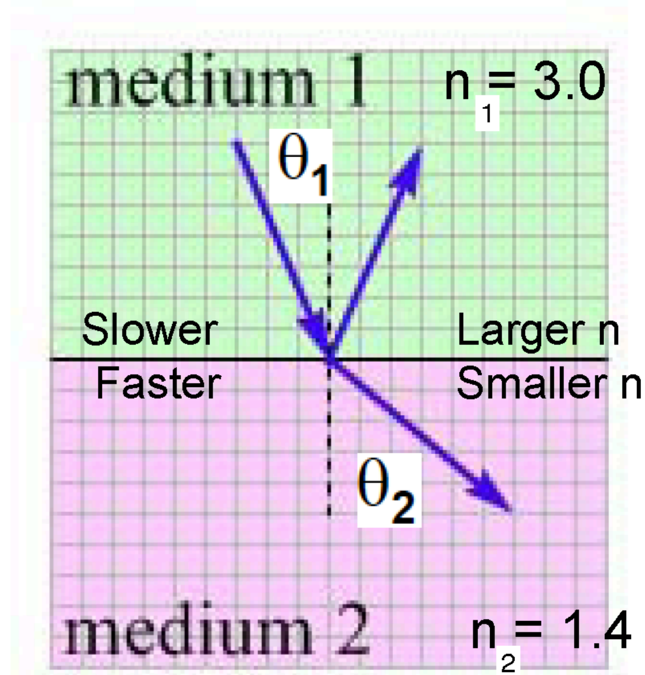
Refraction toward/away from the normal



$$\sin\theta_1 = 1.5 \sin\theta_2$$

$$\theta_1 > \theta_2$$

Light bends *toward* the normal!

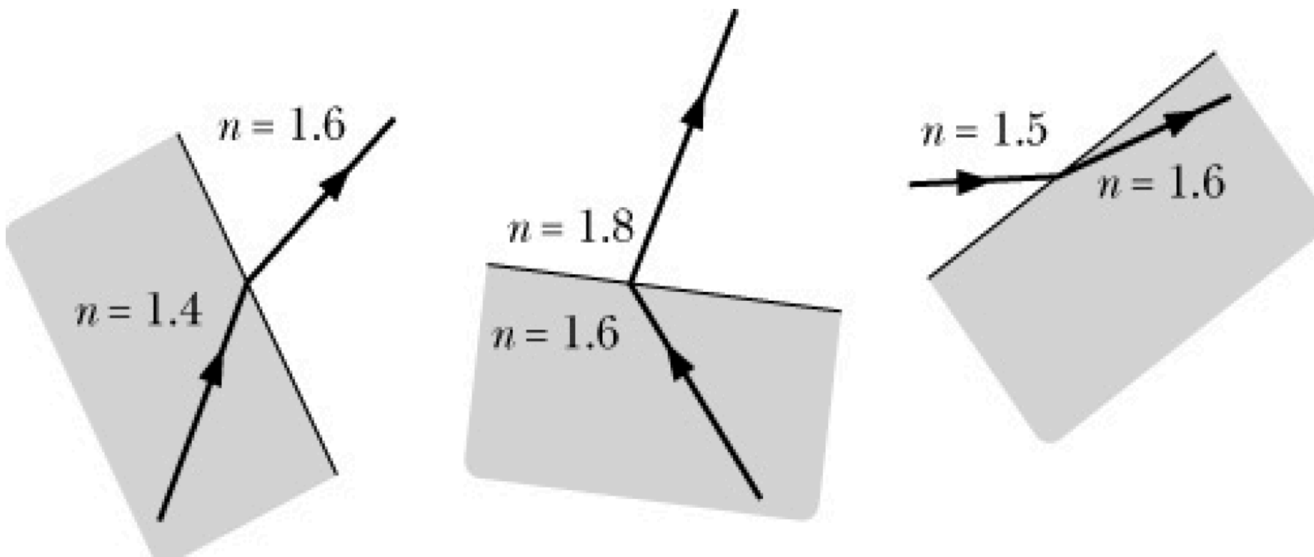


$$3.0 \sin\theta_1 = 1.5 \sin\theta_2$$

$$\theta_1 < \theta_2$$

Light bends *away from* the

Which of these three drawings (if any) show physically possible refraction?



1

2

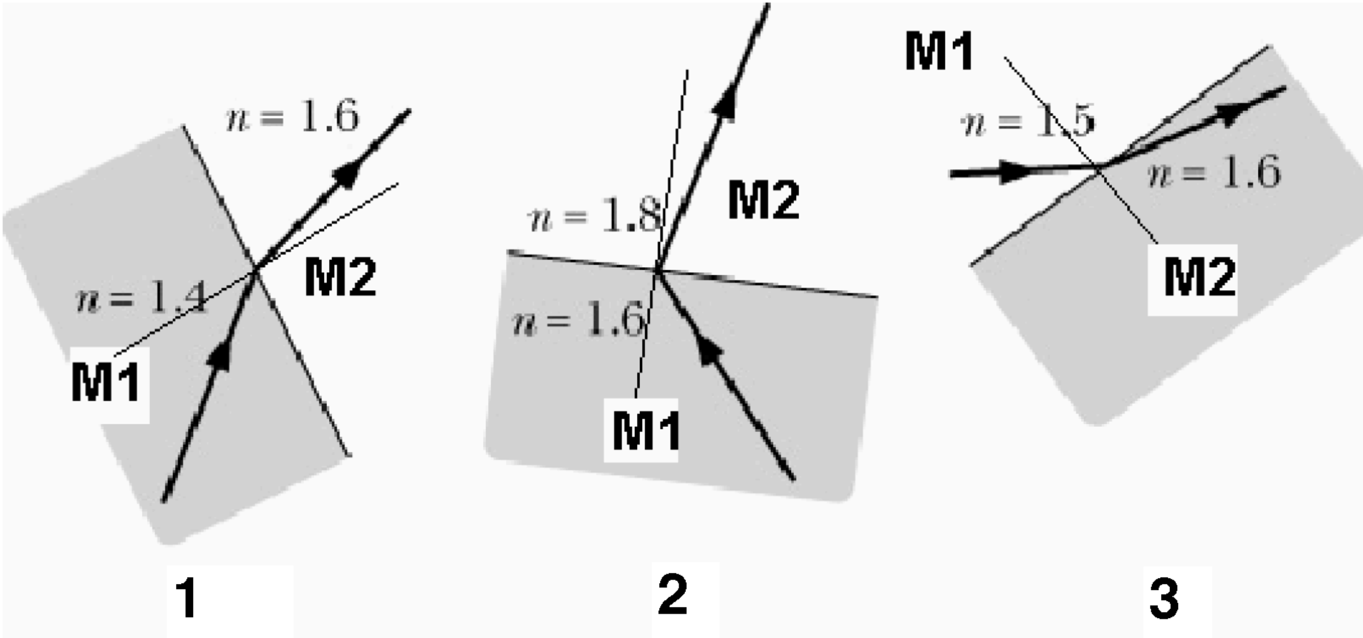
3

4 - for 1 and 2

5 - for 1 and 3

6 - for 2 and 3

7- for all

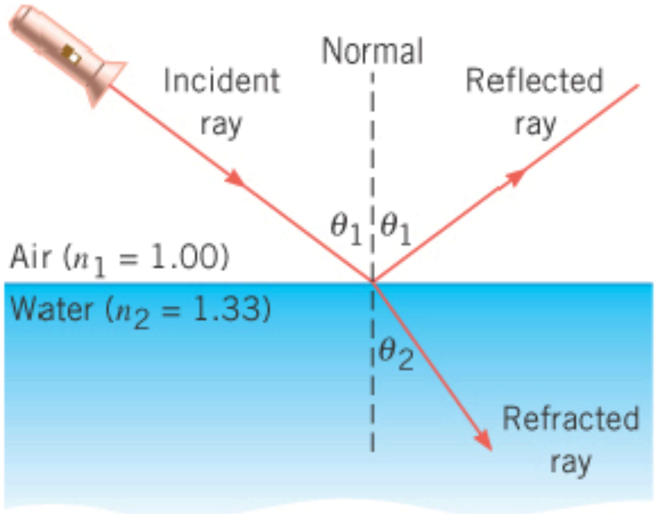


$$\frac{n_2}{n_1} = \frac{\sin(\theta_1)}{\sin(\theta_2)}$$

2 and 3 are impossible

only 1 is possible!

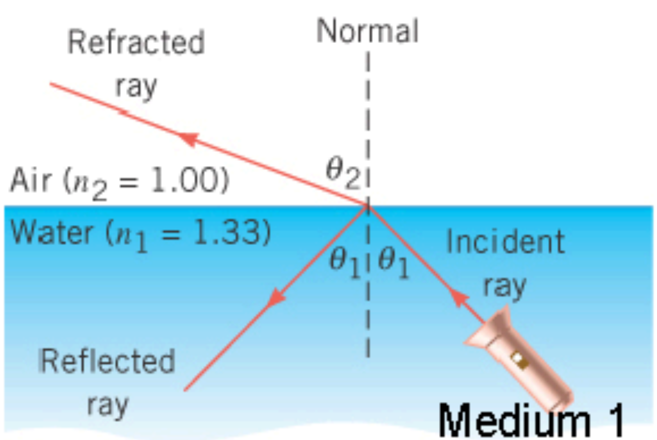
Medium 1



(a)

(a) $$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2} = \frac{(1.00)\sin 46^\circ}{1.33} = 0.54$$

$$\theta_2 = 33^\circ$$



(b)

(b) $$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2} = \frac{(1.33)\sin 46^\circ}{1.00} = 0.96$$

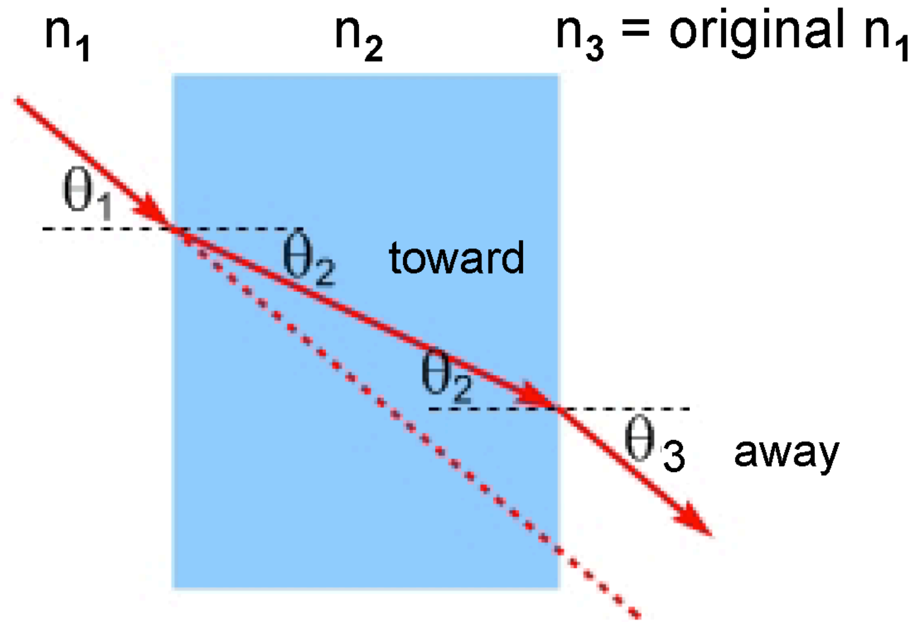
$$\theta_2 = 74^\circ$$

Refraction in a rectangular block

When the light strikes the far side of the glass, how will it emerge?

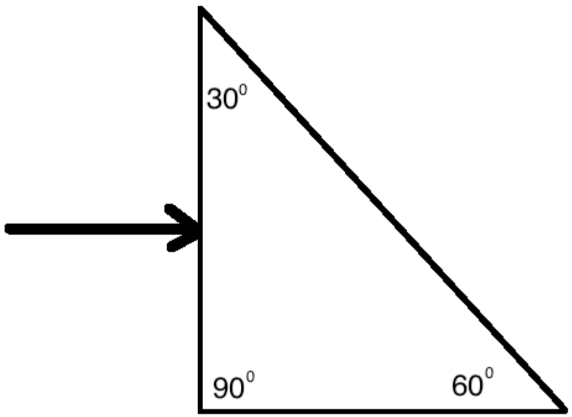
It comes out parallel to the original beam!

<u>This is only true when the sides are parallel.</u>

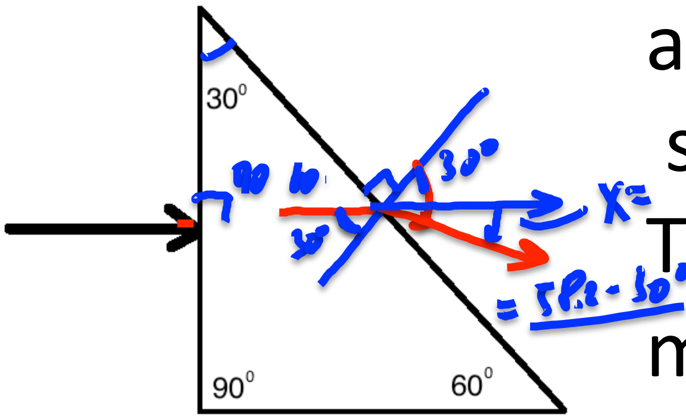


$$n_1 \sin\theta_1 = n_2 \sin\theta_2 = n_{1,3} \sin\theta_3$$

$$\theta_1 = \theta_3$$



a beam of light enters a prism as shown in the diagram on the left. The index of refraction of the material of the prism is n = 1.7. Find the angle at which the light **exits** the prism (measured from its original direction).



a beam of light enters a prism as shown in the diagram on the left. The index of refraction of the material of the prism is n = 1.7. Find the angle at which the light **exits** the prism (measured from its original direction).

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

$\theta_1 = 30°$

$1.7 \cdot \sin 30° = 1 \cdot \sin\theta_2$

$0.85 = \sin\theta_2$ $\theta_2 = \sin^{-1} 0.85 = 58.2°$

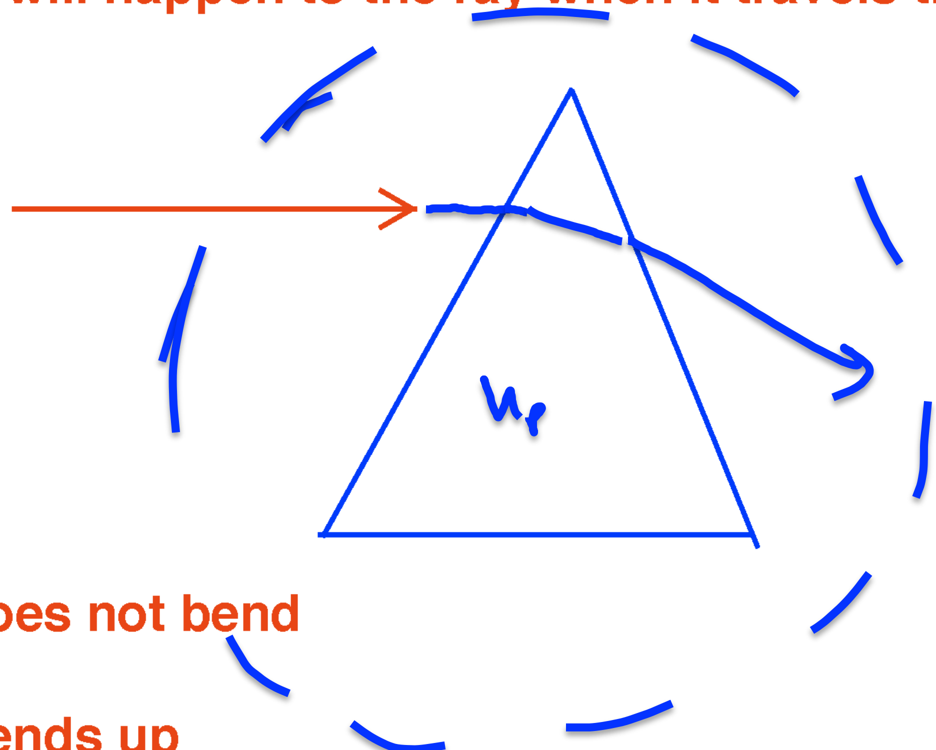
X= ...

1. 58.2° 2. 30° 3. 60° 4. 90° 5. 28.2 6. 14.1° 7. alone

Light is approaching a prism which has index of refraction *higher* than the index of refraction of the medium (see the picture).

$n_p > n_m$

What will happen to the ray when it travels through the prism?



1. it does not bend

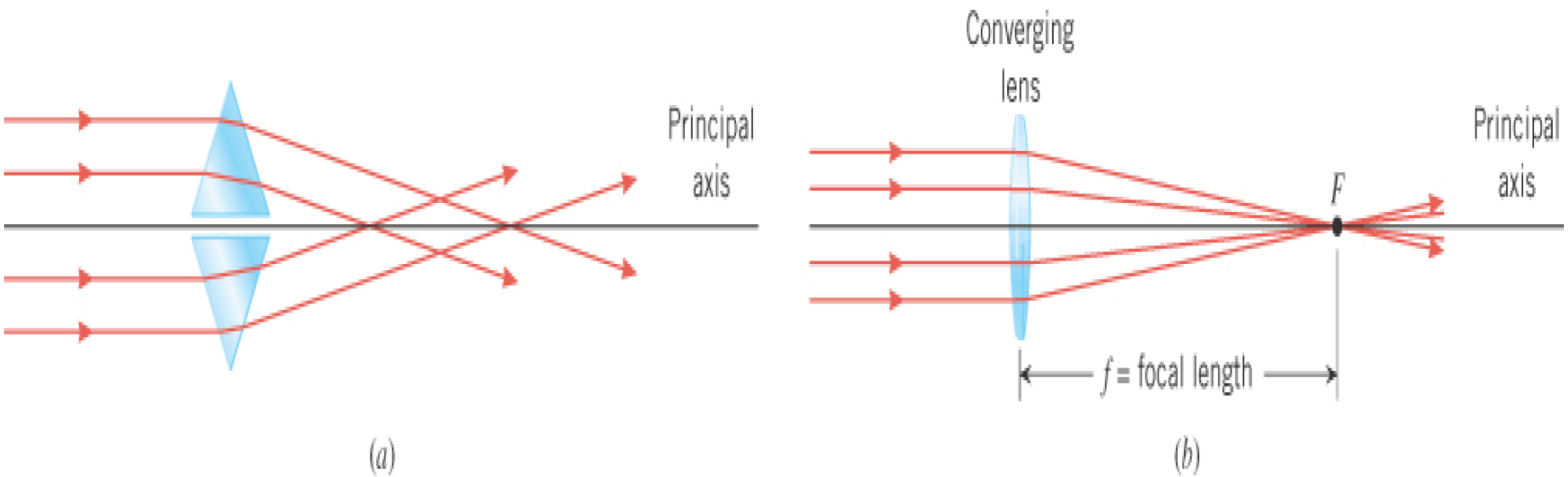
2. it bends up

3. it bends down

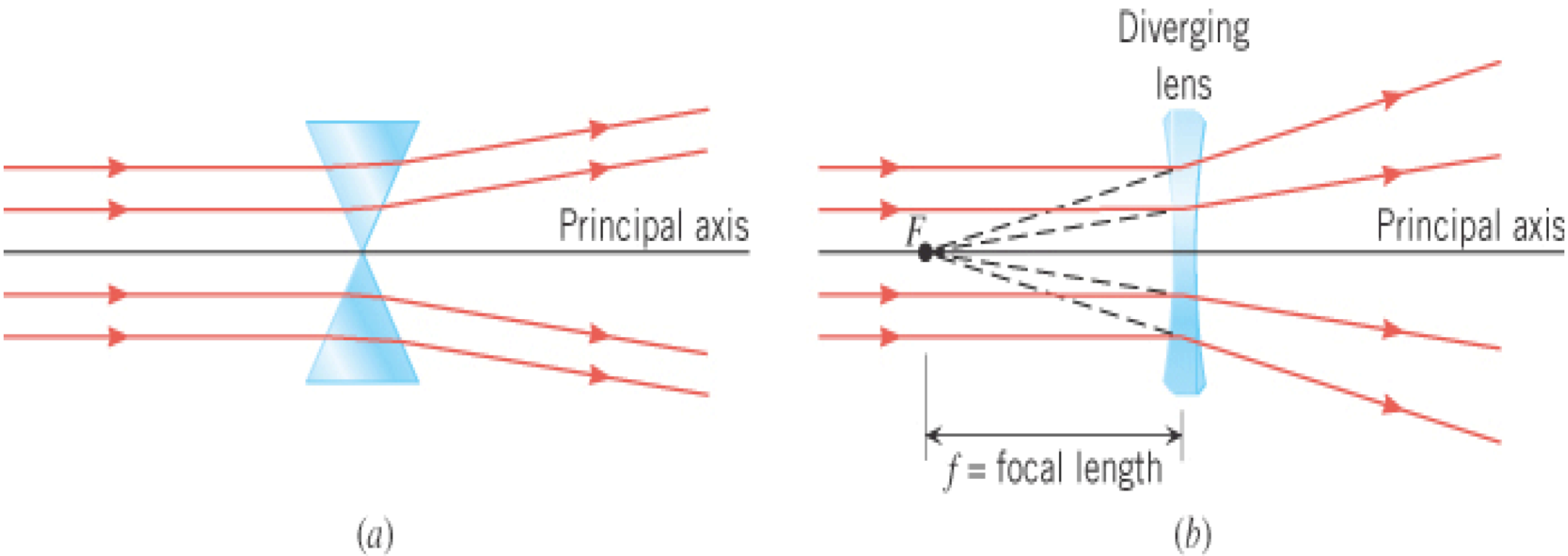
Making Lenses

Lenses refract light in such a way that an image of the light source is formed.

With a converging lens, paraxial rays that are parallel to the principal axis converge to the focal point.



With a diverging lens, paraxial rays that are parallel to the principal axis appear to originate from the focal point.



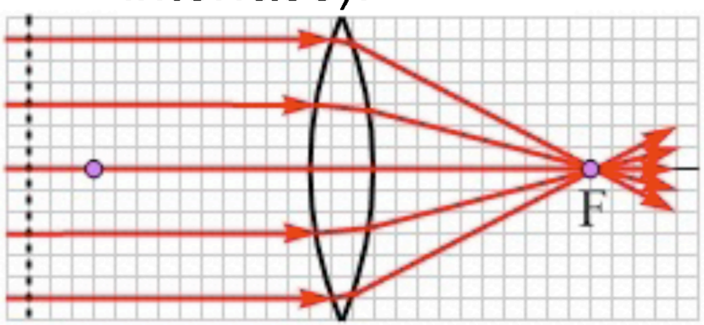
A lens is basically just a set of prisms refracting light!

The focal length

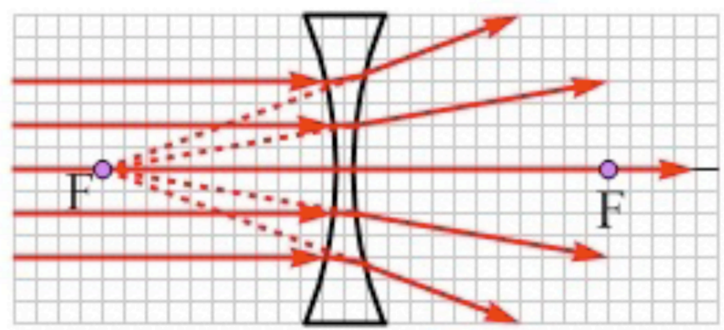
The focal length of a lens is determined by the lensmaker's equation:

$$\frac{1}{f} = \left(\frac{n_{lens}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

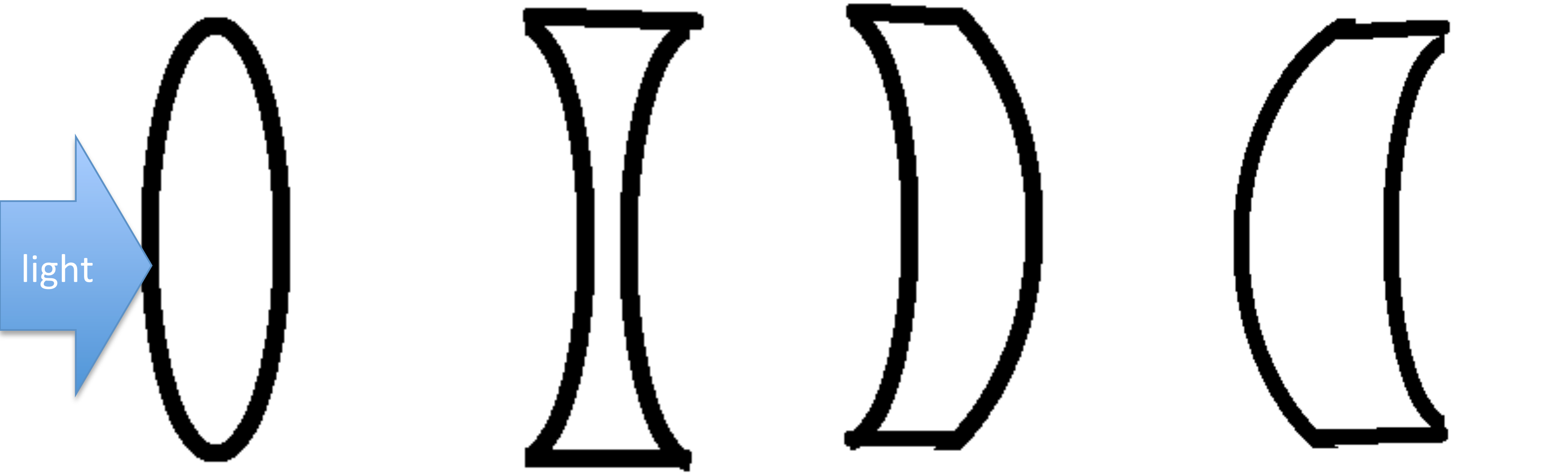
The *R*'s are the radii of curvature of the two surfaces (R < 0 when light encounters a concave interface).



convex lens



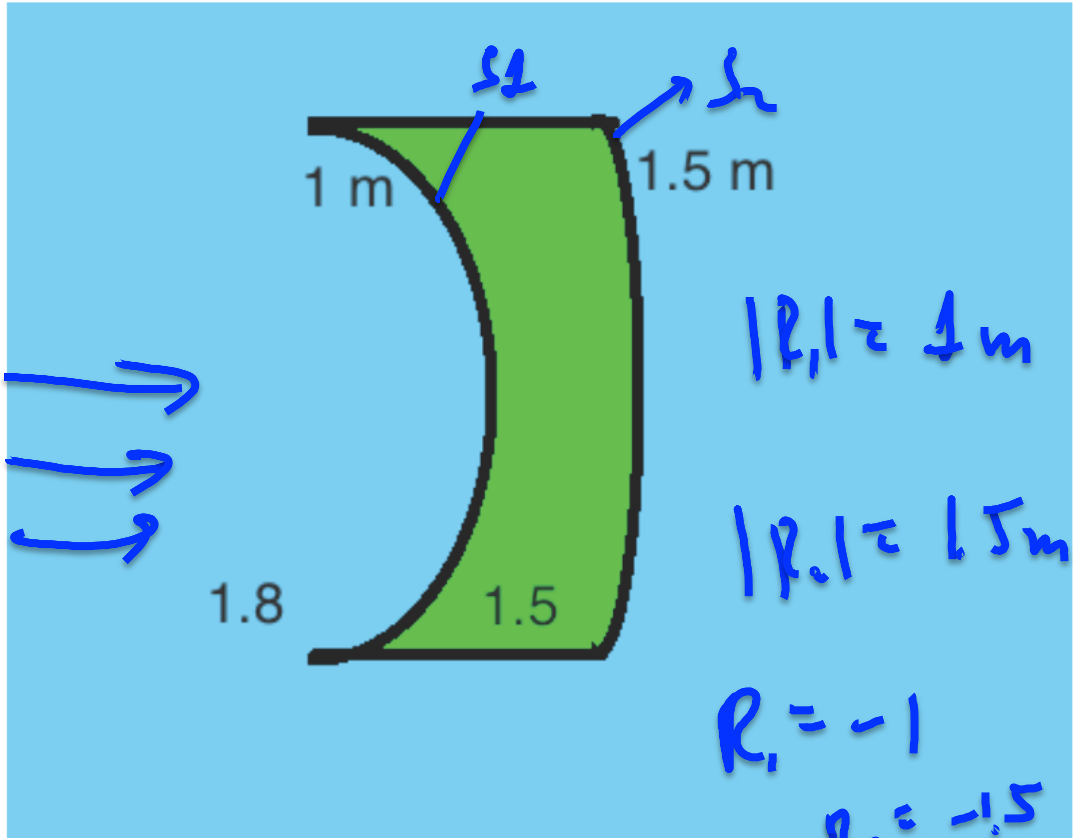
concave lens



(by-convex) (by-concave)

$R_1>0$ $R_2<0$ $R_1<0$ $R_2>0$ $R_1<0$ $R_2<0$ $R_1>0$ $R_2>0$

$$\frac{1}{f}=\left(\frac{n_{lens}}{n_{medium}}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$



$$\frac{1}{f} = \left(\frac{n_{lens}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

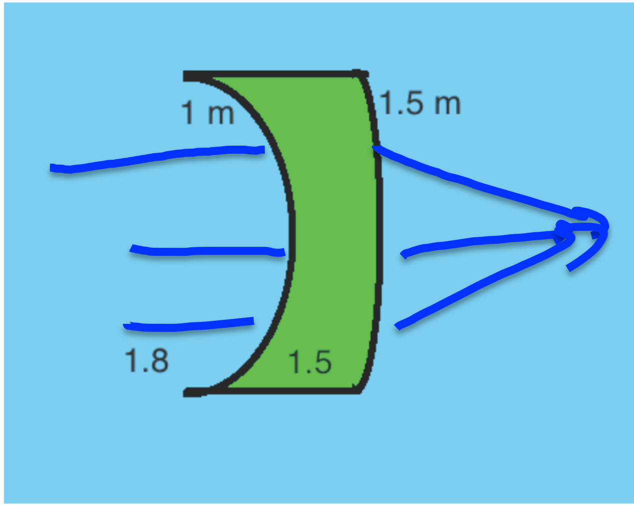
A lens is made of glass with n = 1.5 and immersed into oil with n = 1.8. Lens surfaces have radii of 1 m and 1.5 m.

Find the focal distance of the lens.

This lens is

1. converging

2. diverging



A lens is made of glass with n = 1.5 and immersed into oil with n = 1.8. Lens surfaces have radii of 1 m and 1.5 m.

Find the focal distance of the lens.

This lens is

1. converging

2. diverging <0

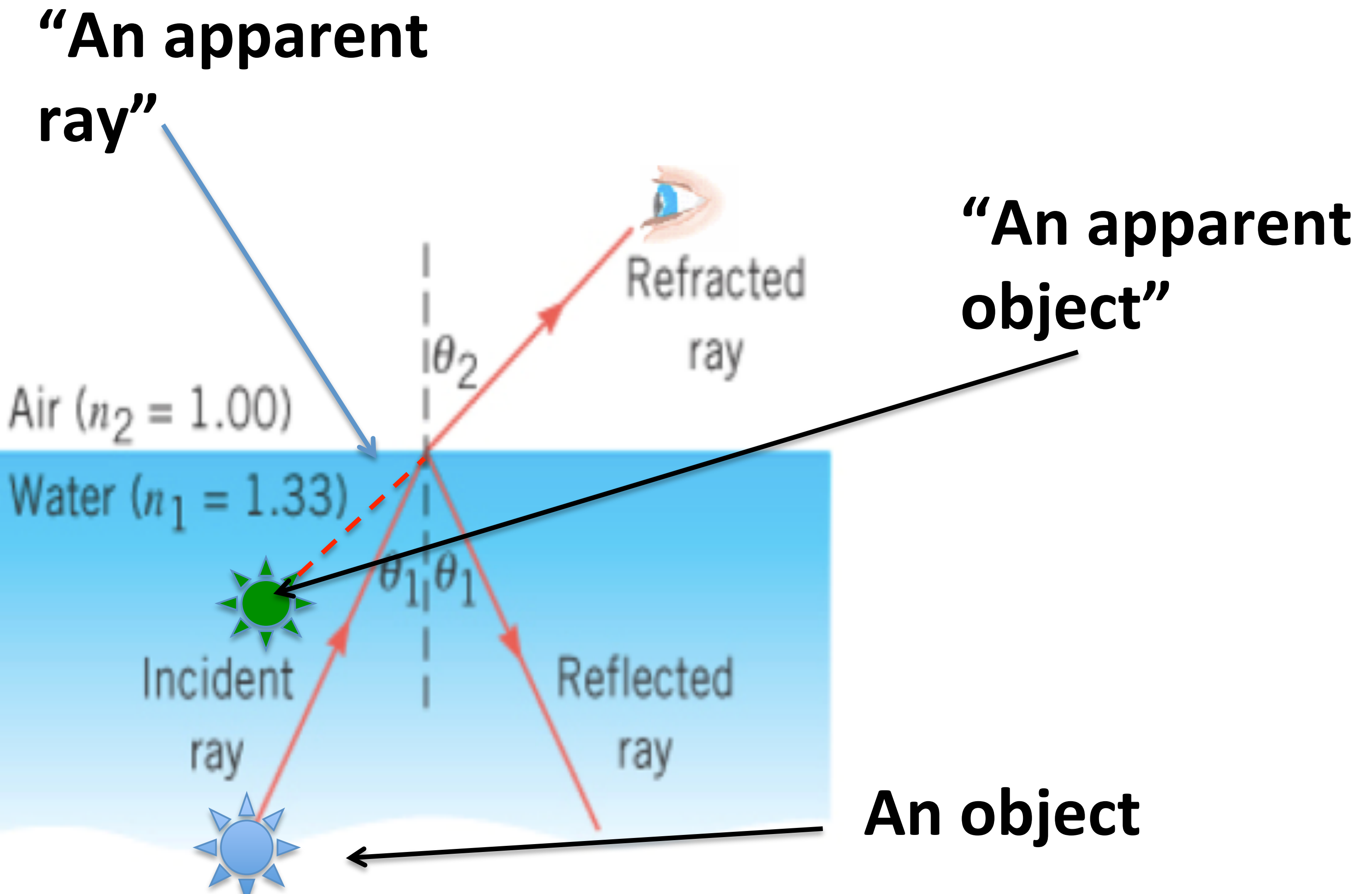
$$\frac{1}{f} = \left(\frac{n_{lens}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

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

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

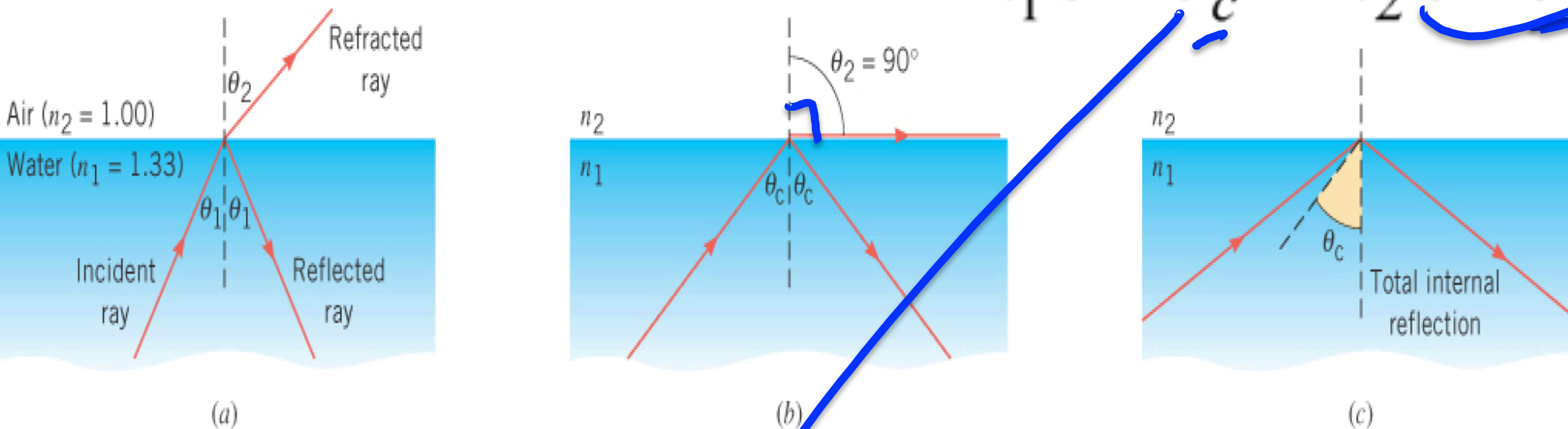
$$\underbrace{-1 + \frac{1}{1.5}}_{<0}$$

$$D = \frac{1}{f} = \left(\underbrace{\frac{1.5}{1.8} - 1}_{<0}\right)\left(\frac{1}{-1} - \frac{1}{-1.5}\right)$$


"An apparent ray"
"An apparent object"
An object
Refracted ray
Air (n_2 = 1.00)
Water (n_1 = 1.33)
θ_2
θ_1
θ_1
Incident ray
Reflected ray

When light passes from a medium of larger refractive index into one of smaller refractive index, the refracted ray bends away from the normal.

$$n_1 \sin\theta_c = n_2 \sin 90^\circ$$

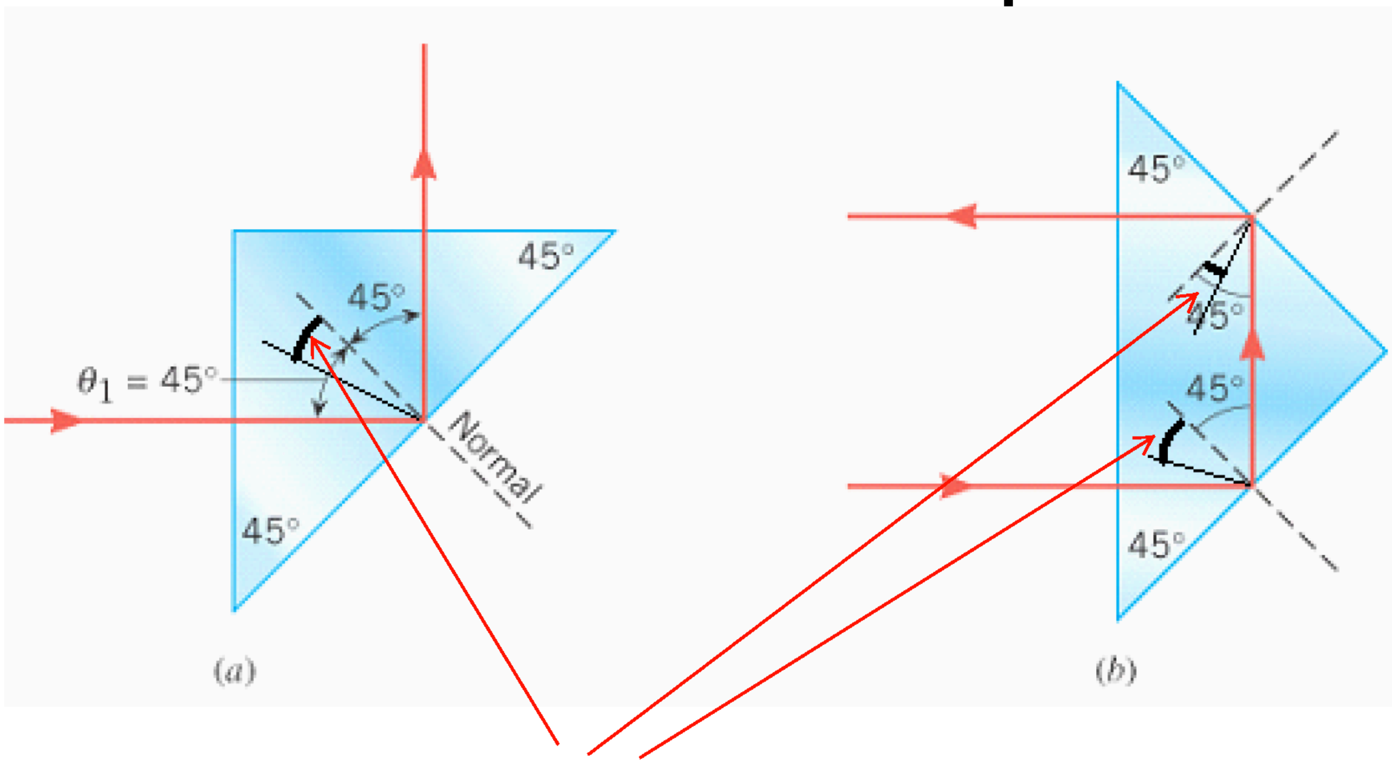


Critical angle

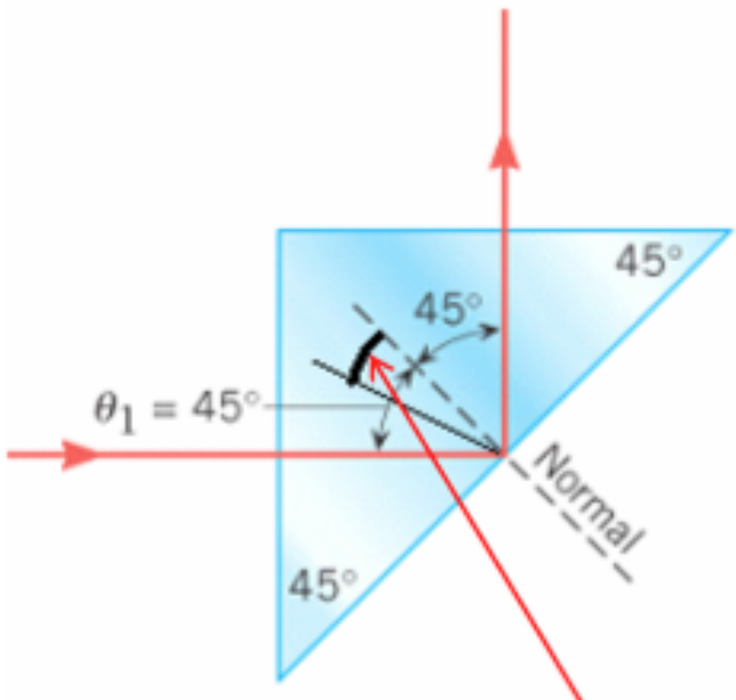
$$\sin\theta_c = \frac{n_2}{n_1} \qquad n_1 > n_2$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Total internal reflection in a prism



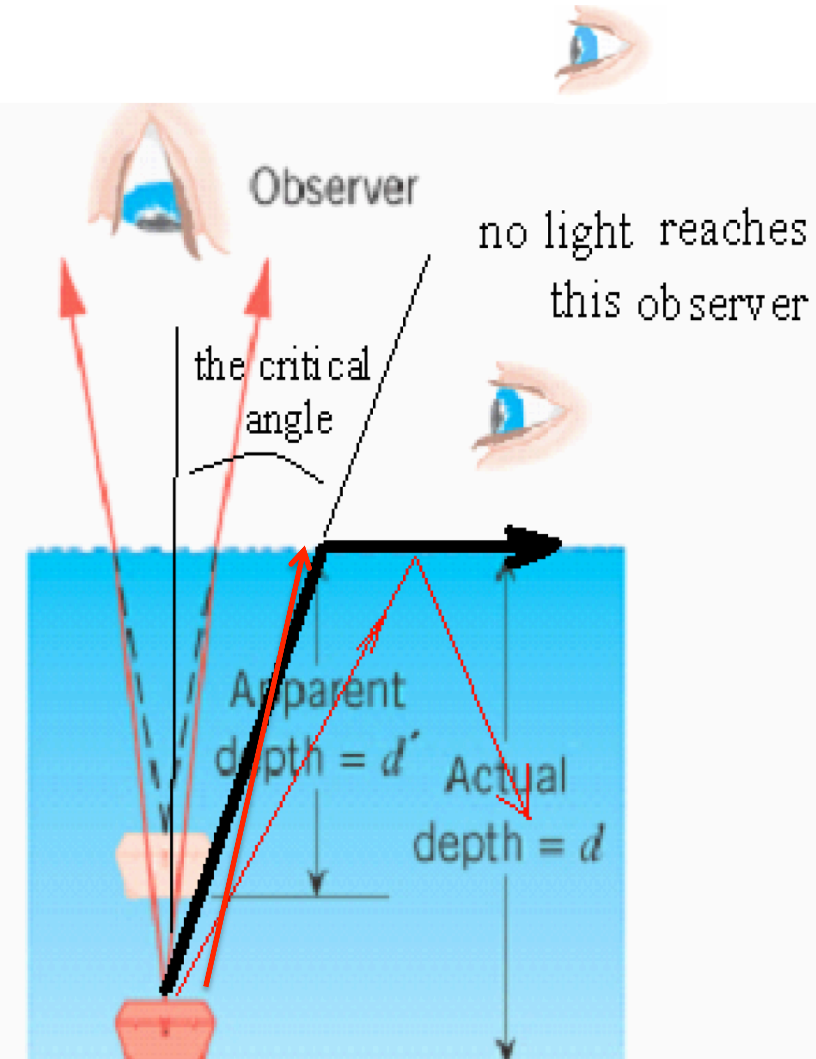
The black lines show the critical angle (which is defined by the index of refraction). When the angle of incidence is greater then the critical angle, the light completely reflects from the surface.



$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

How can we change the critical angle?

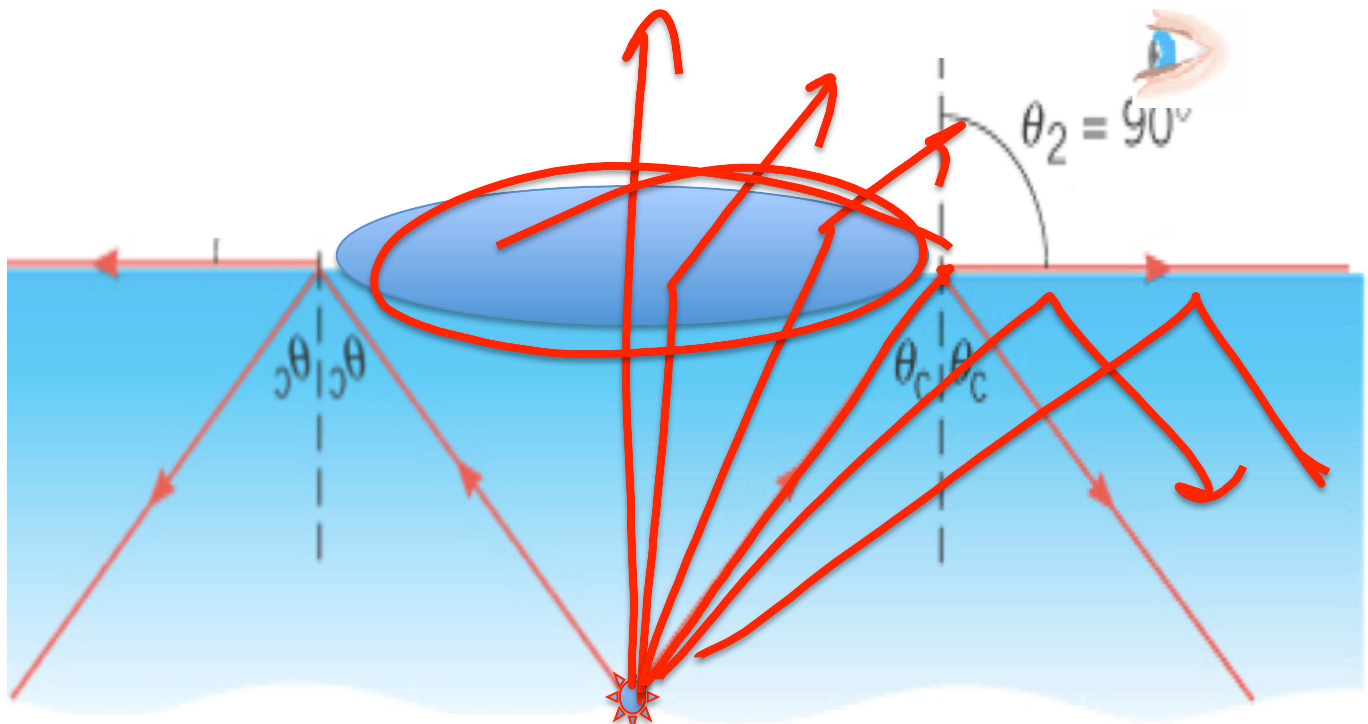
1. **By changing the angle of incidence**
2. **By changing the angle of refraction**
3. **By immersing the prism into water**
4. **We cannot change the critical angle**



Because of the total internal reflection the objects under water seen only within a certain range of angles (and at a different depth).

Behind the critical angle an observer cannot see the chest (no light reflected by the chest, or emitted by the light source reaches the observer).

A light-bulb is 2 m below the surface of water (n = 1.33). What is the radius of the bright circle on the surface of the water?



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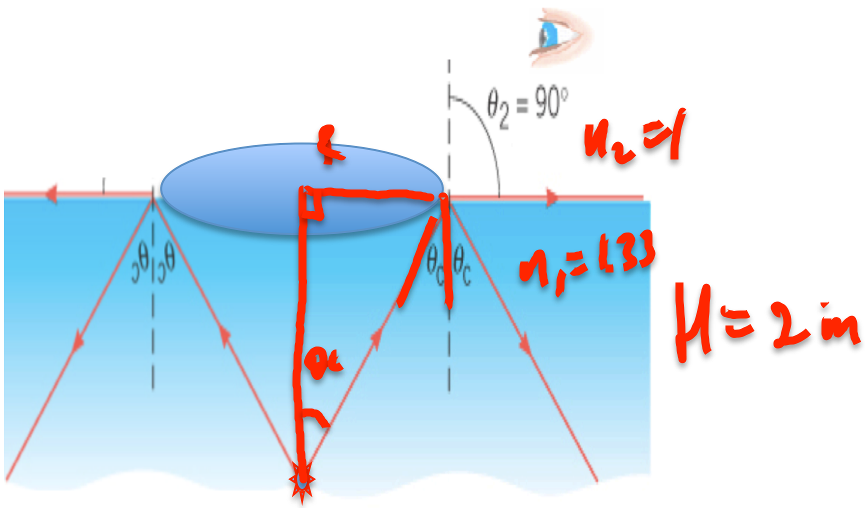

$R = H \cdot \tan\theta_c$

$\sin\theta_c = \ldots$

1. $\frac{n_1}{n_2}$

2. $\frac{n_2}{n_1}$