
Refraction and Lenses

AP Physics B

Refraction

Refraction is based on the idea that LIGHT is passing through one MEDIUM into another. The question is, **WHAT HAPPENS?**



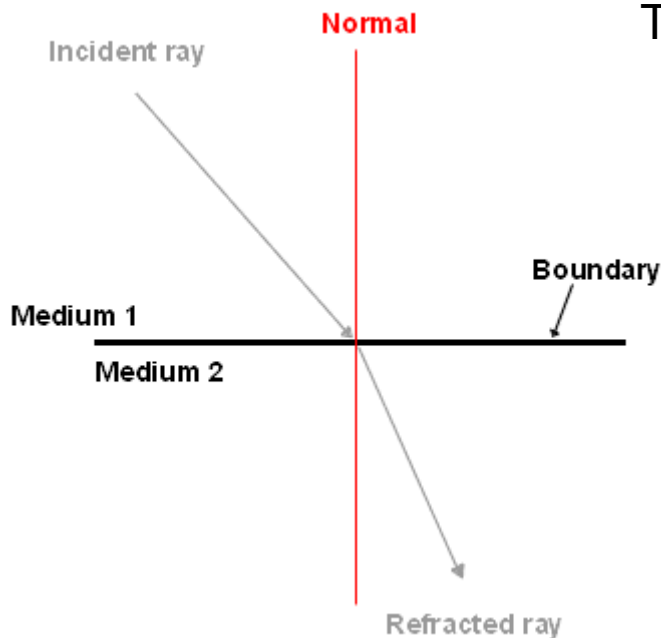
Suppose you are running on the beach with a certain velocity when you suddenly need to run into the water. What happens to your velocity?

IT CHANGES!

Refraction Fact #1: As light goes from one medium to another, the velocity **CHANGES!**

Refraction

Suppose light comes from air, which in this case will be considered to be a vacuum, strikes a boundary at some angle of incidence measured from a normal line, and goes into water.



The ratio of the two speeds can be compared.

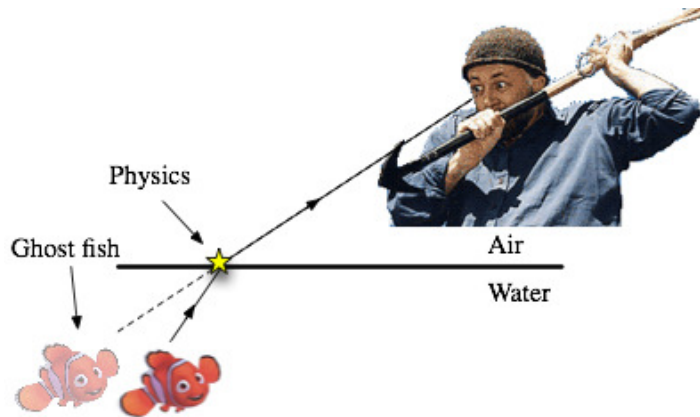
$$n = \frac{\text{Speed of Light in a Vacuum } c}{\text{Speed of Light in a medium } v_m}$$

The denominator in this case will ALWAYS be smaller and produce a unitless value greater or equal to 1. This value is called the new medium's **INDEX OF REFRACTION**, n .

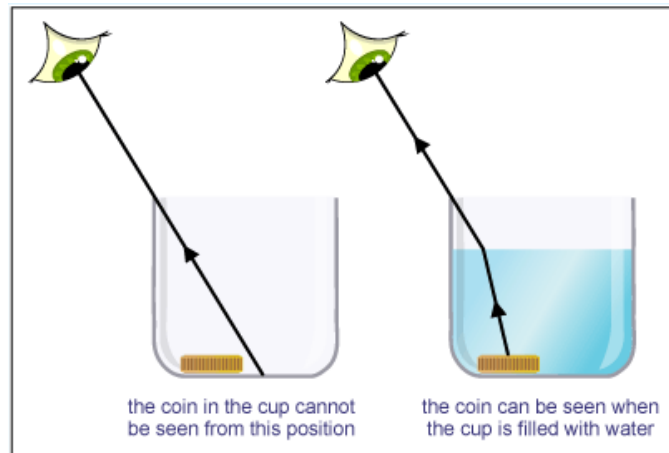
All substances have an index of refraction and can be used to identify the material.

Refraction

Suppose you decide to go spear fishing, but unfortunately you aren't having much luck catching any fish.



The cause of this is due to the fact that light **BENDS** when it reaches a new medium. The object is **NOT** directly in a straight line path, but rather it's image appears that way. The actual object is on either side of the image you are viewing.

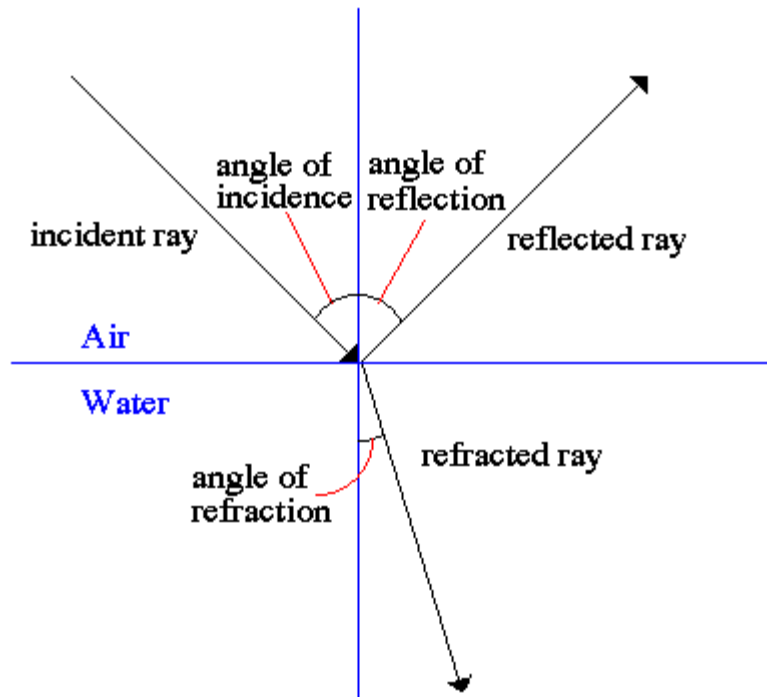


Refraction Fact #2: As light goes from one medium to another, the path **CHANGES!**

Refraction

What EXACTLY is light doing when it reaches a new medium? We don't want you to think ALL of the light refracts.

Reflection and Refraction

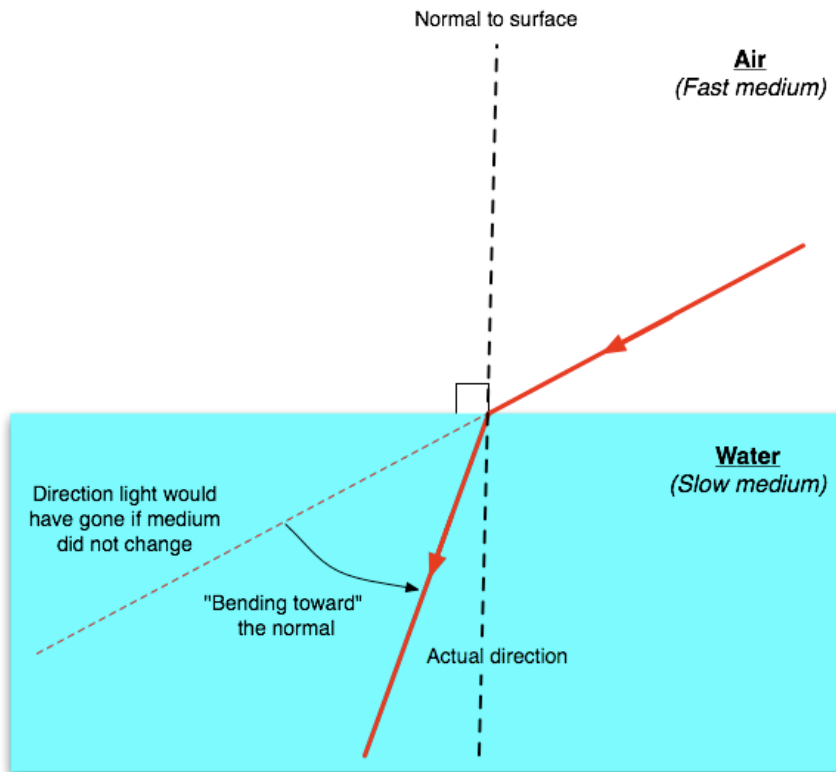


Some of the light REFLECTS off the boundary and some of the light REFRACTS through the boundary.

Angle of incidence = Angle of Reflection

Angle of Incidence > or < the Angle of refraction depending on the direction of the light

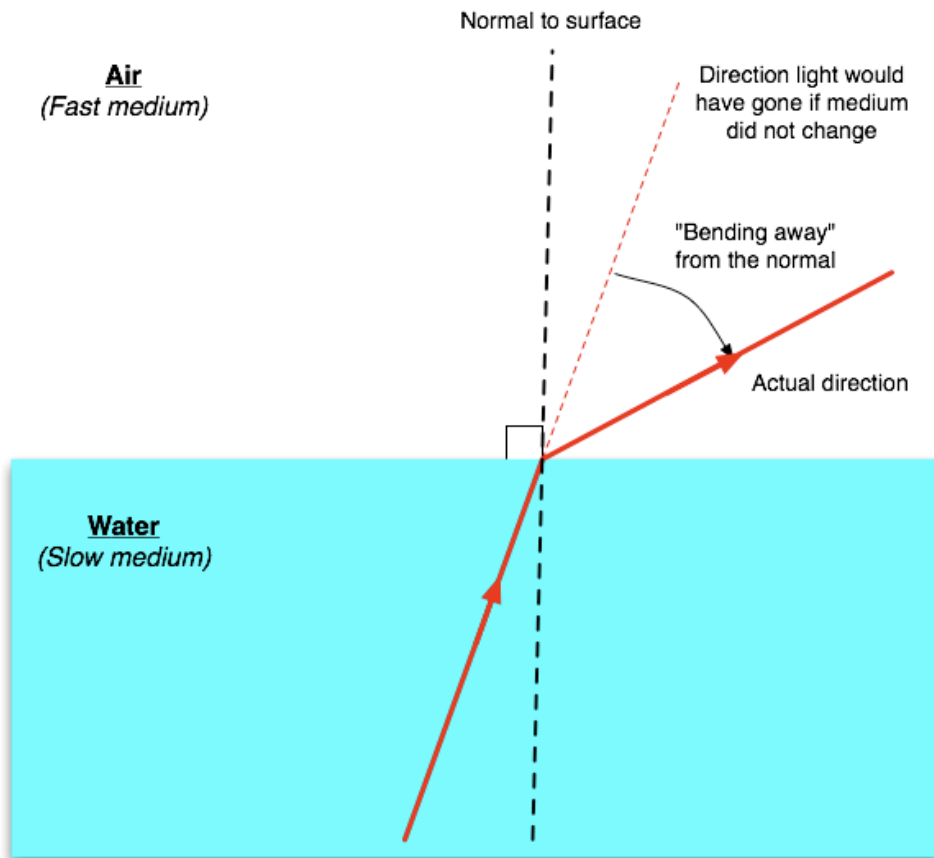
Refraction – Going from Air to Water



The index of refraction, n , for air (vacuum) is equal to 1. The index of refraction for water is 1.33.

If you are going from a LOW “ n ” to a HIGH “ n ”, your speed DECREASES and the angle BENDS TOWARDS the normal

Refraction – Going from Water into Air



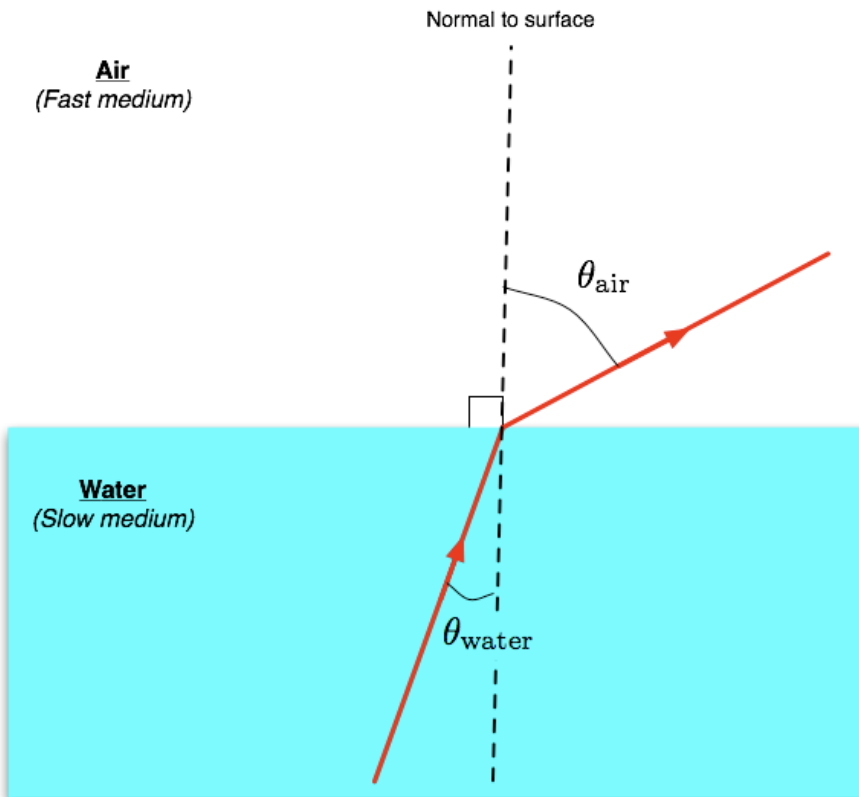
The index of refraction, n , for air (vacuum) is equal to 1. The index of refraction for water is 1.33.

If you are going from a HIGH “ n ” to a LOW “ n ”, your speed INCREASES and the angle BENDS AWAY the normal

Note: If the angles are EQUAL, then the “ n ” must be equal for each. The ray will pass straight through.

Refraction – Snell's Law

A scientist by the name of Snell discovered that the ratios of the index's and the ratio of the sine of the angles are the same value!



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

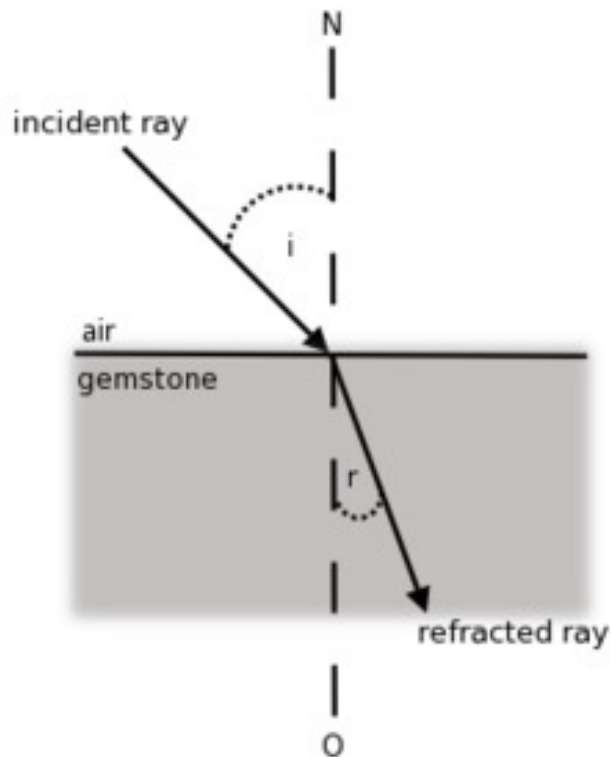
Snell's Law

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

$$n_{\text{air}} \sin \theta_{\text{air}} = n_{\text{water}} \sin \theta_{\text{water}}$$

Example

The refractive index of the gemstone, Aquamarine, is 1.577. Suppose a ray of light strikes a horizontal boundary of the gemstone with an angle of incidence of 23 degrees from air.



Calculate the SPEED of light in Aquamarine

$$n = \frac{c}{v_m} \rightarrow v_m = \frac{c}{n} = \frac{3 \times 10^8}{1.577}$$

$$v_m = \mathbf{1.90 \times 10^8 \text{ m/s}}$$

Calculate the angle of refraction within Aquamarine

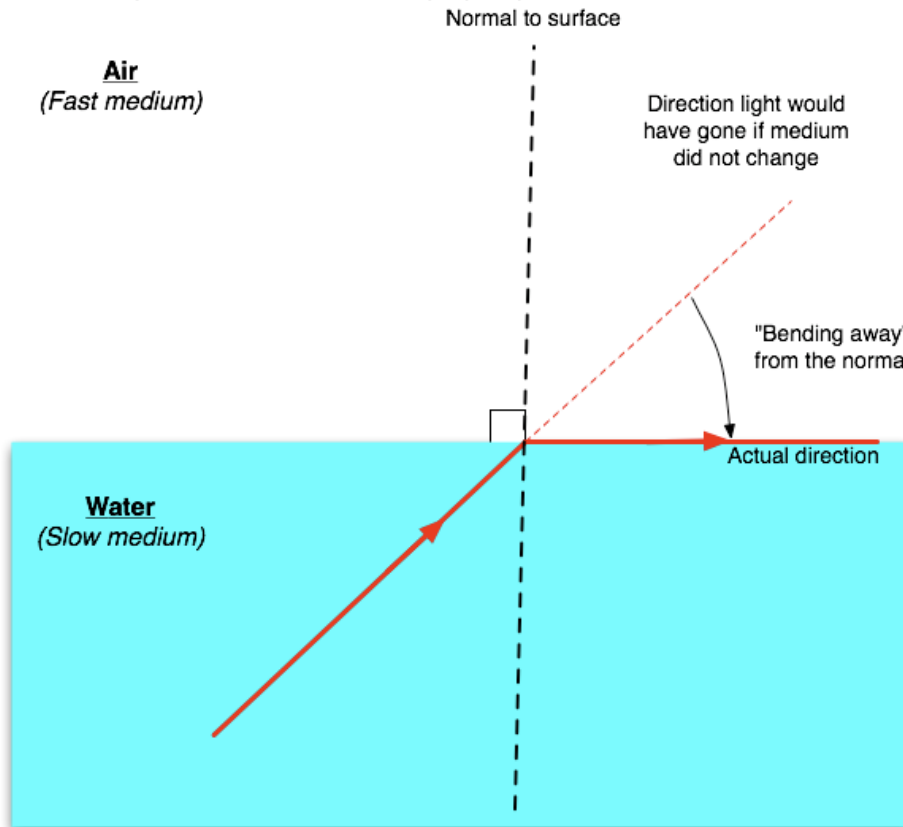
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$(1)(\sin 23) = 1.577 \sin \theta_2$$

$$\theta = \sin^{-1}\left(\frac{\sin 23}{1.577}\right) = \mathbf{14.34 \text{ degrees}}$$

Total Internal Reflection

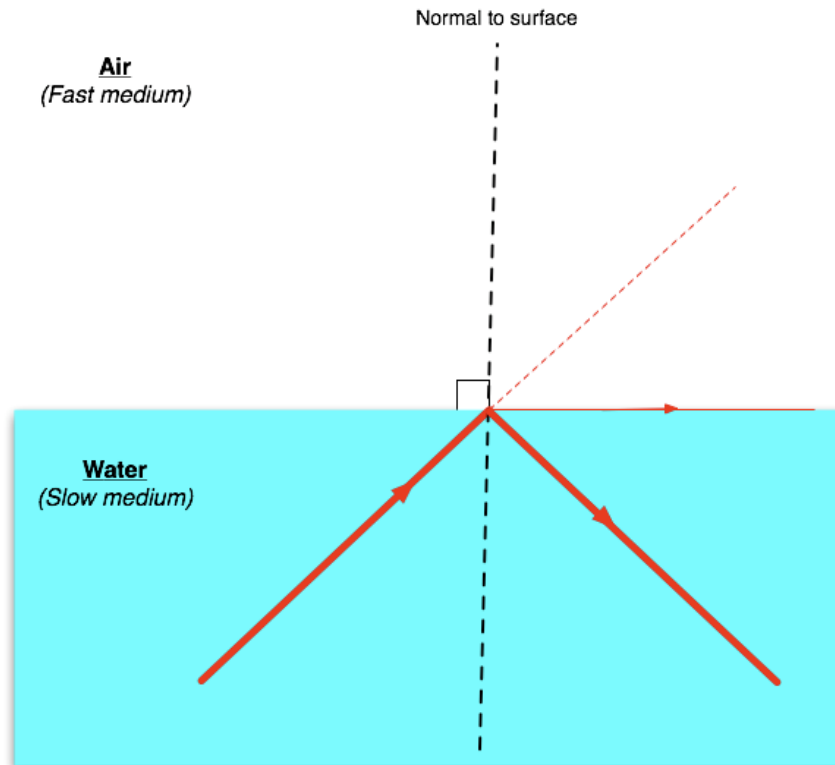
There is a special type of refraction that can occur **ONLY** when traveling from a HIGH “n” medium to a LOW “n” medium.



Suppose we are traveling FROM water and going into air. Should the **ANGLE OF INCIDENCE** get **TOO LARGE**, the angle of refraction will **EQUAL 90 DEGREES**. We call this special angle of incidence the **CRITICAL ANGLE**, θ_c , for that material (water in this case)

Total Internal Reflection

If we **EXCEED** the critical angle, for that material, the ray will reflect INTERNALLY within the material. We call this idea **TOTAL INTERNAL REFLECTION**.

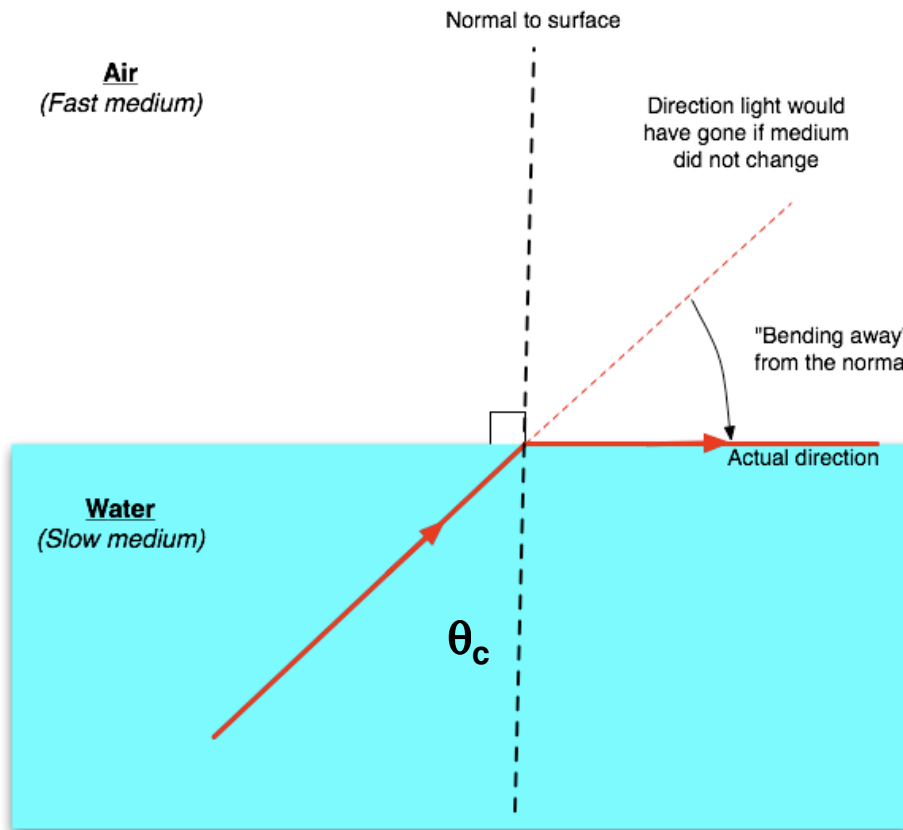


In this figure, the angle of incidence EXCEEDS the critical angle for water and the ray reflects according to the law of reflection at the boundary.

The Critical Angle

So the question is , **how can you calculate the critical angle?**

Remember, it is when the refracted ray is equal to 90 degrees

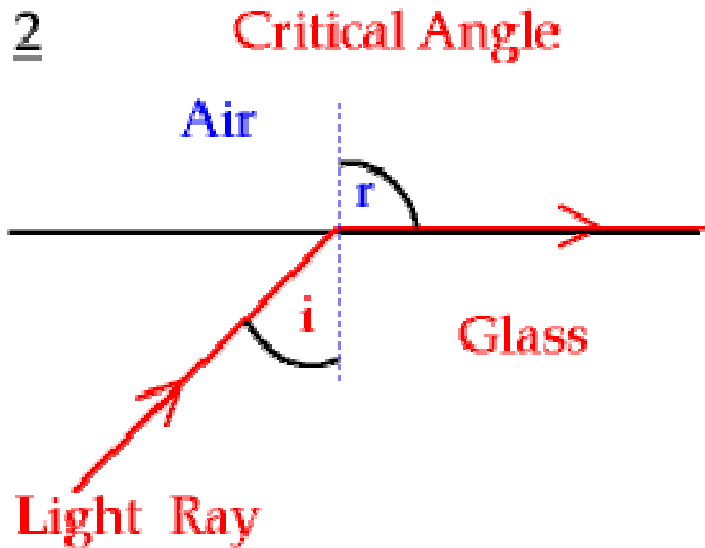


$$n_1 \sin \theta_c = n_2 \sin \theta_2, \sin 90 = 1$$

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

Example

Suppose a light ray is traveling in heavy flint glass($n = 1.65$) and once it strikes the boundary, enters air. Calculate the critical angle for flint glass.



$$n_1 \sin \theta_c = n_2 \sin \theta_2, \sin 90 = 1$$

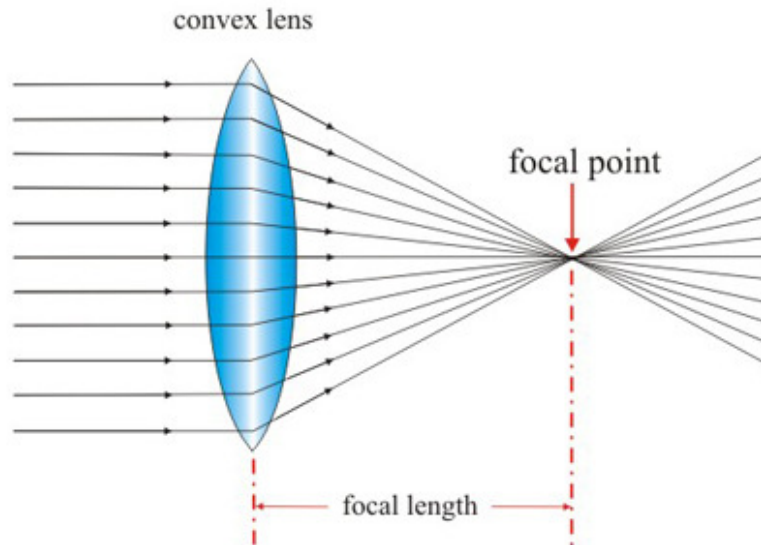
$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\sin \theta_c = \frac{1}{1.65} \rightarrow \theta_c = \sin^{-1}\left(\frac{1}{1.65}\right)$$

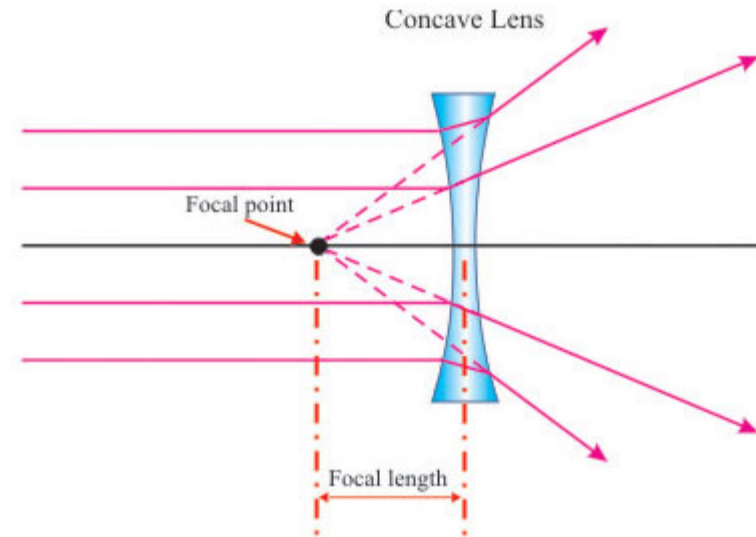
$$\theta_c = \mathbf{37.3 \text{ degrees}}$$

Lenses – An application of refraction

There are 2 basic types of lenses



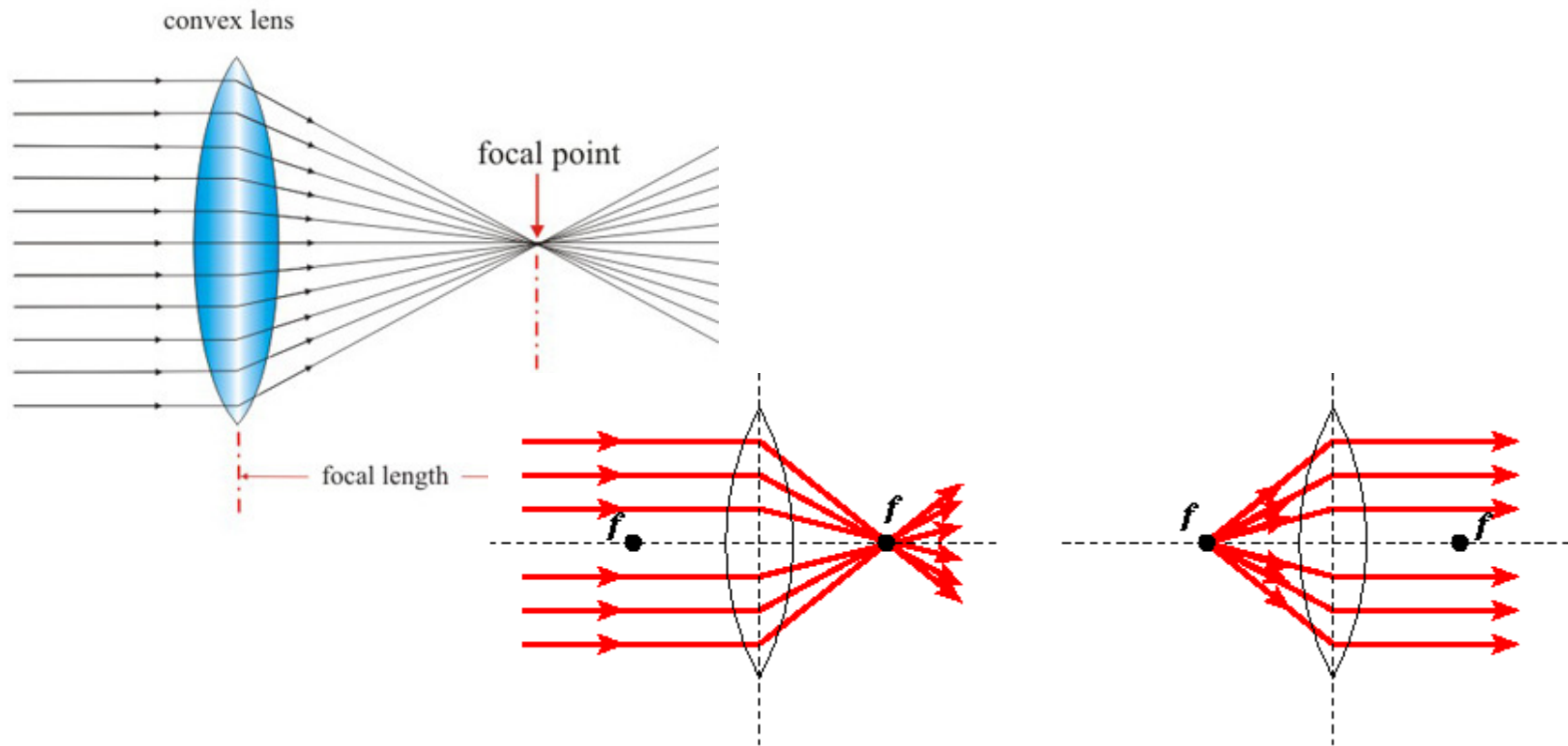
A converging lens (Convex) takes light rays and bring them to a point.



A diverging lens (concave) takes light rays and spreads them outward.

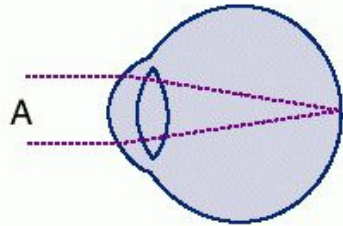
Converging (Convex) Lens

Much like a mirror, lenses also take light rays from infinity and converge them to a specific point also called the **FOCAL POINT, f** . The difference, however, is that a lens does not have a center of curvature, C , but rather has a focal point on EACH side of the lens.

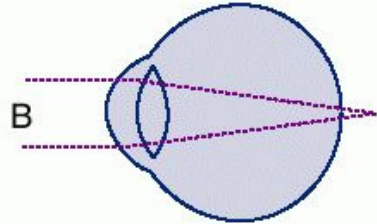


Applications of Converging Lenses

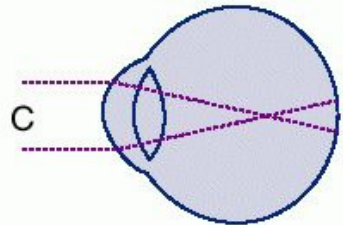
Obviously, converging lenses play an important role in our lives as our eyes are these types of lenses. Often times we need additional corrective lenses to fix our vision.



In figure A, we see an eye which converges what we see on the retina.



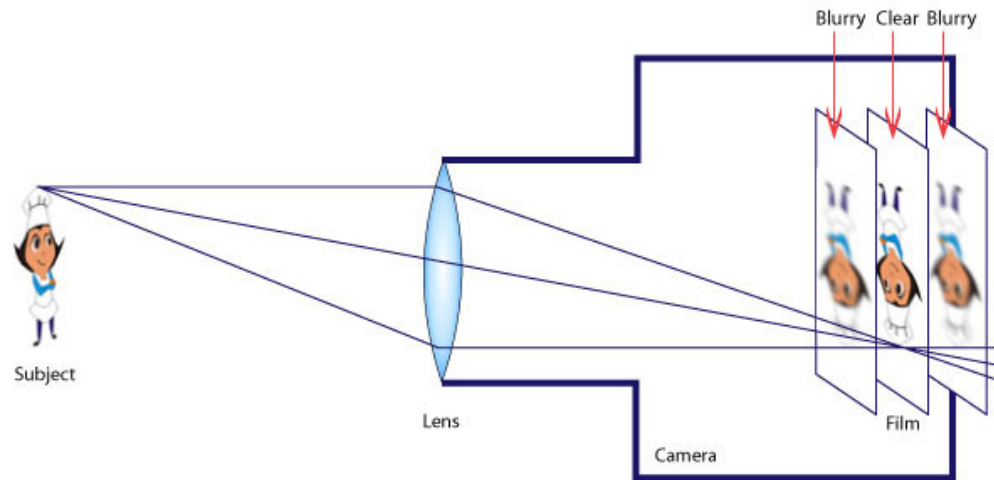
In figure B, we see an eye which converges too LATE. The eye itself is often too short and results in the person being far sighted.



In figure C, we see an eye which converges too SOON. The eye itself is often too long and results in the person being near sighted

In the later 2 cases, a convex or concave lens is necessary to ensure the image is on the retina.

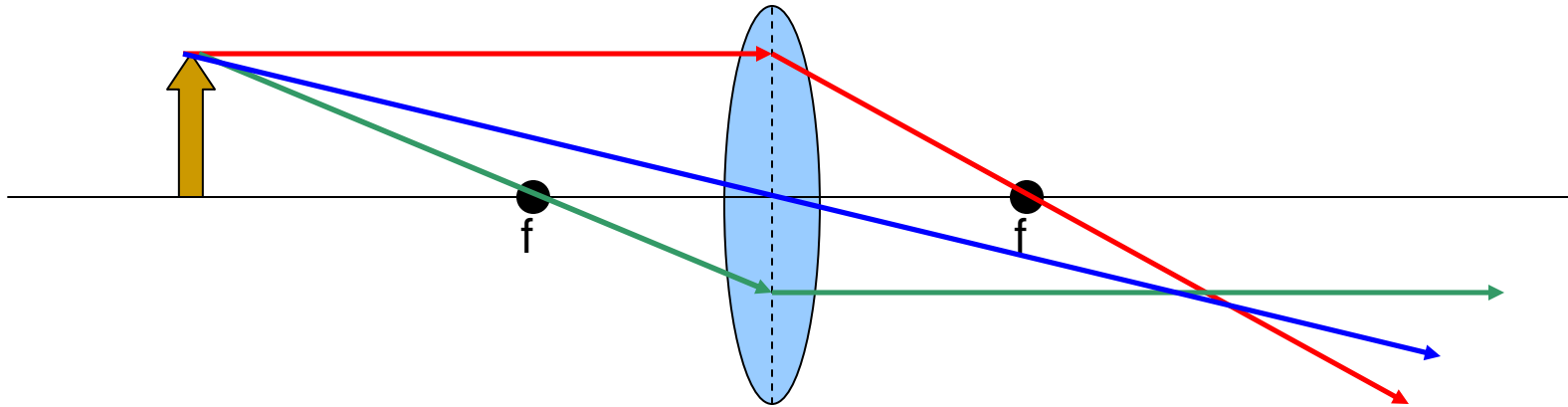
Applications of Converging Lenses



A camera uses a lens to focus an image on photographic film.

Ray Diagrams

The rules for ray diagrams are the SAME for lenses as they were for mirrors except you go THROUGH the lens after refraction and instead of going through, C (center of curvature) you go through the actual center of the lens.



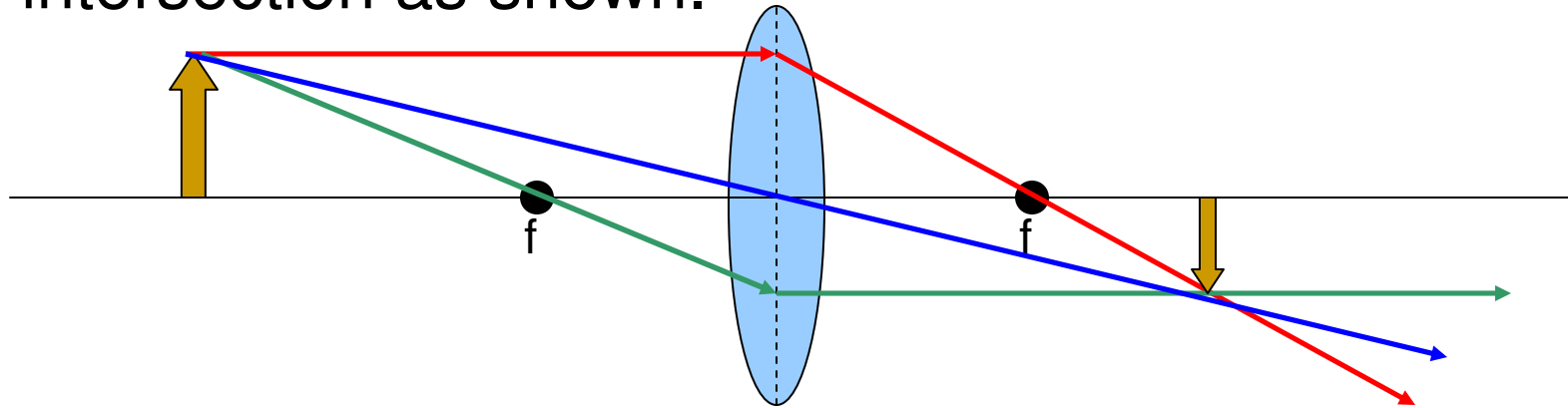
Rule #1: Draw a ray, starting from the top of the object, parallel to the principal axis, then through “f” after refraction.

Rule #2: Draw a ray, starting from the top of the object, through “f”, then parallel to the principal axis, after refraction.

Rule #3: Draw a ray through the center of the lens.

Ray Diagrams

As before, you draw the image down to the intersection as shown.



Since this image could be projected on to a screen it is a **REAL IMAGE** and real images **ALWAYS** are found on the **OPPOSITE** side of the lens from the object.

Likewise, virtual images would appear on the **SAME SIDE** as the object.

The characteristics in this case are still inverted and reduced.

Lenses – The Mirror/Lens Equation

To CALCULATE the image's position and characteristics you use the same equations you used for mirrors.

An object is placed 35 cm in front of a converging lens with focal length of 20 cm. Calculate the image's position relative to the lens as well as the image's characteristics.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad M = -\frac{d_i}{d_o}$$

$$\frac{1}{20} = \frac{1}{35} + \frac{1}{d_i} \quad M = -\frac{d_i}{35}$$

$$d_i = 46.7 \text{ cm} \quad M = -1.33x$$

This image is **REAL** (since the object distance is positive) and on the **OTHER** side of the lens. The image is **INVERTED** and **ENLARGED**.