# Refraction and Lenses

Honors Physics

# 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?
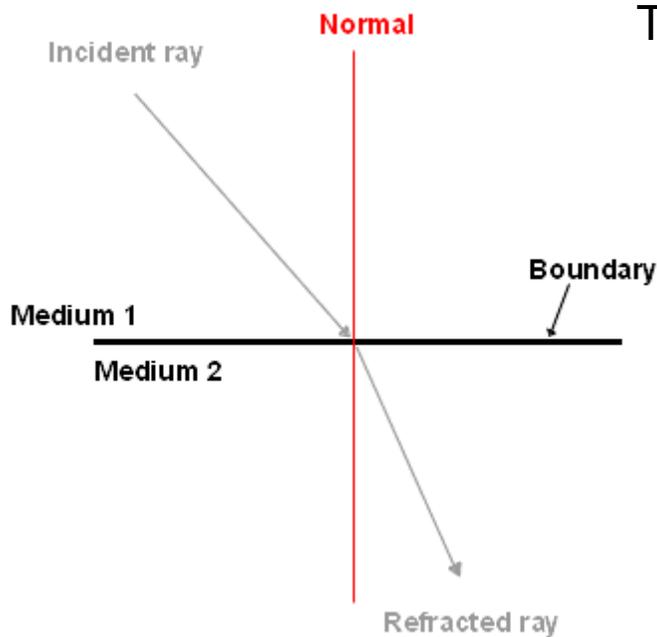
IT CHANGES!

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.

Normal

Incident ray

Boundary

Medium 1

Medium 2

Refracted ray

The ratio of the two speeds can be compared.

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

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.
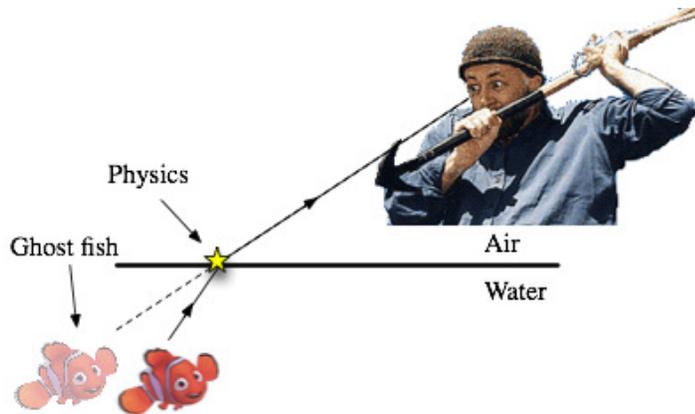


The cause of this is due to the fact that light BENDS when it reaches a new medium. The object is NOT directly in a straight line path, but rather it's image appears that way. The actual object is on either side of the image you are viewing.
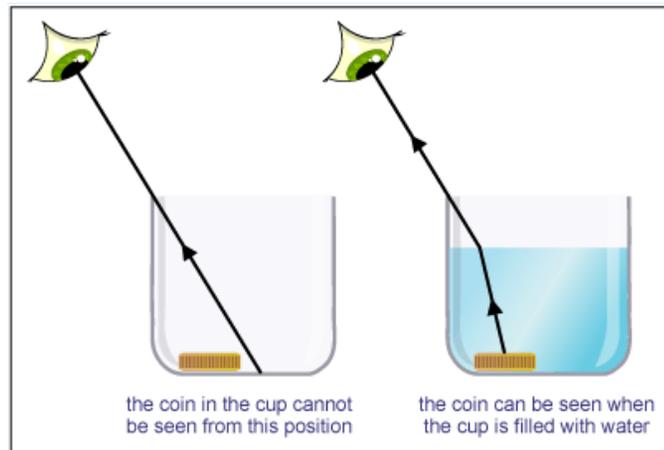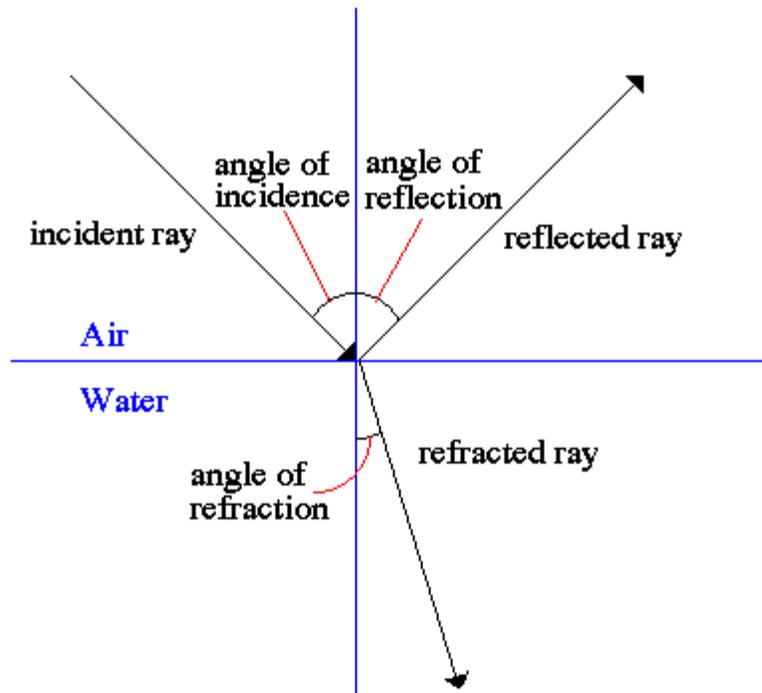
Refraction Fact #2: As light goes from one medium to another, the path CHANGES!

# 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

incident ray
angle of incidence
angle of reflection
reflected ray
Air
Water
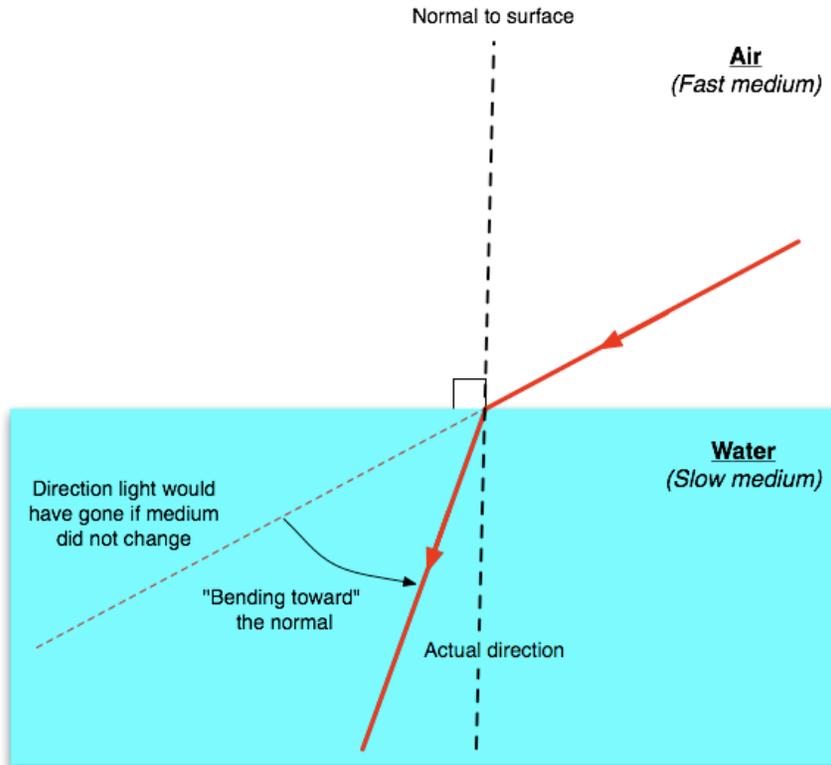angle of refraction
refracted ray

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

Angle of incidence = Angle of Reflection

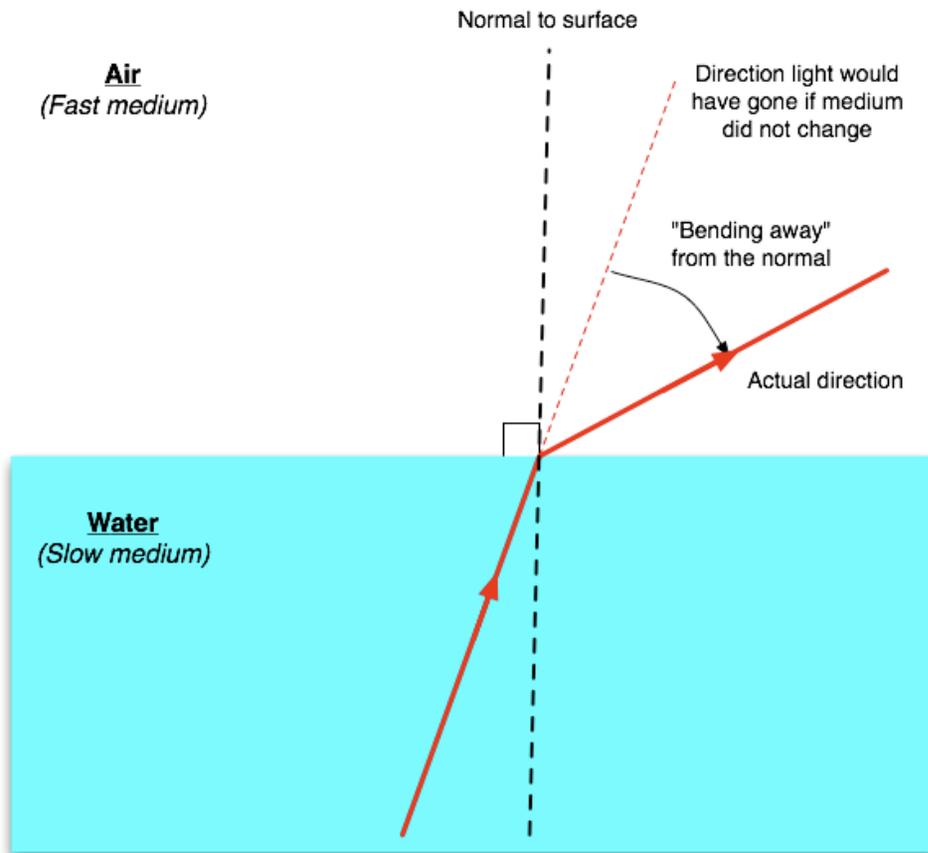Angle of Incidence > or < the Angle of refraction depending on the direction of the light

# Refraction – Going from Air to Water



The index of refraction, n, for air (vacumm) 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

**Normal to surface**

**Air**
*(Fast medium)*

Direction light would have gone if medium did not change

"Bending away" from the normal

Actual direction

**Water**
*(Slow medium)*
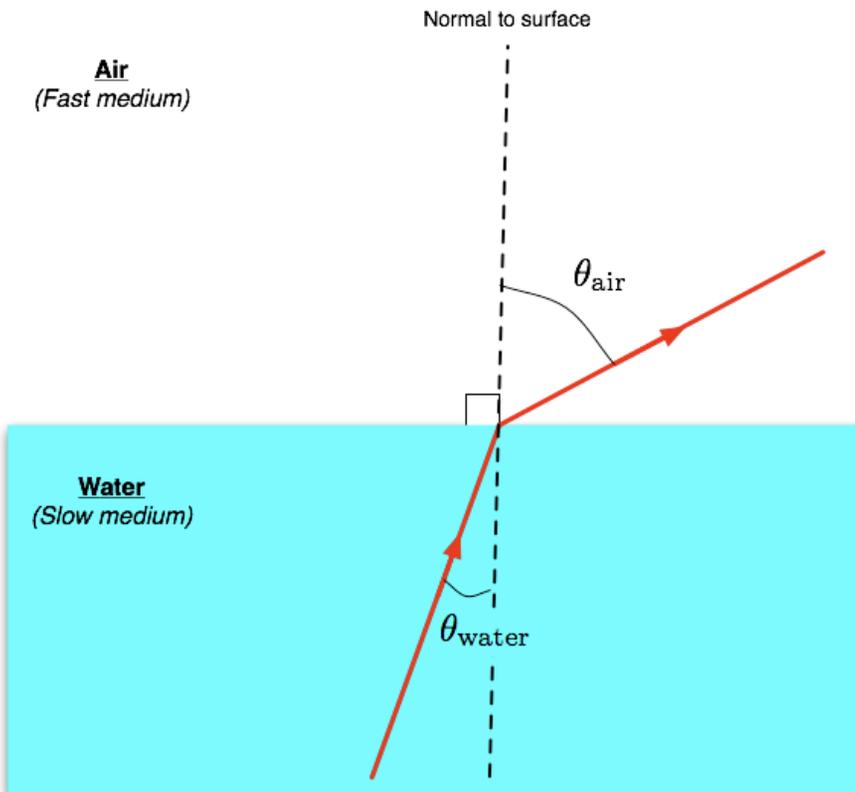
The index of refraction, n, for air (vacumm) is equal to 1. The index of refraction for water is 1.33.

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!

Normal to surface

**Air**
*(Fast medium)*

$\theta_{air}$

**Water**
*(Slow medium)*

$\theta_{water}$

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta 1}$$

$$Snell's\ Law$$

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

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

# 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.
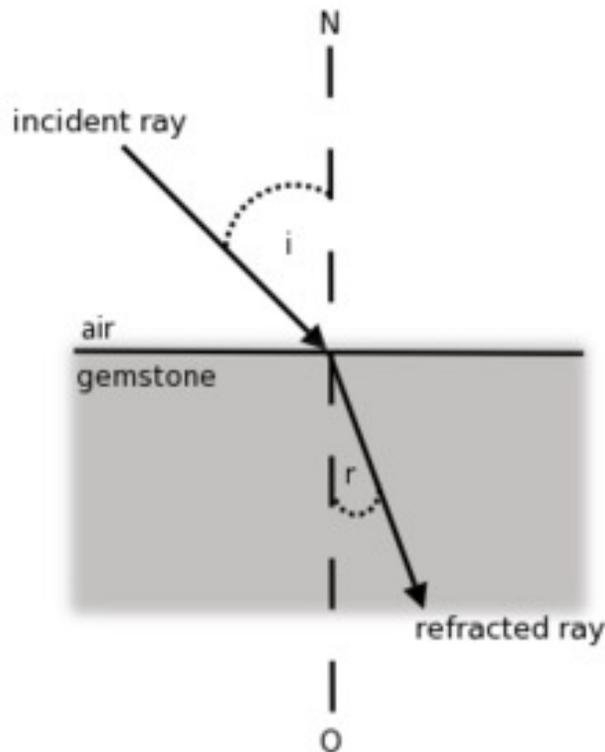


Calculate the SPEED of light in Aquamarine

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

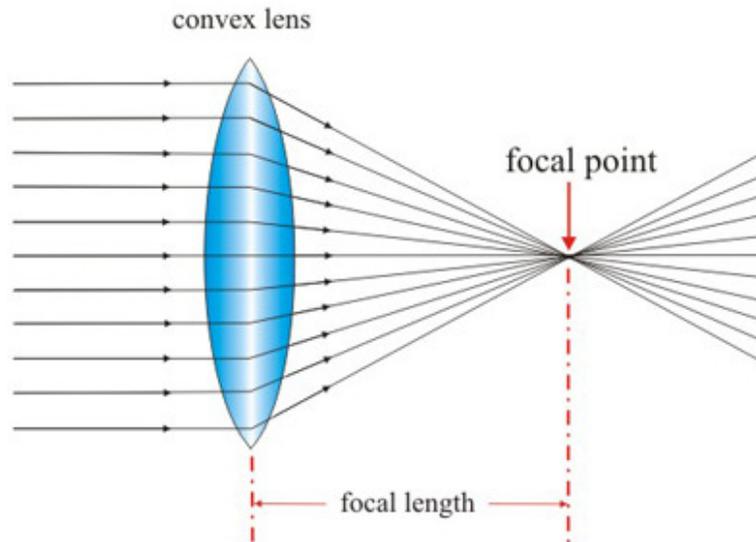$v_m = $ **1.90 x 10⁸ m/s**

Calculate the angle of refraction within Aquamarine

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

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

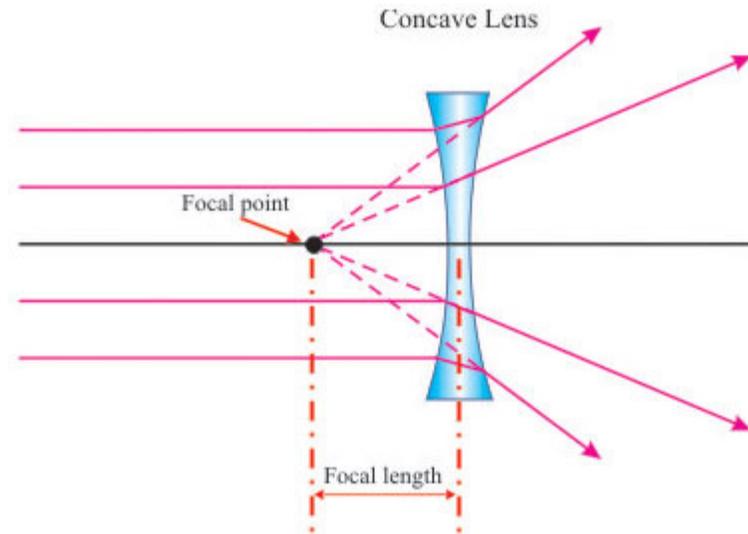$$\theta = \sin^{-1}(\frac{\sin 23}{1.577}) = \quad \textbf{14.34 degrees}$$

# Lenses – An application of refraction

## There are 2 basic types of lenses



**convex lens**

focal point

focal length

**Concave Lens**

Focal point

Focal length

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.
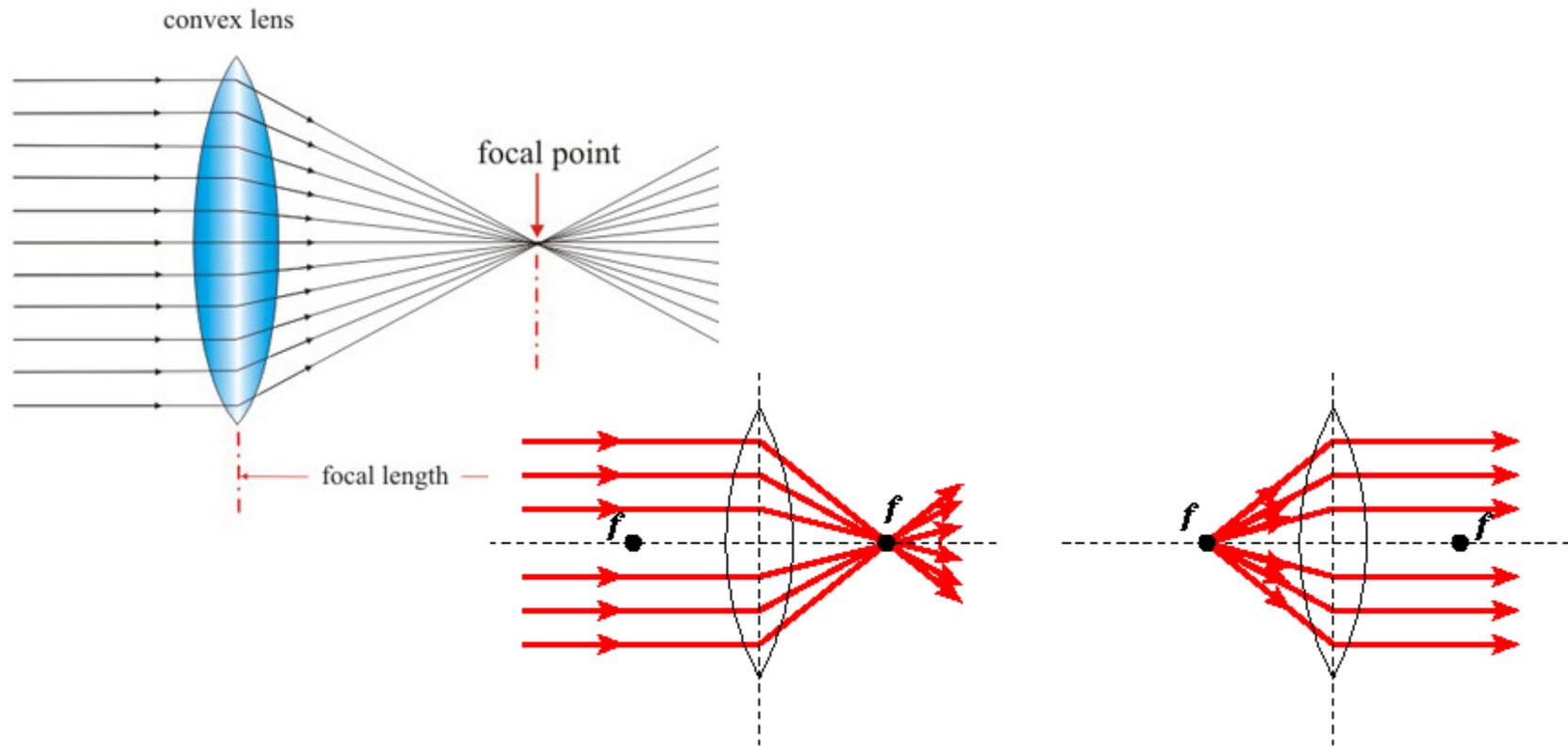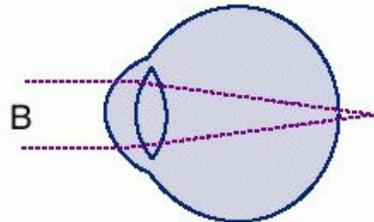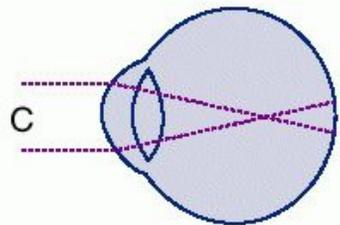
# Applications of Converging Lenses

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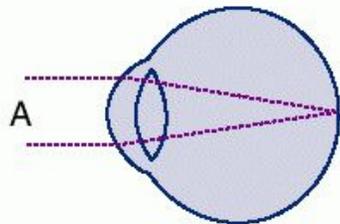
In figure A, we see an eye which converges what we see on the retina.

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.
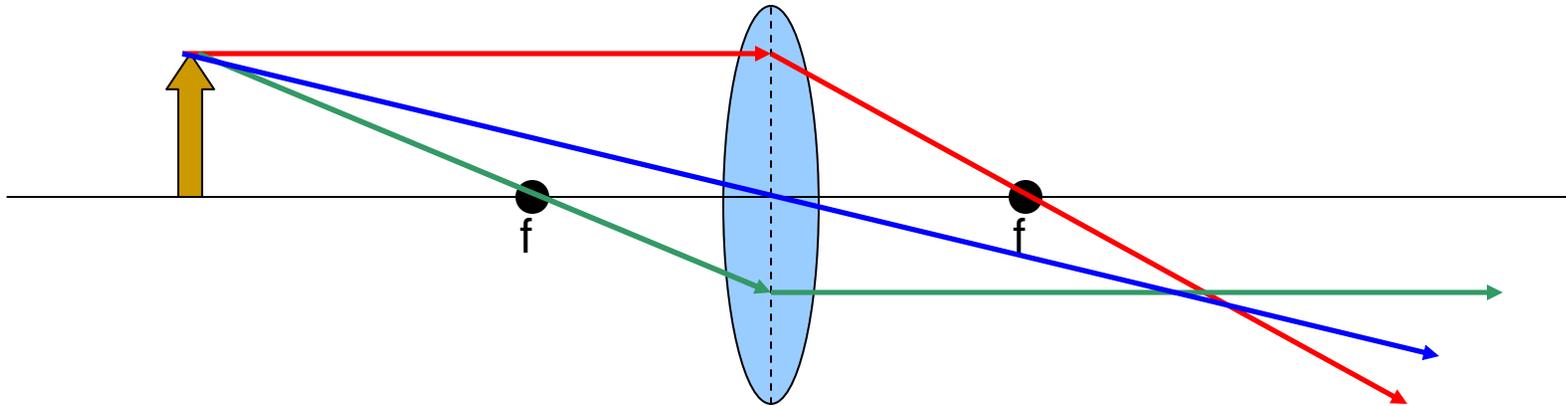
# Applications of Converging Lenses
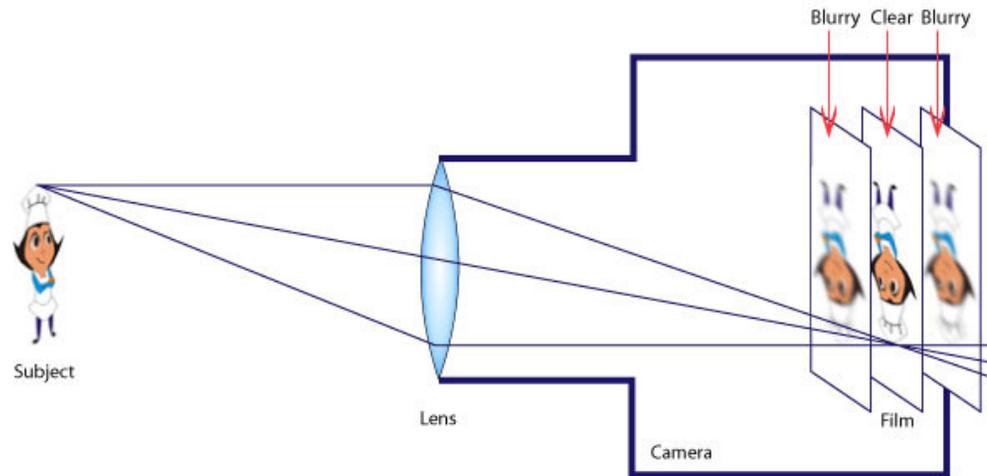


A camera uses a lens to focus an image on photographic film.

# 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.
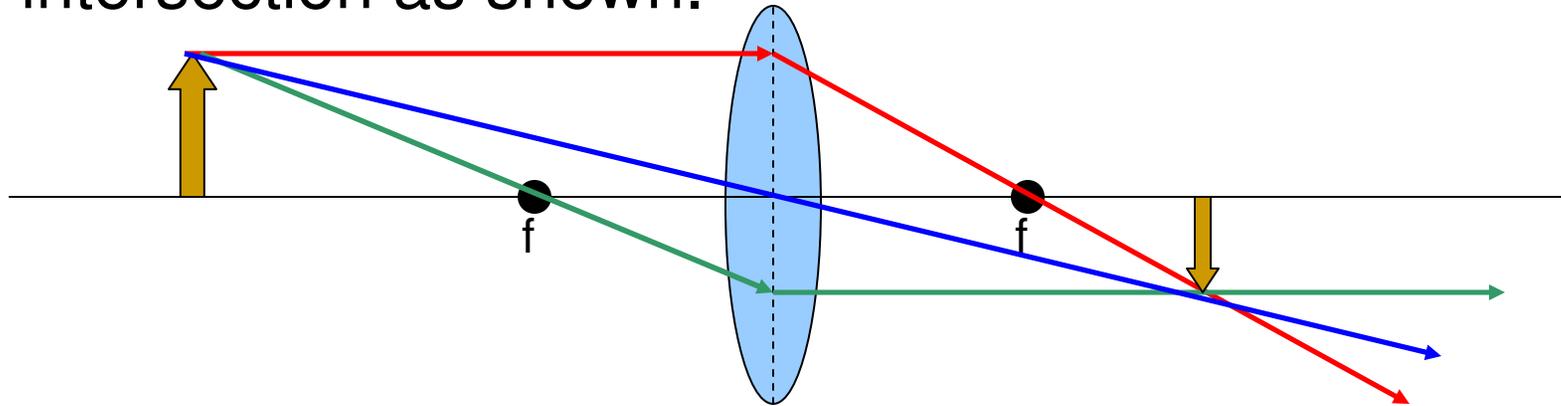Rule #2: Draw a ray, starting from the top of the object, through "f", then parallel to the principal axis, after refraction.
Rule #3: Draw a ray through the center of the lens.

# 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.

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

$$M = -\frac{d_i}{d_o}$$

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

$$\frac{1}{20} = \frac{1}{35} + \frac{1}{d_i}$$

$$M = -\frac{d_i}{35}$$

$$d_i = \text{46.7 cm}$$

$$M = \text{-1.33x}$$