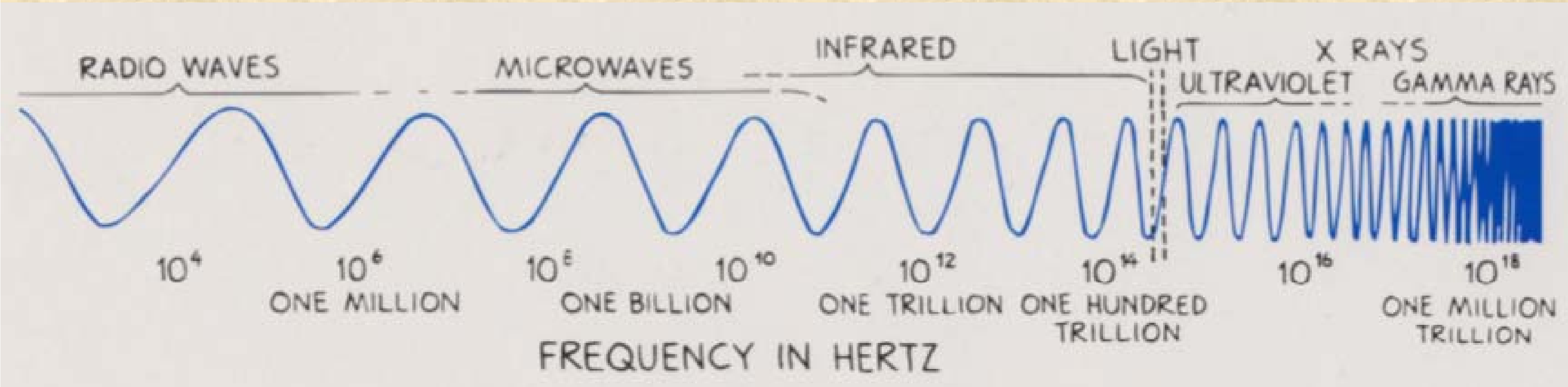
Science Olympiad

Optics

Color and Shadows

The Electromagnetic Spectrum.

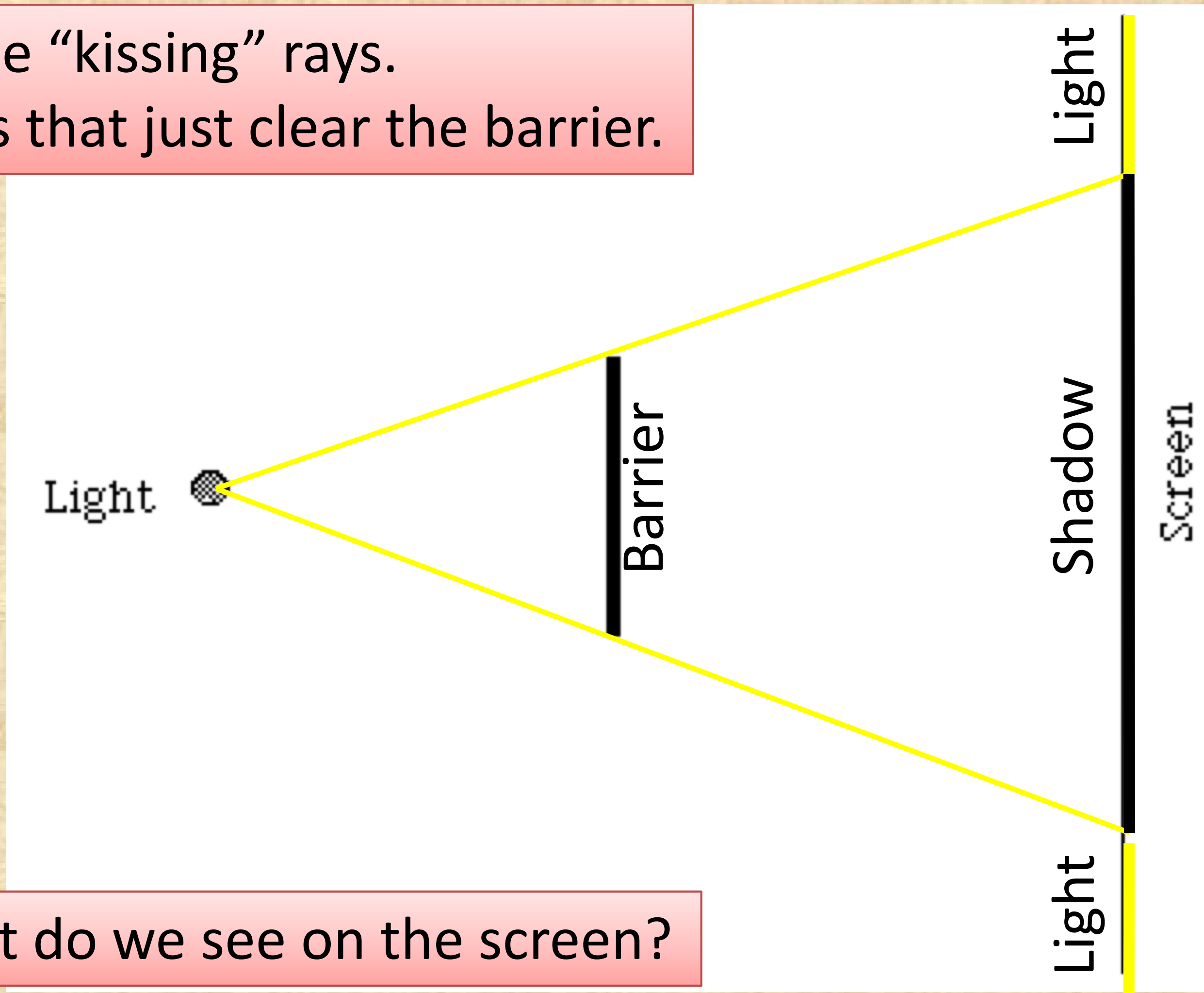


Behavior of Light: Shadows - One Light Bulb

Use rays to predict what one would observe if there was one light source.

Draw the “kissing” rays.

The rays that just clear the barrier.

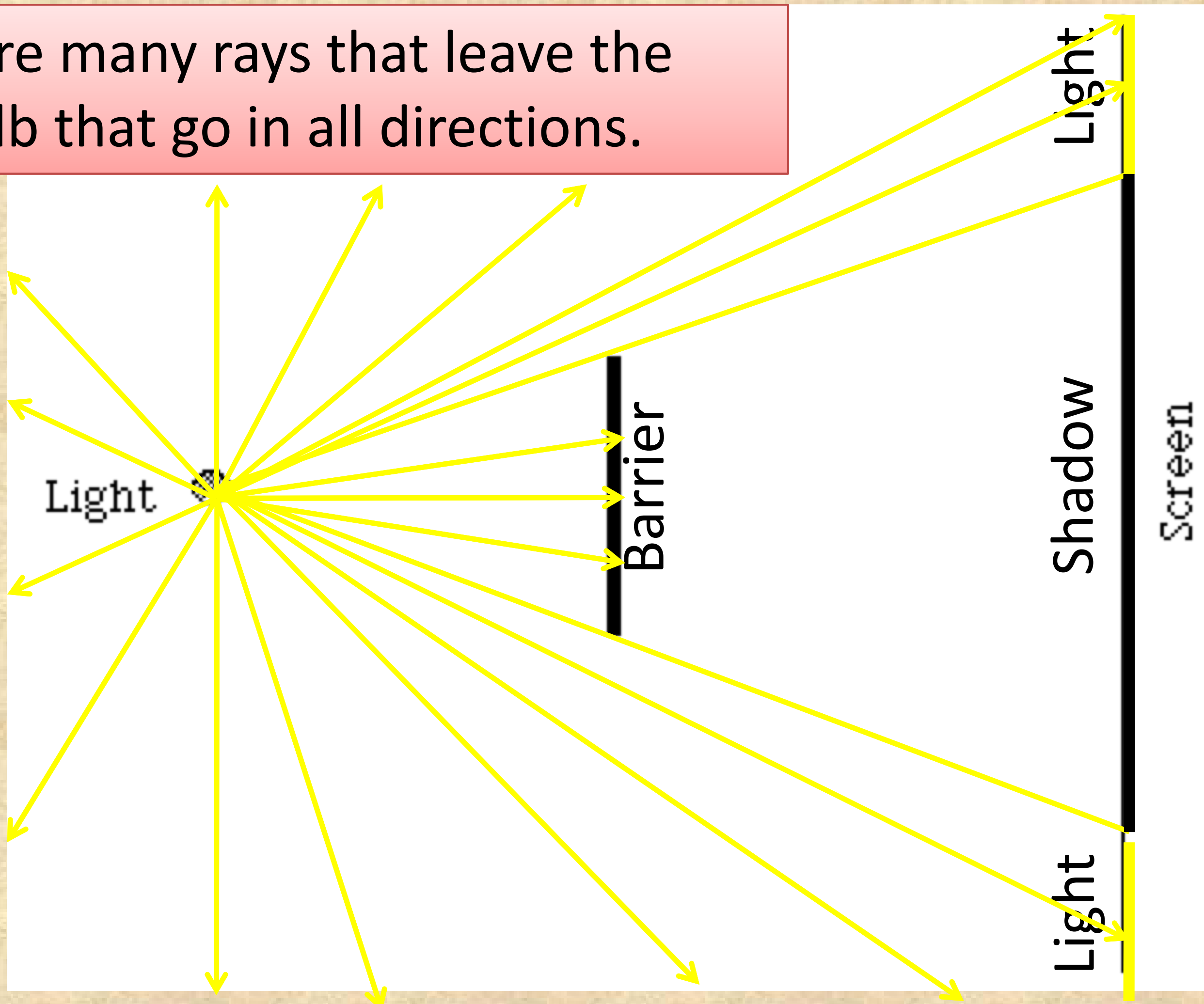


So, what do we see on the screen?

Behavior of Light: Shadows - One Light Bulb

Use rays to predict what one would observe if there was one light source.

There are many rays that leave the light bulb that go in all directions.

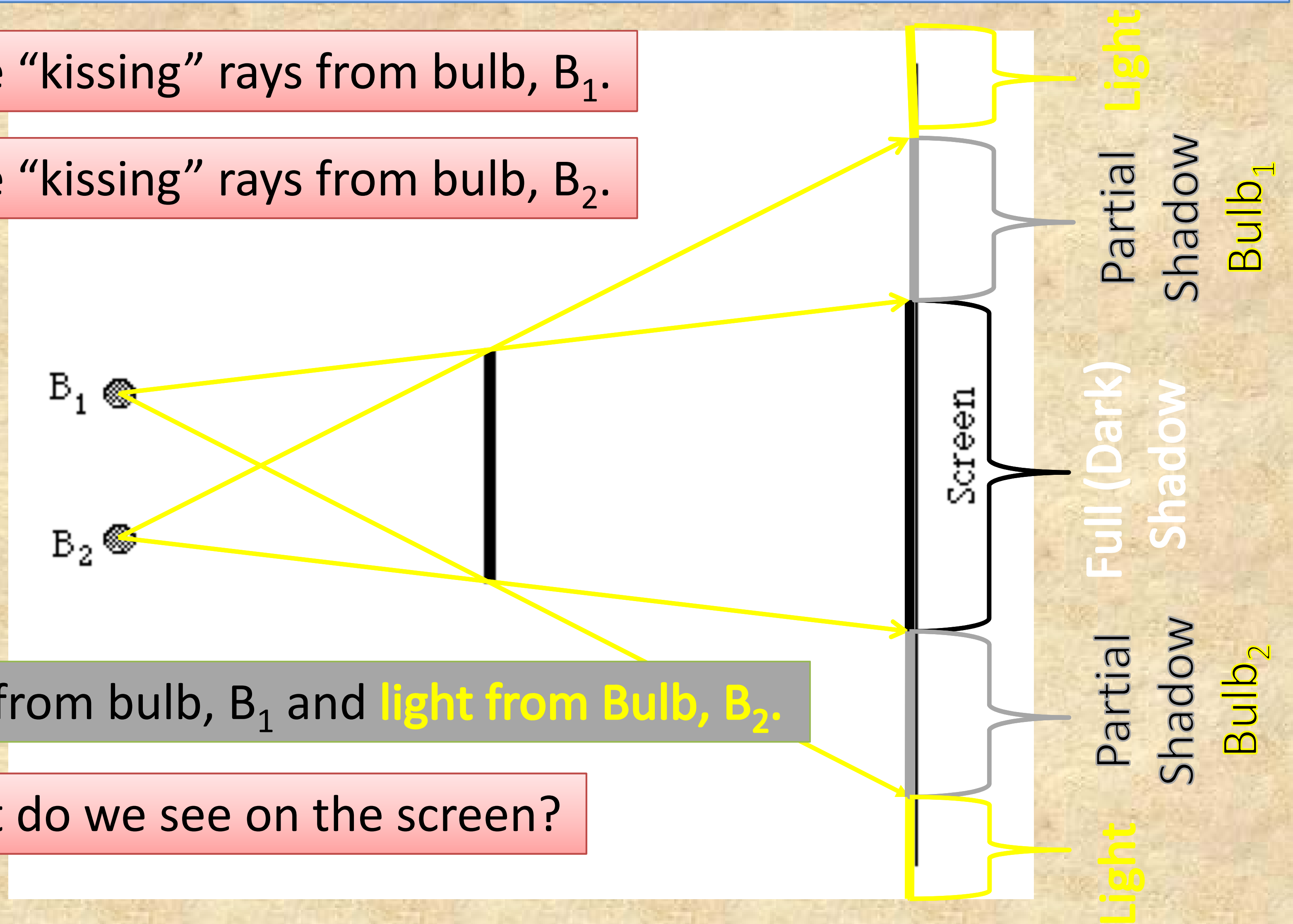


Behavior of Light - Two Light Bulbs

Use rays to predict what one would observe if there were two light sources.

Draw the "kissing" rays from bulb, B_1.

Draw the "kissing" rays from bulb, B_2.

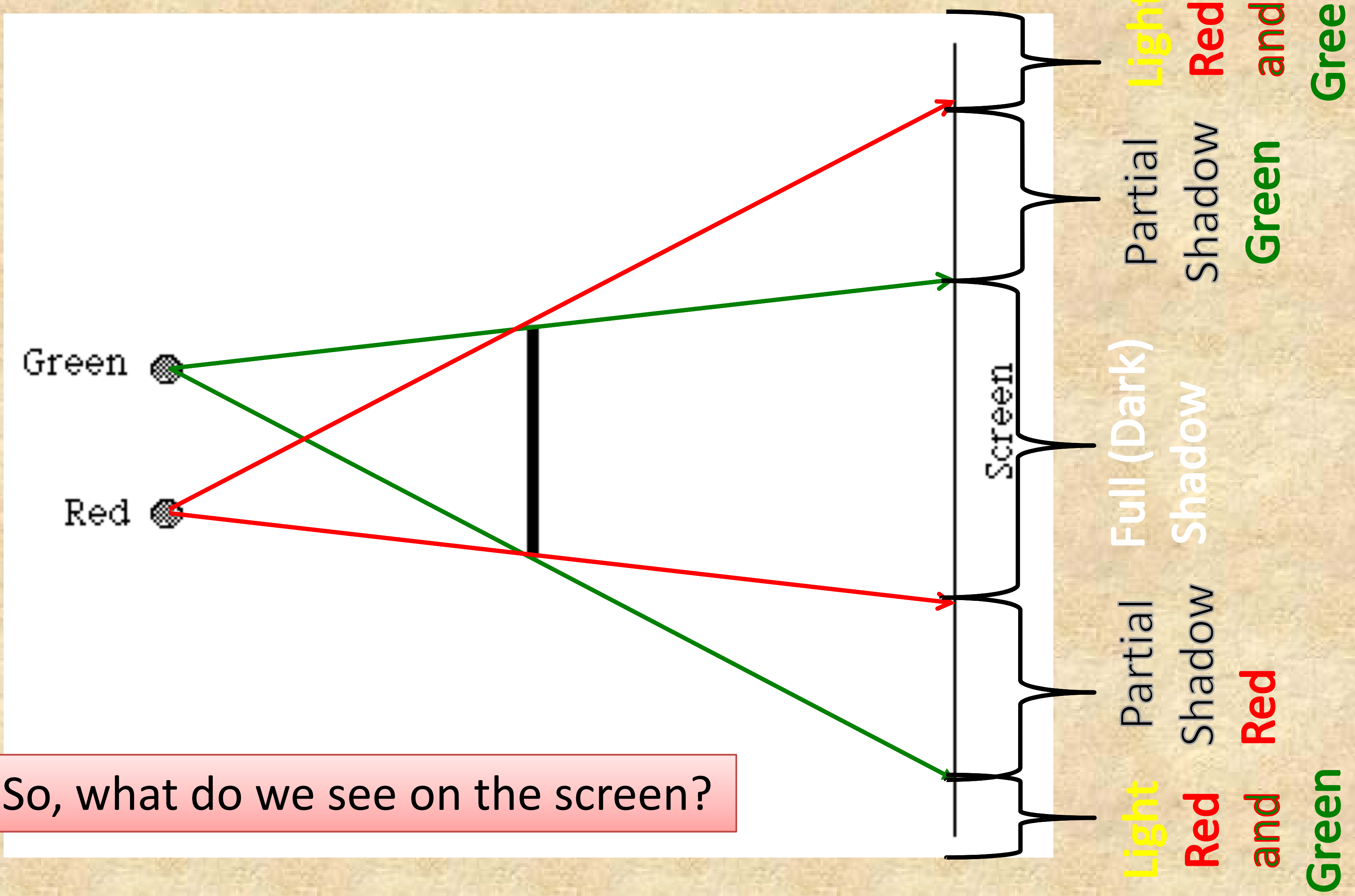


Shadow from bulb, B_1 and **light from Bulb, B_2.**

So, what do we see on the screen?

Behavior of Light - Two Light Bulbs

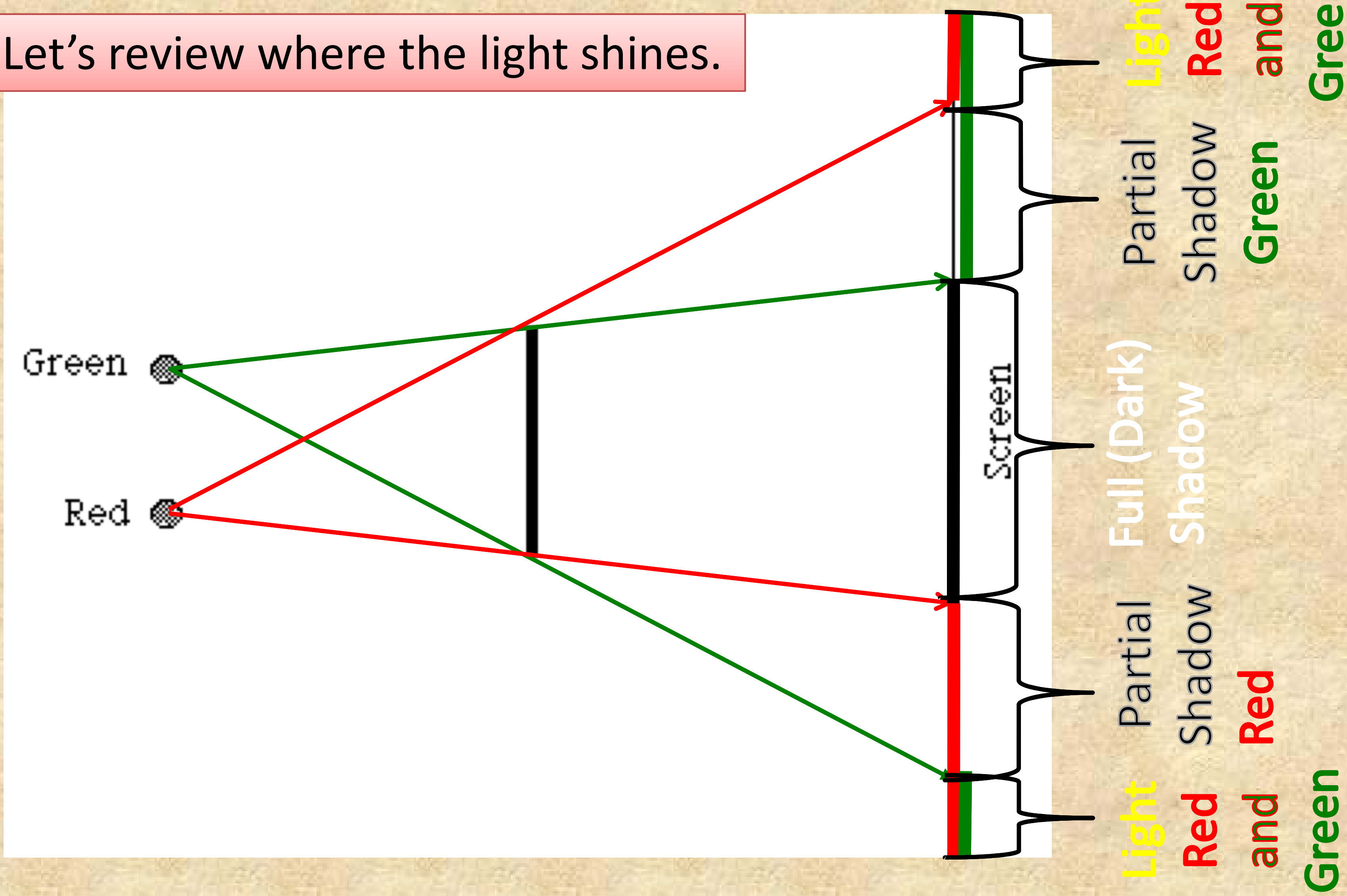
Use rays to predict what one would observe if there were two light sources of different colors.



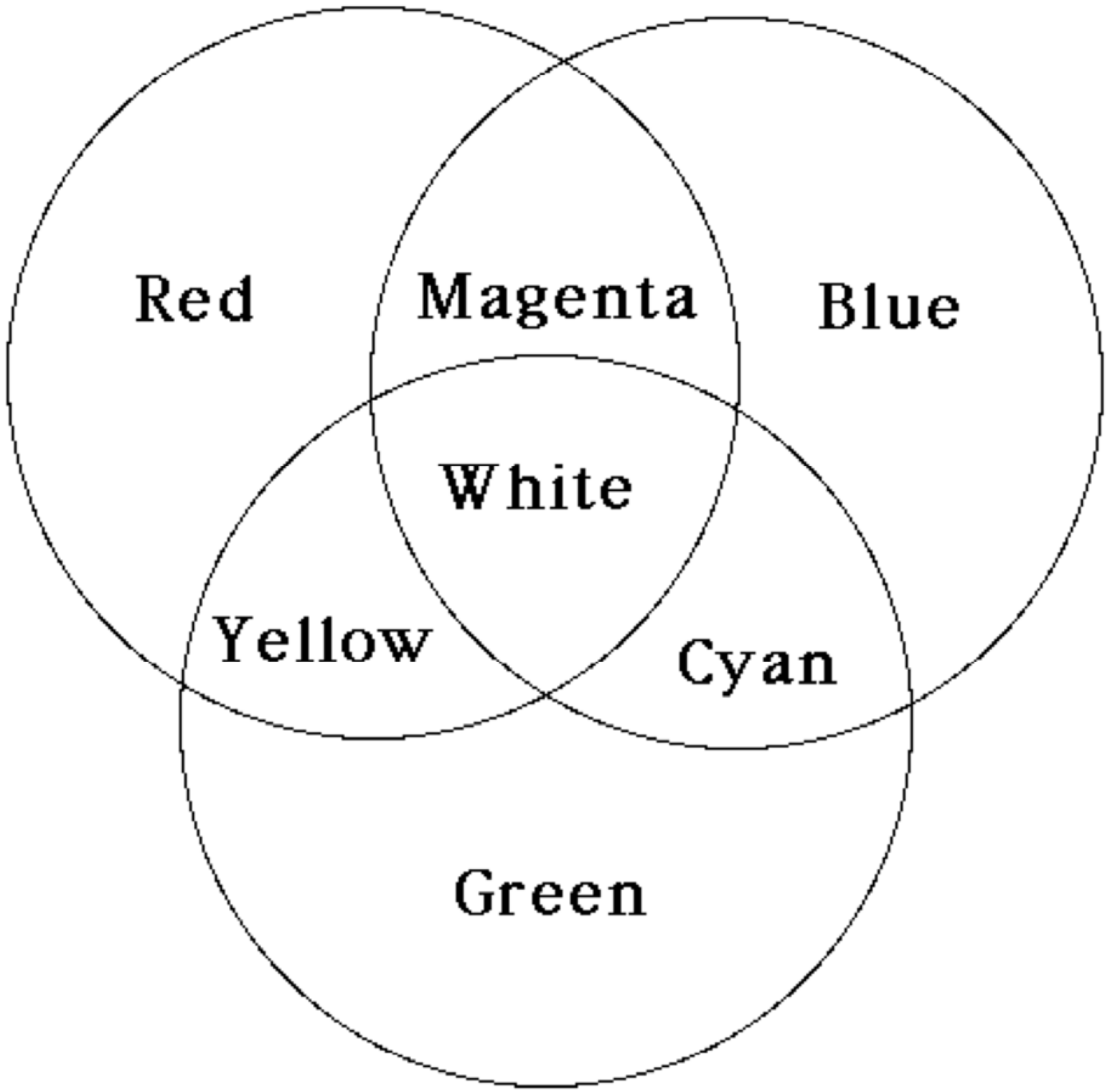
So, what do we see on the screen?

Behavior of Light - Two Light Bulbs
Use rays to predict what one would observe if there were two light sources of different colors.

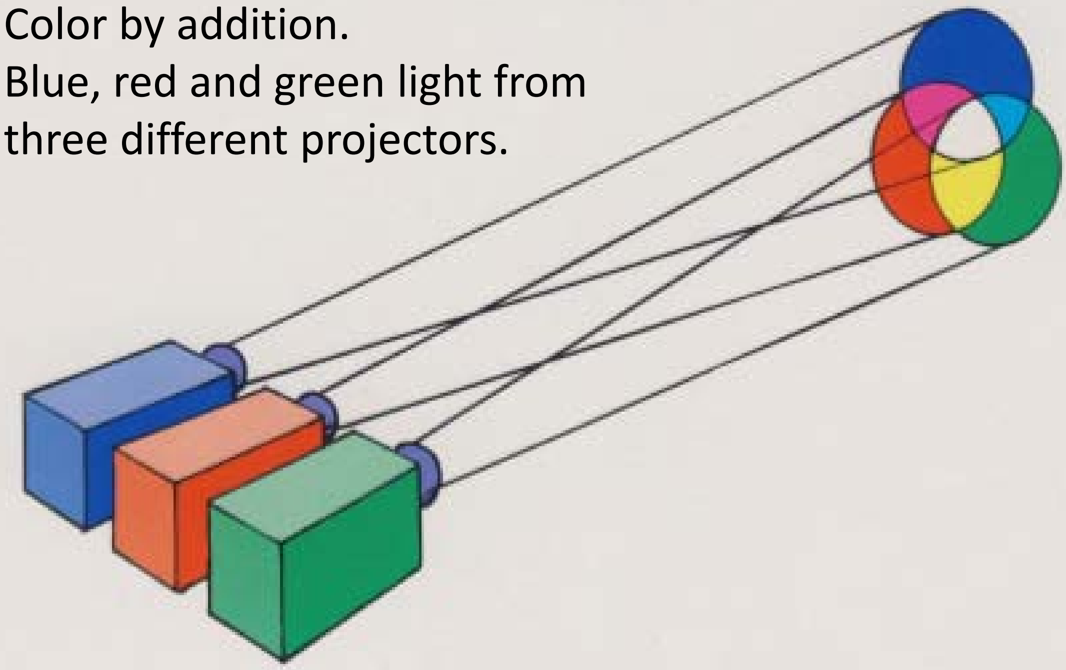
Let's review where the light shines.



Color By Addition. ~ Light!



Color by addition.
Blue, red and green light from three different projectors.

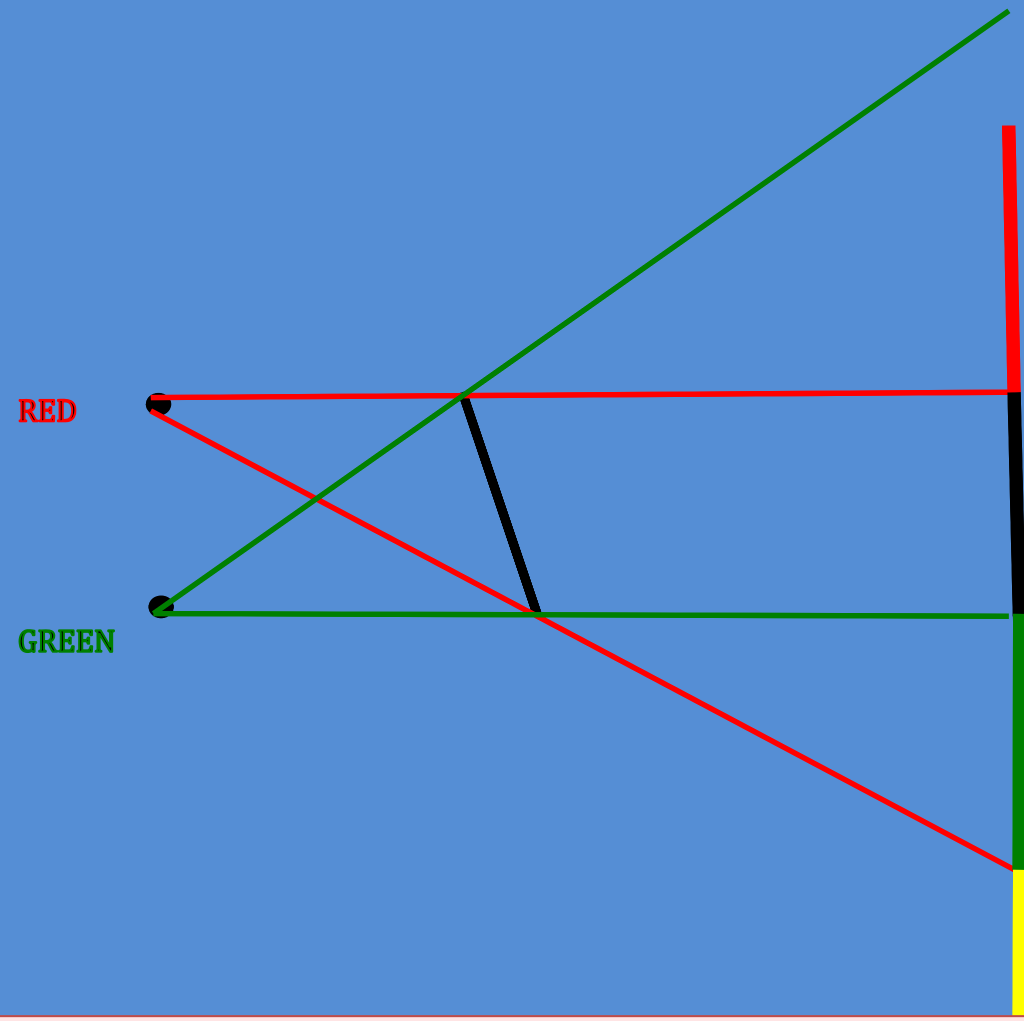


RED + GREEN = YELLOW

RED + BLUE = MAGENTA

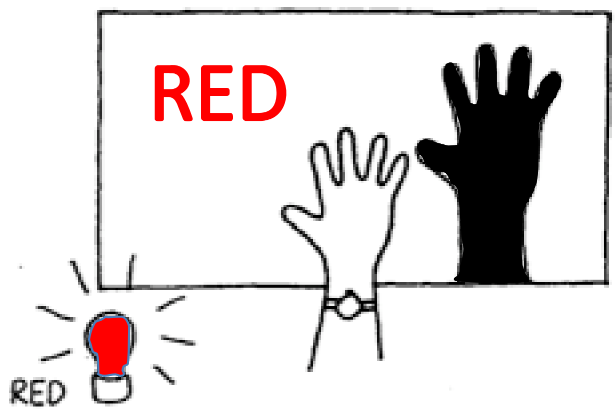
BLUE + GREEN = CYAN

RED + BLUE + GREEN = WHITE



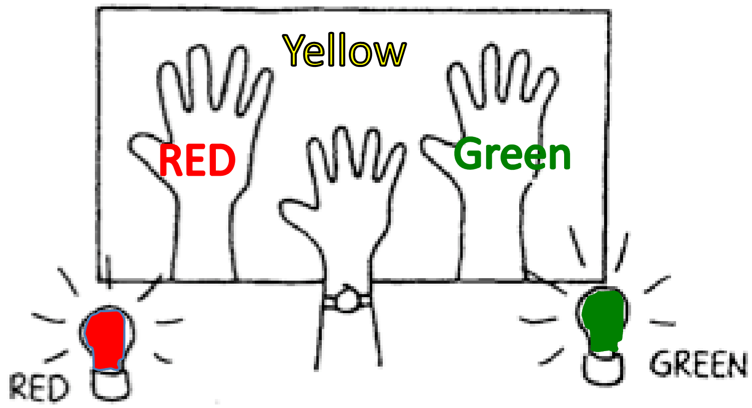
Now you try this one and then I will show you the results.

1. The sketch shows the shadow of your hand held in front of a white screen in a darkened room. The light source is red, so the screen looks red and the shadow looks black. Color the sketch with colored markers, or label the colors with pen or pencil.

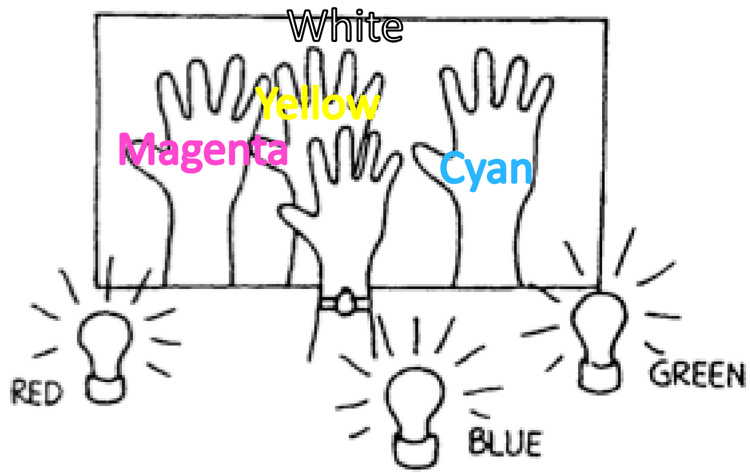


SHADOW

2. A green lamp is turned on and makes a second shadow. The formerly black shadow cast by the red light is no longer black, but is illuminated with green light. So it is green. Color or mark it green. The shadow cast by the green lamp is not black, because it is illuminated with the red light. Color or mark its color. The background receives a mixture of red and green light. Figure out what color the background will appear, then color or label it.



3. A blue lamp is turned on and three shadows of your hand appear. Color or label the appropriate colors of the shadows and the background.

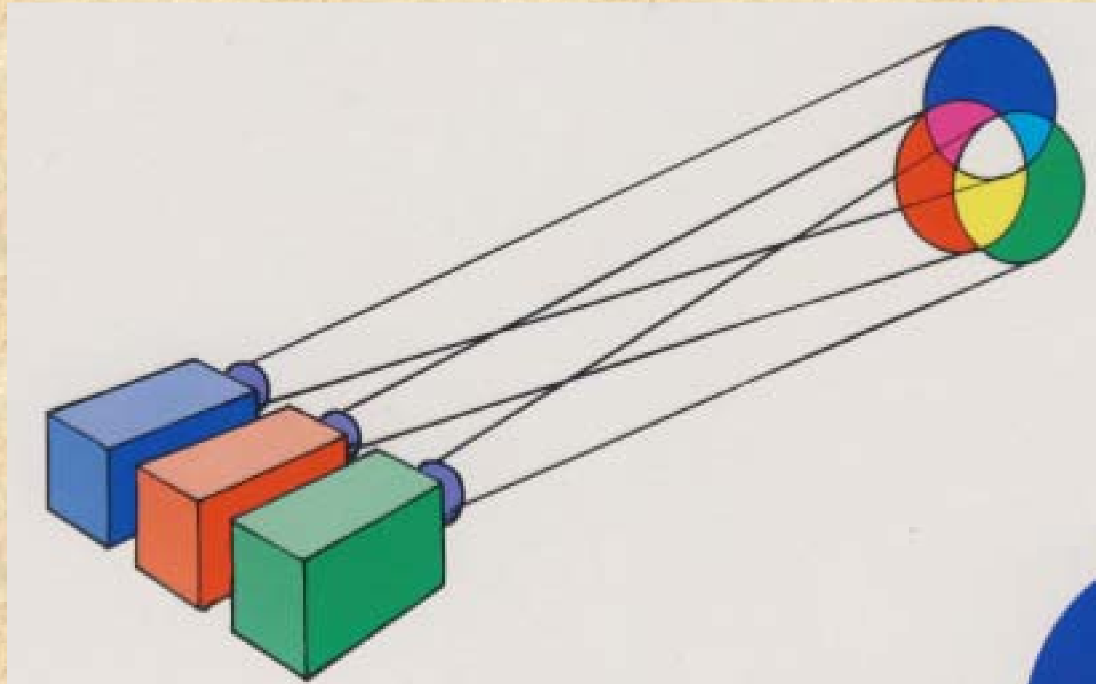


RED + BLUE = MAGENTA

RED + GREEN = YELLOW

BLUE + GREEN = CYAN

RED + BLUE + GREEN = WHITE



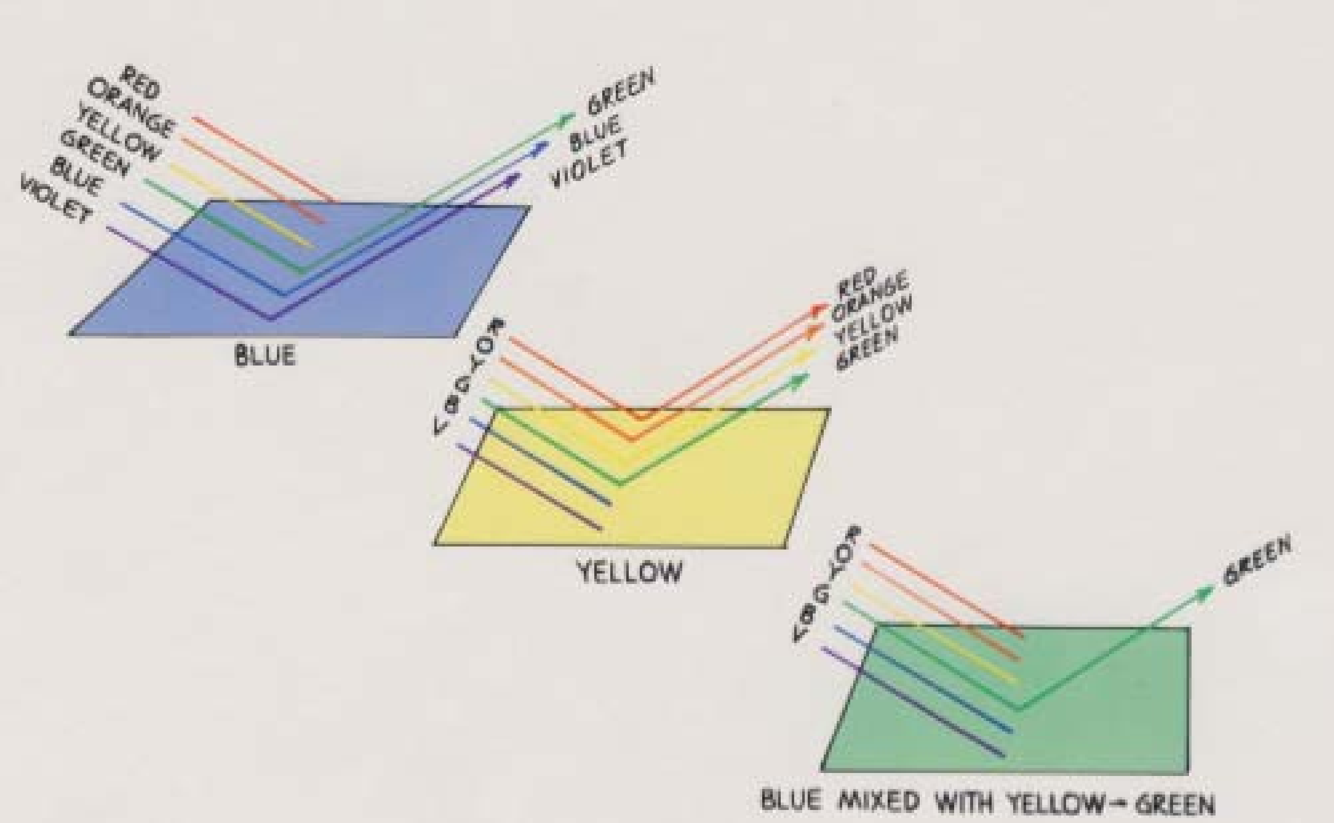



Table 28.1 Color Subtraction

Pigment	Absorbs	Reflects
red	blue, green	red
green	blue, red	green
blue	red, green	blue
yellow	blue	red, green
cyan	red	green, blue
magenta	green	red, blue

Science Olympiad

Ray Optics

Reflection

Lab - Reflection - Law of Reflection Part 1

Where does the reflection of something appear? Select what you think is correct.

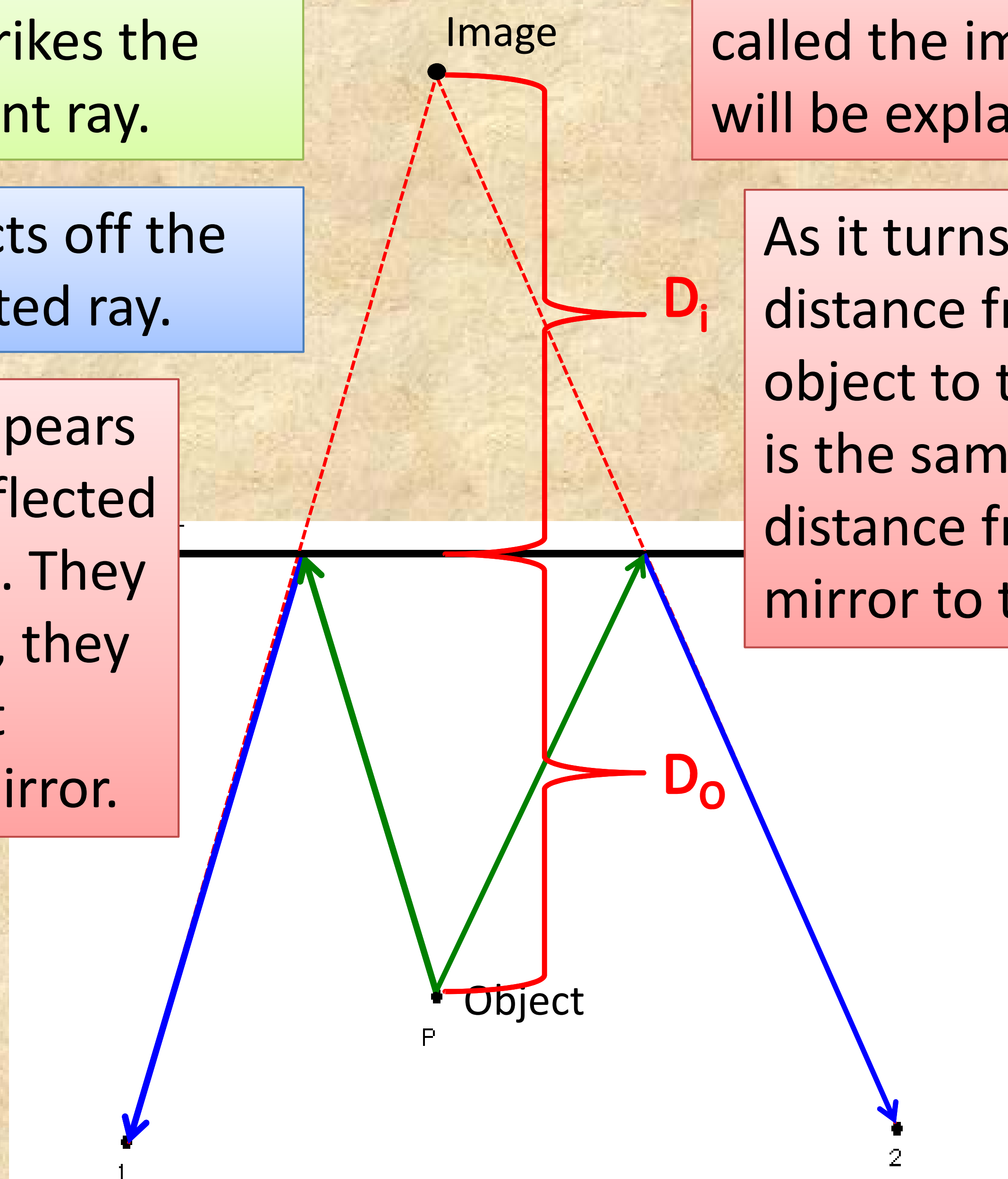
a) In front of the mirror.
b) On the mirror.
c) Behind the mirror.
d) In the mirror.

When you look in a mirror where does the reflection appear?

A ray of light leaves the object and strikes the mirror, incident ray.

The ray reflects off the mirror, reflected ray.

The image appears where the reflected rays intersect. They are diverging, they only intersect behind the mirror.



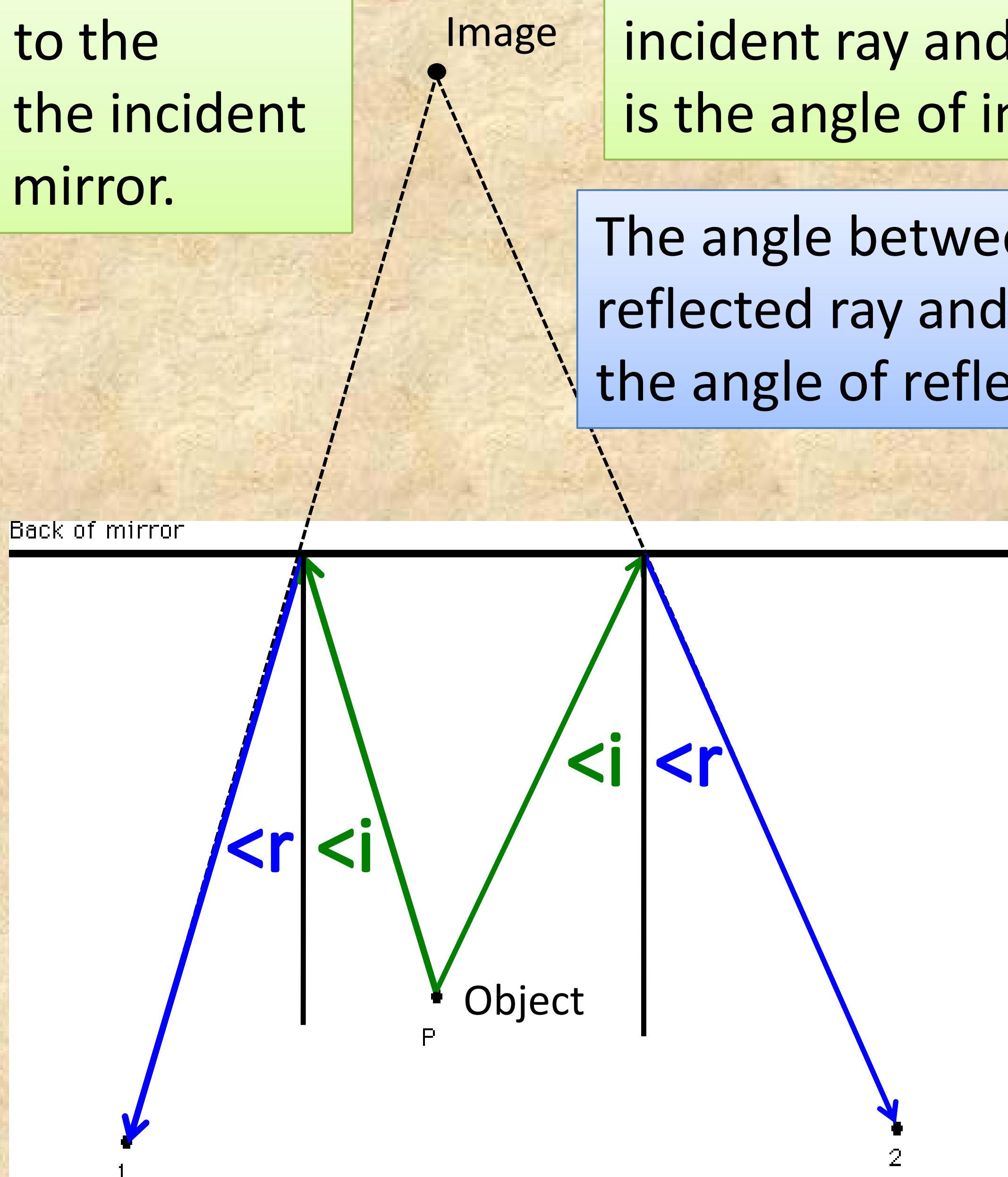
Where they intersect is called the image. More will be explained later.

As it turns out, the distance from the object to the mirror, D_o, is the same as the distance from the mirror to the object, D_i.

Draw a normal (line perpendicular to the mirror) where the incident ray strikes the mirror.

The angle between the incident ray and the normal is the angle of incidence, <i.

The angle between the reflected ray and the normal is the angle of reflection, <r.



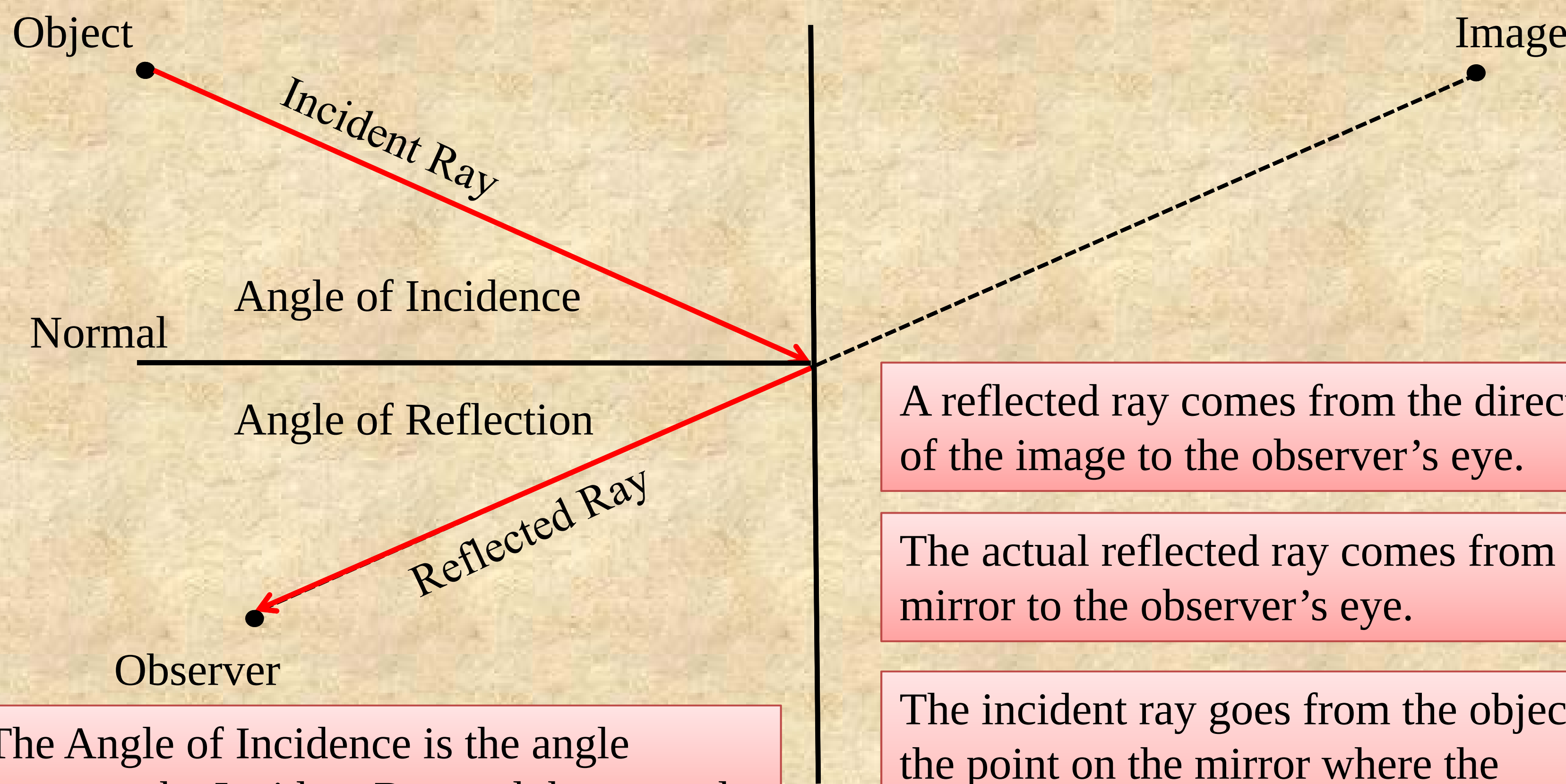
Law of Reflection

The angle of incidence equals the angle of reflection.   <i = <r

The incident ray, the reflected ray and the normal line to the point of reflection all lie in the same plane.

In other words, the angle of incidence and the angle of reflection lie in the same plane.

1. Locating objects in a plane mirror. A geometric analysis.



A reflected ray comes from the direction of the image to the observer's eye.

The actual reflected ray comes from the mirror to the observer's eye.

The incident ray goes from the object to the point on the mirror where the reflected ray touches the mirror.

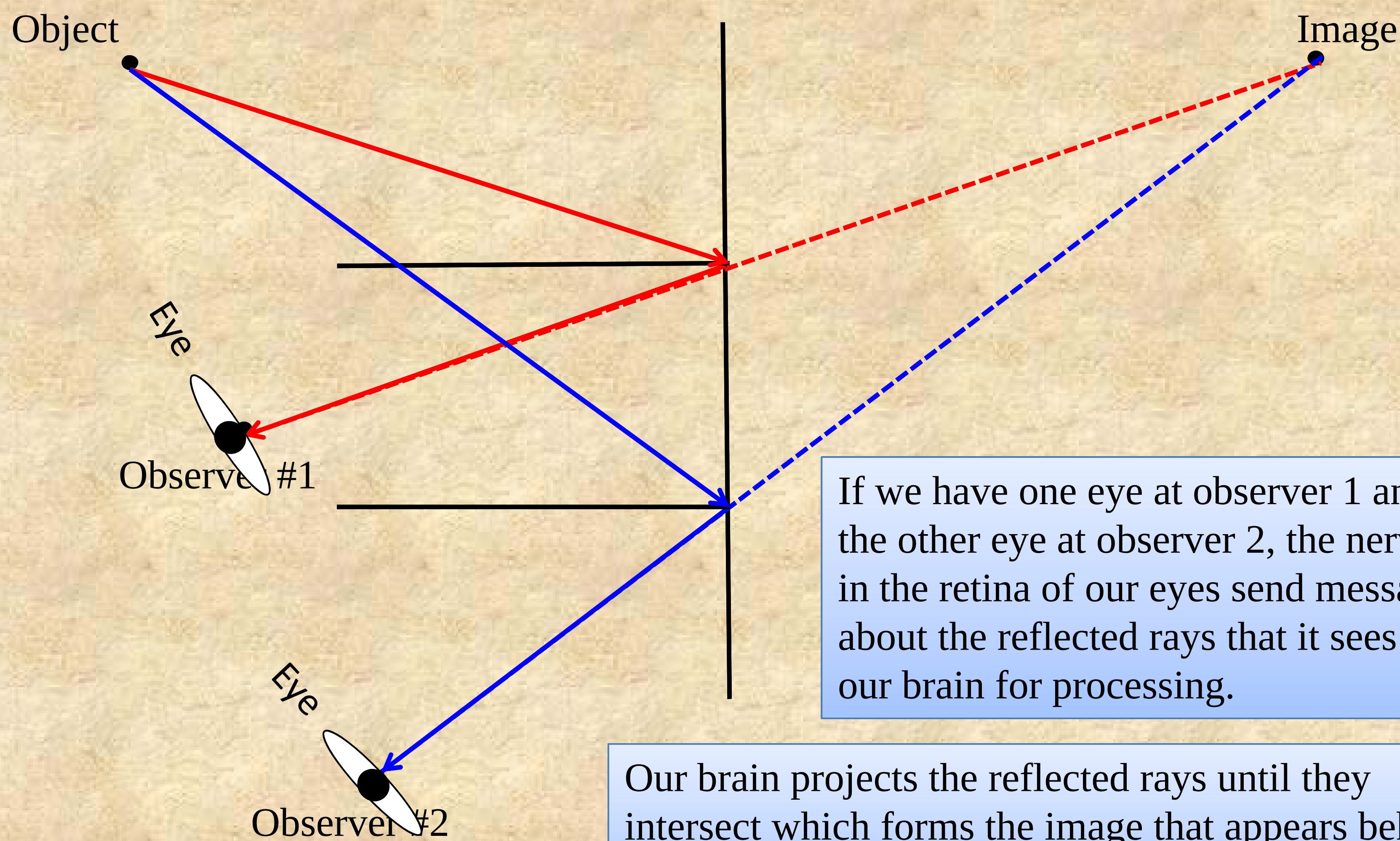
The Angle of Incidence is the angle between the Incident Ray and the normal.

The Angle of Reflection is the angle between the Reflected Ray and the normal.

The normal is drawn perpendicular to the mirror where the incident ray and reflected ray meet.

2. Seeing objects in a mirror. A geometric analysis.

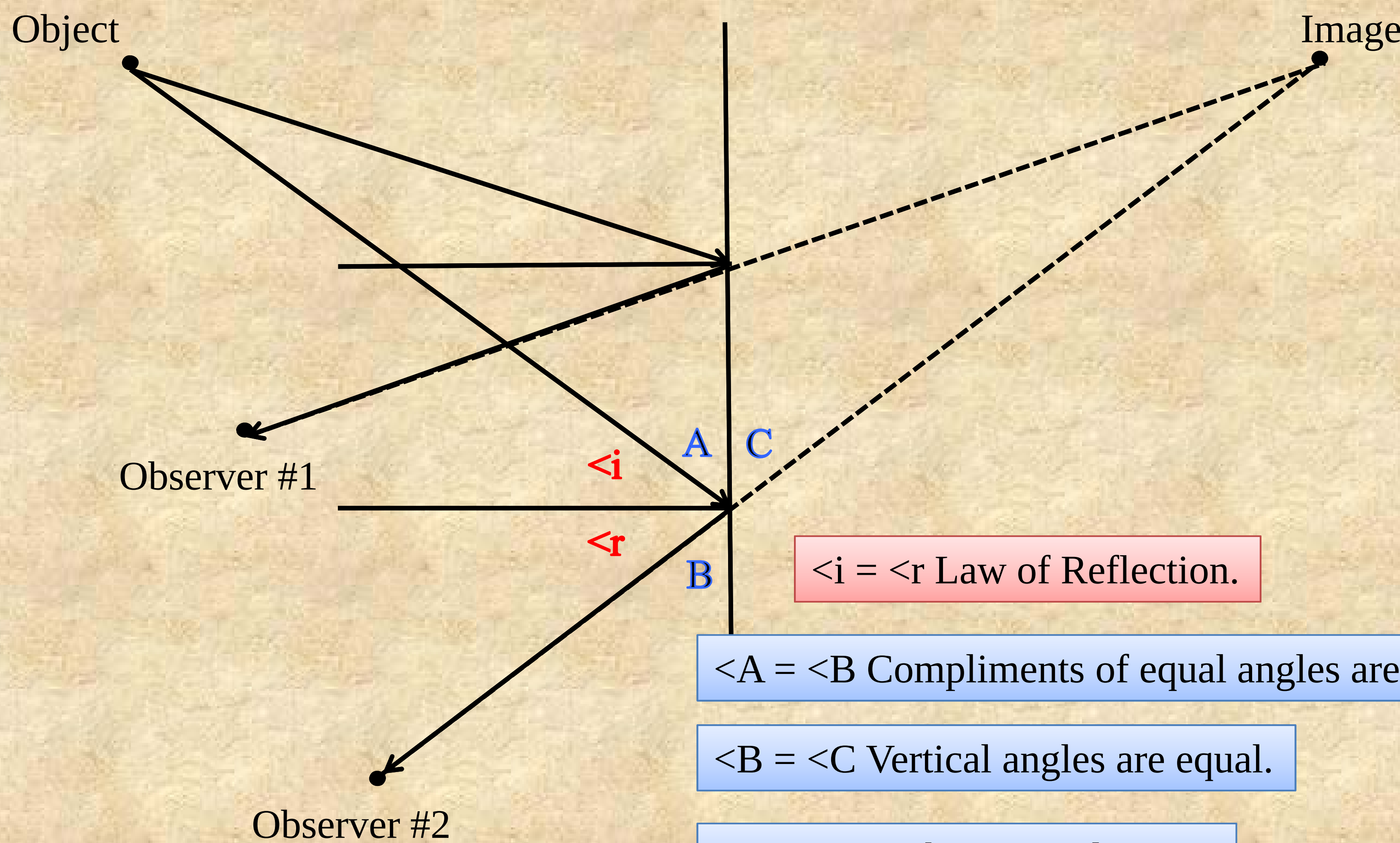
What makes the image appear behind the mirror? There are no rays of light back there.



If we have one eye at observer 1 and the other eye at observer 2, the nerves in the retina of our eyes send messages about the reflected rays that it sees to our brain for processing.

Our brain projects the reflected rays until they intersect which forms the image that appears behind the mirror..

2. Seeing objects in a mirror. A geometric analysis.



<i = <r Law of Reflection.

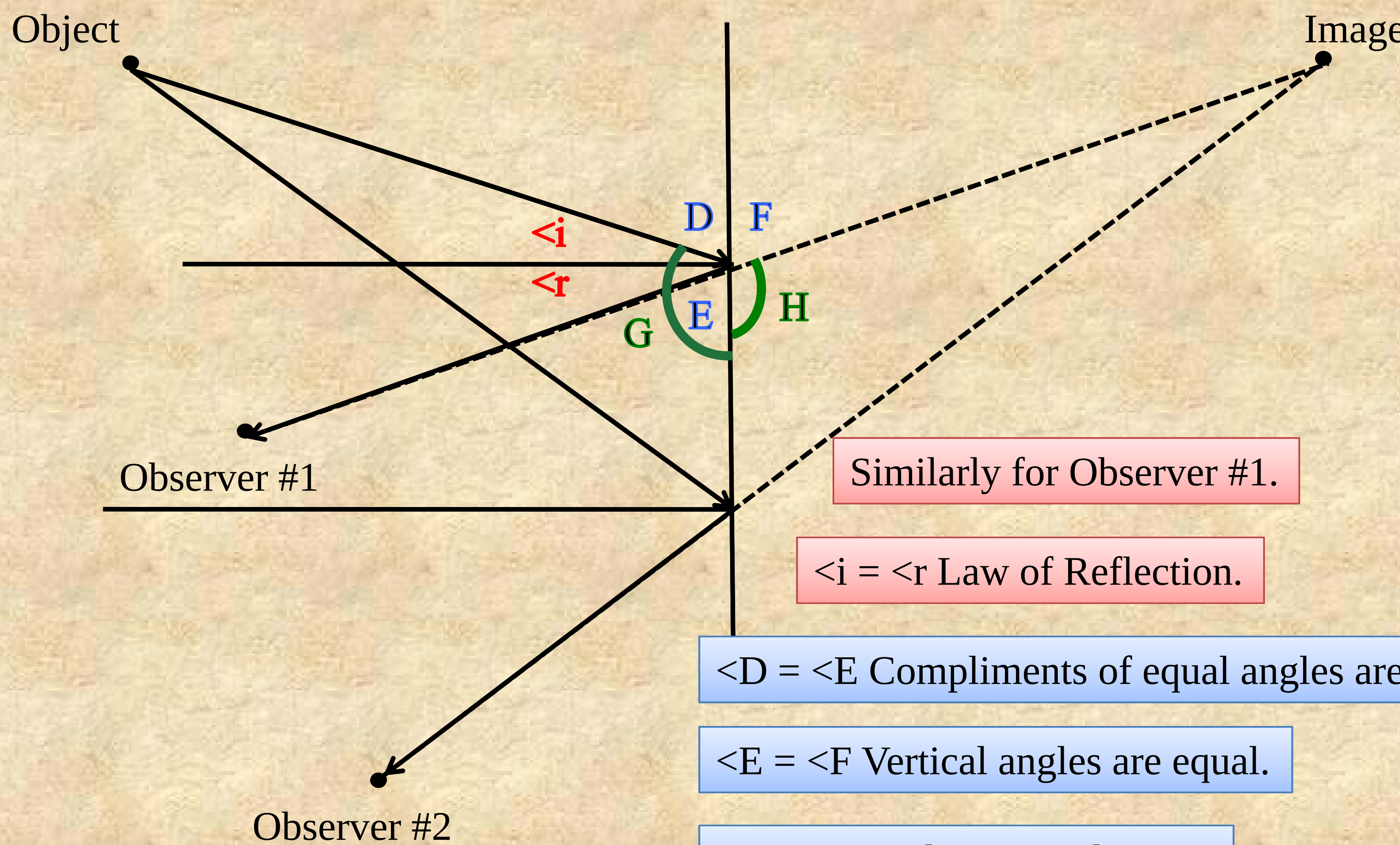
<A = <B Compliments of equal angles are equal.

<B = <C Vertical angles are equal.

<A = <C Both are equal to <B.

2. Seeing objects in a mirror. A geometric analysis.

<G = <H Supplements of equal angles are equal.



Similarly for Observer #1.

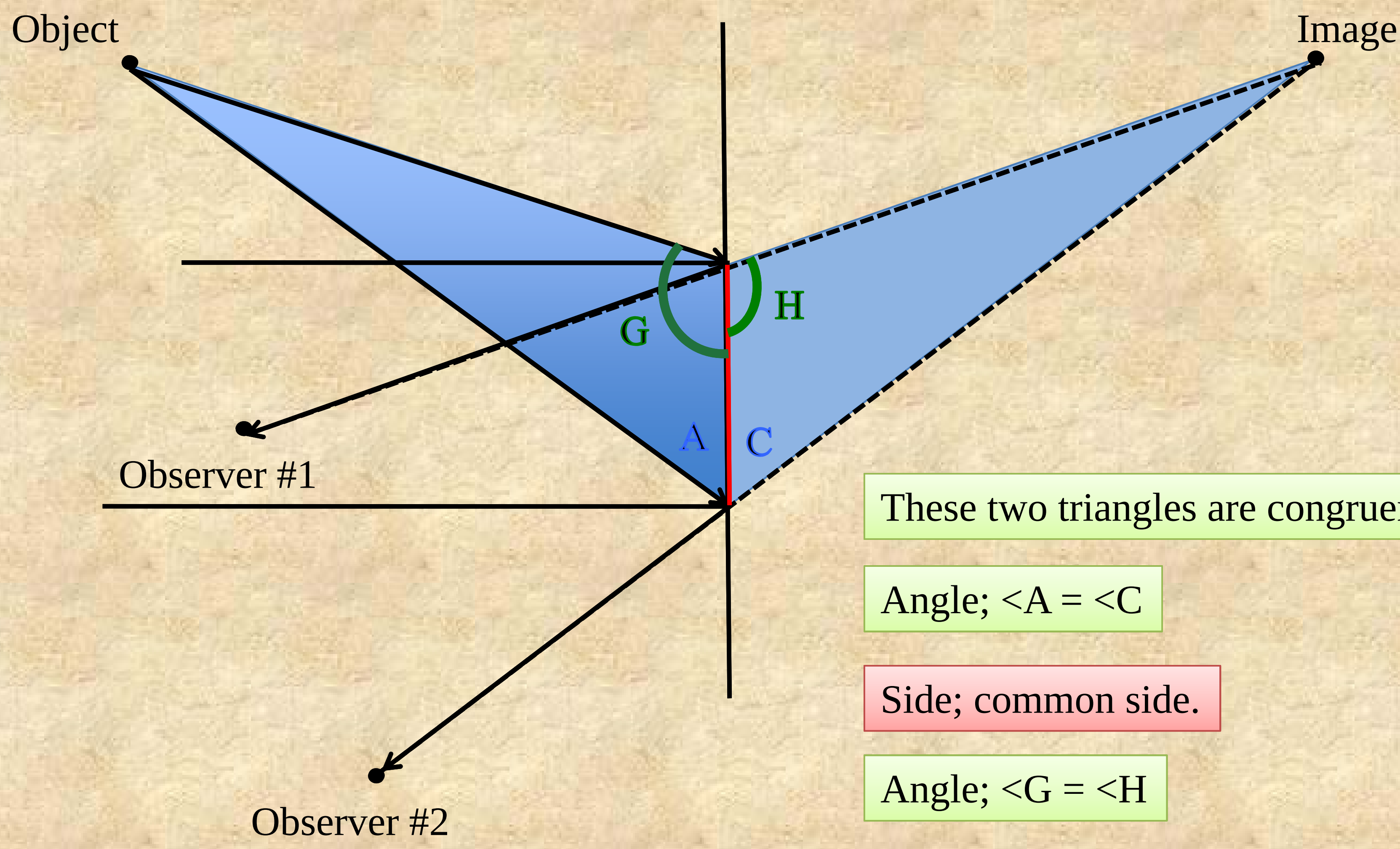
<i = <r Law of Reflection.

<D = <E Compliments of equal angles are equal.

<E = <F Vertical angles are equal.

<D = <F Both are equal to <E.

2. Seeing objects in a mirror. A geometric analysis.



These two triangles are congruent.

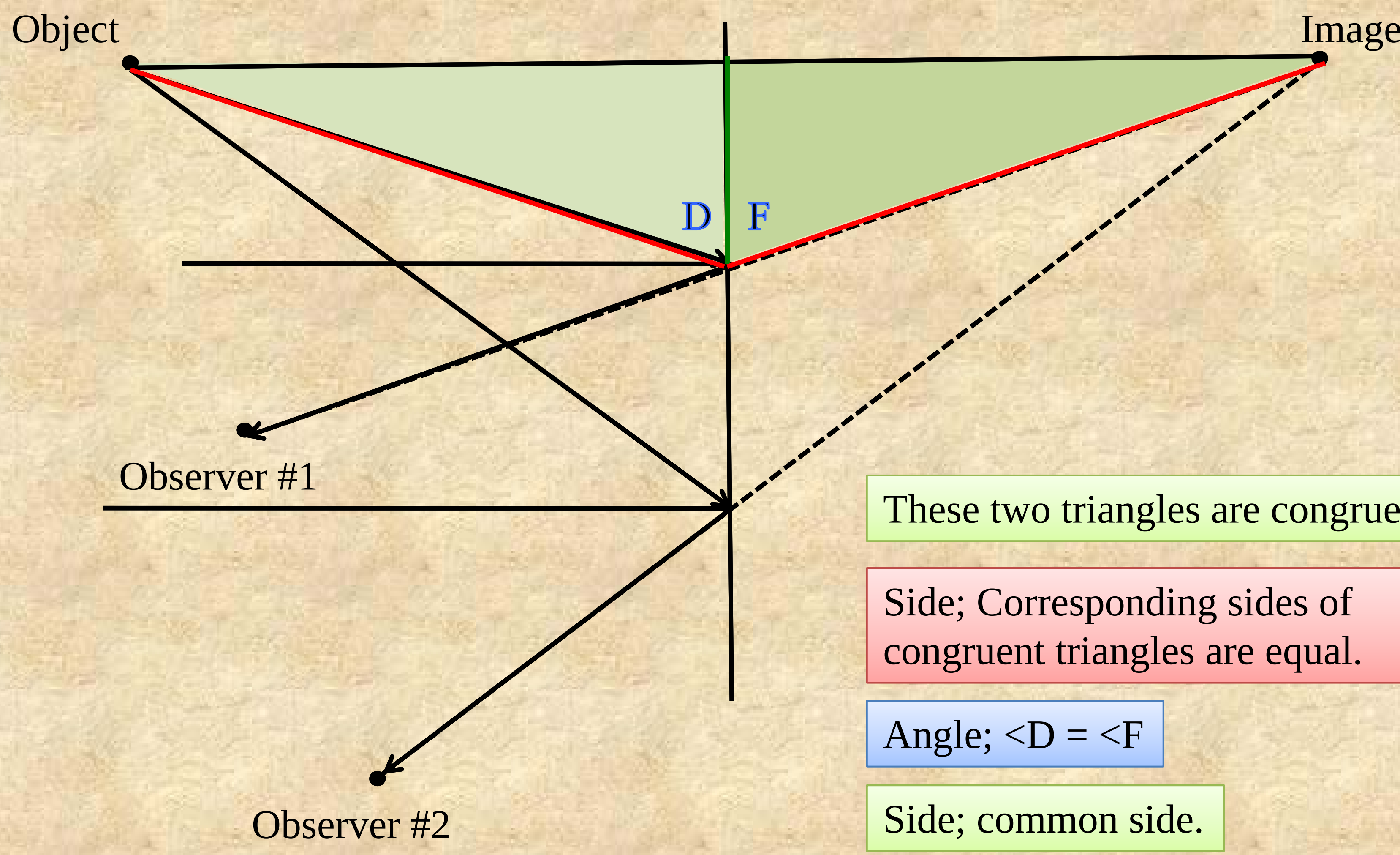
Angle; <A = <C

Side; common side.

Angle; <G = <H

2. Seeing objects in a mirror. A geometric analysis.

Draw a straight line from object to image.



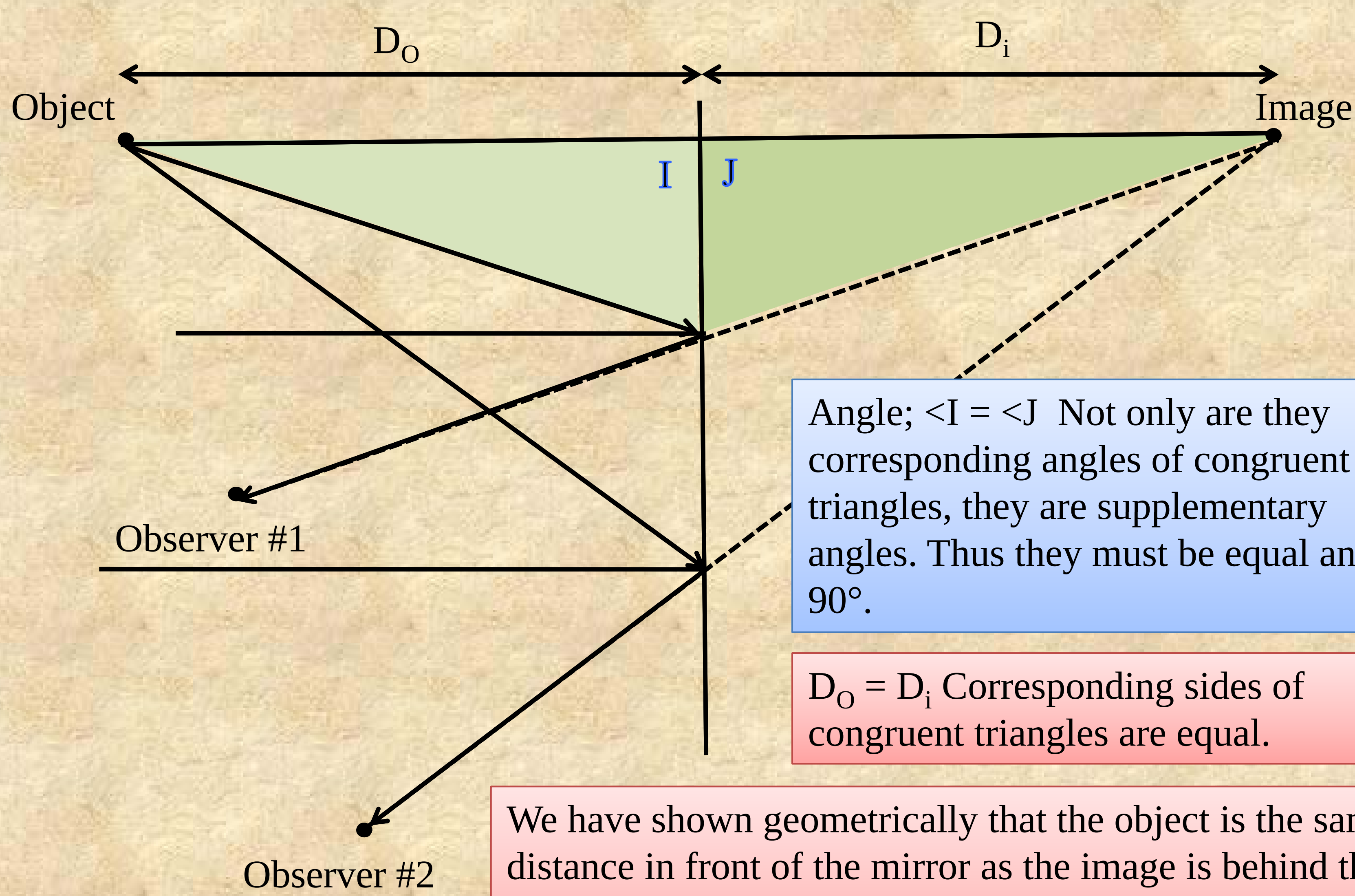
These two triangles are congruent.

Side; Corresponding sides of congruent triangles are equal.

Angle; <D = <F

Side; common side.

2. Seeing objects in a mirror. A geometric analysis.



Angle; <I = <J Not only are they corresponding angles of congruent triangles, they are supplementary angles. Thus they must be equal and 90°.

$D_O = D_i$ Corresponding sides of congruent triangles are equal.

We have shown geometrically that the object is the same distance in front of the mirror as the image is behind the mirror. Both object and image lie on a line perpendicular to the mirror surface.

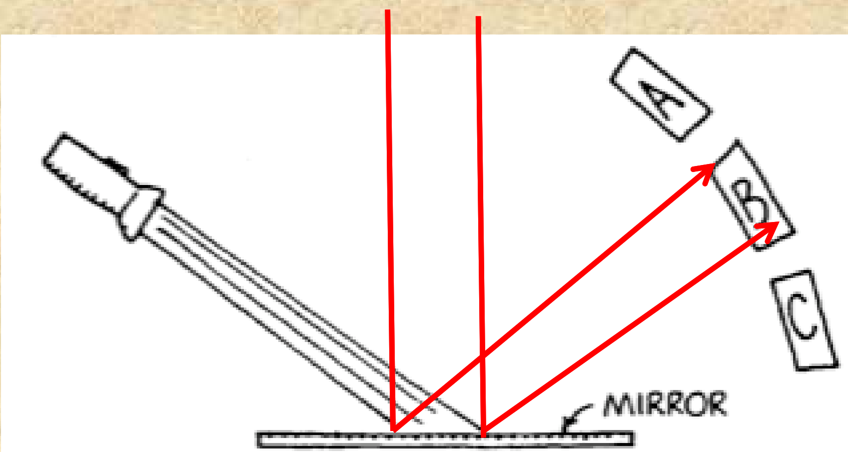
To Summarize

The object is the same distance in front of the mirror as the image is behind the mirror. Both object and image lie on a line perpendicular to the mirror surface.

Law of Reflection:

- The angle of incidence equals the angle of reflection. <i = <r
- The incident ray, the reflected ray and the normal line to the point of reflection all lie in the same plane.

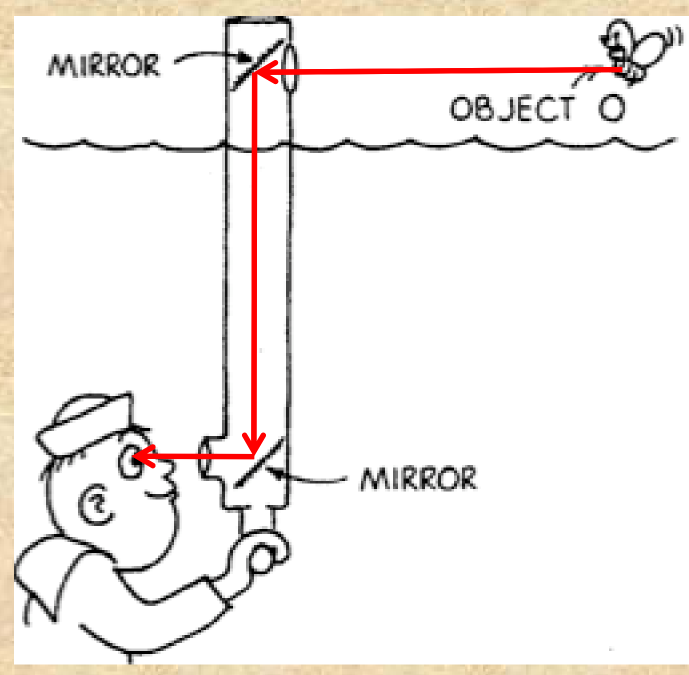
1. Light from a flashlight shines on a mirror and illuminates one of the cards. Draw the reflected beam to indicate the illuminated card.



Let's look at the extremes. Draw each normal to the mirror.

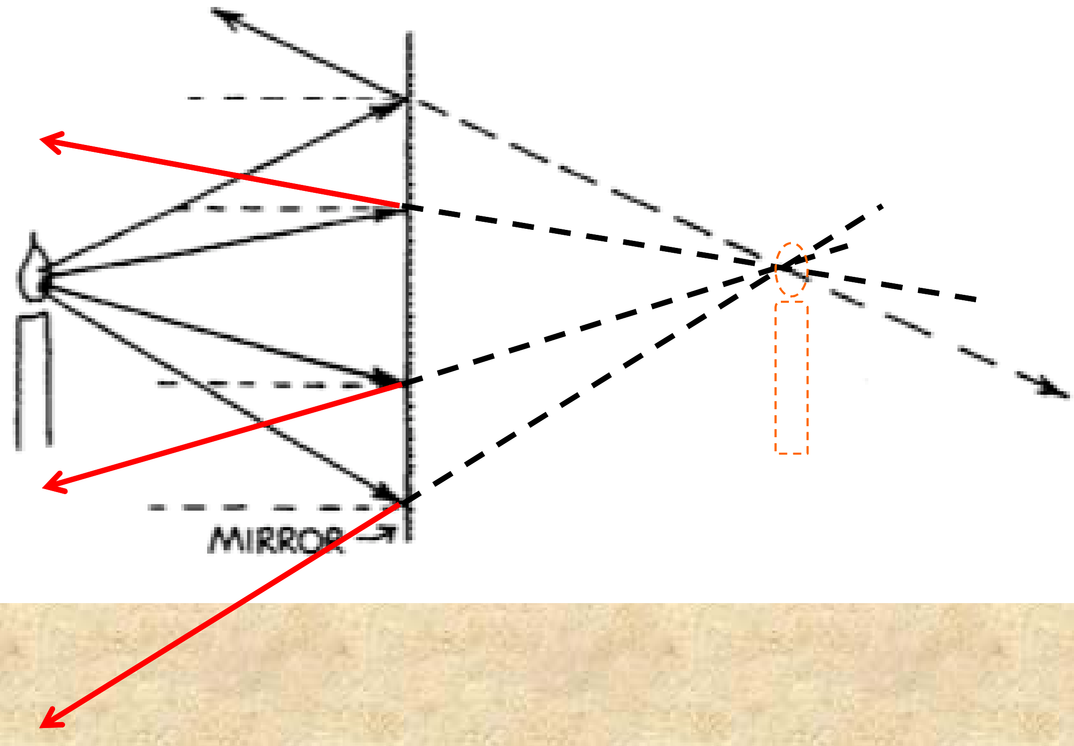
Draw reflected rays. Remember <i = <r

2. A periscope has a pair of mirrors in it. Draw the light path from object "O" to the eye of the observer.

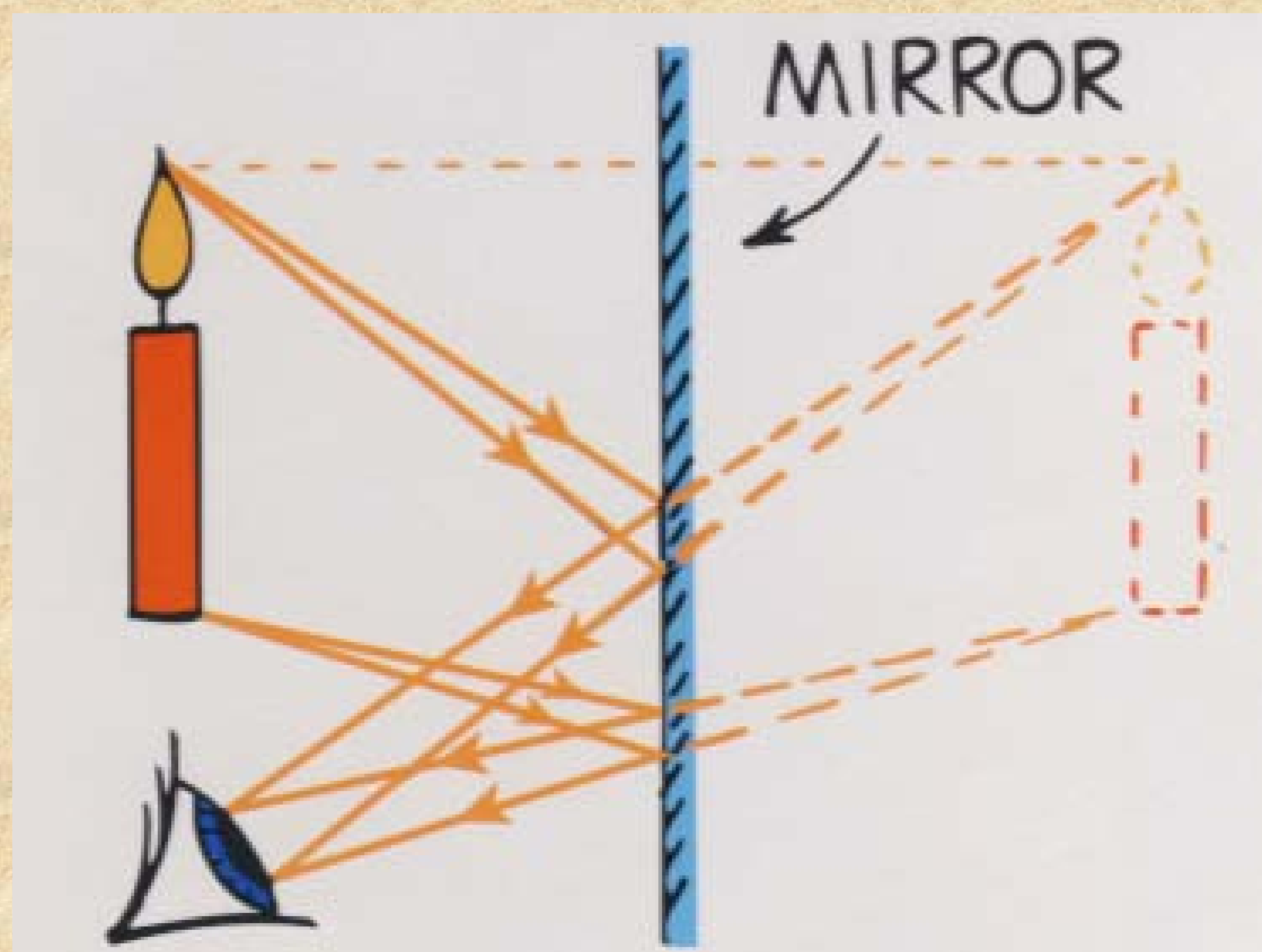


In order to see the bird, where is the starting point of the light?

3. The ray diagram below shows the extension of one of the reflected rays from the plane mirror. Complete the diagram by (1) carefully drawing the three other reflected rays, and (2) extending them behind the mirror to locate the image of the flame. (Assume the candle and image are viewed by an observer on the left.)

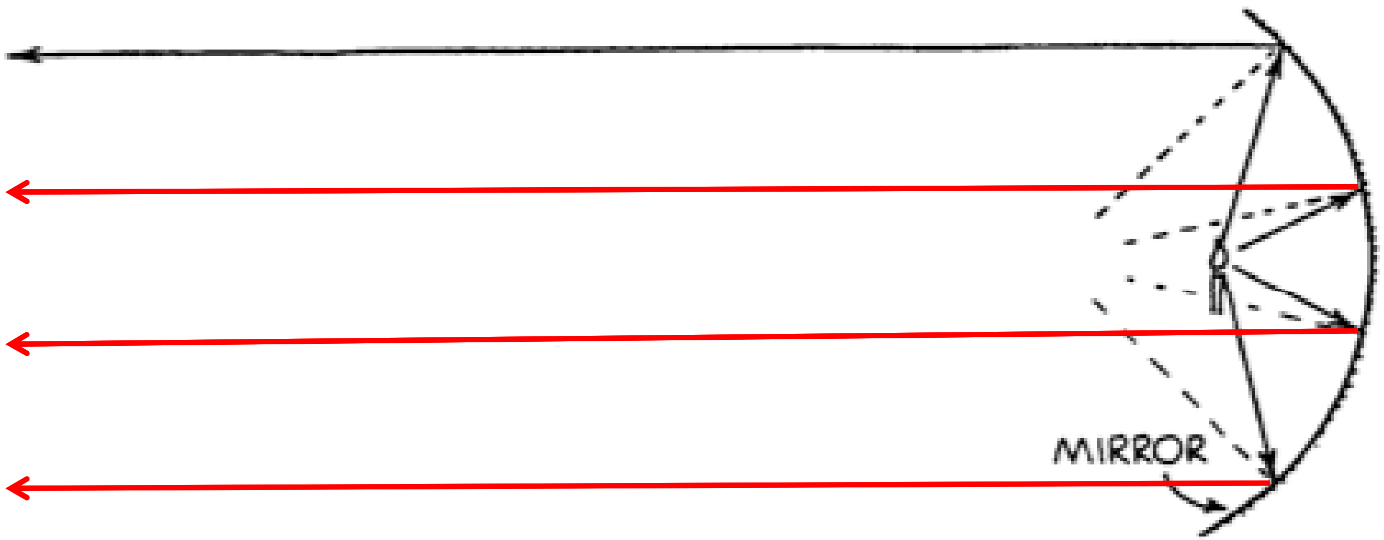


Remember the Law of Reflection. <i = <r

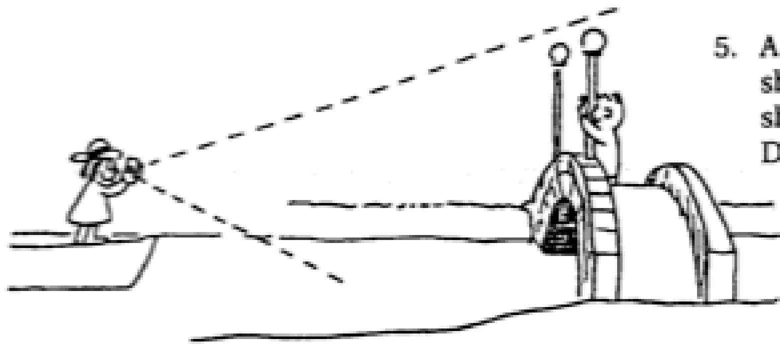


Our mind locates where the reflected rays intersect, that is our mind projects the diverging reflected rays behind the mirror until they intersect and form the image.

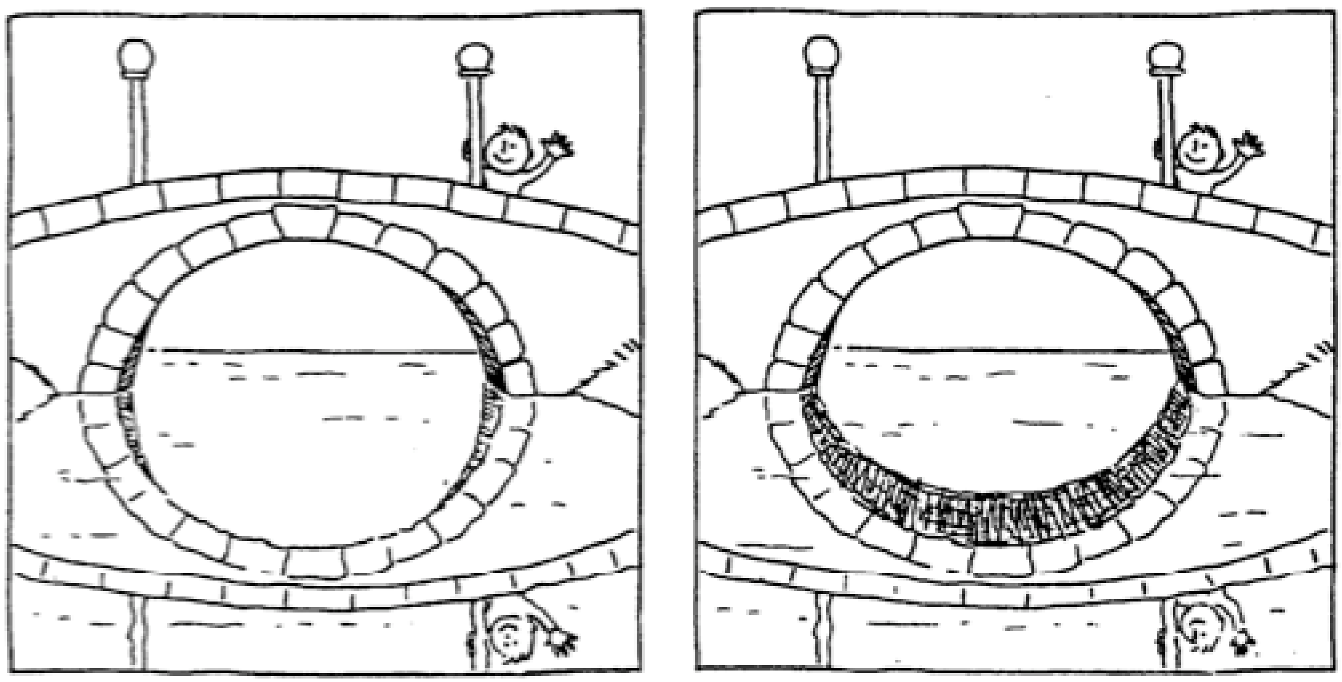
4. The ray diagram below shows the reflection of one of the rays that strikes the parabolic mirror. Notice that the law of reflection is obeyed, and the angle of incidence (from the normal, the dashed line) equals the angle of reflection (from the normal). Complete the diagram by drawing the reflected rays of the other three rays that are shown. (Do you see why parabolic mirrors are used in automobile headlights?)



Remember the Law of Reflection. <i = <r
Be careful, this time the mirror is not a plane (flat) mirror.



5. A girl takes a photograph of the bridge as shown. Which of the two sketches correctly shows the reflected view of the bridge? Defend your answer.



The right view is correct. The reflected view shows the underside of the bridge, or what you would see if your eye were as far below the water surface as your eye is above it.

Incident Ray.

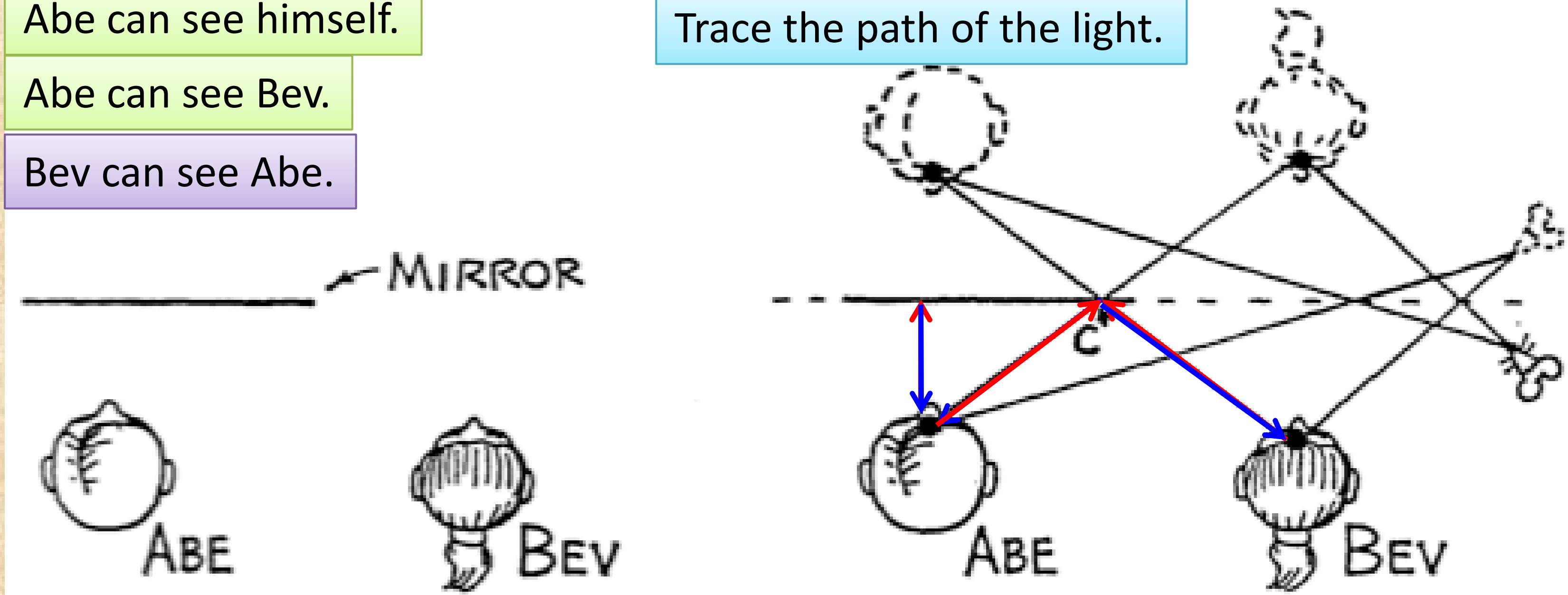
Reflected Ray.

Abe can see himself.

Abe can see Bev.

Bev can see Abe.

Trace the path of the light.

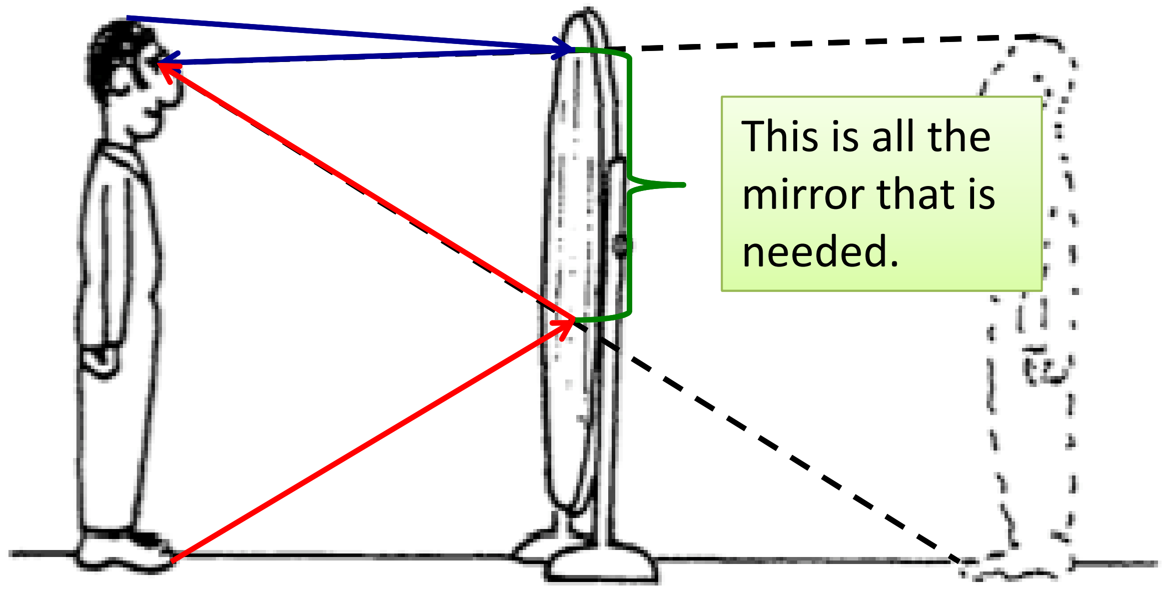


Abe and Bev both look in a plane mirror directly in front of Abe (left, top view). Abe can see himself while Bev cannot see herself—but can Abe see Bev, and can Bev see Abe? To find the answer we construct their artificial locations "through" the mirror, the same distance behind as Abe and Bev are in front (right, top view). If straight-line connections intersect the mirror, as at point C, then each sees the other. The mouse, for example, cannot see or be seen by Abe and Bev.

The path of the ray of light is reversible.

The mouse cannot see any of the reflections and neither Abe nor Bev can see the reflection of the mouse.

Harry Hotshot views himself in a full-length mirror (right). Construct straight lines from Harry's eyes to the image of his feet, and to the top of his head. Mark the mirror to indicate the minimum area Harry uses to see a full view of himself.



Does this region of the mirror depend on Harry's distance from the mirror? **No!**

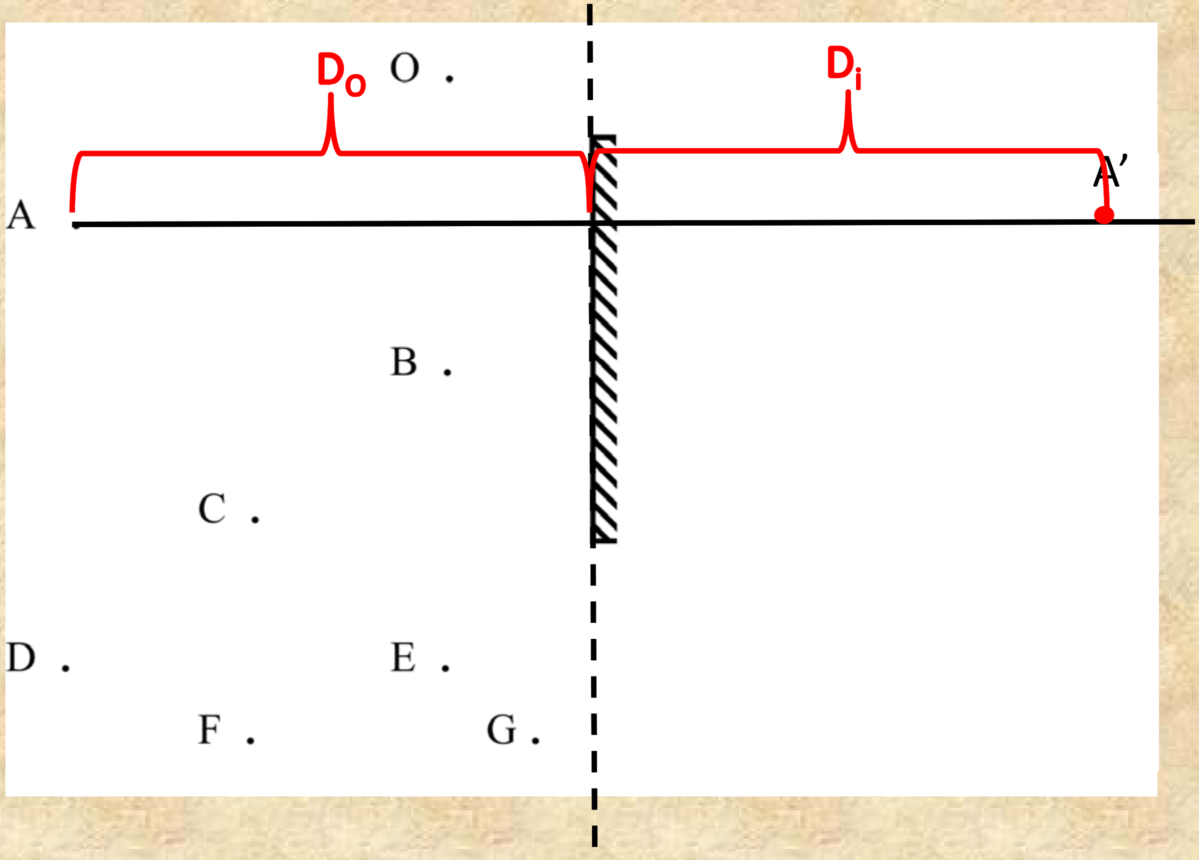
Rays of light have to come to our eye from the direction of the image.

The actual path of light so that we can see our feet.

The actual path of light so that we can see the top of our head.

1. Which of the points shown can be seen reflected in the mirror by an observer at point O?

For construction purposes the mirror line may be extended.

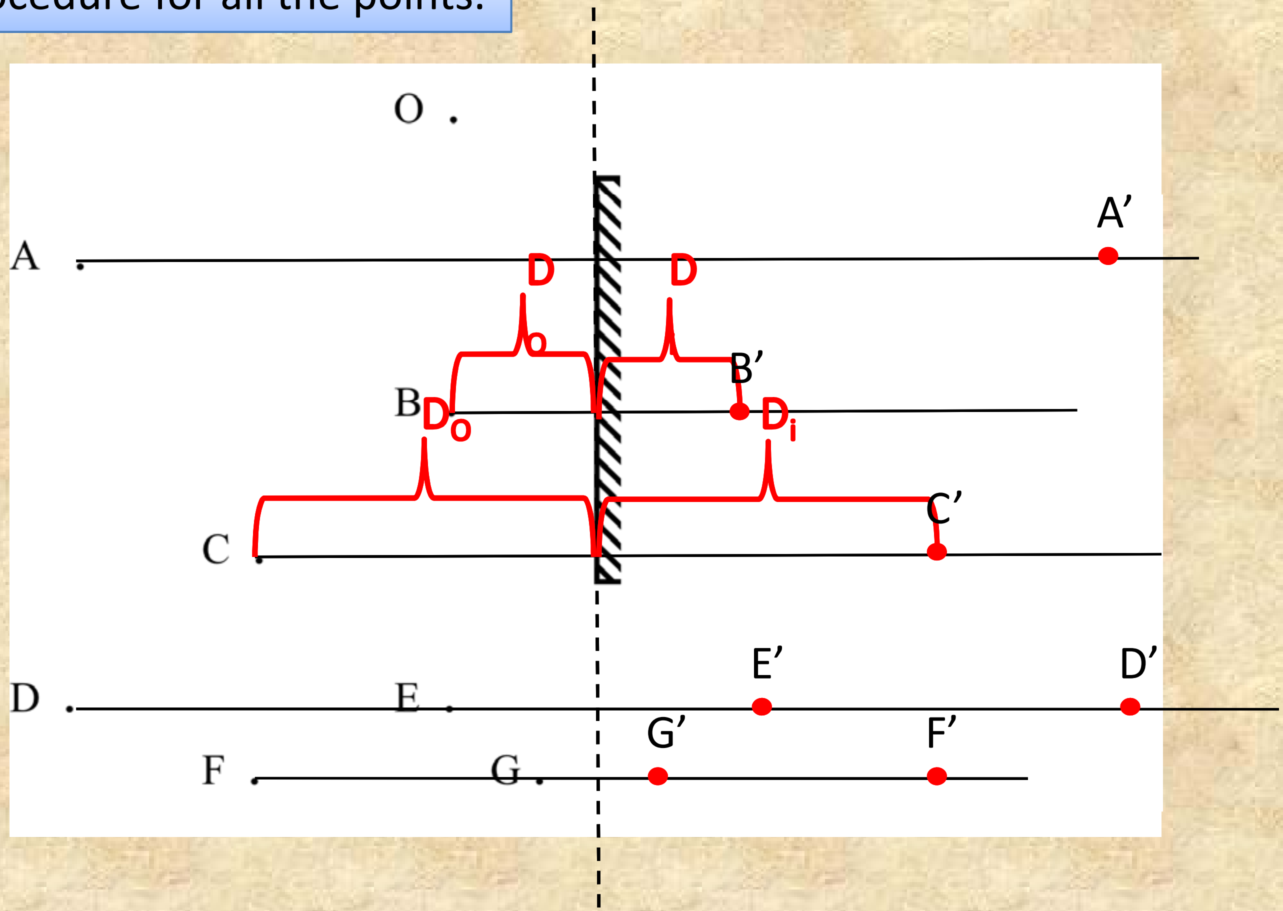


Draw a line from the object perpendicular to the mirror to a distance behind the mirror.

Measure D_O and then measure the same distance behind the mirror to locate the image.

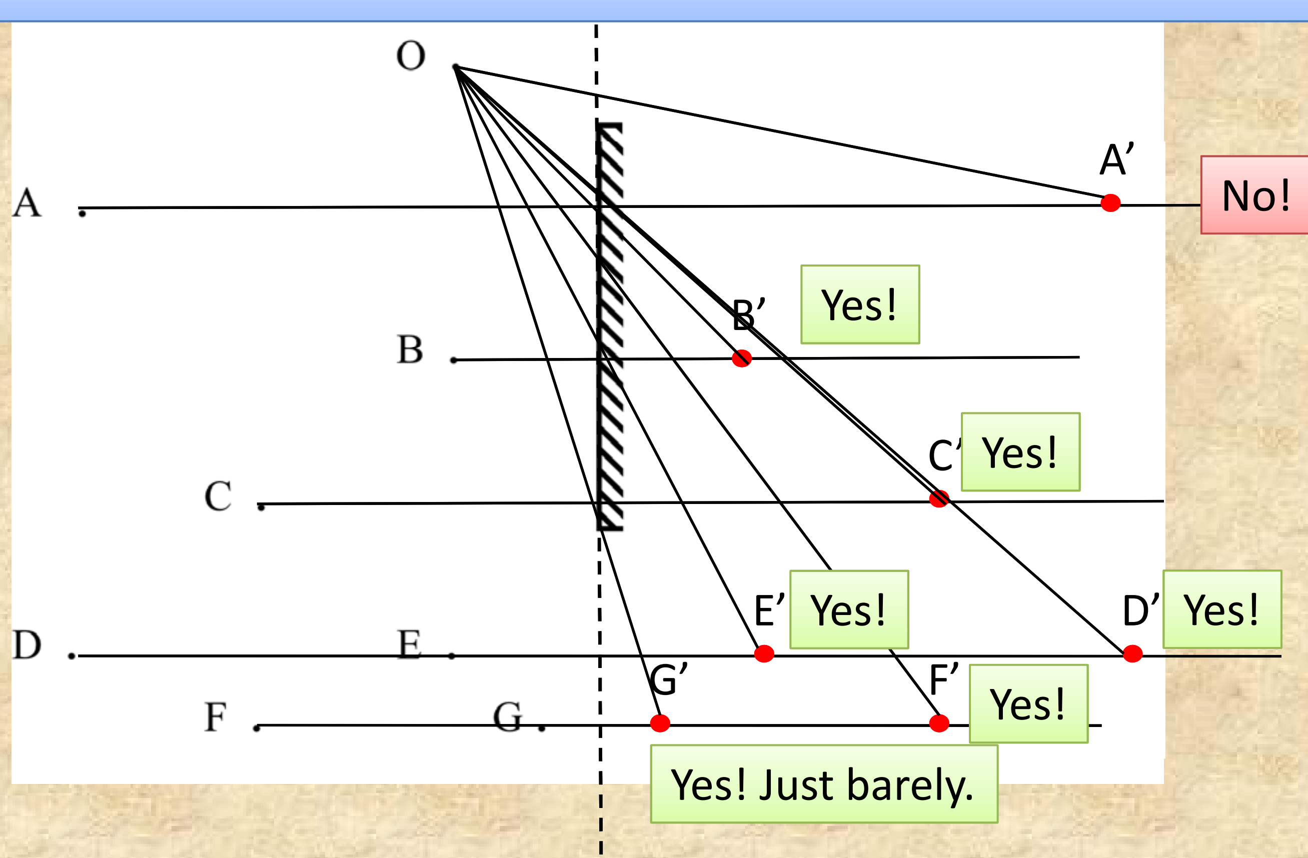
1. Which of the points shown can be seen reflected in the mirror by an observer at point O?

Repeat the procedure for all the points.



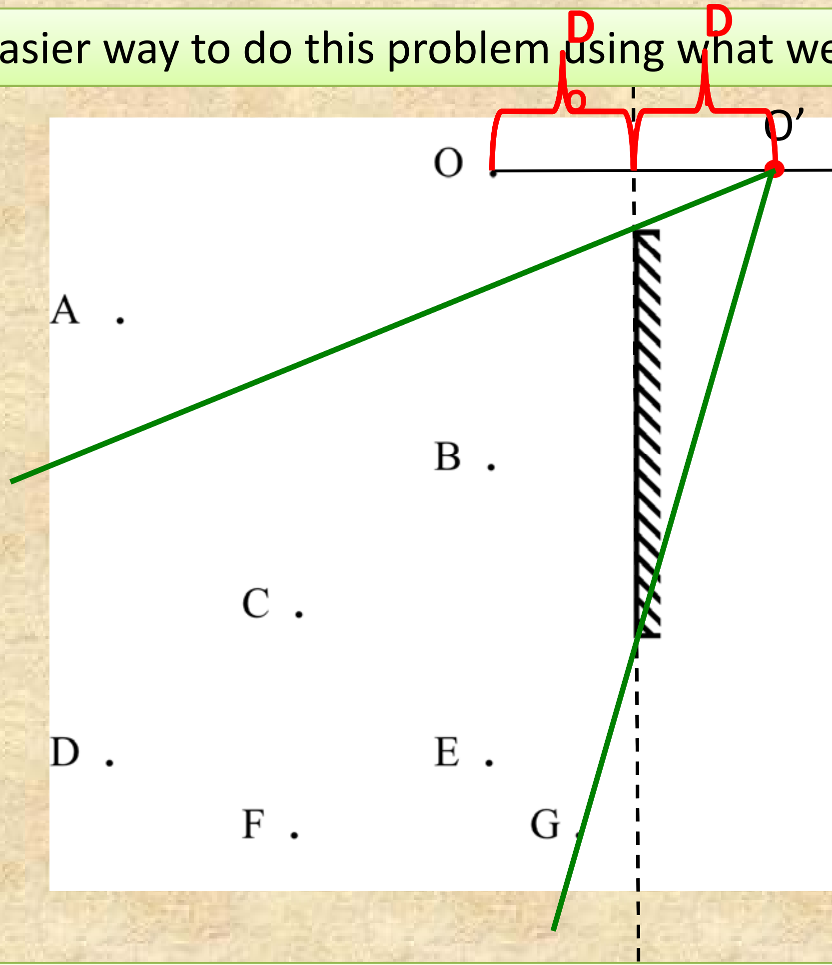
1. Which of the points shown can be seen reflected in the mirror by an observer at point O?

Draw a line from the observer, O, to the each image in order to see if if the necessary reflected ray hits the mirror.



1. Which of the points shown can be seen reflected in the mirror by an observer at point O?

Is there an easier way to do this problem using what we know about reflection?



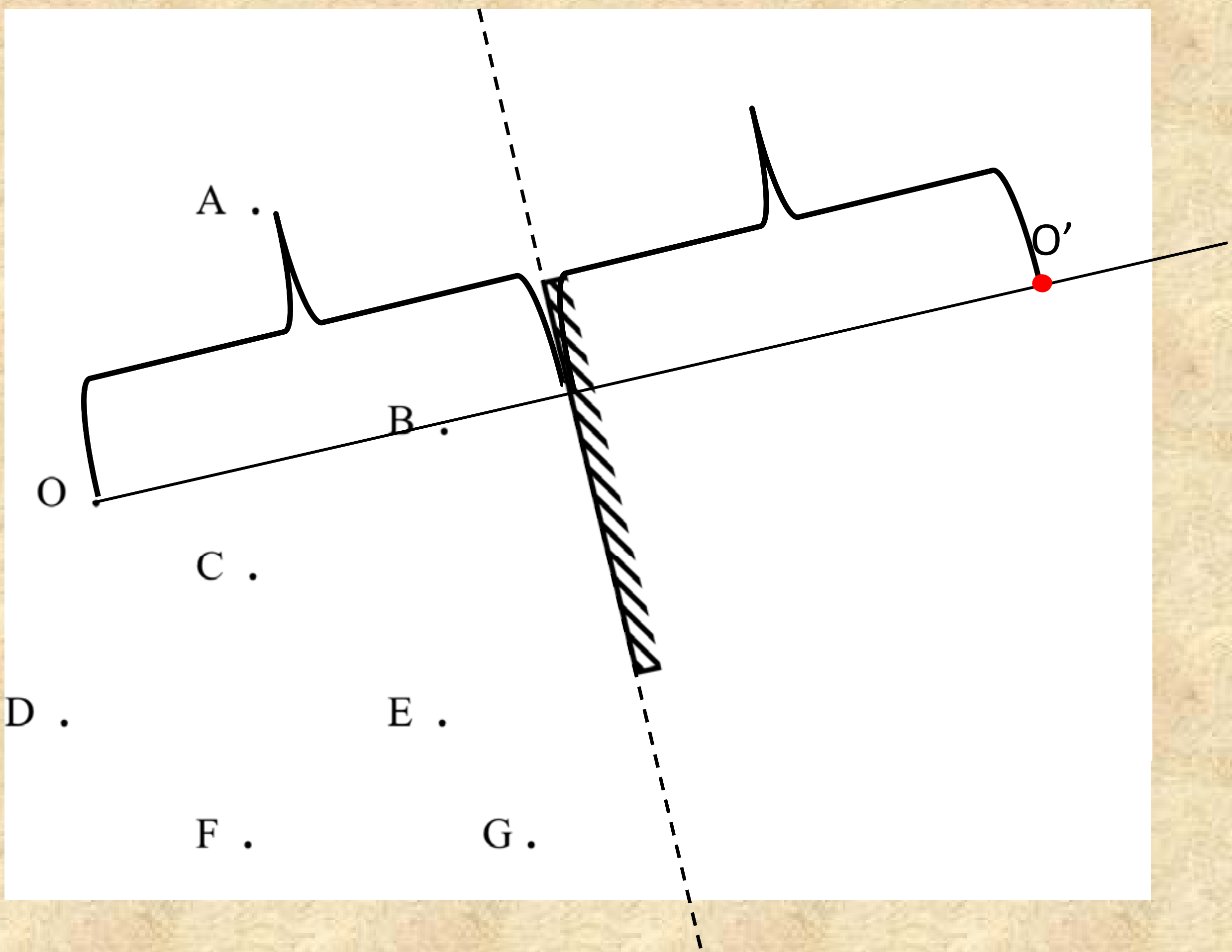
From O’ draw the kissing rays to the mirror. These show the extremes that the observer can see in the mirror.

Cannot see A, but can see B, C, D, E, F and maybe G.

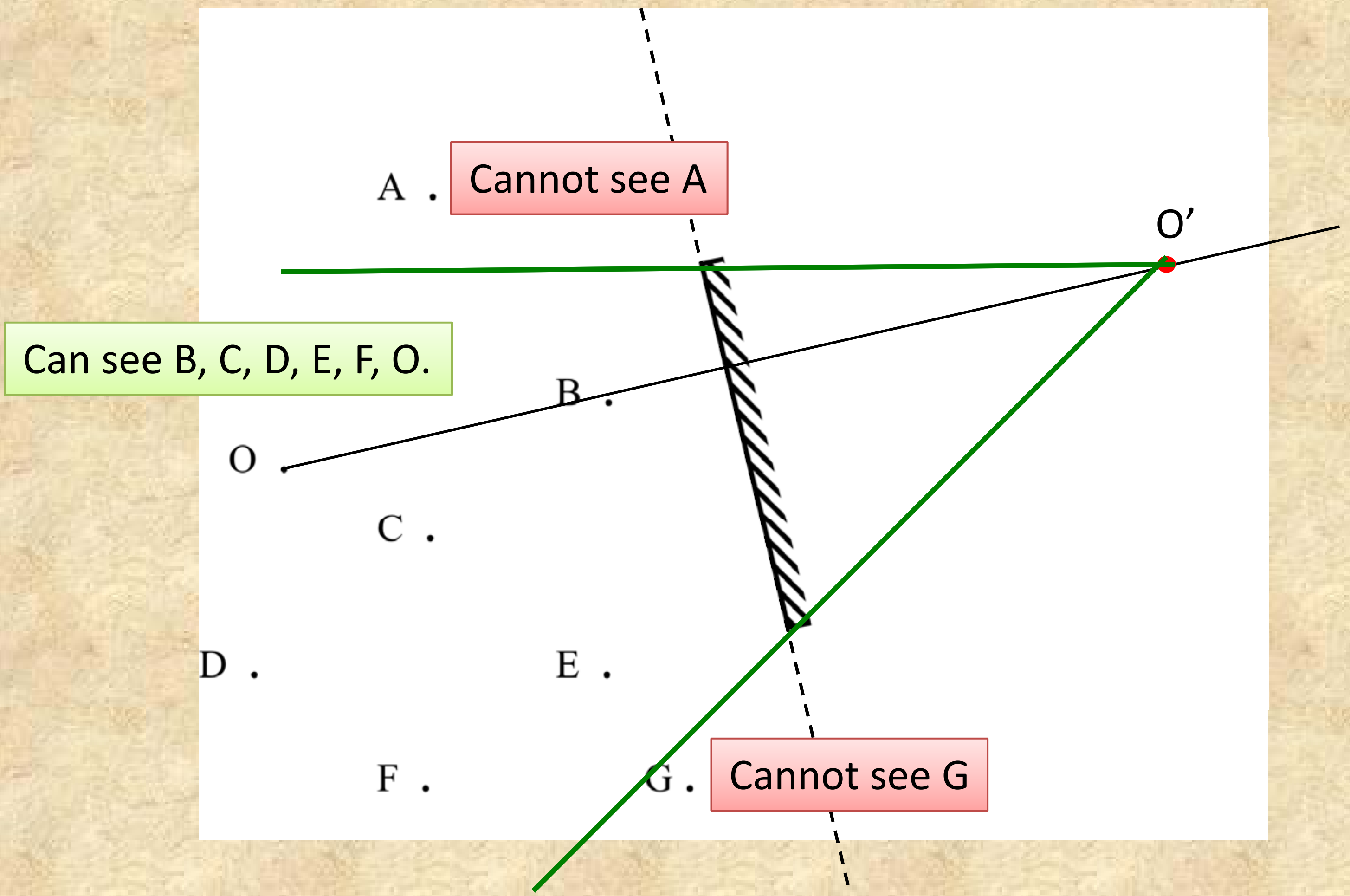
The path of a ray of light is reversible. Which means if I can see you, then you can see me.

So, find the image of the observer, O.

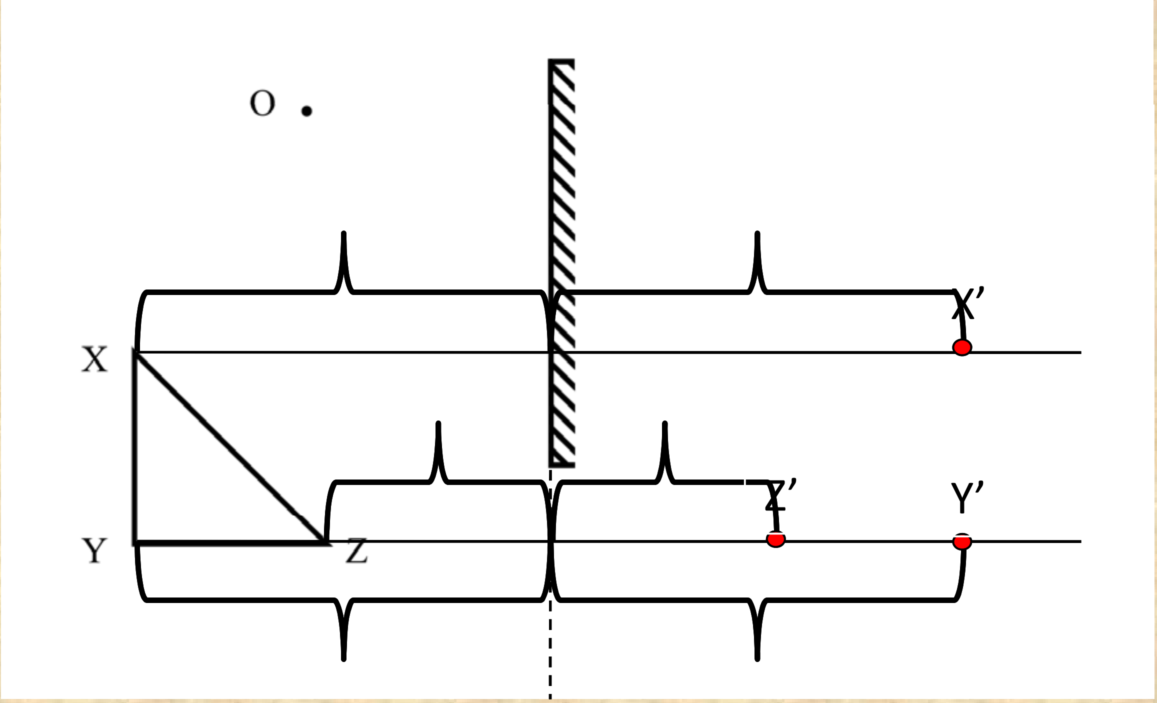
2. Which of the points shown can be seen reflected in the mirror by an observer at point O?



2. Which of the points shown can be seen reflected in the mirror by an observer at point O?

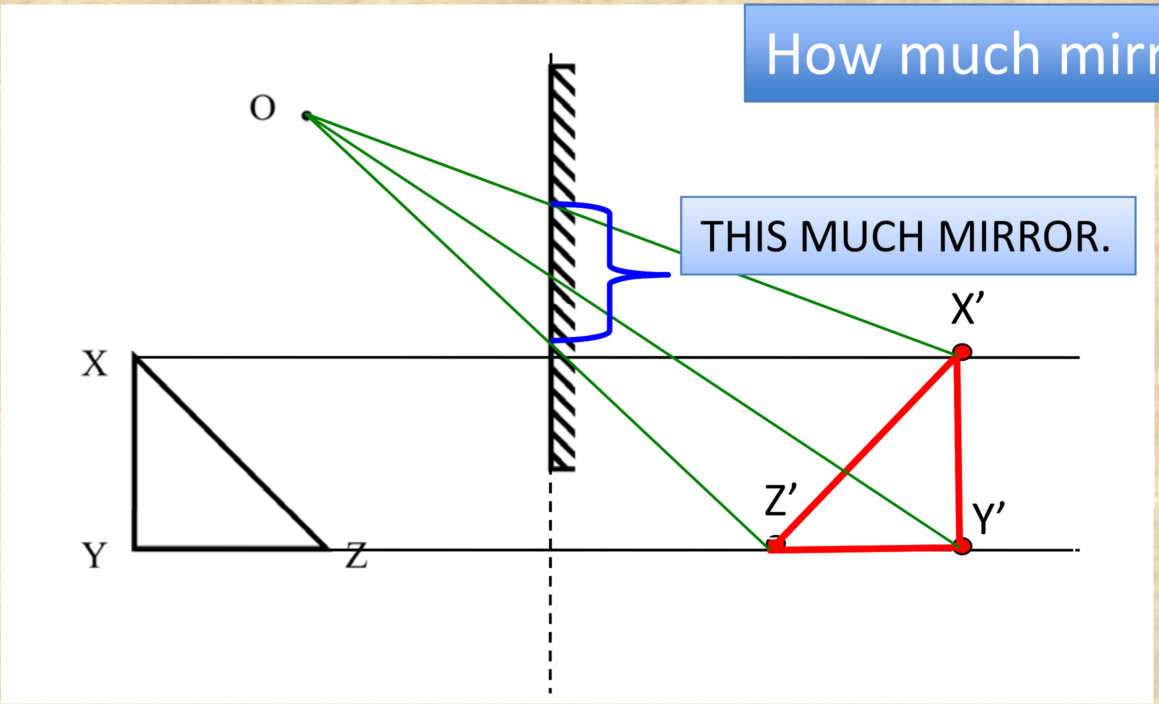


3. Locate and draw the image of triangle XYZ. Then indicate the smallest mirror that will allow all of the reflection of the object to be seen by an observer at point O.

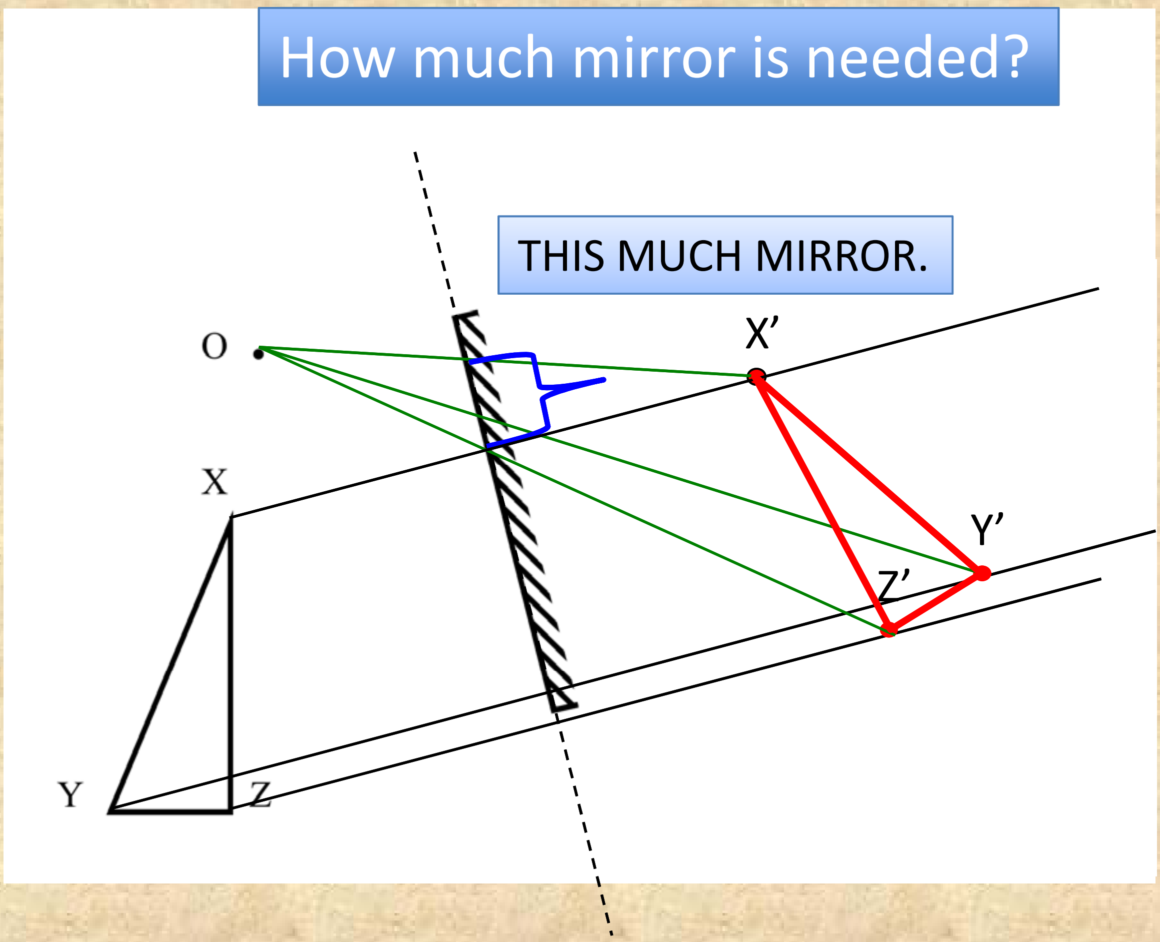


3. Locate and draw the image of triangle XYZ. Then indicate the smallest mirror that will allow all of the reflection of the object to be seen by an observer at point O.

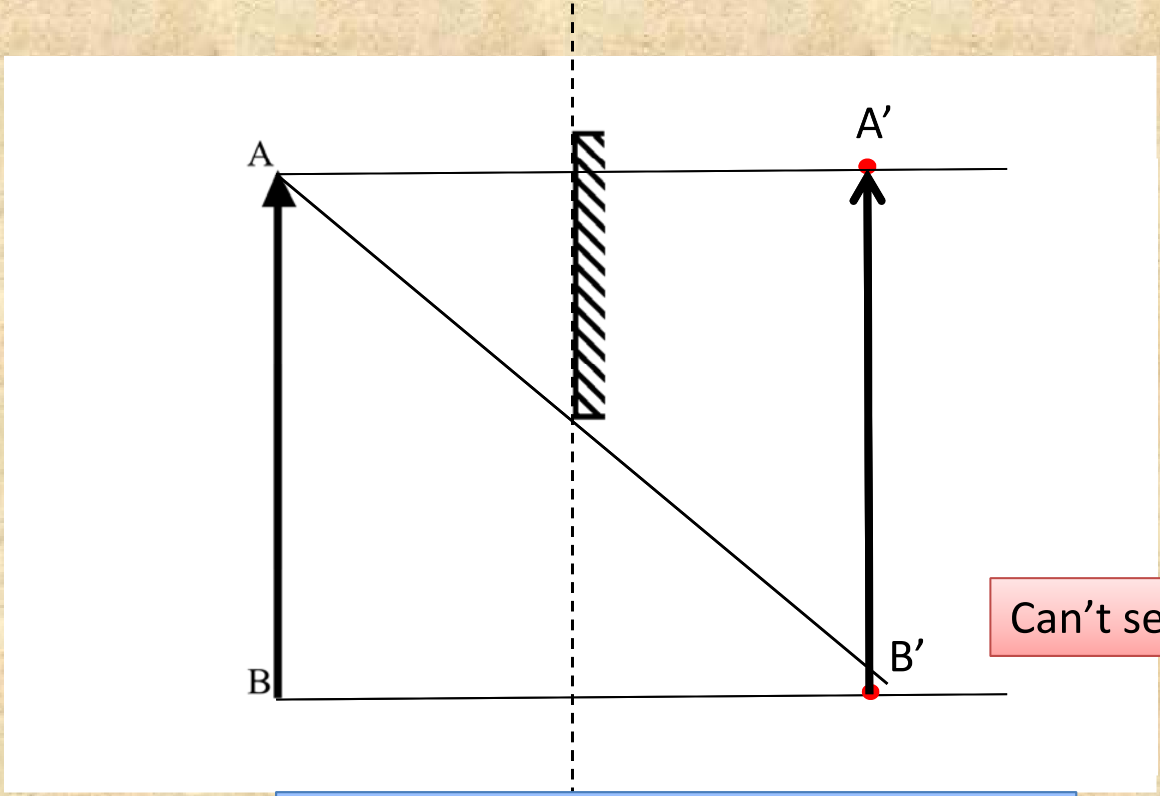
How much mirror is needed?



4. Locate and draw the image of triangle XYZ. Then indicate the smallest mirror that will allow all of the reflection of the object to be seen by an observer at point O.



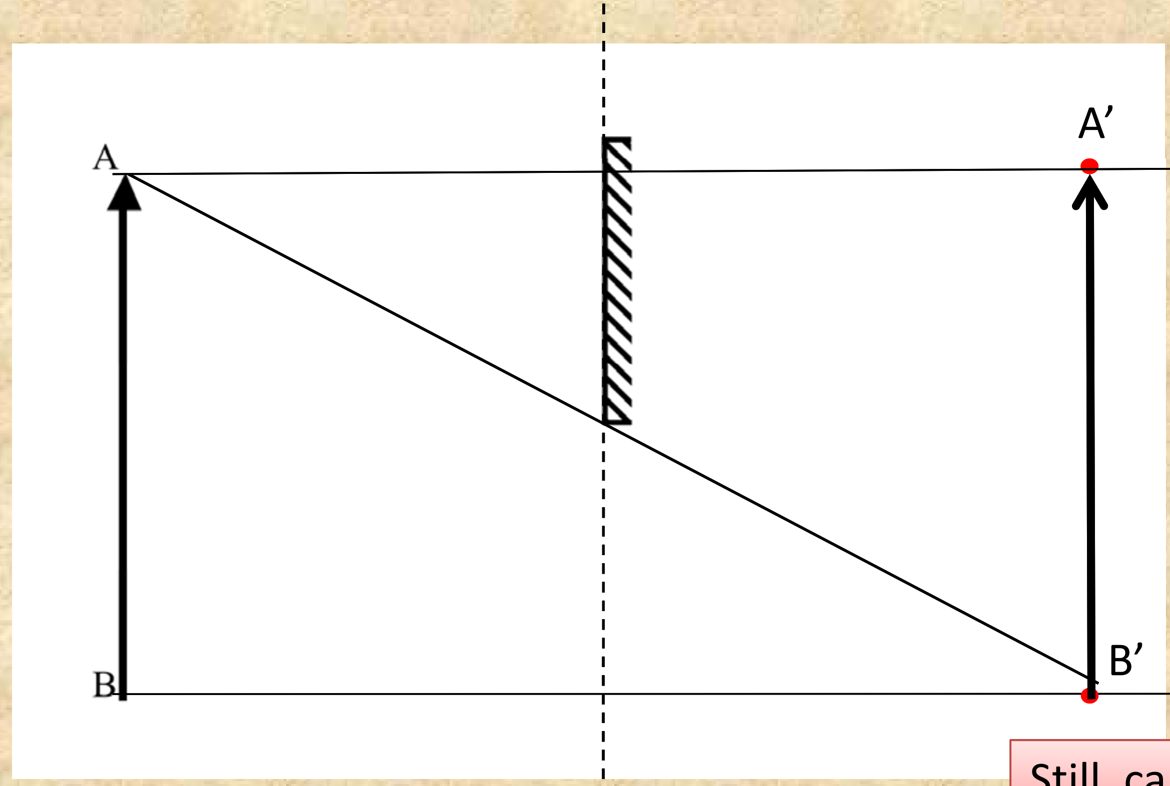
5. The drawing below shows woman AB with eyes at A and feet at B standing in front of a mirror. Show whether the woman can see all of her reflection in the mirror.



Can't see feet.

How much mirror is needed?

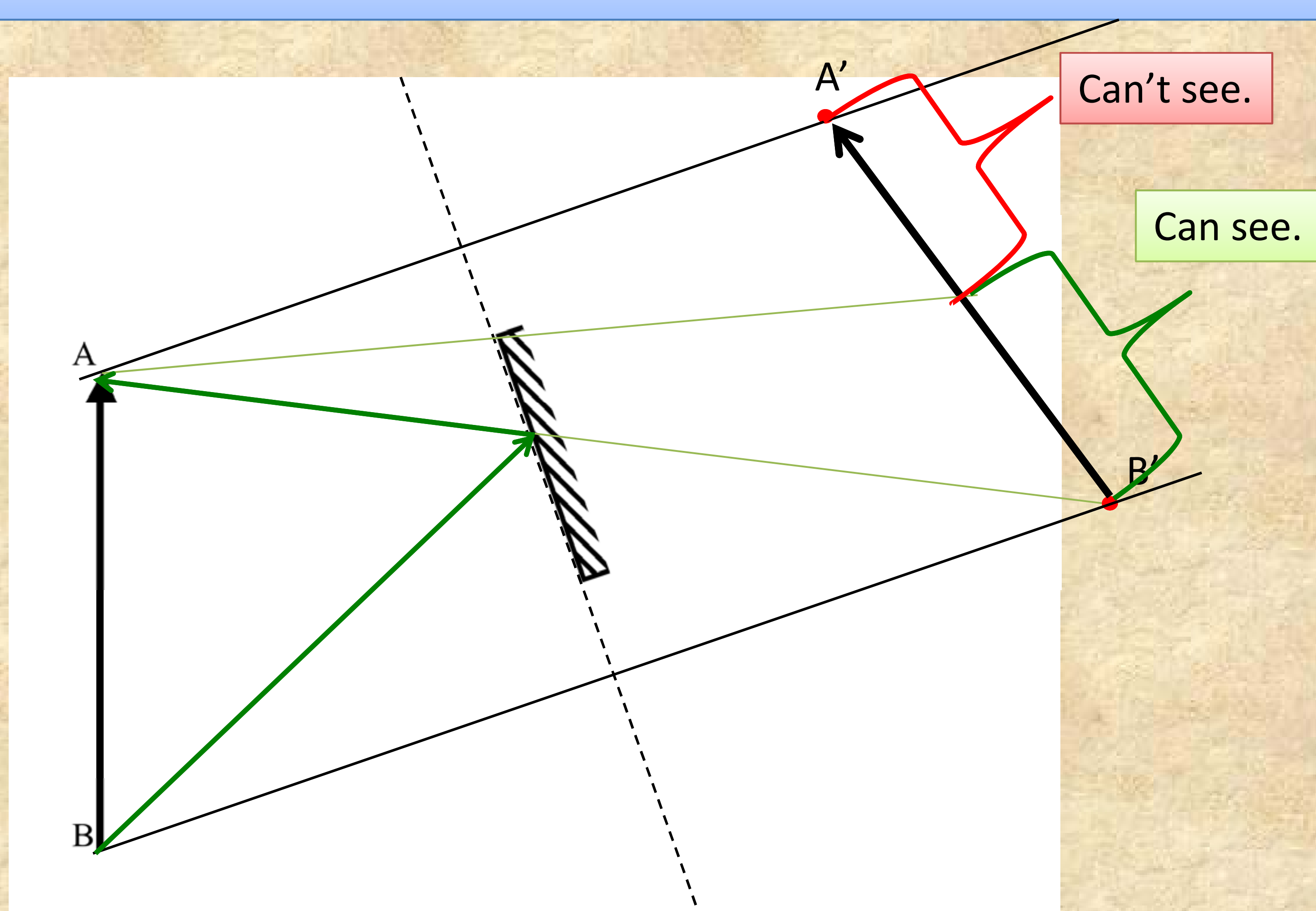
6. If the woman steps back farther from the mirror will she see more of herself? Do a similar analysis as you did in problem #5



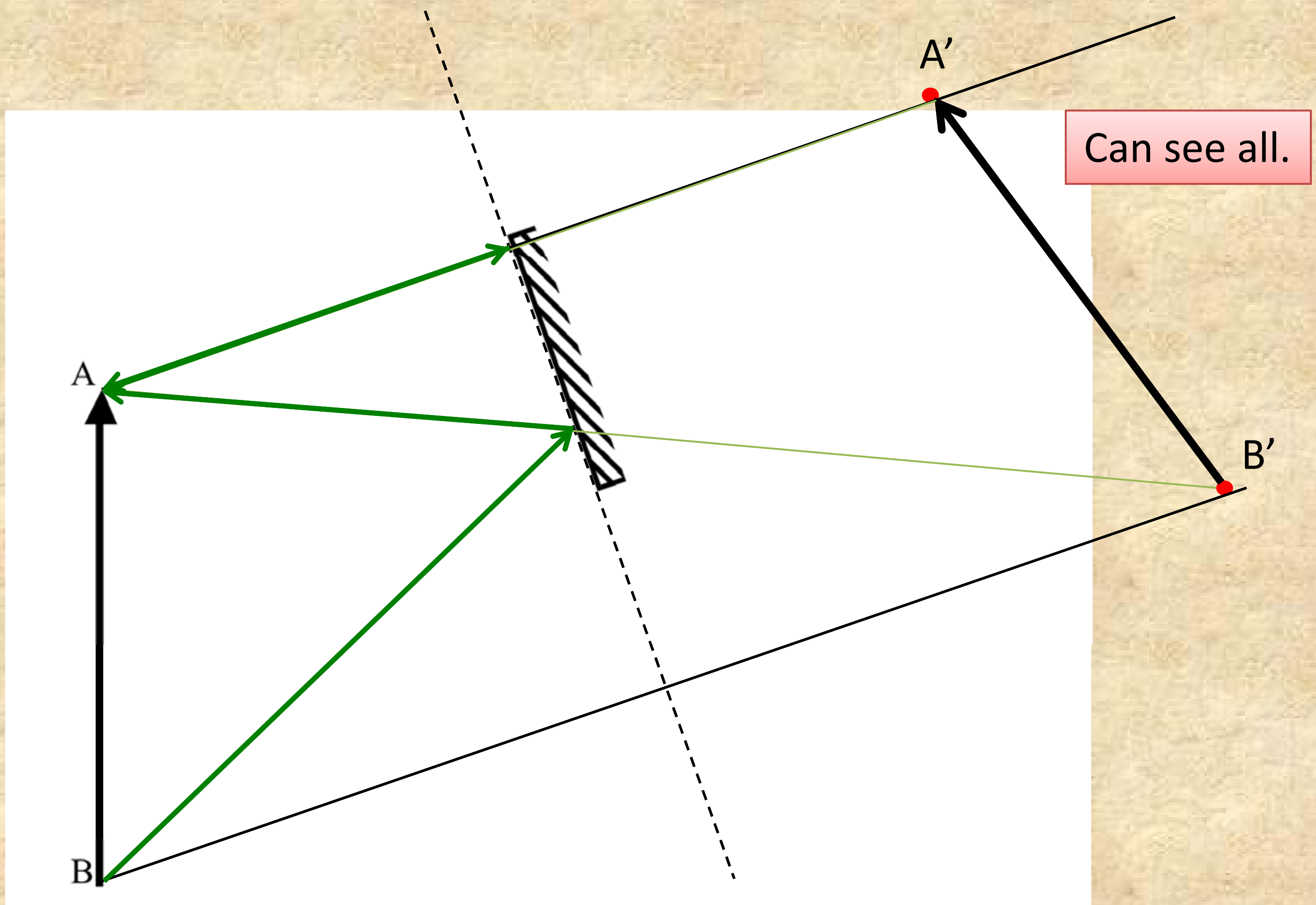
Still, can’t see feet.

How much mirror is needed?

7. The drawings below show man AB with eyes at A and feet at B standing in front of a mirror. Show whether the man can see all of his reflection in mirror.



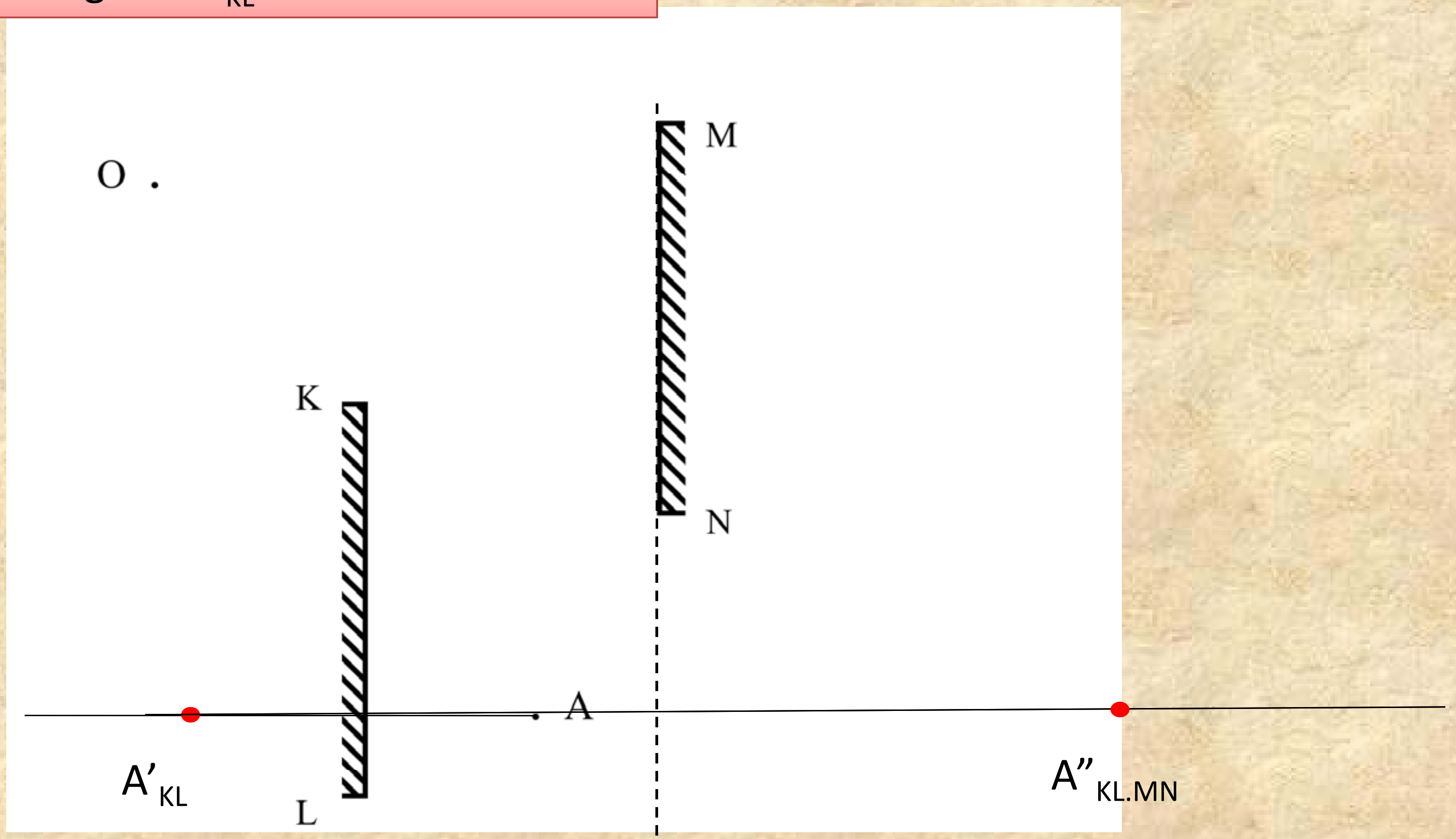
7. The drawings below show man AB with eyes at A and feet at B standing in front of a mirror. Show whether the man can see all of his reflection in mirror.



10. There are two mirrors KL and MN facing each other. Can the observer see the object at point A by looking in a mirror? If yes, trace the path of light from object "A" to the observer.

In order to see A it must be a double reflection. Locate the image of A behind mirror KL.

Locate the image of A'_{KL} behind mirror MN.

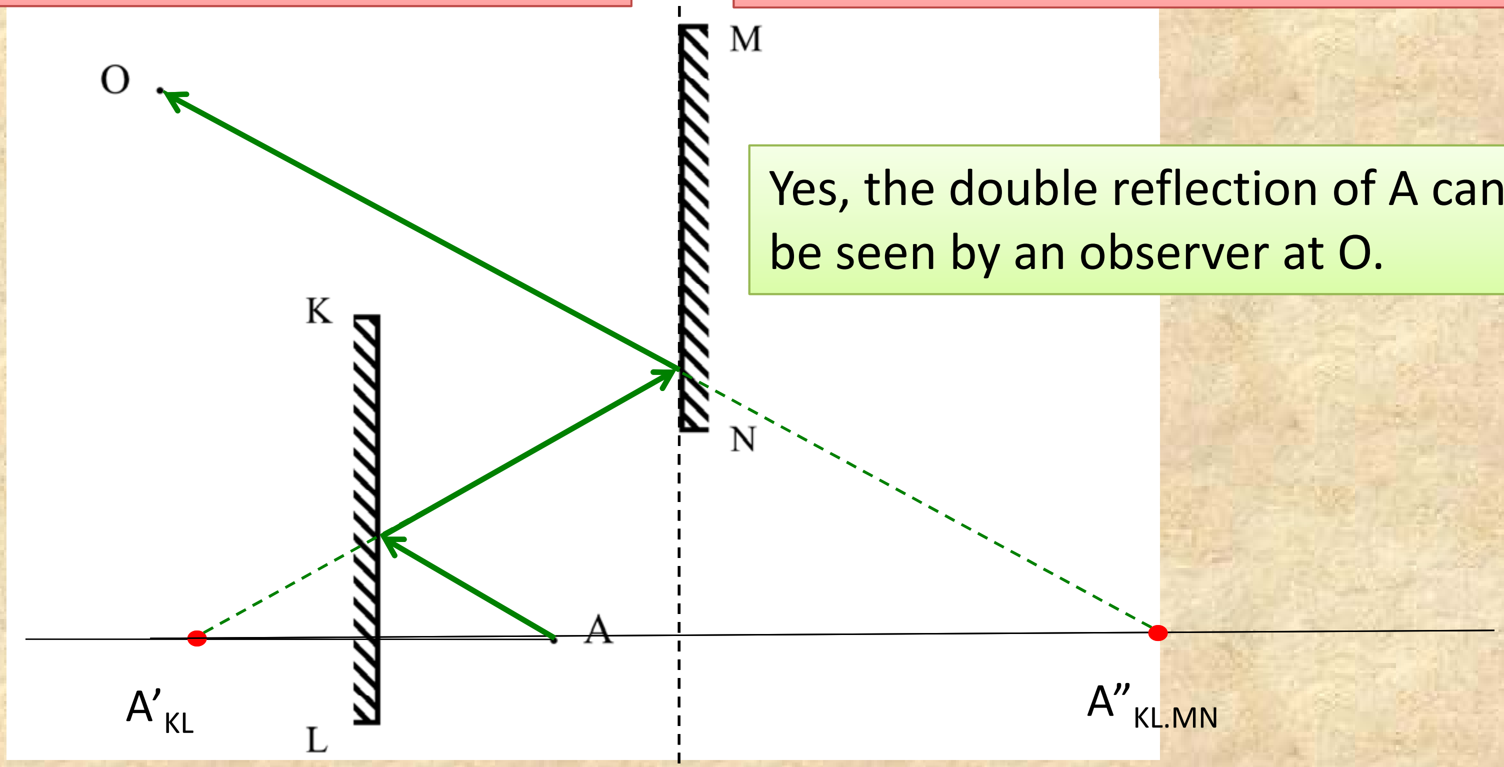


10. There are two mirrors KL and MN facing each other. Can the observer see the object at point A by looking in a mirror? If yes, trace the path of light from object "A" to the observer.

Trace reflected ray from $A''_{KL,MN}$ to observer.

Trace incident ray to mirror MN from A'_{KL} its object.

Trace incident ray to mirror KL from A its object.

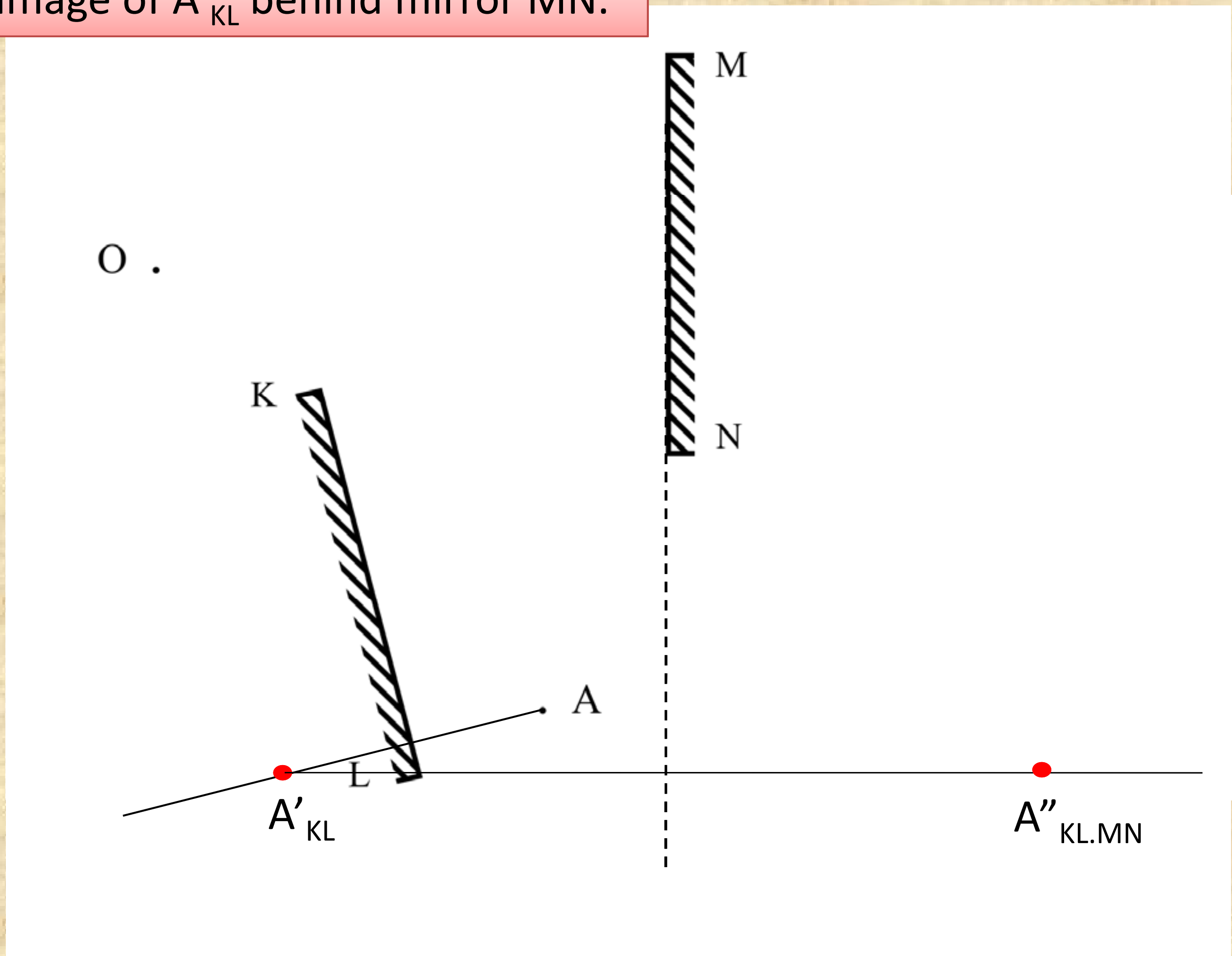


Yes, the double reflection of A can be seen by an observer at O.

11. There are two mirrors KL and MN facing each other. Can the observer see the double reflection of object at point A? If yes, trace the path of light from object "A" to the observer.

In order to see A it must be a double reflection. Locate the image of A behind mirror KL.

Locate the image of A'_{KL} behind mirror MN.

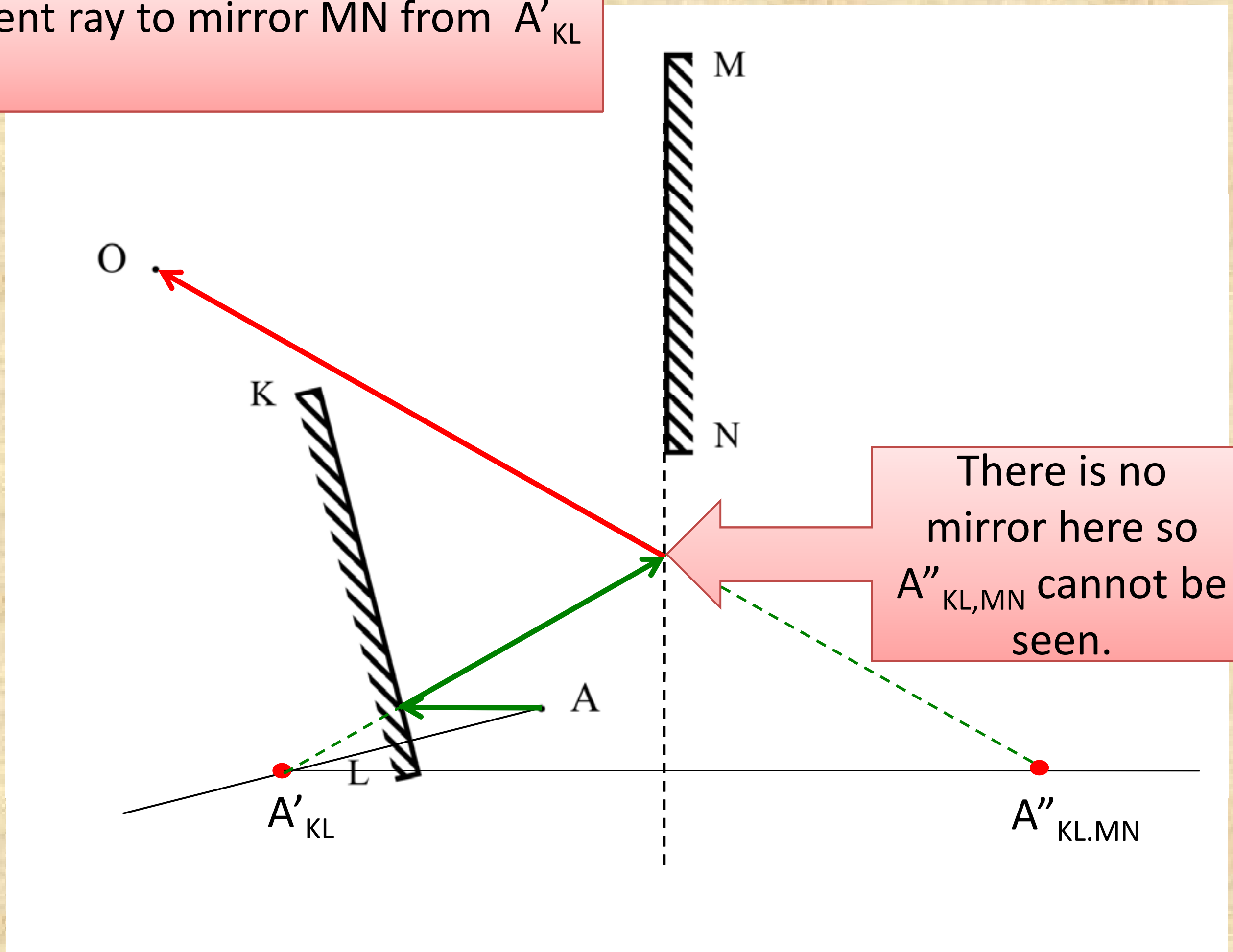


11. There are two mirrors KL and MN facing each other. Can the observer see the double reflection of object at point A? If yes, trace the path of light from object "A" to the observer.

Trace reflected ray from A"$_{KL,MN}$ to observer.

Trace incident ray to mirror KL from A its object.

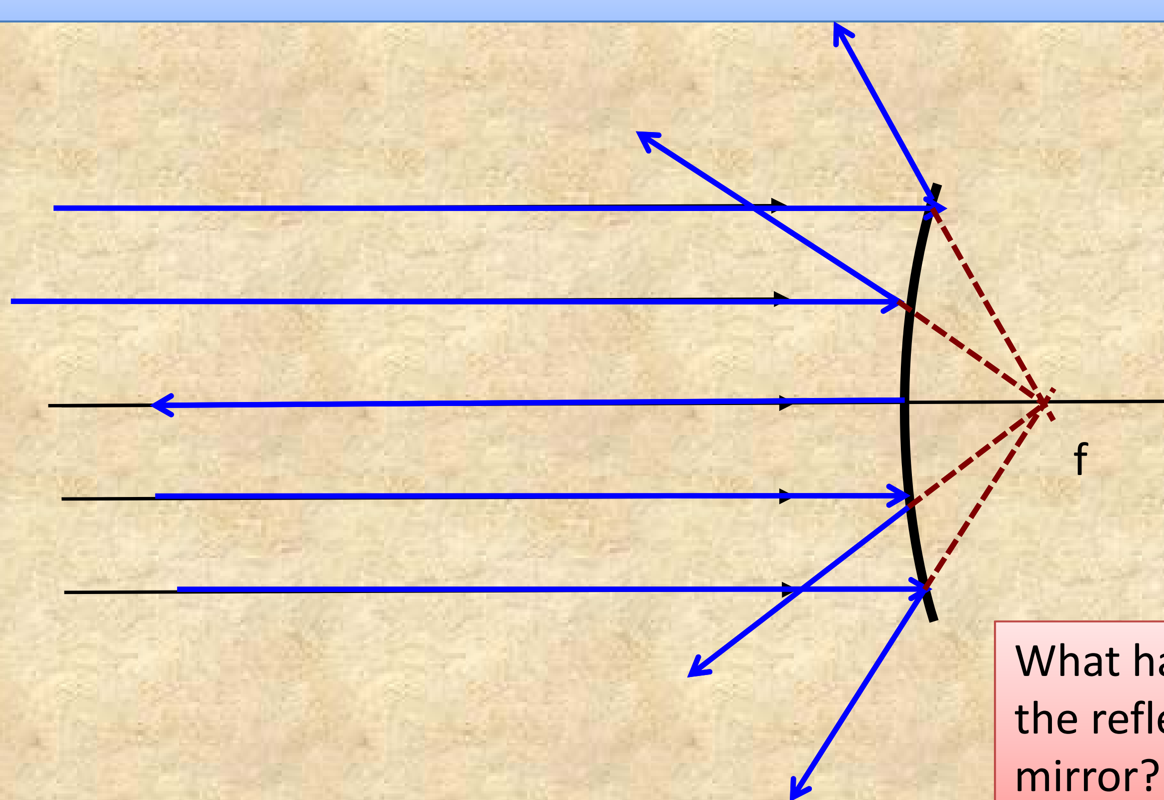
Trace incident ray to mirror MN from A'$_{KL}$ its object.



There is no mirror here so A"$_{KL,MN}$ cannot be seen.

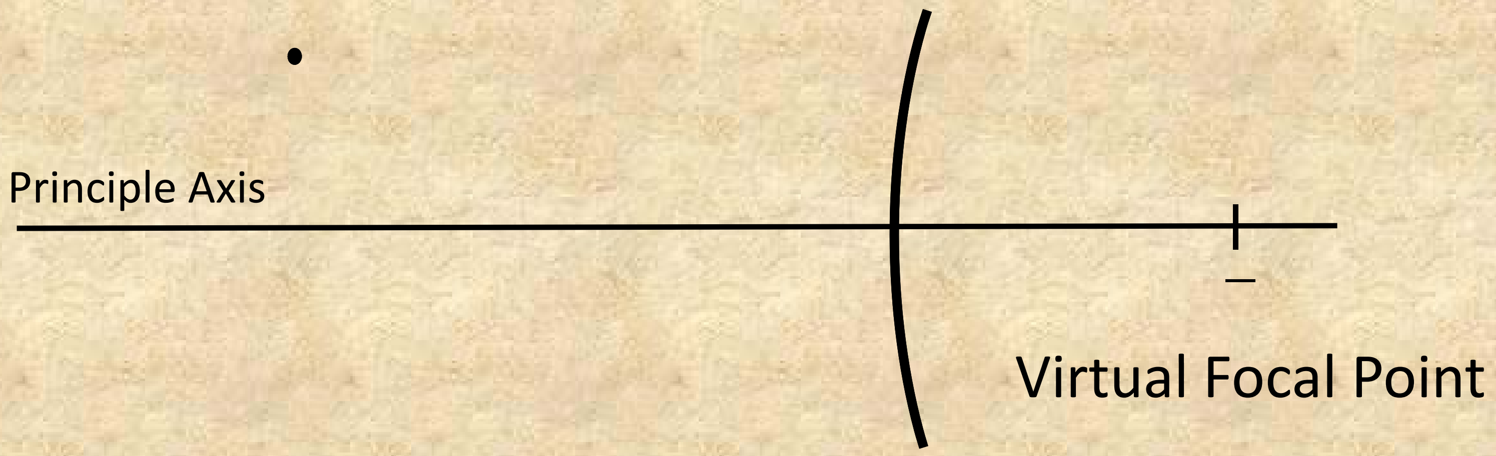
Curved Mirrors

1. For the **convex mirror** shown below, show how each of the rays is reflected off the convex mirror.

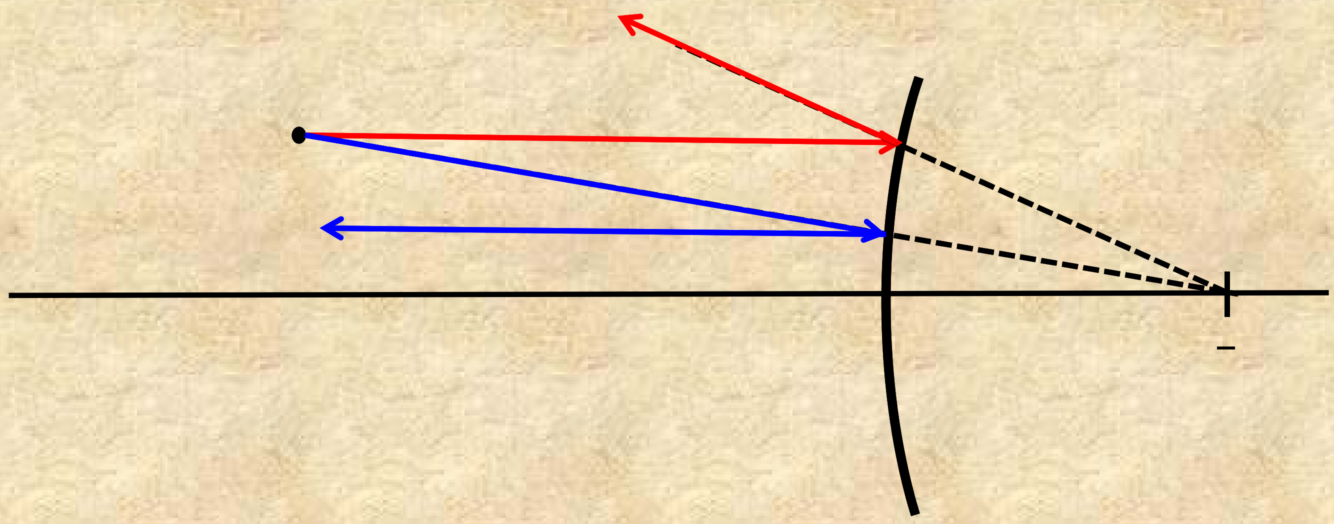


The reflected rays appear to all come from a point. Since they don't actually come from this point we refer to it as a virtual focal point.

What happens if we extend the reflected rays behind the mirror?



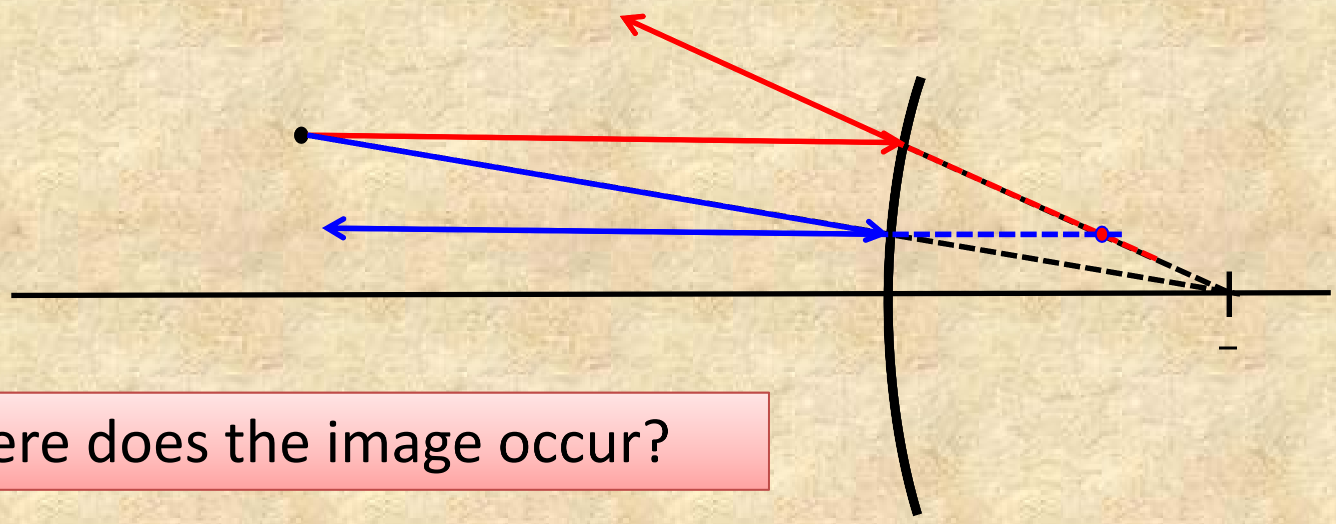
Principle Axis: A line that is drawn to the center of the mirror and that is perpendicular to a tangent to the arc of the mirror at its center.



A ray of light that approaches the mirror parallel to the principle axis reflects off the mirror as if it came from the virtual focal point.

Remember that the path of a ray of light is reversible.

A ray of light that approaches the mirror in the direction of the virtual focal point reflects off the mirror parallel to the principle axis.

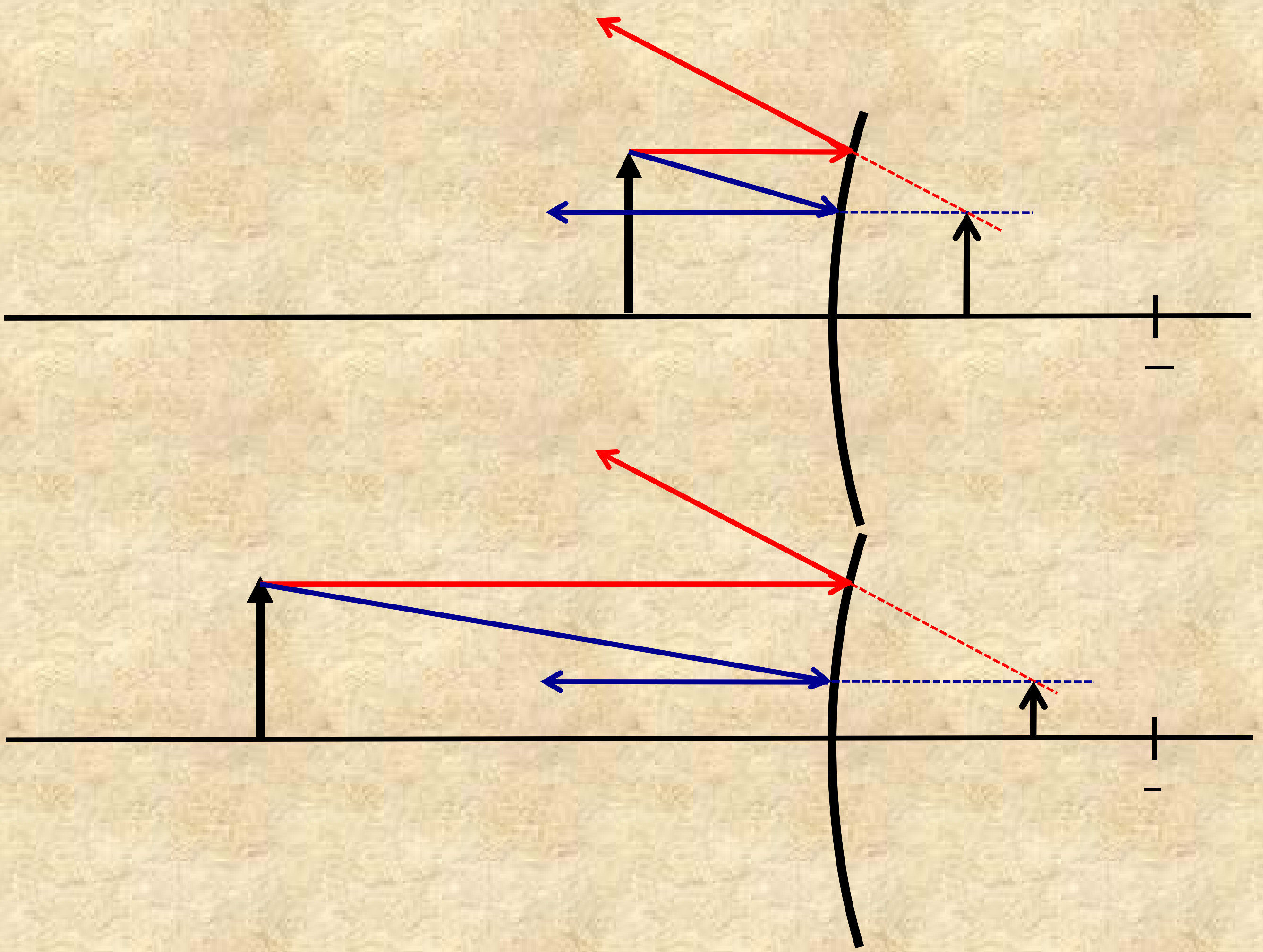


Where does the image occur?

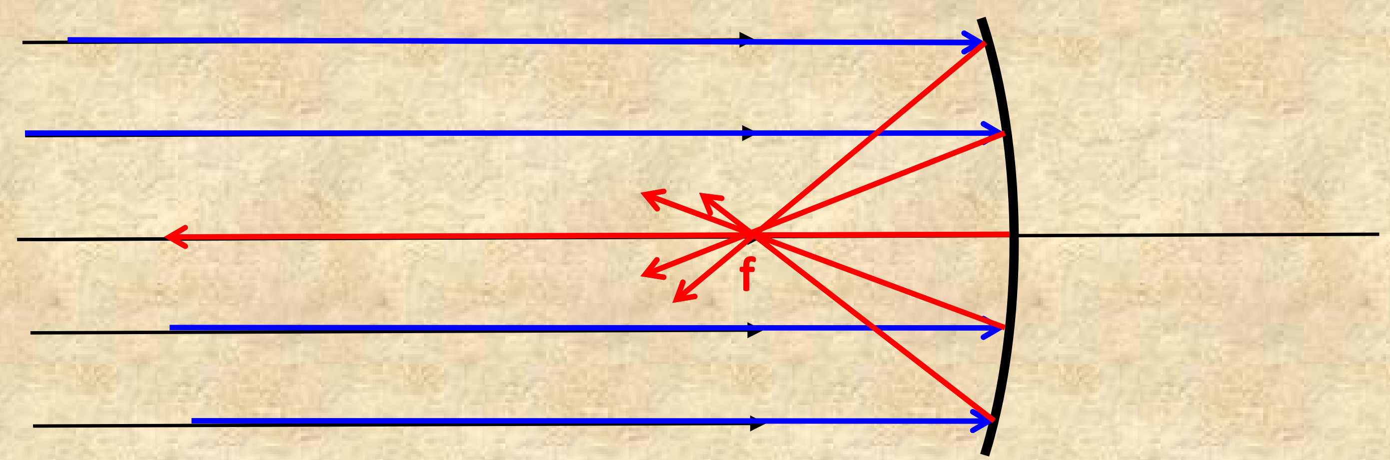
Extend the reflected rays behind the mirror until they intersect.

The image appears where the reflected rays intersect.

2. Draw the images in the following convex mirrors.

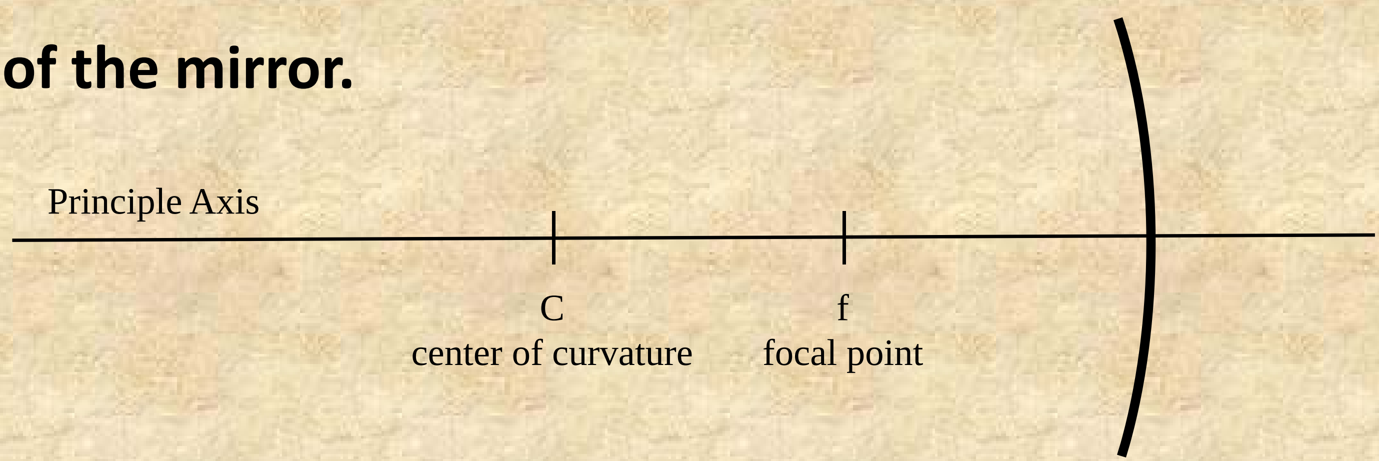


3. For the **concave mirror** shown below, show how each of the rays is reflected off the concave mirror.



All the reflected rays converge at a point called the focal point or the primary focus.

4. **Parts of the mirror.**

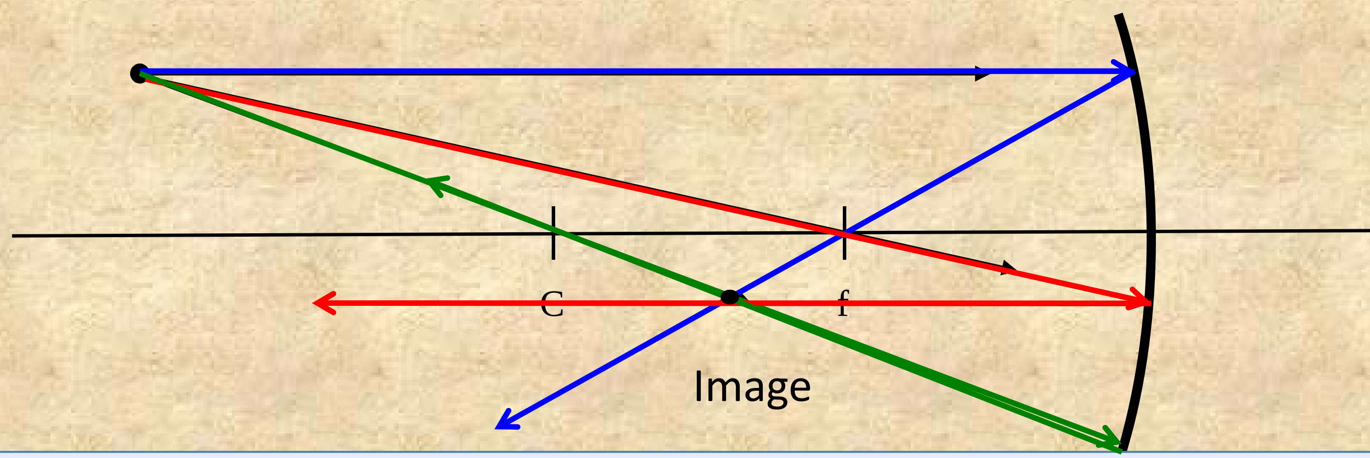


The line that intersects the mirror at the very center and is perpendicular to a tangent to the arc of the mirror at that point is called the **principle axis.**

The point on the principle axis where all the rays that approach the mirror parallel to the principle axis reflect and then cross is called the **focal point.**

The center of the circle that is drawn to make the shape of the mirror is called the **center of curvature**. The focal point is half way from the center of curvature to the mirror.

5. As rays of light approach the mirror three of the rays are easy to use to trace their path off of the mirror.

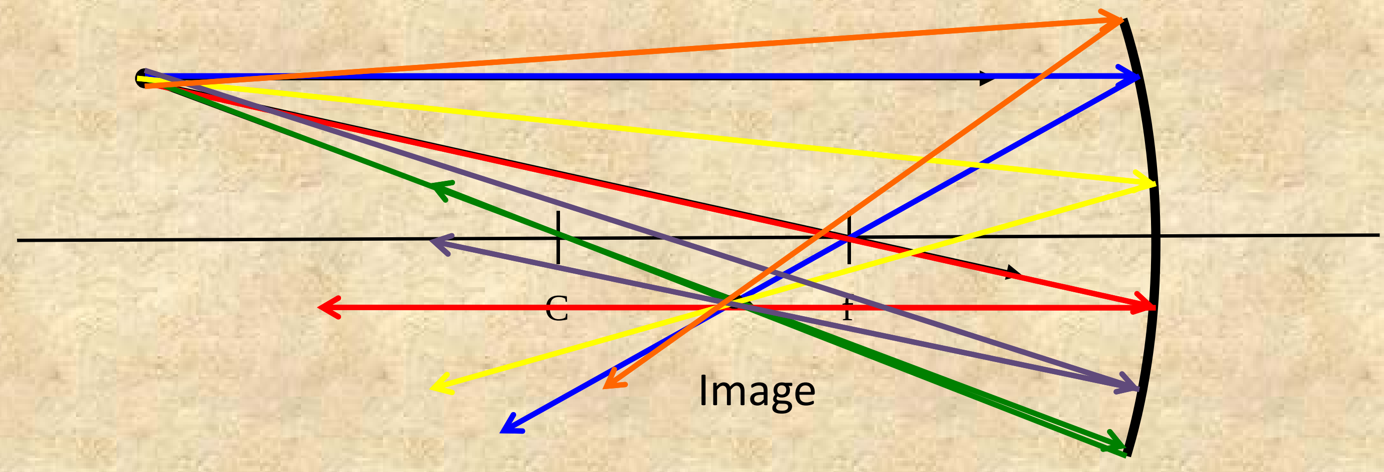


A ray of light that approaches the mirror parallel to the **principle axis** reflects off the mirror and passes through the focal point.

A ray of light that passes through the **focal point** as it approaches the mirror reflects off the mirror parallel to the principle axis.

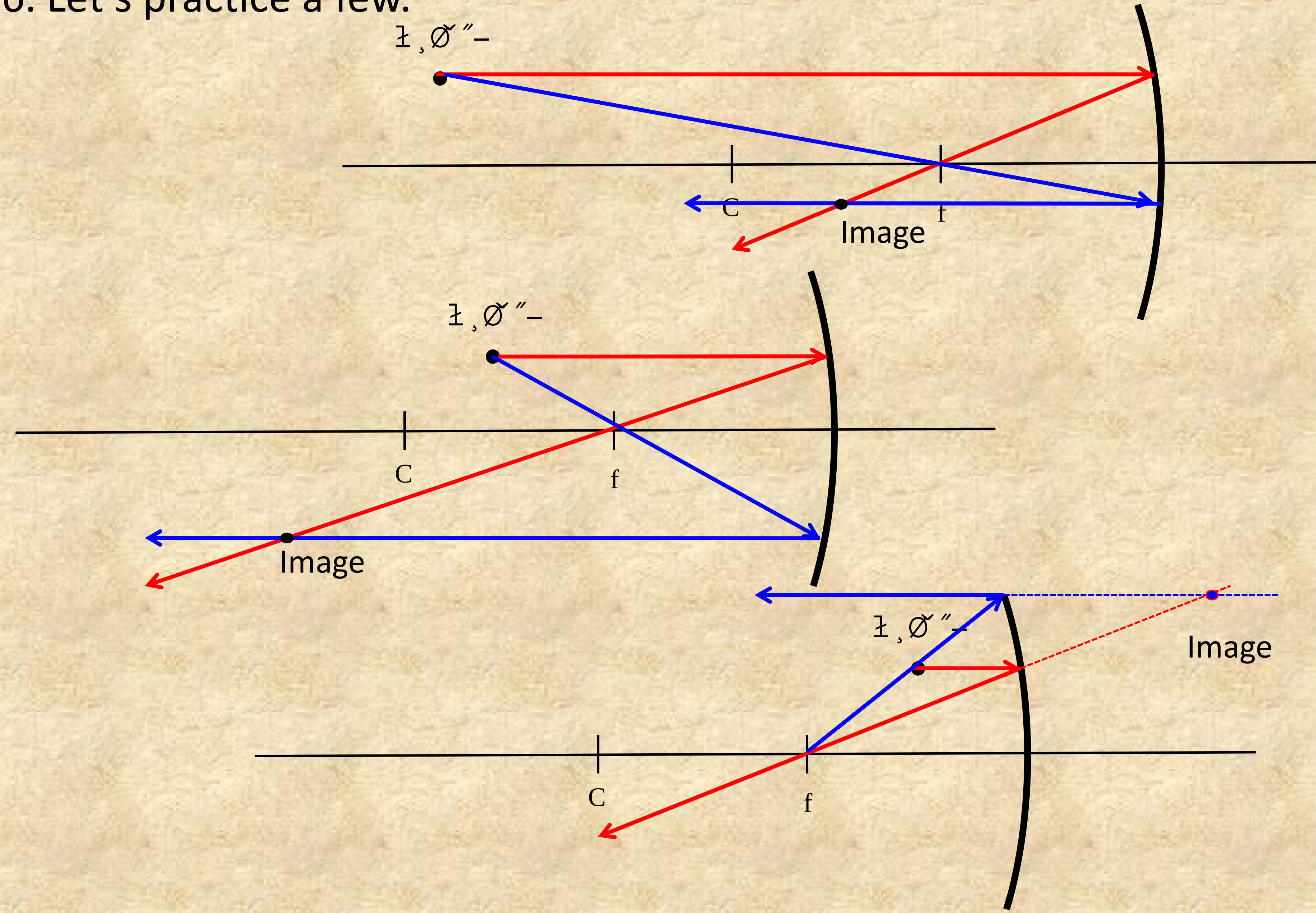
A ray of light that passes through the **center of curvature** as it approaches the mirror reflects off the mirror along the same path.

5. As rays of light approach the mirror three of the rays are easy to use to trace their path off of the mirror.

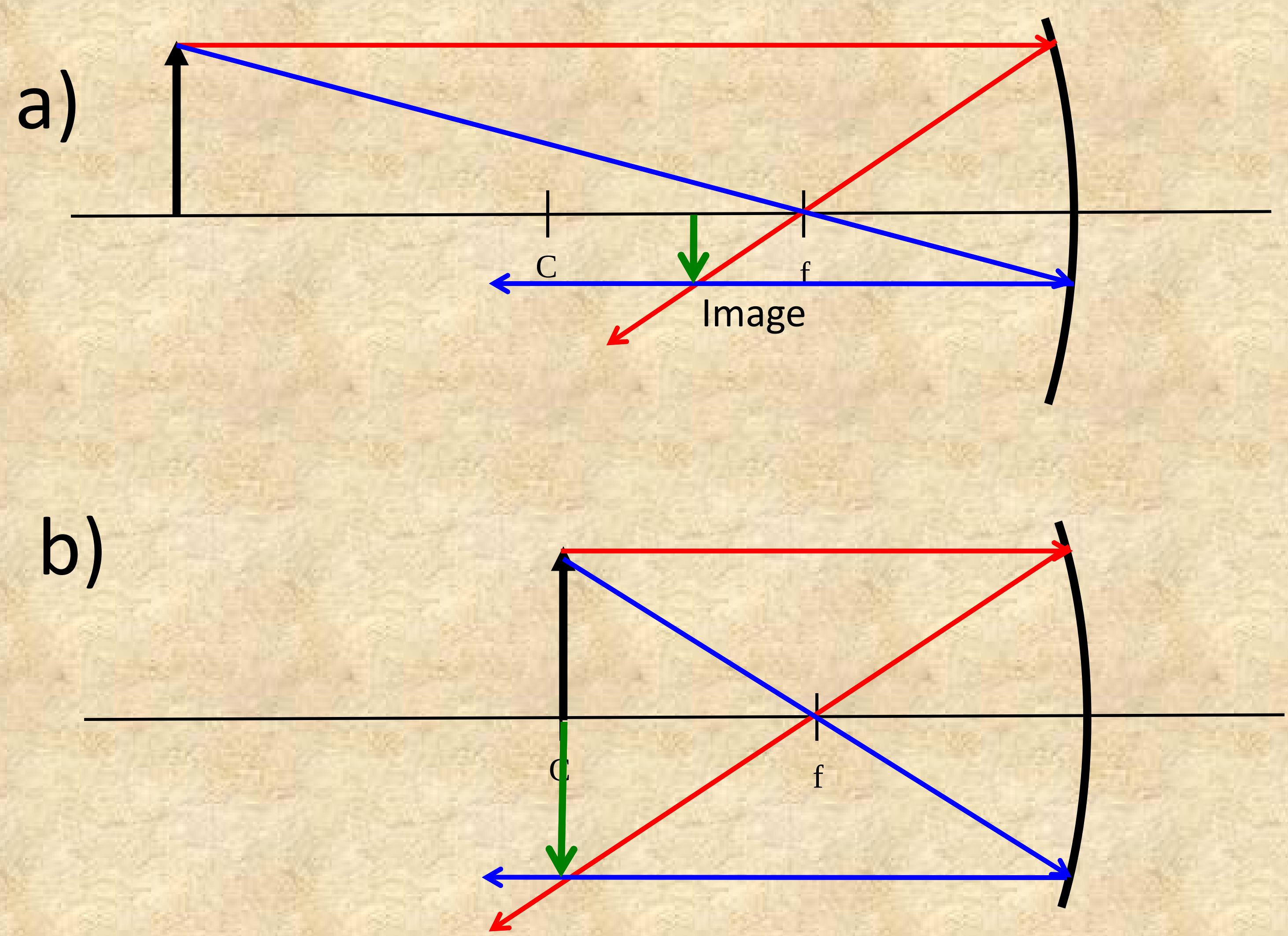


All rays of light that leave the object and strike the mirror reflect so that they pass through the image. The three that we illustrated are the easy ones to trace.

6. Let's practice a few.

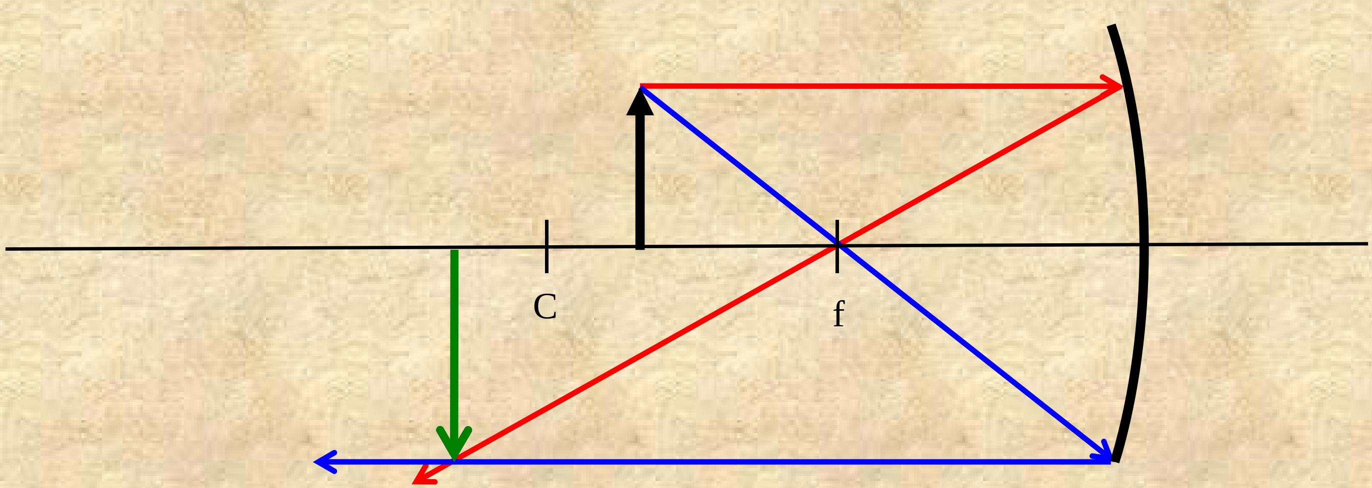


7. Instead of just a point, what if the object has some height, like an arrow.

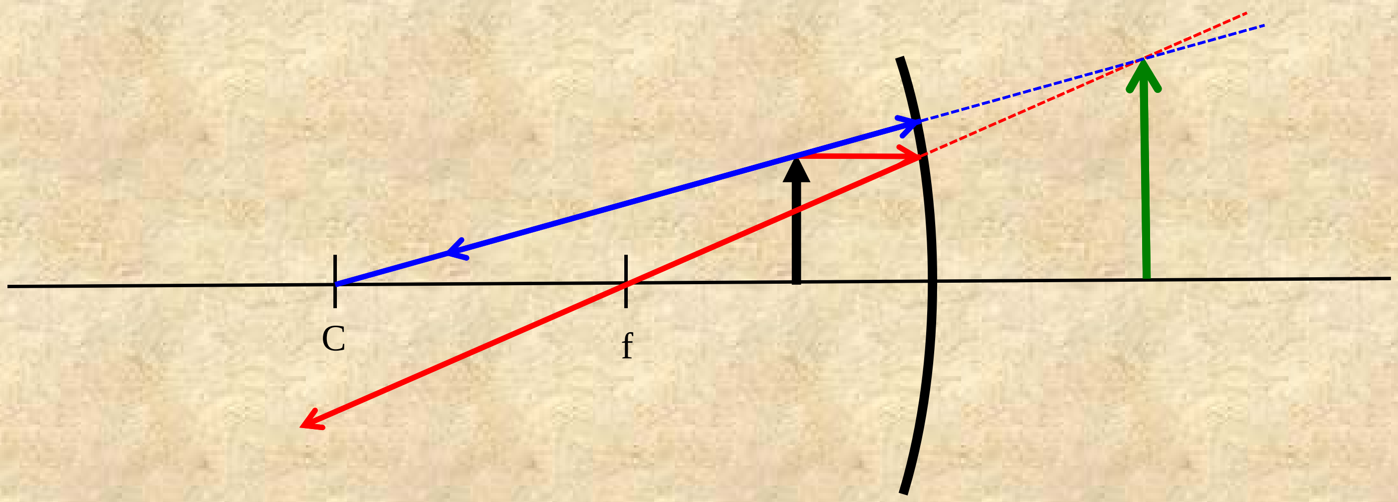


7. Instead of just a point, what if the object has some height, like an arrow.

c)



d)



8. There are two types of images that are formed as illustrated above in #7.

a) The image in a, b, and c is called a **real image**. List some of the characteristics of a real image.

1. The image is in front of the mirror.

2. The image is inverted (upside down).

3. Real light rays cross to form the image.

4. The image can be shown on a screen.

b) The image in d is called a **virtual image**. List some of the characteristics of a virtual image.

1. The image is behind the mirror.

2. The image is erect.

3. Projected (by the brain) light rays cross to form the image.

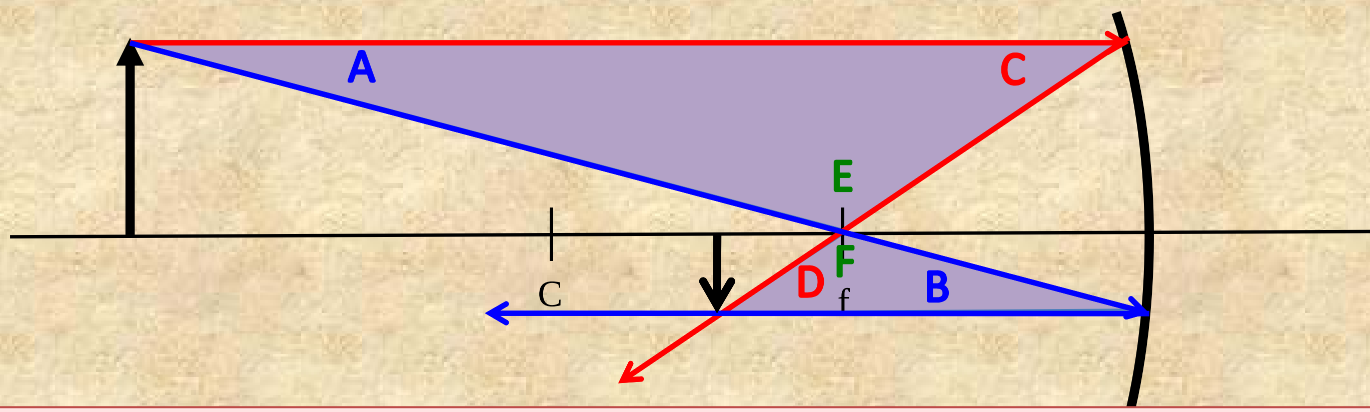
4. The image cannot be shown on a screen.

Complete the following table to help illustrate how the image changes as the object is placed at different distances from the screen.

Object Location	Image Location	Image size relative to object size	Type of image
Beyond "C"	Between f & C	Smaller	Real
at “C”	At C	Same Size	Real
between “C” and “f”	Beyond C	Larger	Real
between “f” & the mirror	Behind the Mirror	Larger	Virtual
at the vertex of the mirror	At the Mirror	Same Size	Virtual
at the focal point	At ∞	X X X X	X X X X
at infinity	At f	X X X X	X X X X

Let’s see if we can derive some equations for spherical mirrors.

<A = <B. When two parallel lines are cut by a transversal the alternate interior angles are equal.



<C = <D. When two parallel lines are cut by a transversal the alternate interior angles are equal.

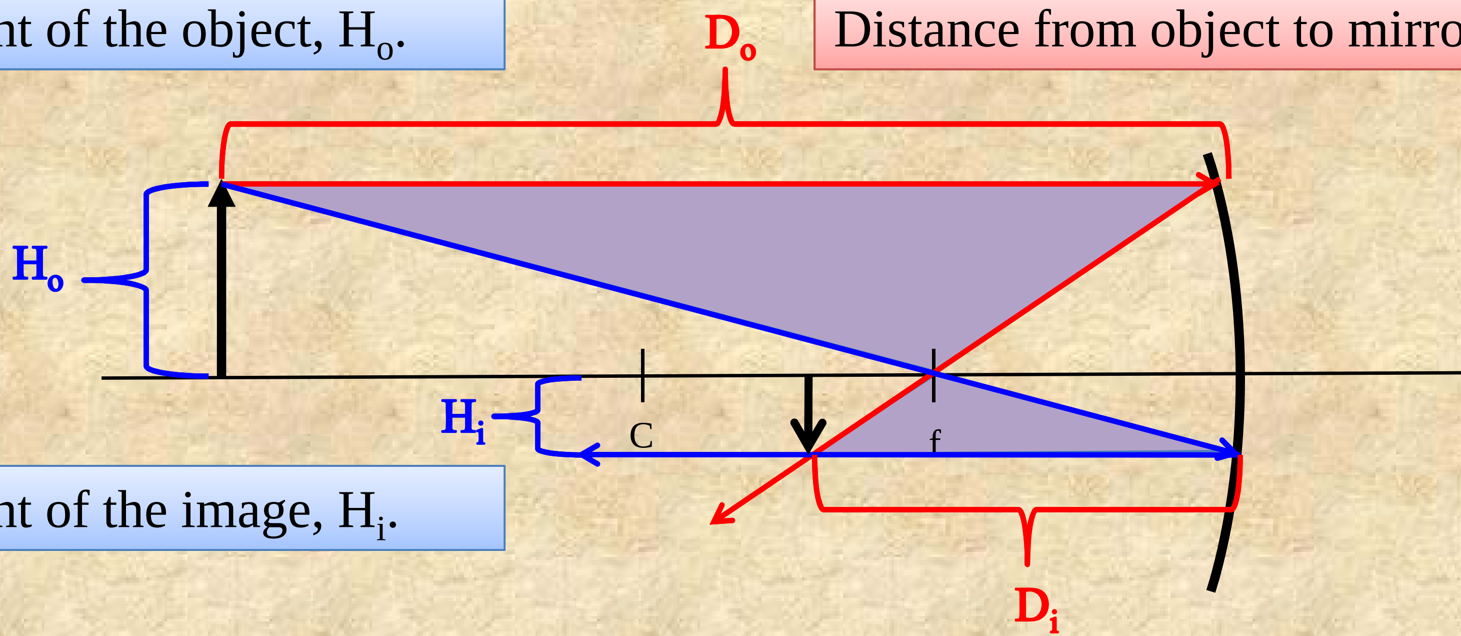
<E = <F. Vertical angles are equal.

Triangle ACE is similar to triangle BDF. AAA = AAA

Let’s see if we can derive some equations for spherical mirrors.

Height of the object, H_o.

Distance from object to mirror, D_o.



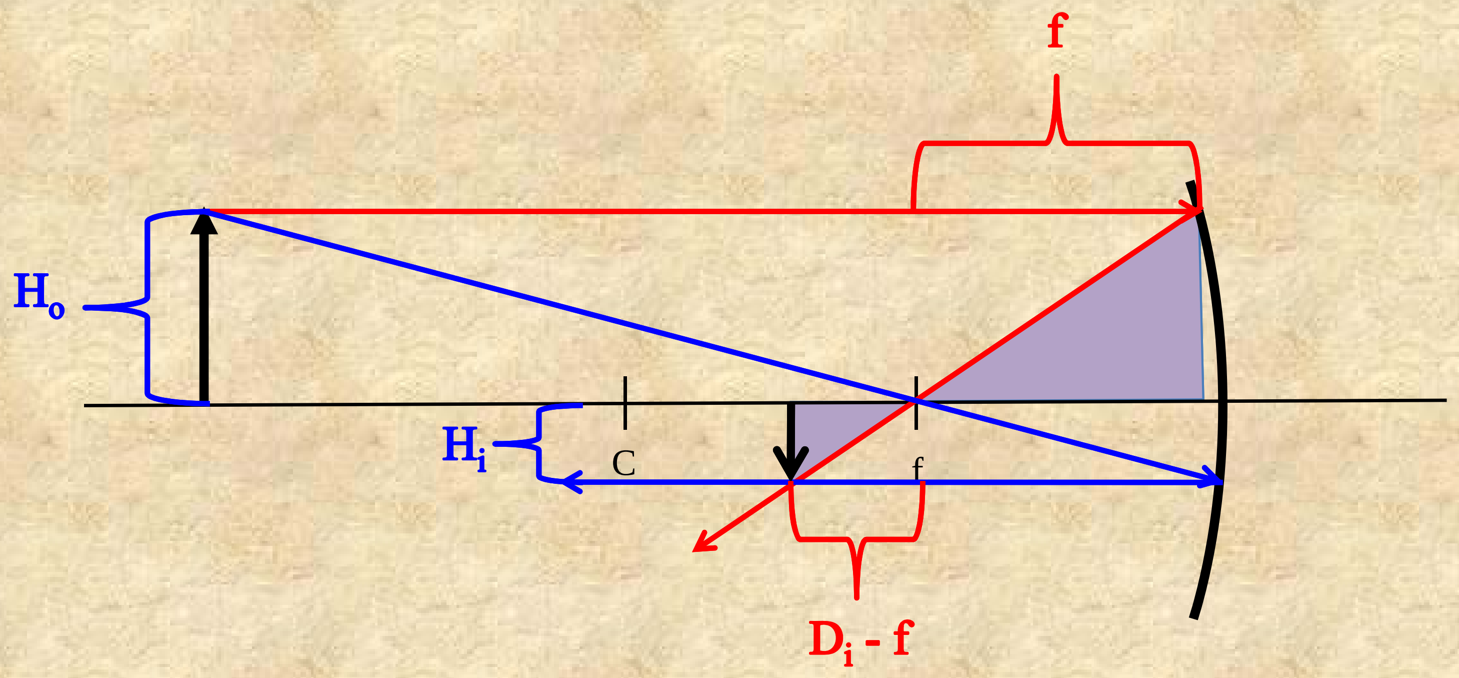
Height of the image, H_i.

Distance from image to mirror, D_i.

Corresponding sides of similar triangles are proportional.

$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$

Let’s see if we can derive some equations for spherical mirrors.

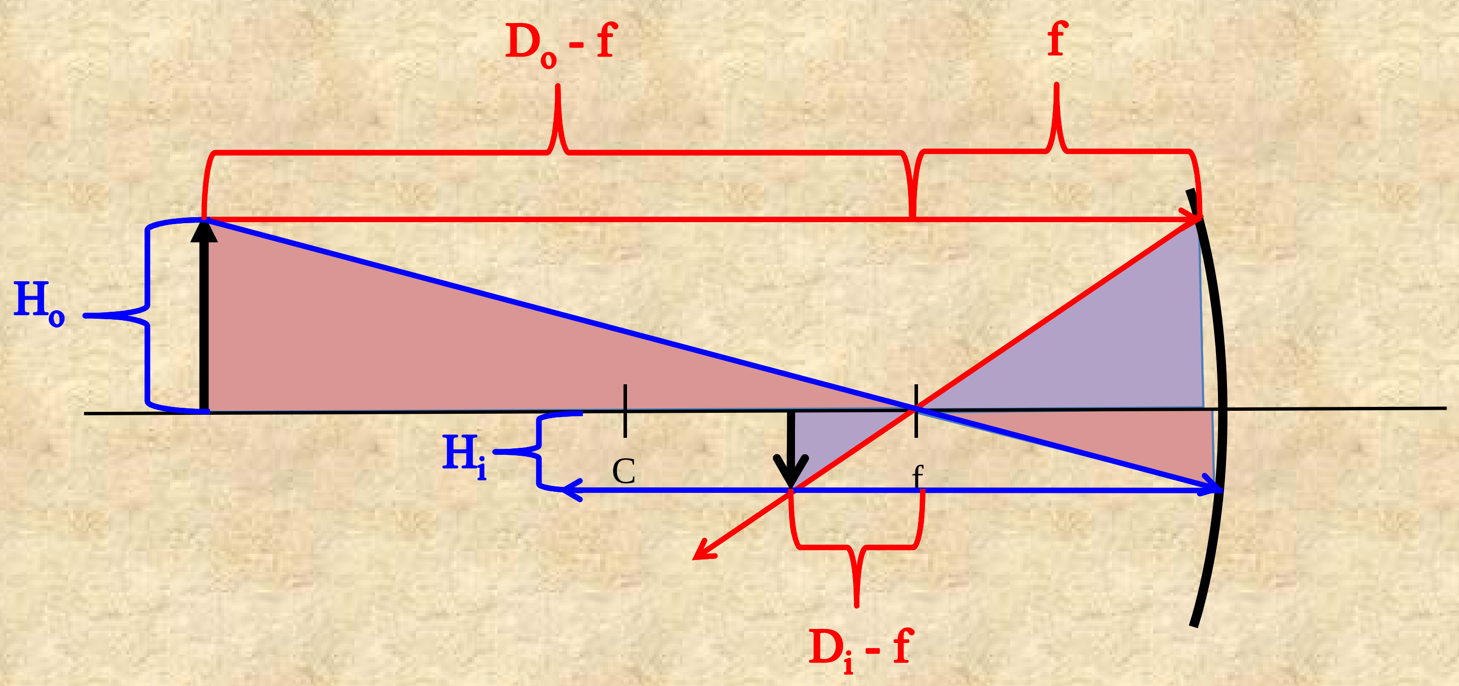


Similarly we can show that these two triangles are similar.

Corresponding sides of similar triangles are proportional.

$$\frac{H_i}{H_o} = \frac{D_i - f}{f}$$

Let's see if we can derive some equations for spherical mirrors.

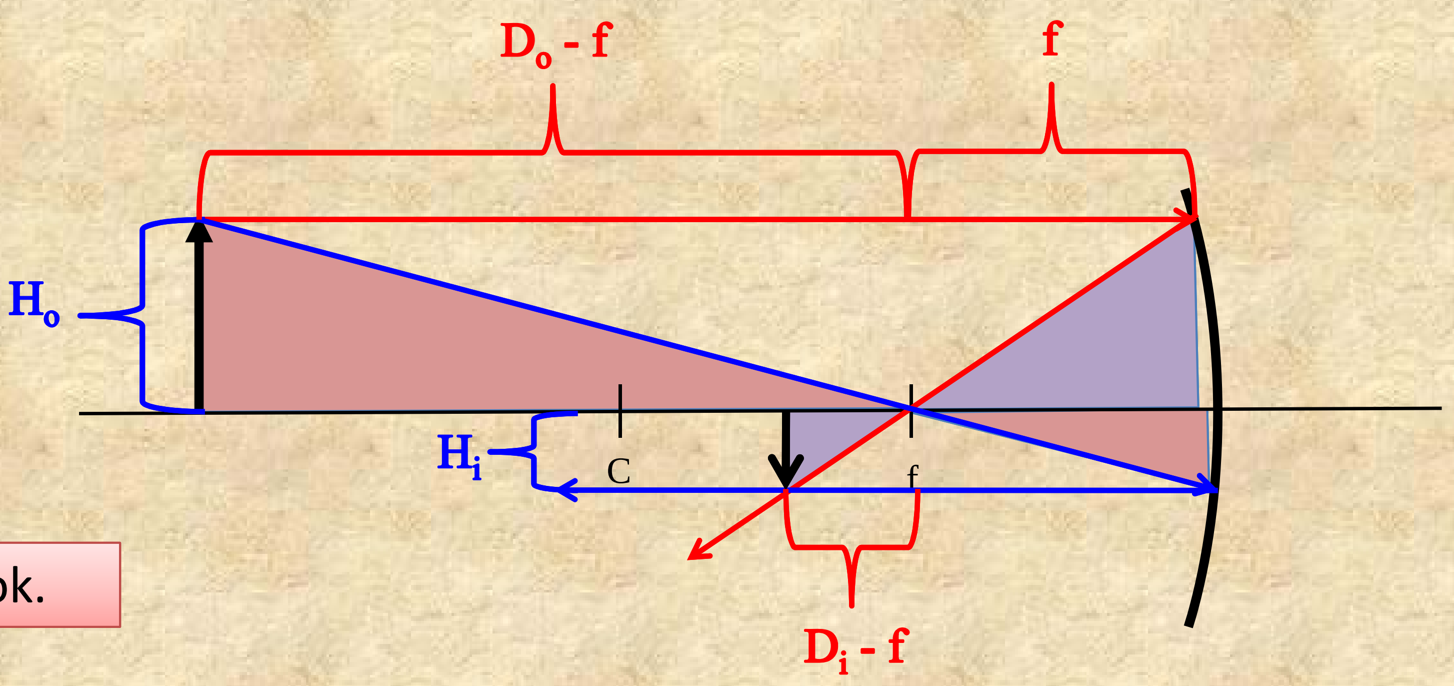


Lastly, we can show that these two triangles are similar.

Corresponding sides of similar triangles are proportional.

$$\frac{H_i}{H_o} = \frac{f}{D_o - f}$$

Let’s see if we can derive some equations for spherical mirrors.



So, look.

$$\frac{H_i}{H_o} = \frac{f}{D_o - f} \quad \text{and} \quad \frac{H_i}{H_o} = \frac{D_i - f}{f} \quad \text{then} \quad \frac{f}{D_o - f} = \frac{D_i - f}{f}$$

Cross multiply

$$f^2 = DoD_i - D_of - D_if + f^2 \qquad DoD_i = D_of + D_if$$

Let's see if we can derive some equations for spherical mirrors.

$DoD_i = D_of + D_if$

Divide through by f.

$DoD_i/f = D_o + D_i$

Divide through by D_0D_i.

$1/f = 1/D_o + 1/D_i$

If breaking a plane mirror causes seven years of bad luck, what happens if you break a curved mirror?

If, I do, I die!

To summarize:

$H_i/H_o = D_i/D_o$ which is also the magnification, M

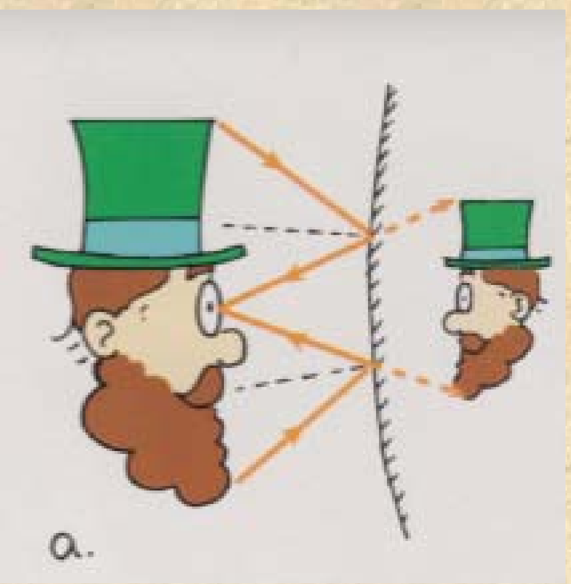
$H_i/H_o = f/(D_o – f) = (D_i – f)/f$

$1/f = 1/D_o + 1/D_i$

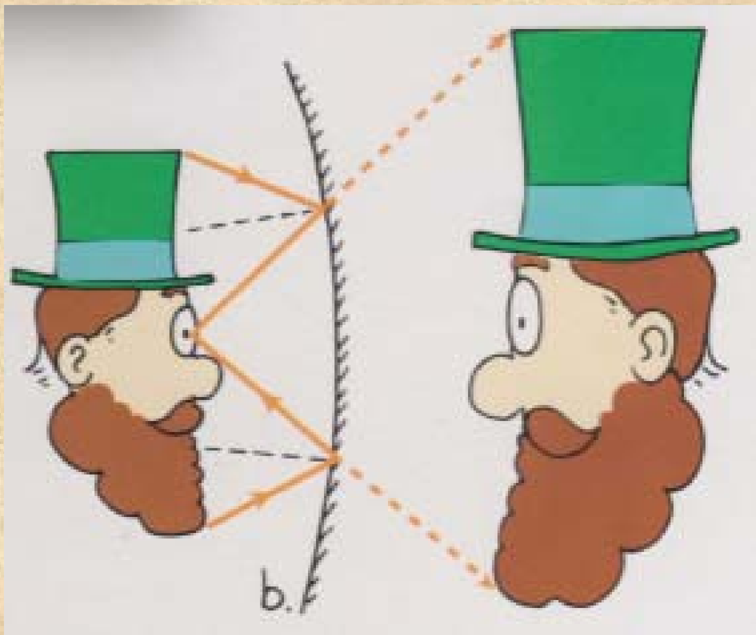
If D_i is negative, then the image is behind the mirror.

If D_i is negative, then H_i will also be negative and the image is virtual.

Both convex mirrors and concave mirrors can produce virtual images.
What is the difference between virtual images produced by a convex mirror and virtual images produced by a concave mirror?



Convex mirrors have a virtual focal point, so the focal length of a convex mirror is negative.



Convex mirrors produce only virtual images that can be the same size as the object or smaller.

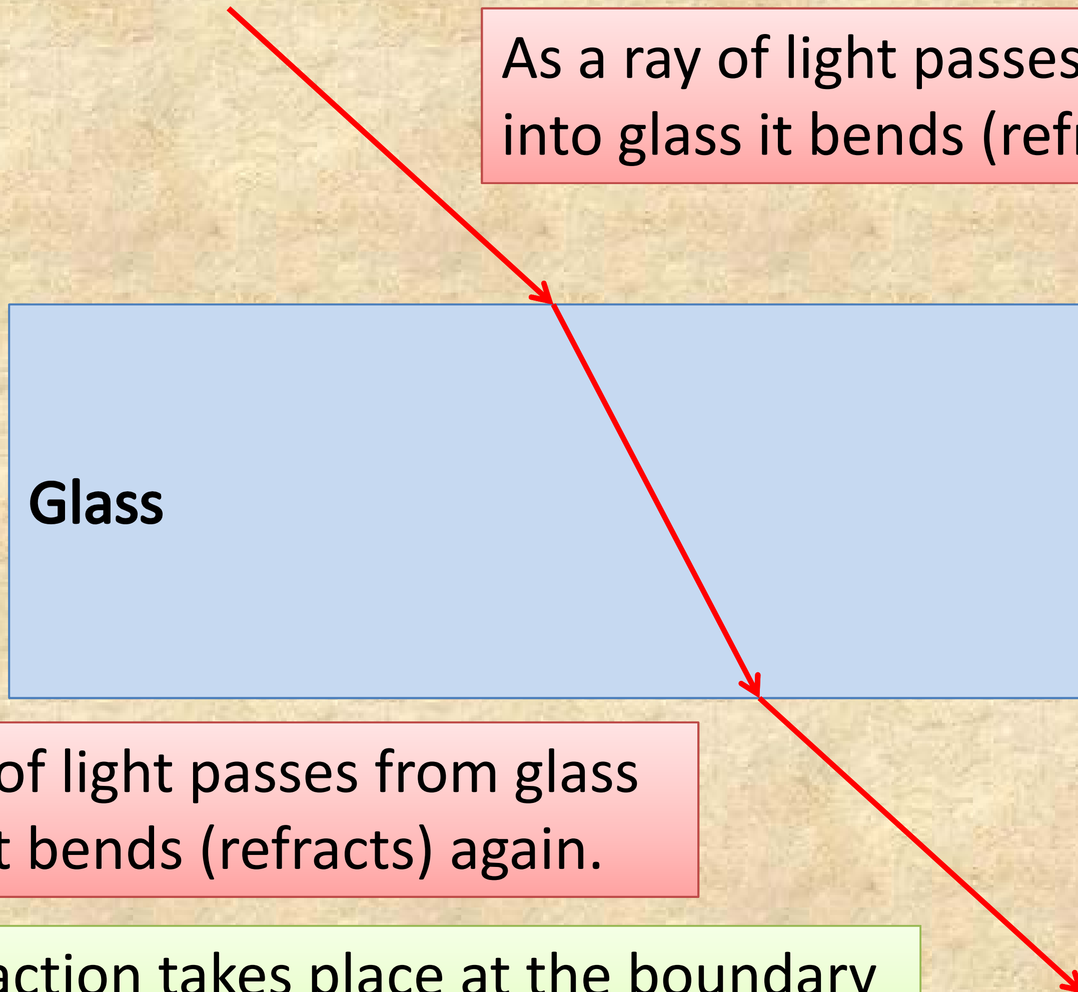
Concave mirrors produce virtual images when the object is between the focal point and the mirror. The virtual images are the same size as the object or larger.

Science Olympiad

Ray Optics

Refraction

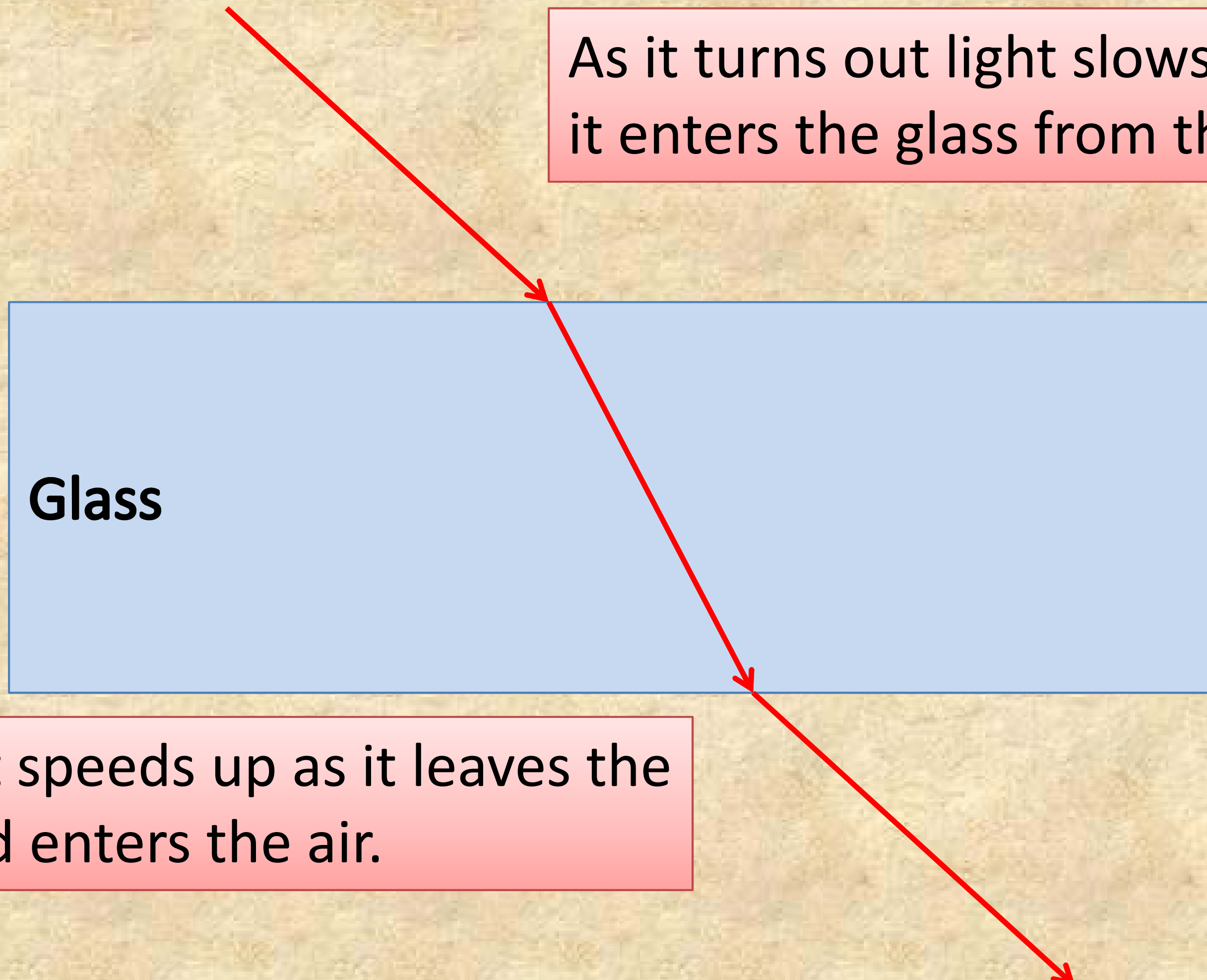
As a ray of light passes from air into glass it bends (refracts).



As a ray of light passes from glass into air it bends (refracts) again.

The refraction takes place at the boundary between the air and the glass (interface).

As it turns out light slows down as it enters the glass from the air.



The light speeds up as it leaves the glass and enters the air.

By definition the index of refraction for glass:

n_{glass} = speed of light in air/speed of light in glass

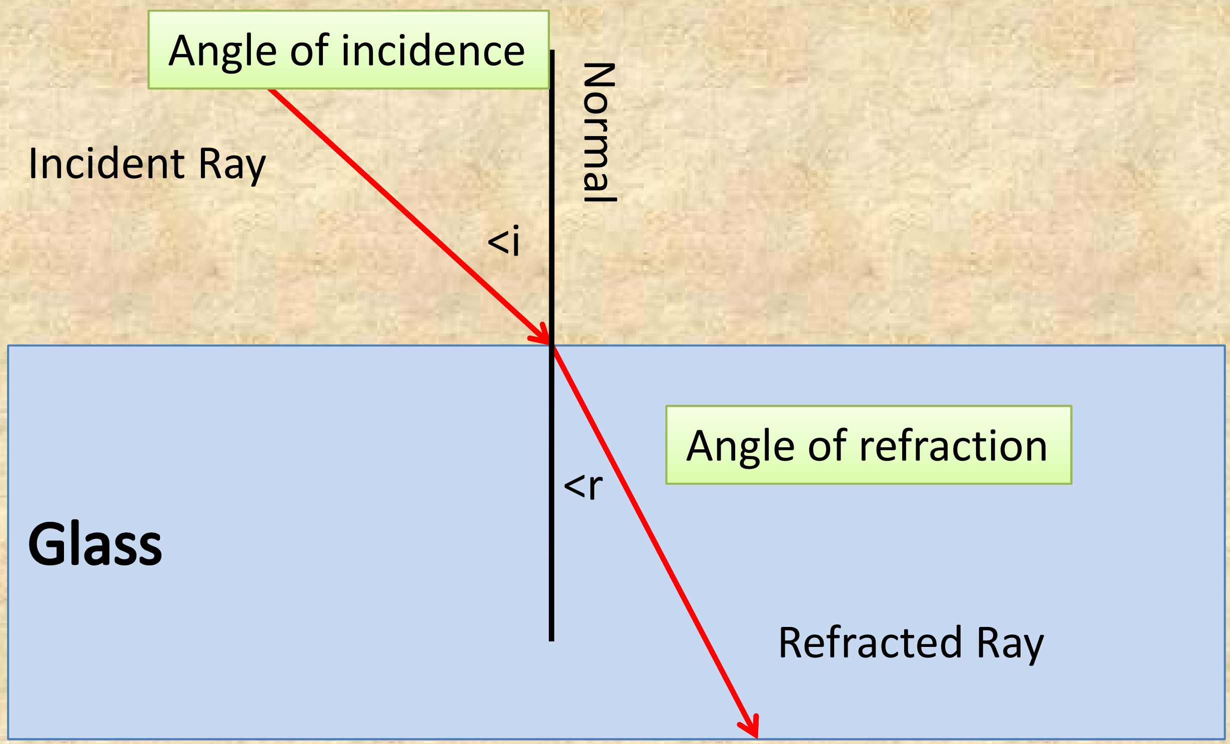
Actually the index of refraction for glass:
n_{glass} = speed of light in a vacuum/speed of light in glass

The index of refraction for air, $n_{air} = 1.00029$
Yes, light refracts when it comes from space and enters our atmosphere. In this case it is significant, but for our use in normal life the difference is not significant.

n_{Subs} = speed of light in a vacuum/speed of light in the substance.

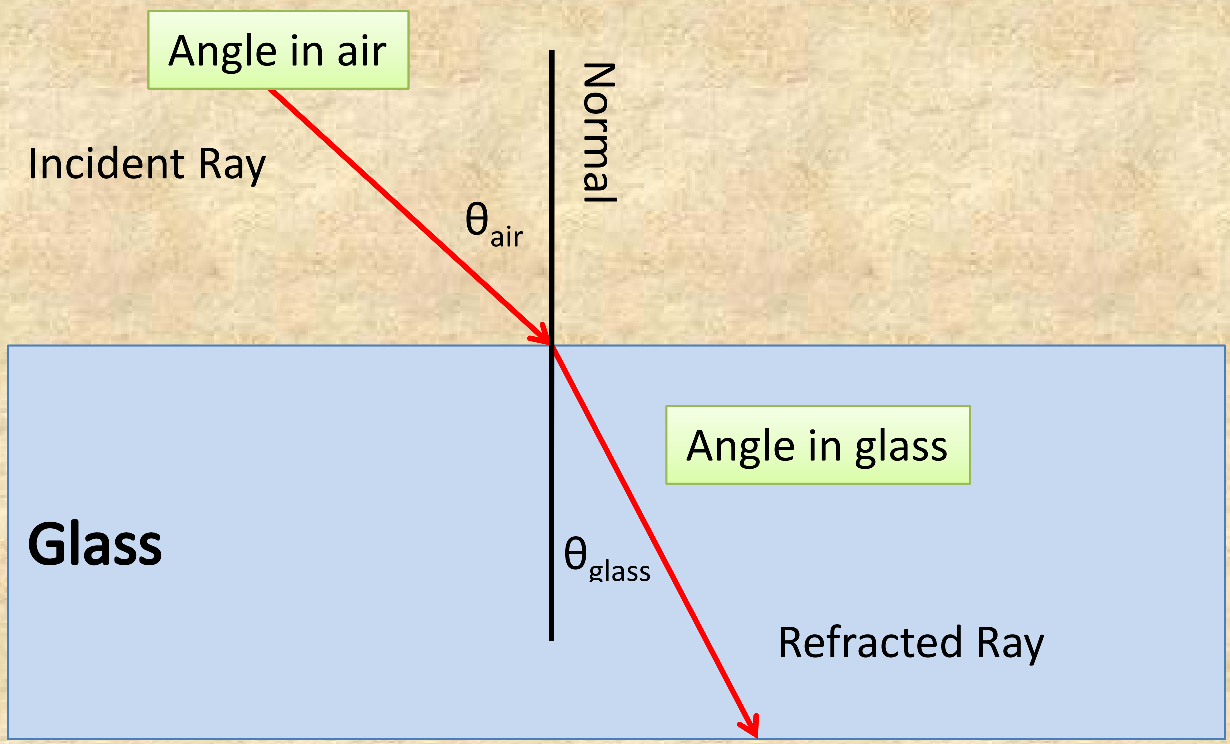
$n_{Subs} \cong$ speed of light in a air/speed of light in the substance.

To three significant figures, they are essentially the same.



A scientist name Snell noticed after many trials found that there is a relationship between the angle of incidence and the angle of refraction.

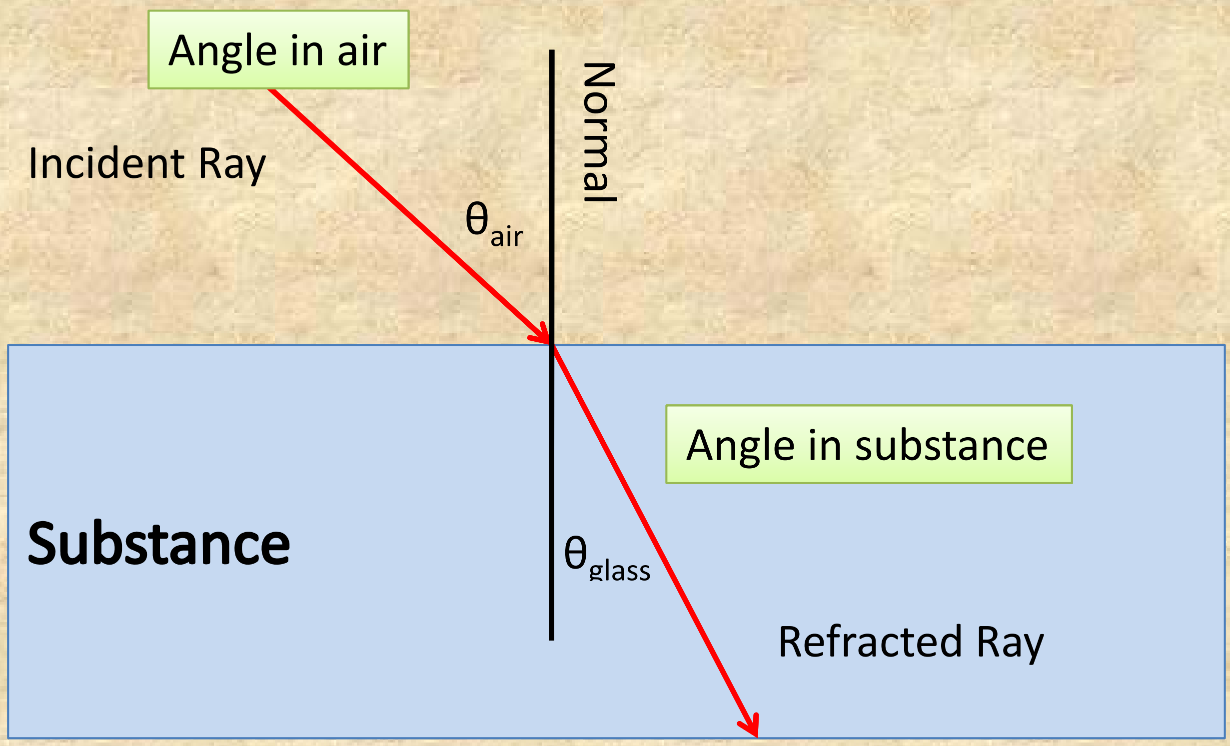
The ratio sin<i/sin<r is a constant.



It is also true that in refraction that the path of a ray of light is reversible.

The ratio $\sin\theta_{air}/\sin\theta_{glass}$ is a constant.

$$n_{glass} = v_{vac}/v_{glass} = \sin\theta_{vac}/\sin\theta_{glass} \cong v_{air}/v_{glass} = \sin\theta_{air}/\sin\theta_{glass}$$



$n_{Sub} = v_{vac}/v_{Sub} = \sin\theta_{vac}/\sin\theta_{Sub} \cong v_{air}/v_{Sub} = \sin\theta_{air}/\sin\theta_{Sub}$

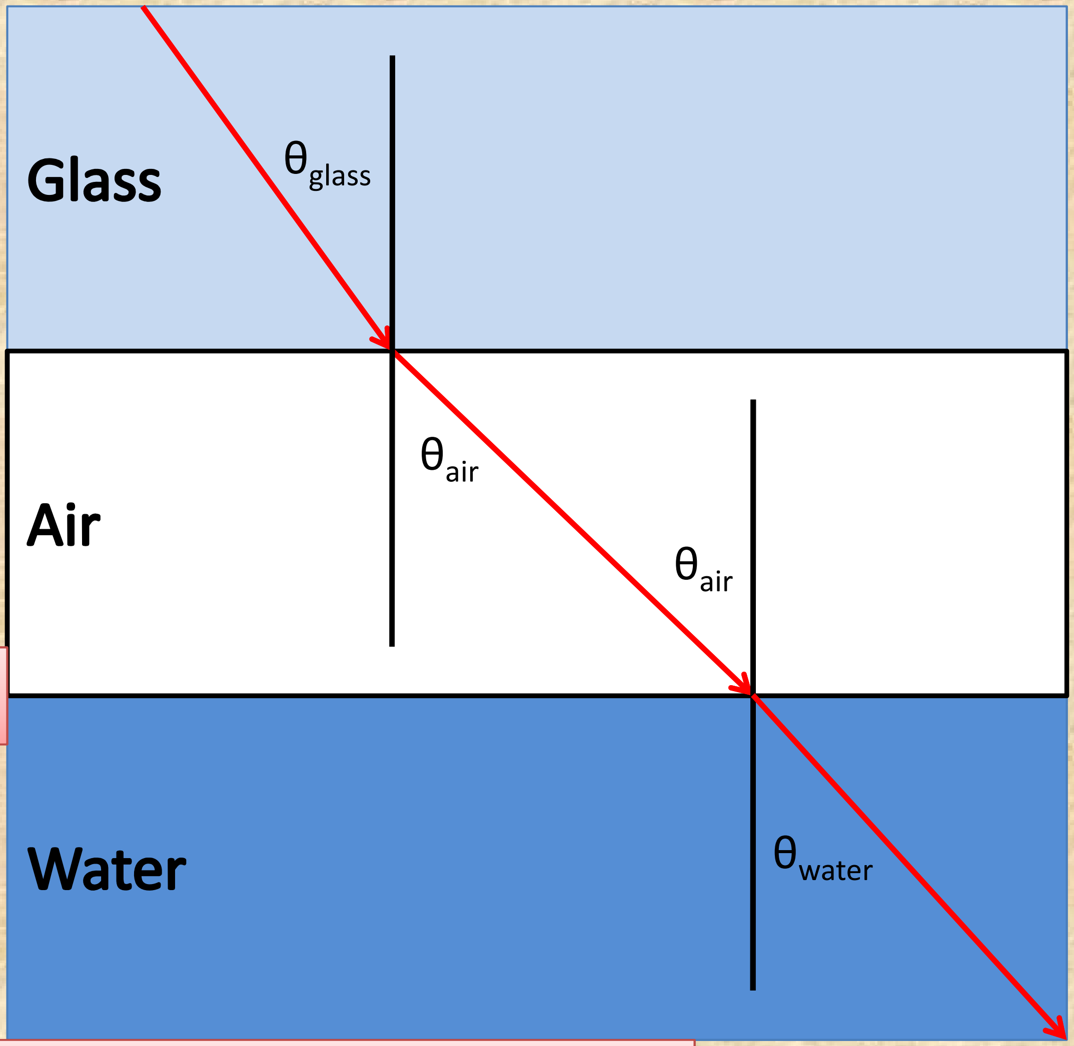
So what happens if one of the substances is something other than air? All these indices involve air and some substance. Let's say light is going from glass to water.

First Interface

$n_{glass} = \sin\theta_{air}/\sin\theta_{glass}$

Second Interface

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



To start, let's put air between the glass and water.

First Interface

$n_{glass} = \sin\theta_{air}/\sin\theta_{glass}$

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

Second Interface

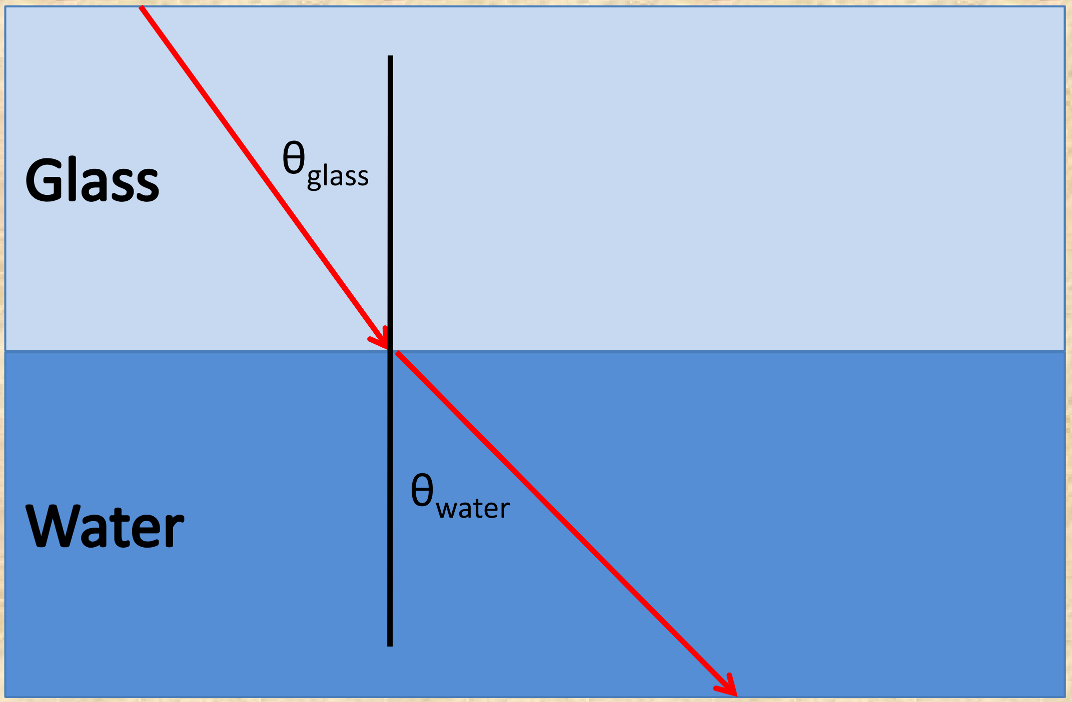
$n_{water} = \sin\theta_{air}/\sin\theta_{water}$

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

If the interfaces are parallel then the two angles, θ_{air} are the same.

Substituting: $n_{glass}\sin\theta_{glass} = n_{water}\sin\theta_{water}$

If we push the air out.



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

To generalize: $n_X\sin\theta_X = n_y\sin\theta_y = n_z\sin\theta_z = \ldots$ as long as the interfaces are parallel.

Some indices of refraction:

n_{air} = 1.00029

n_{water} = 1.33

$n_{glycerine}$ = 1.47

n_{Lucite} = 1.49

$n_{crown\ glass}$ = 1.52

$n_{diamond}$ = 2.42

In general the more dense the substance the greater the index of refraction.

As light goes from a less dense substance (lower index of refraction) to a denser substance (higher index of refraction) the light ray bends towards the normal. <i is greater than <r.

As light goes from a denser substance to a less dense substance the light ray bends away from the normal. <i is less than <r.

Some indices of refraction:

n_{air} = 1.00029

n_{water} = 1.33

$n_{glycerin}$ = 1.47

n_{Lucite} = 1.49

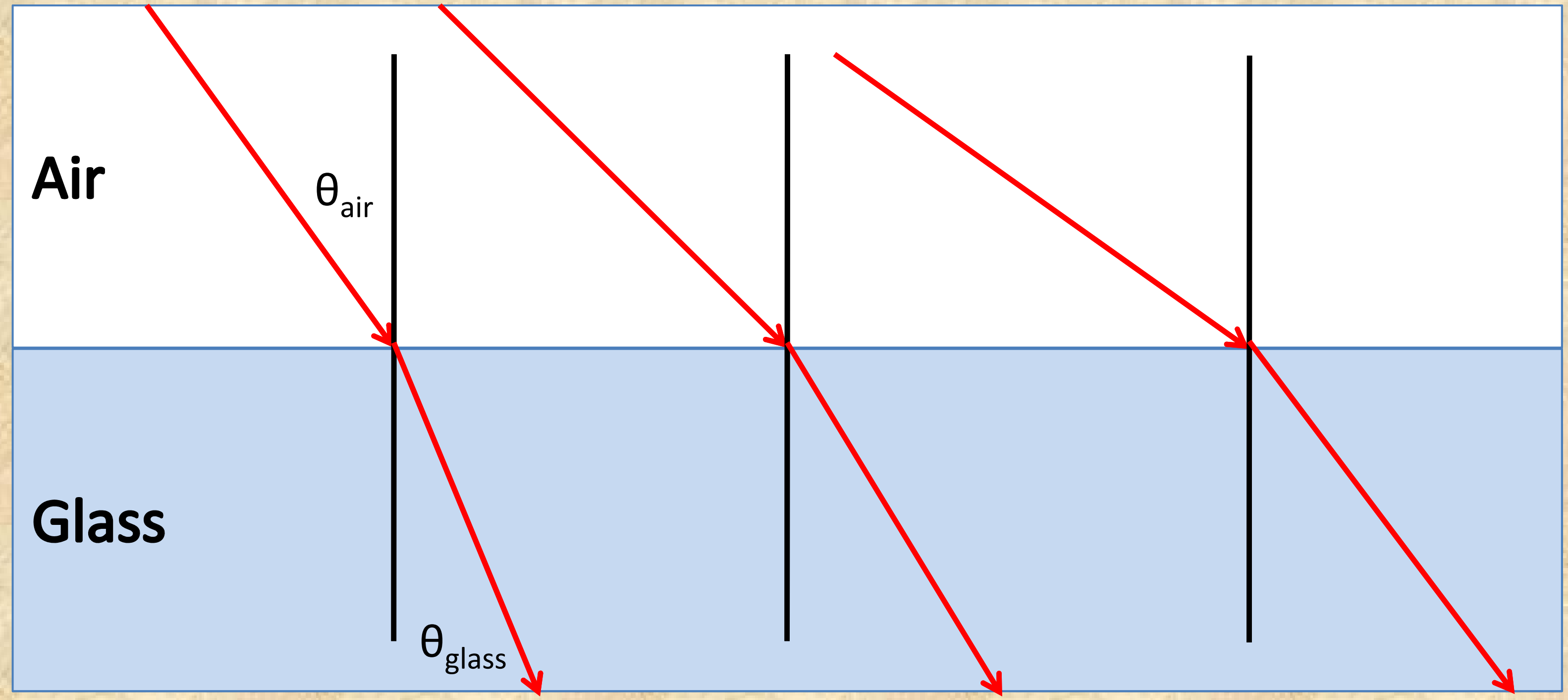
$n_{crown\ glass}$ = 1.52

$n_{diamond}$ = 2.42

As light goes from a less dense substance (lower index of refraction) to a denser substance (higher index of refraction) the light ray bends towards the normal. <i is greater than <r.

No matter how big the angle of incidence in the less dense substance the angle of refraction in the denser substance will be smaller.

The largest angle of incidence in the less dense substance is 90°, so the angle of refraction in the denser substance will always be less than 90°.



No matter how big the angle of incidence in the air the angle of refraction in the glass will be smaller.

Some indices of refraction:

n_{air} = 1.00029

n_{water} = 1.33

$n_{glycerine}$ = 1.47

n_{Lucite} = 1.49

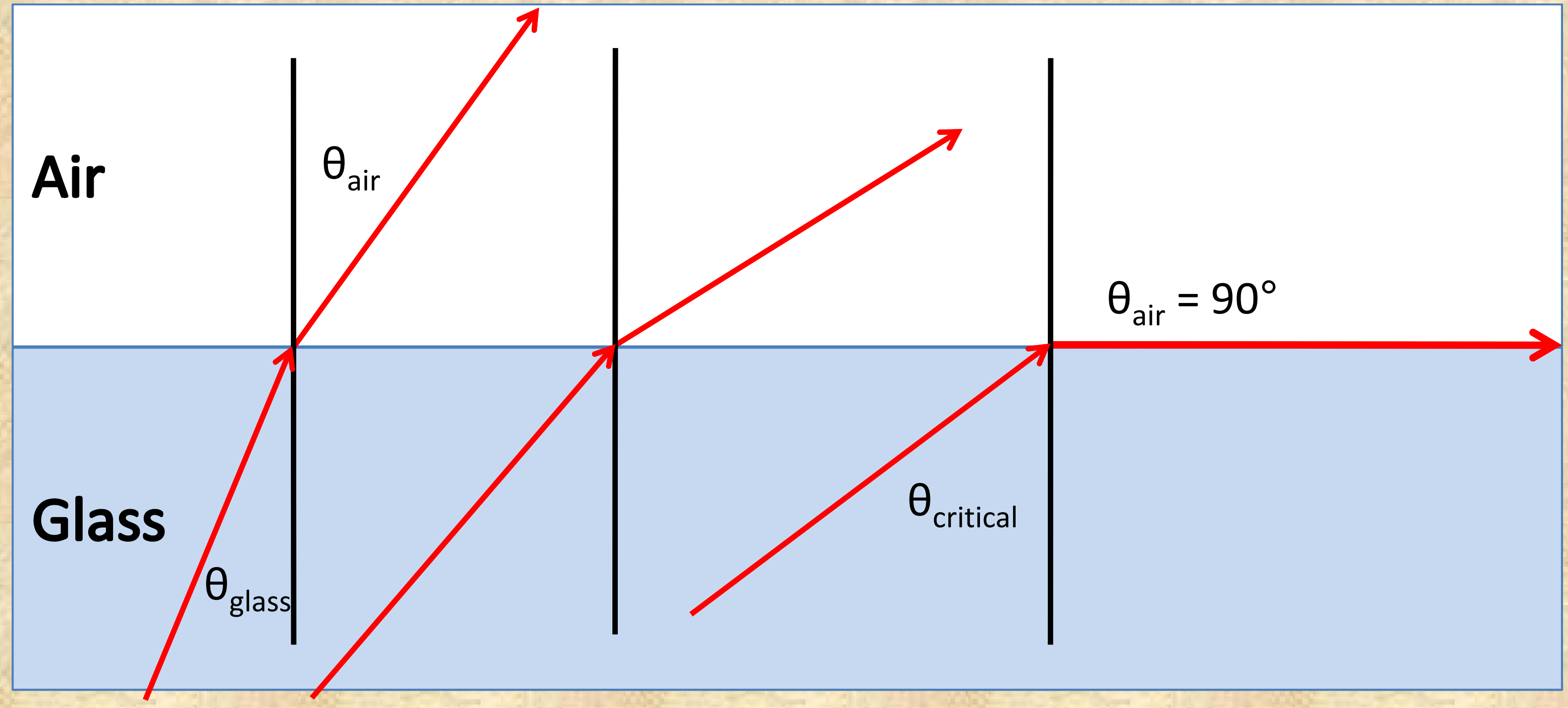
$n_{crown\ glass}$ = 1.52

$n_{diamond}$ = 2.42

As light goes from a denser substance to a less dense substance the light ray bends away from the normal. $<i$ is less than $<r$.

No matter how big the angle of incidence in the denser substance the angle of refraction in the less dense substance will be bigger.

This leads to a problem because the largest possible angle of refraction in the less dense substance is 90°. So what happens as the angle of incidence gets bigger and bigger?



No matter how big the angle of incidence in the glass the angle of refraction in the air will be bigger.

Eventually the angle of refraction in the air will be 90°.
We call the angle of incidence in this case the critical angle.

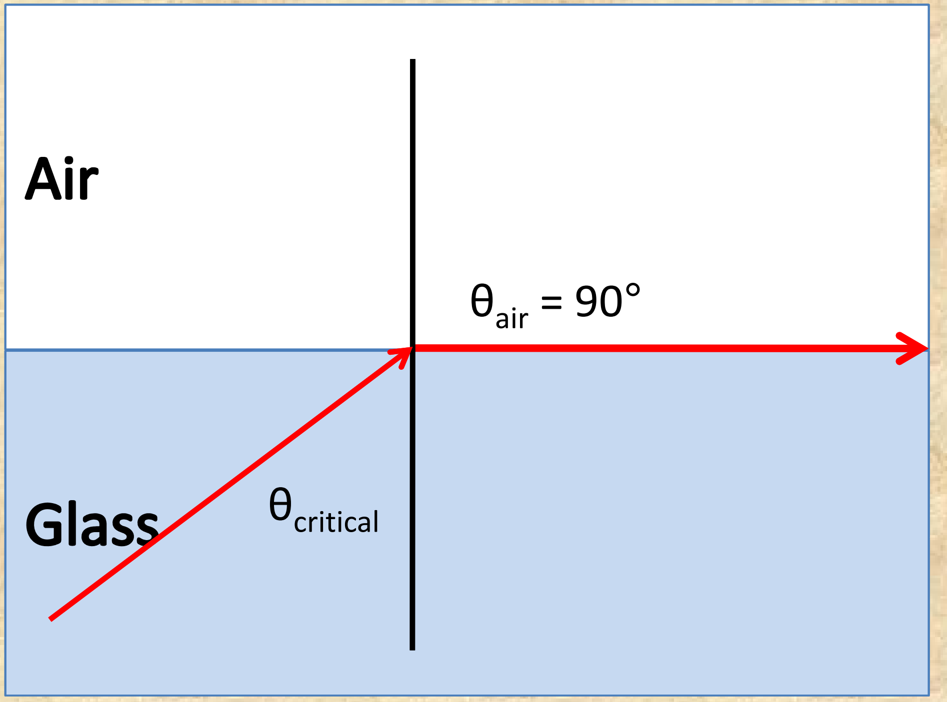
In this case:

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

$$n_{glass}\sin\theta_{critical} = 1.00\text{Sin}90°$$

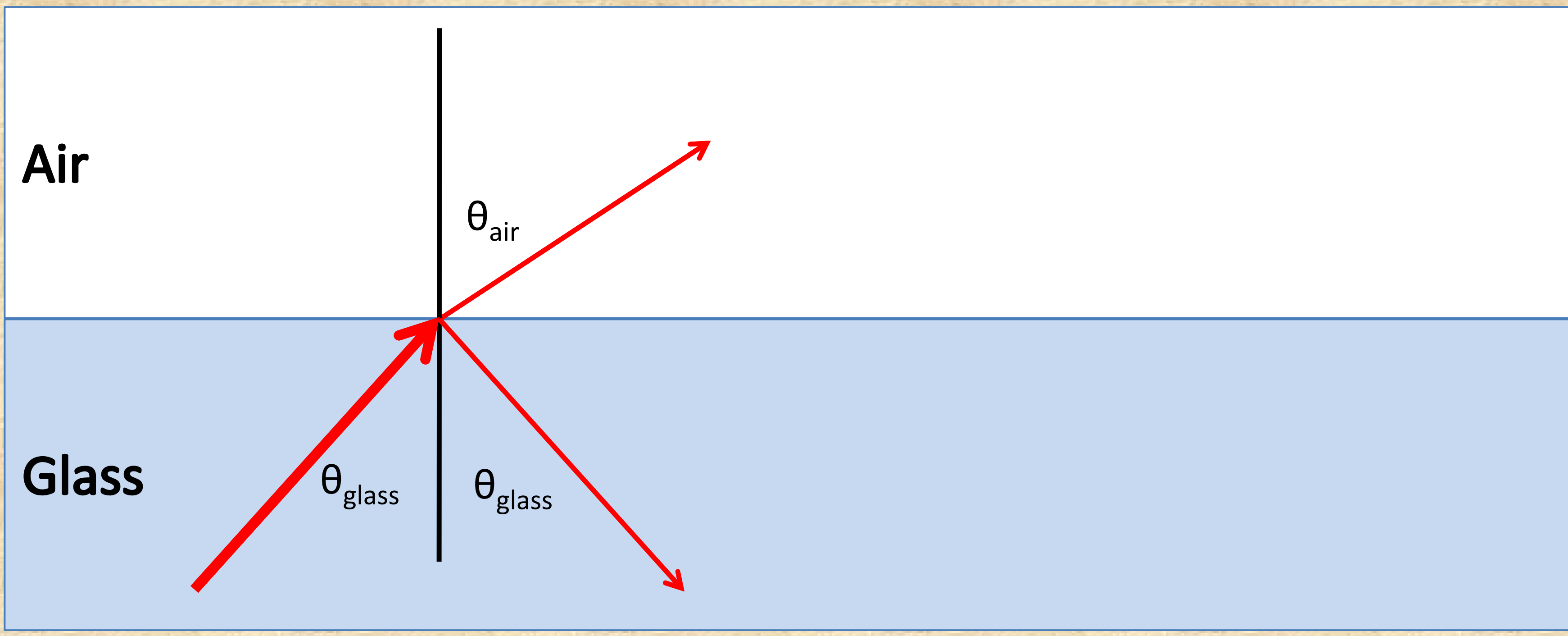
$$n_{glass}\sin\theta_{critical} = 1$$

$$\sin\theta_{critical} = 1/n_{glass}$$



$$\theta_{critical} = \sin^{-1}(1/n_{glass}) = \sin^{-1}(1/1.52) = 41.1°$$

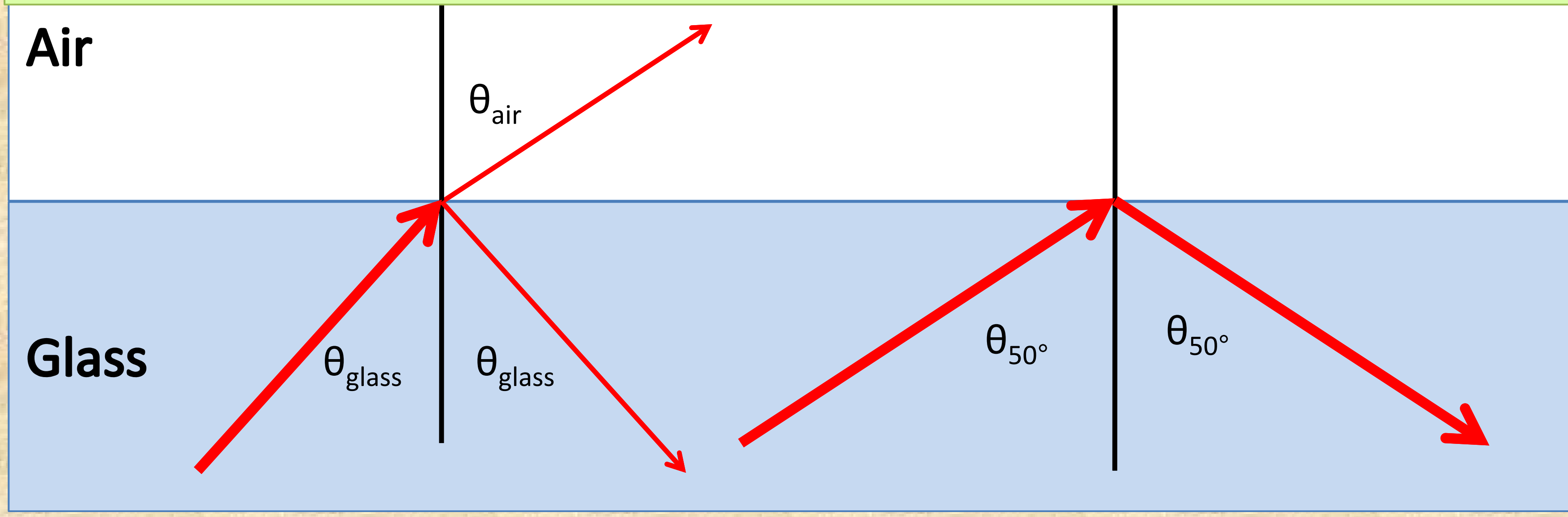
So what happens when the angle of incidence in the glass is greater than 41.1°?



Actually when the incident ray strikes the interface some is refracted obeying the Law of Refraction.

Some is also reflected internally in the glass obeying the law of reflection.

For this situation (glass to air) a ray with an angle of incidence greater than 41.1° will be totally reflected internally.



When the angle of incidence is greater than the critical angle, then there is no refraction. No ray enters the air!

All of the ray is reflected internally obeying the law of reflection.

This is called "Total Internal Reflection."

In general terms:

$n_x \sin\theta_{critical} = n_y \sin\theta_y = n_y \sin 90° = n_y$

$\theta_{critical} = \sin^{-1}(n_y/n_x)$

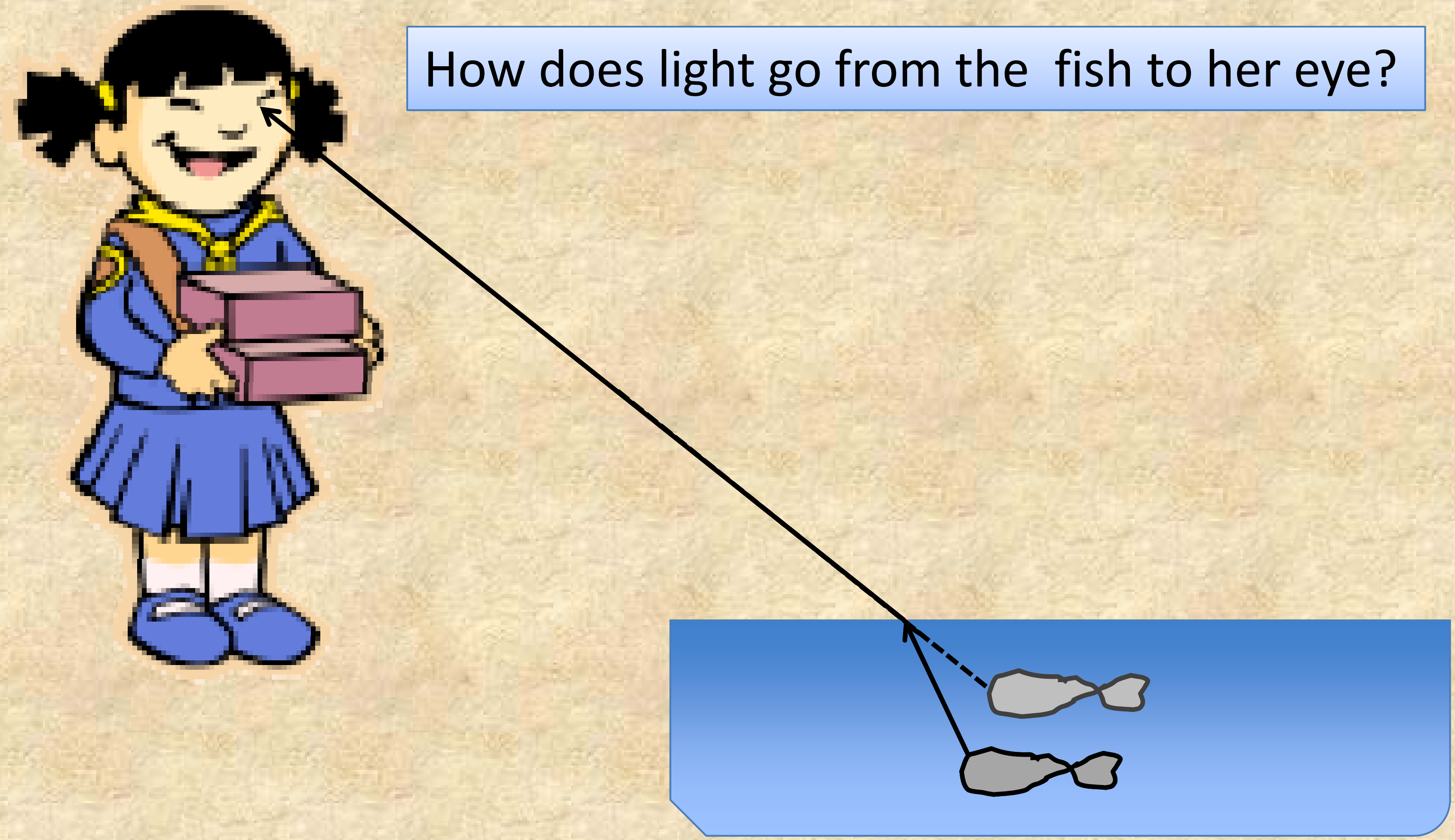
This only happens when light passes from a denser substance to a less dense substance. In other words when light goes from a substance with a big index of refraction to a substance with a smaller index of refraction. It would happen when light goes from glass to water, but not when light goes from water to glass.

$n_{glass} = 1.52 > n_{water} = 1.33$

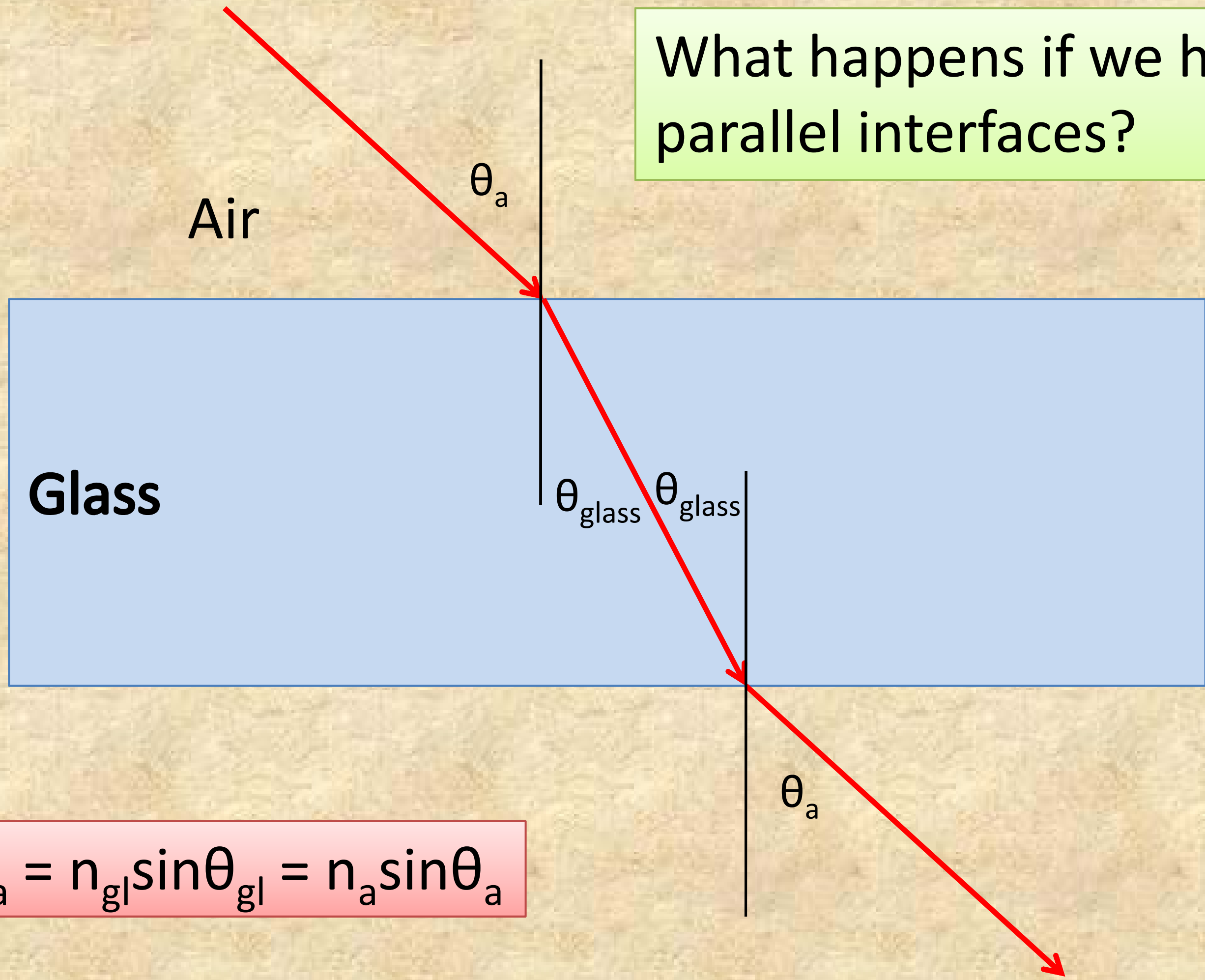
$n_x > n_y$

Where does she see the fish?

How does light go from the fish to her eye?



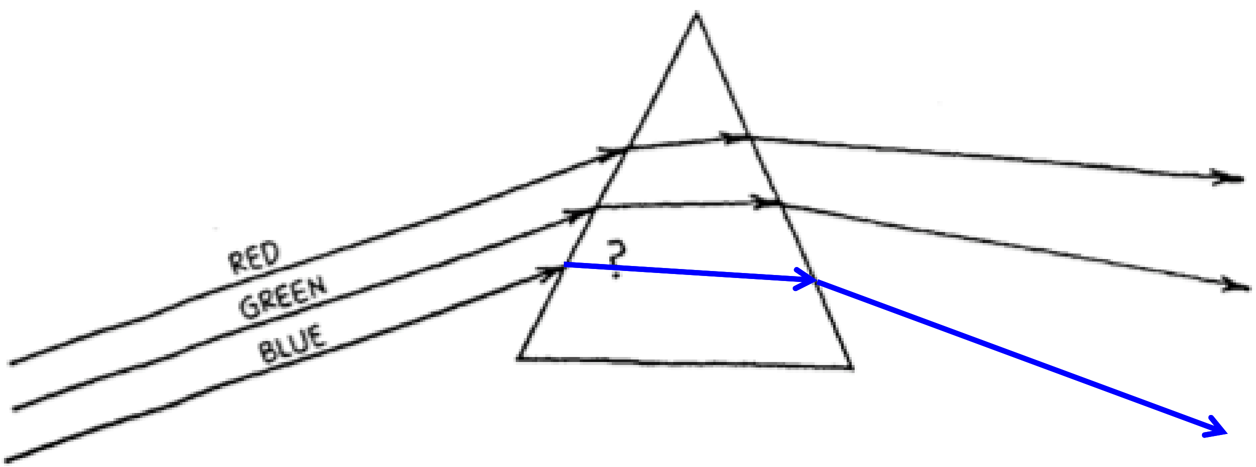
What happens if we have parallel interfaces?



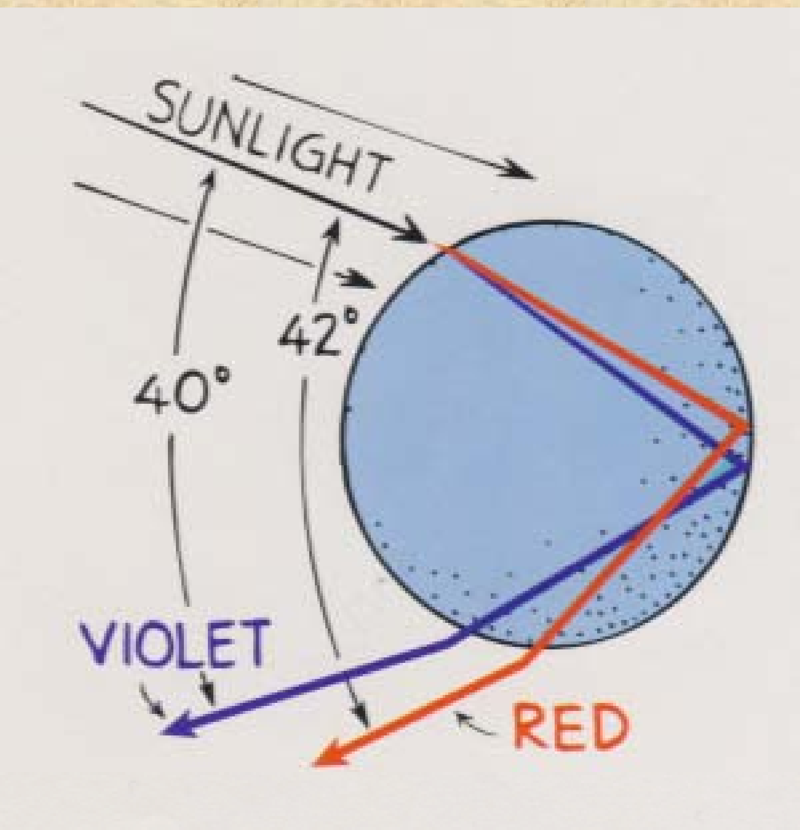
$n_a \sin\theta_a = n_{gl} \sin\theta_{gl} = n_a \sin\theta_a$

The angle of incidence in air at the first interface equals the angle of refraction in air at the second interface.

2. Red, green, and blue rays of light are incident upon a glass prism as shown. The average speed of red light in the glass is less than in air, so the red ray is refracted. When it emerges into the air it regains its original speed and travels in the direction shown. Green light takes longer to get through the glass. Because of its slower speed it is refracted as shown. Blue light travels even slower in glass. Complete the diagram by estimating the path of the blue ray.



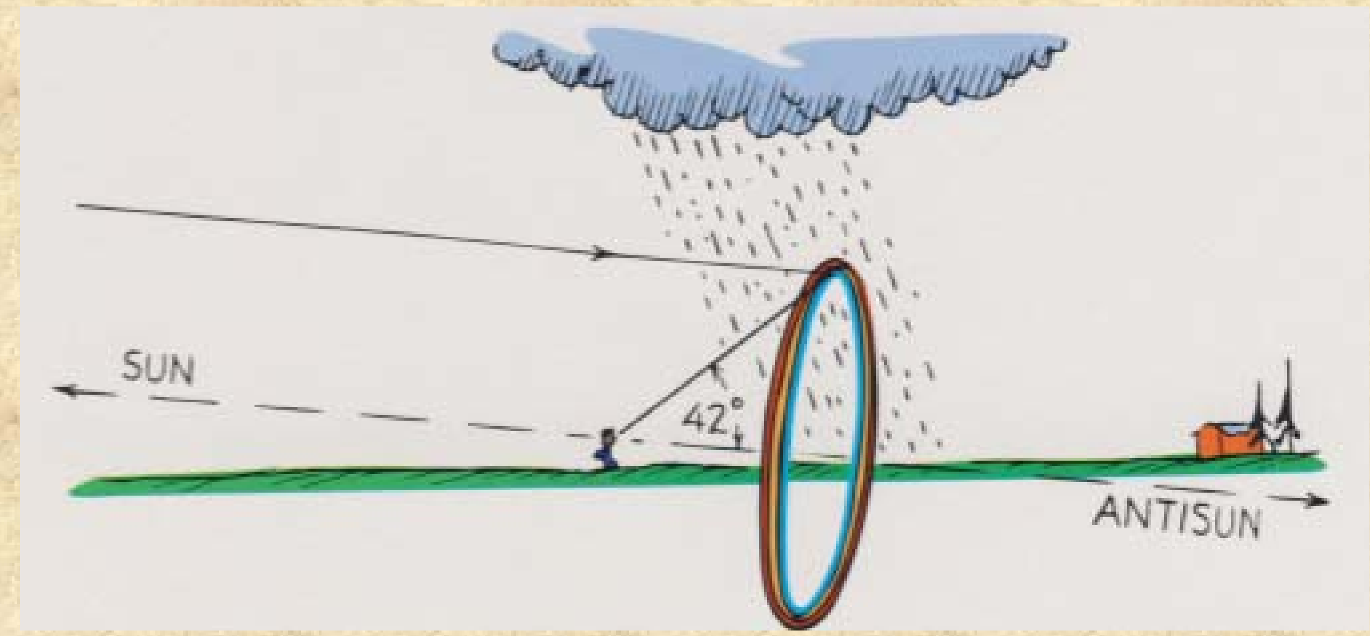
What happens with sunlight and water droplets in the sky?



The light is refracted as it enters the water droplet, then there is total internal reflection, and then the ray is refracted again as it leaves the water droplet.

The index of refraction for blue light is slightly greater than the index of refraction of the red light, so the blue ray is refracted more.

What happens with sunlight and water droplets in the sky?

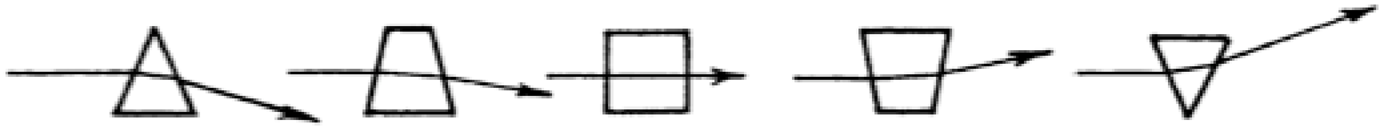


If it is raining, but the sun starts to shine. If you place your back to the sun you may see a rainbow.

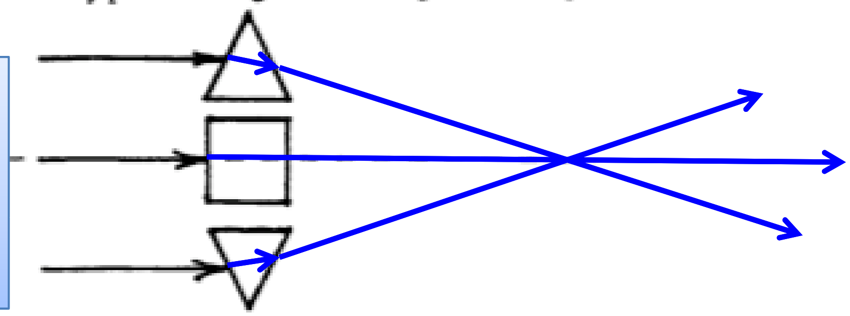
The lower the sun is in the sky, the better the chance that you will see a rainbow.

Lenses

Rays of light bend as shown when passing through the glass blocks.

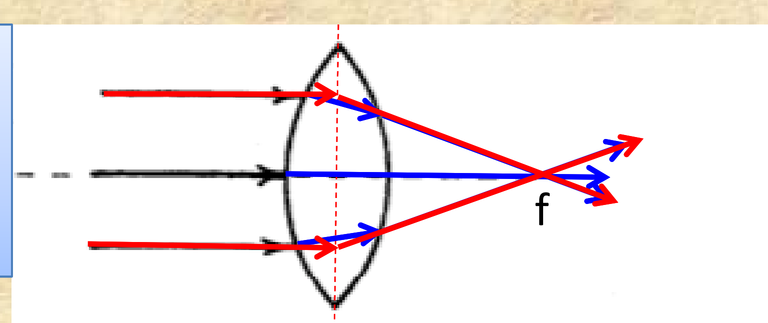


1. Show how light rays bend when they pass through the arrangement of glass blocks shown below.



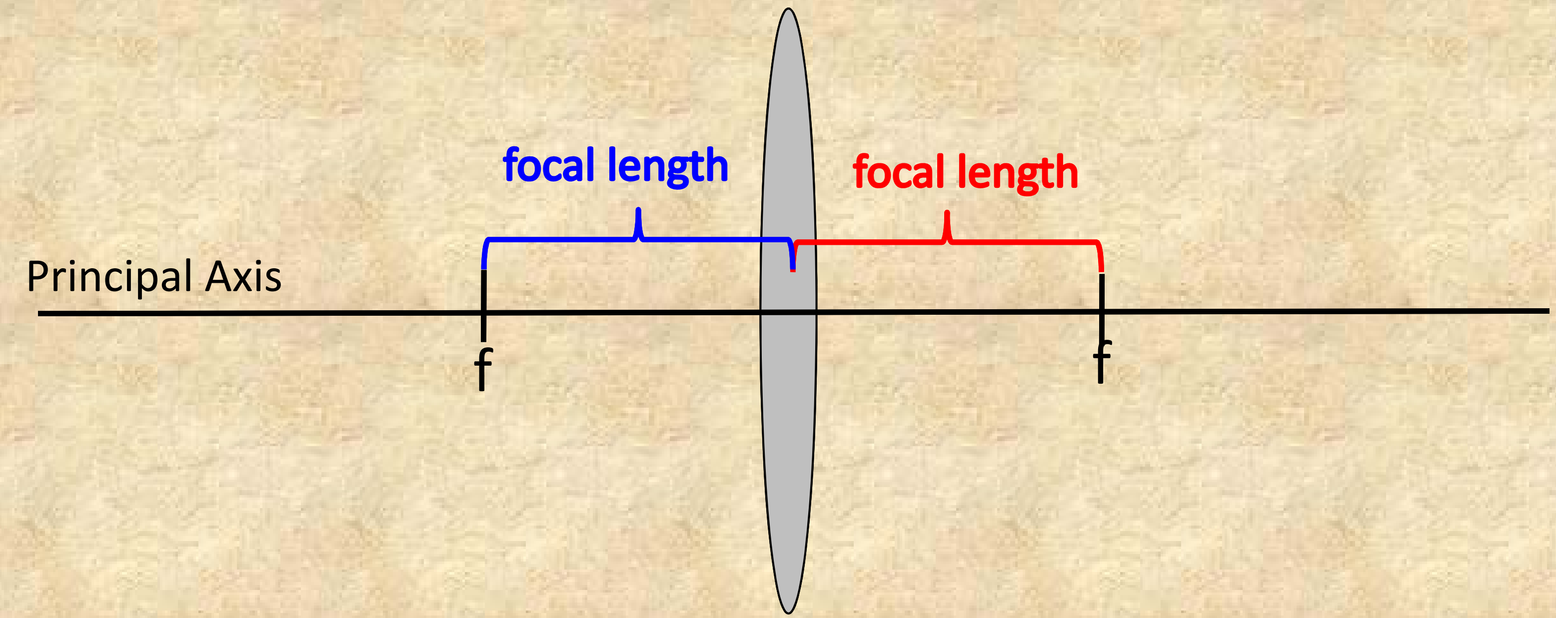
Note that the ray bends towards the fatter part of the triangular prism.

Since the light rays converge, we call this a converging lens.



If the lens is relatively thin, we can approximate the path by drawing a ray that is parallel to the principal axis to the center of the lens and then drawing it so it passes through the focal point.

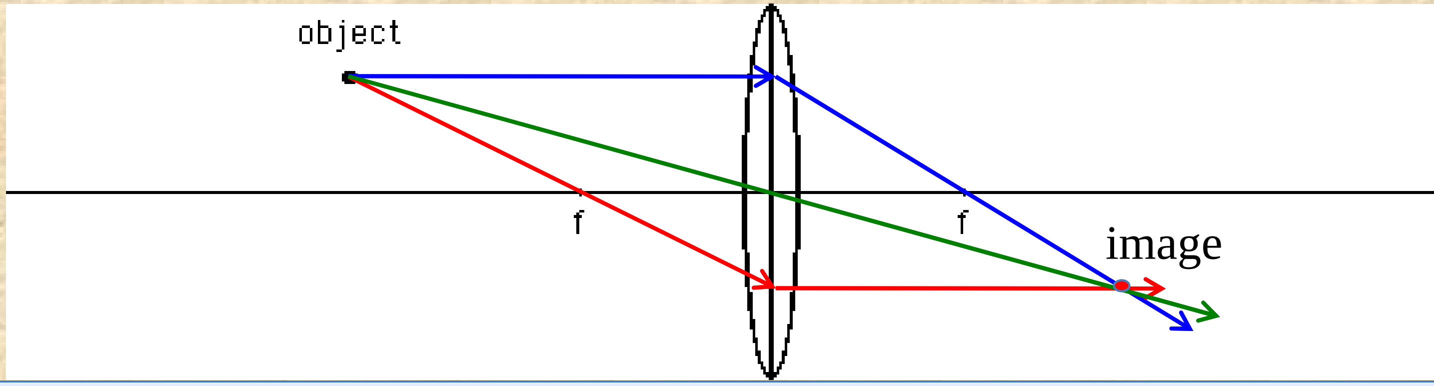
The path of a ray of light is reversible. We illustrated that rays traveling parallel to the principal axis from left to right converge at a point called the focal point on the right side of the lens.



Then rays traveling parallel to the principal axis from right to left converge at a point called the focal point on the left side of the lens.

A lens will have two focal points, both on the principal axis and one on each side of the lens. Each the same distance from the lens.

1. Locate the image of the object shown.



A ray that is parallel to the principal axis refracts through the lens and passes through the focal point on the other side of the lens.

A ray that passes through the focal point refracts through the lens and continues parallel to the principal axis.

A ray that passes through the center of the lens continues along in a straight line.

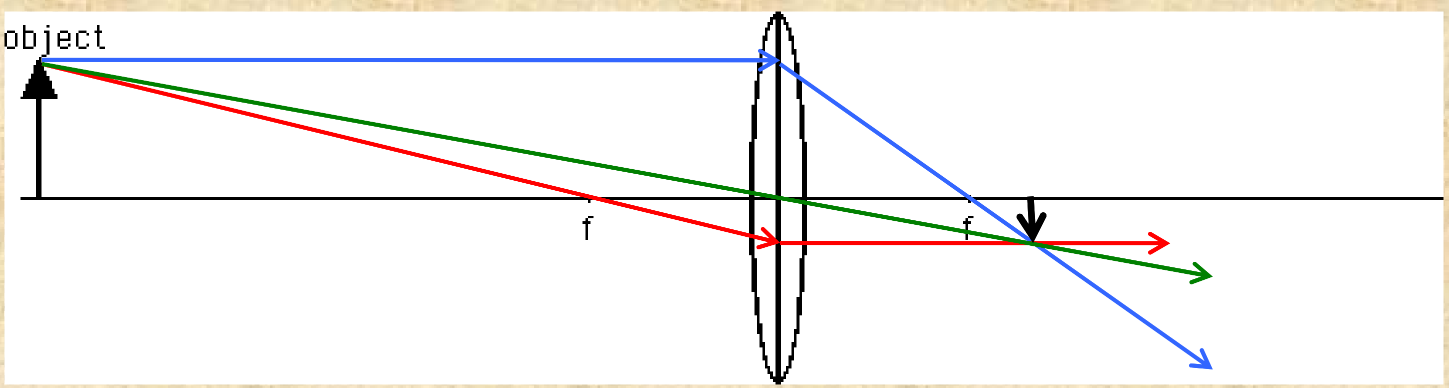
Remember that these are the easy rays. All rays that leave the object and strike the lens intersect to form the image.

2. Where is the image when the object is far from the lens?

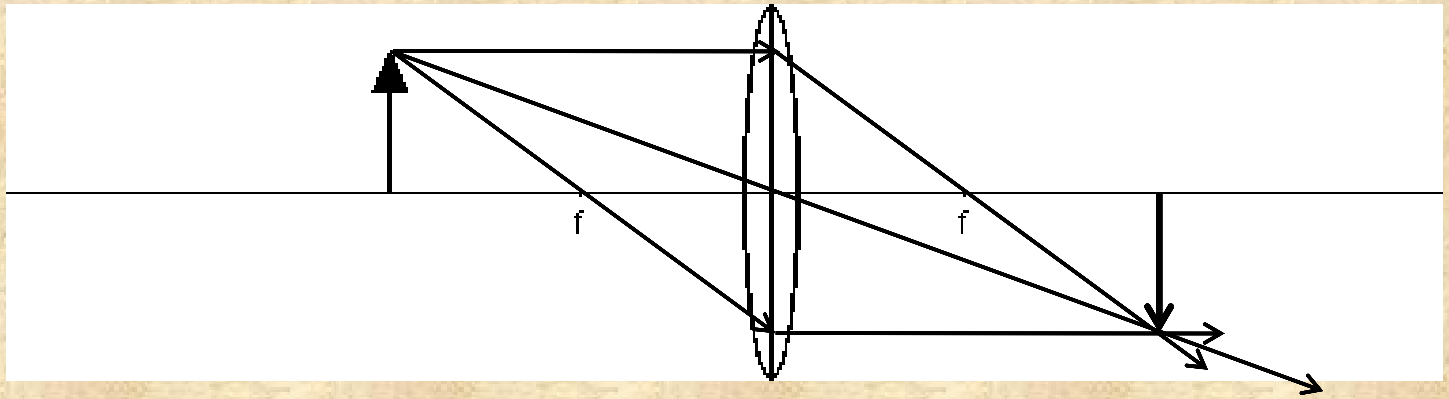
You can use any two of the following rays to locate the image.

- Ray parallel to principal axis
- **Ray that goes in through the focal point**
- **Ray that passes through the center of the lens**

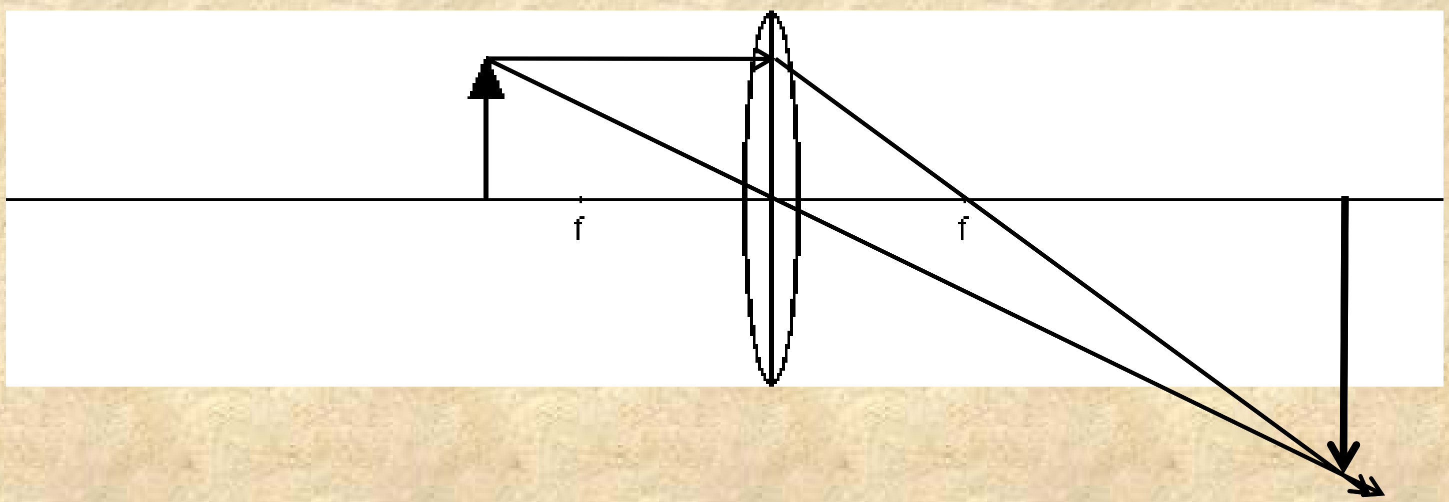
Sometimes it is easy to use all three, but you only need two of them.



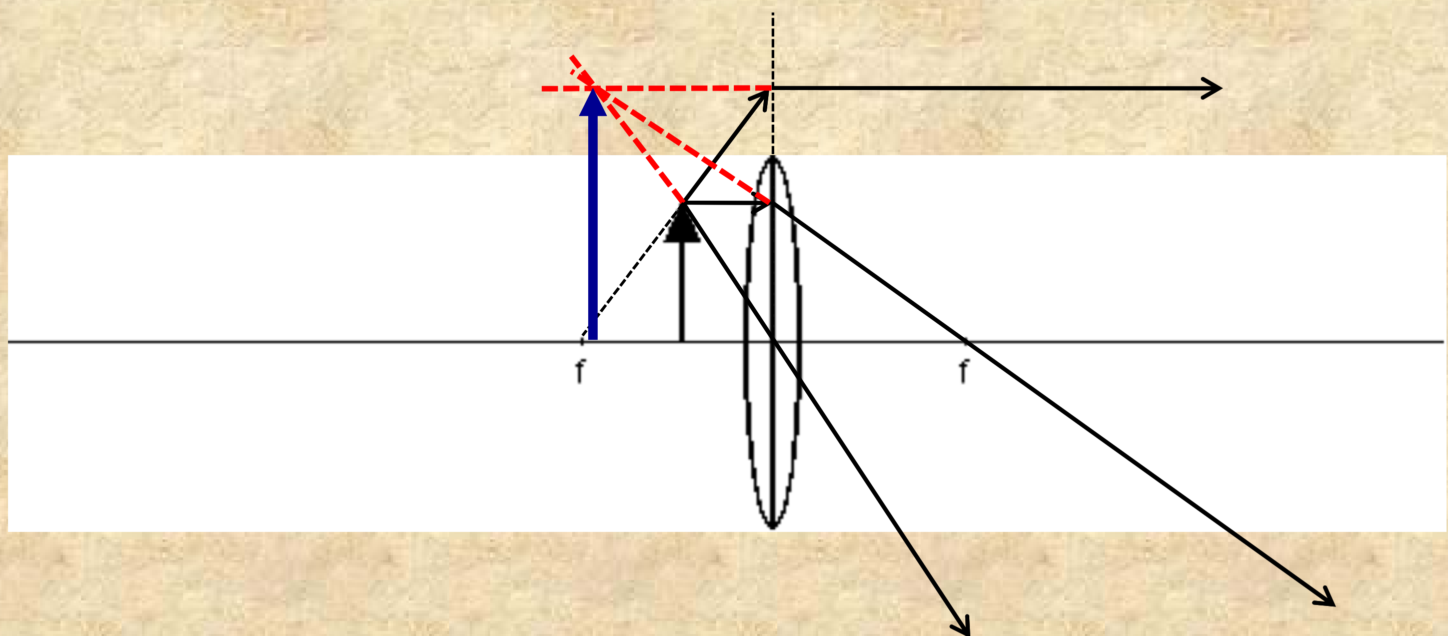
3. Where is the image when the object is twice the focal length (2f) from the lens?



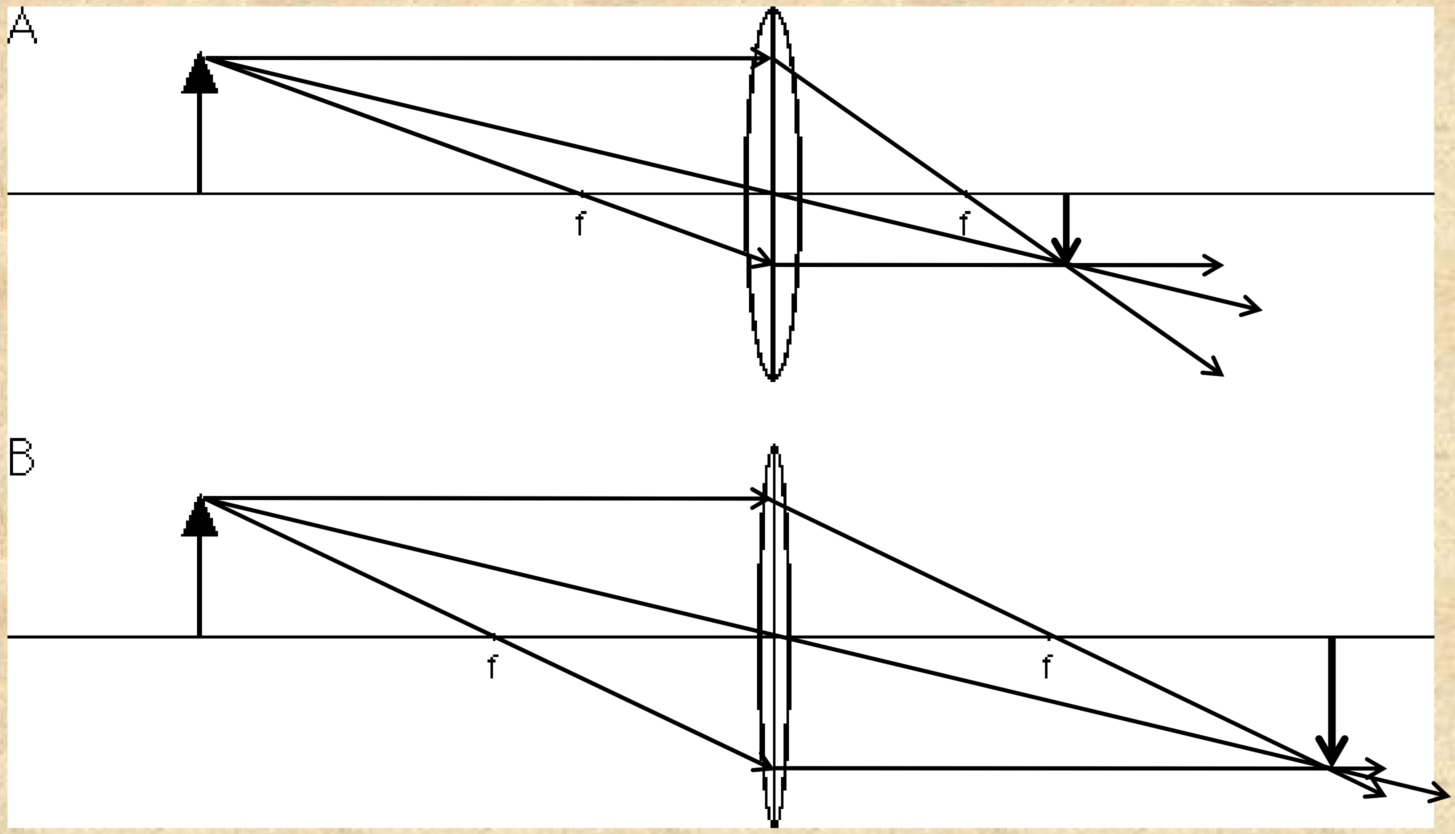
4. Where is the image when the object is between 2f and f from the lens?

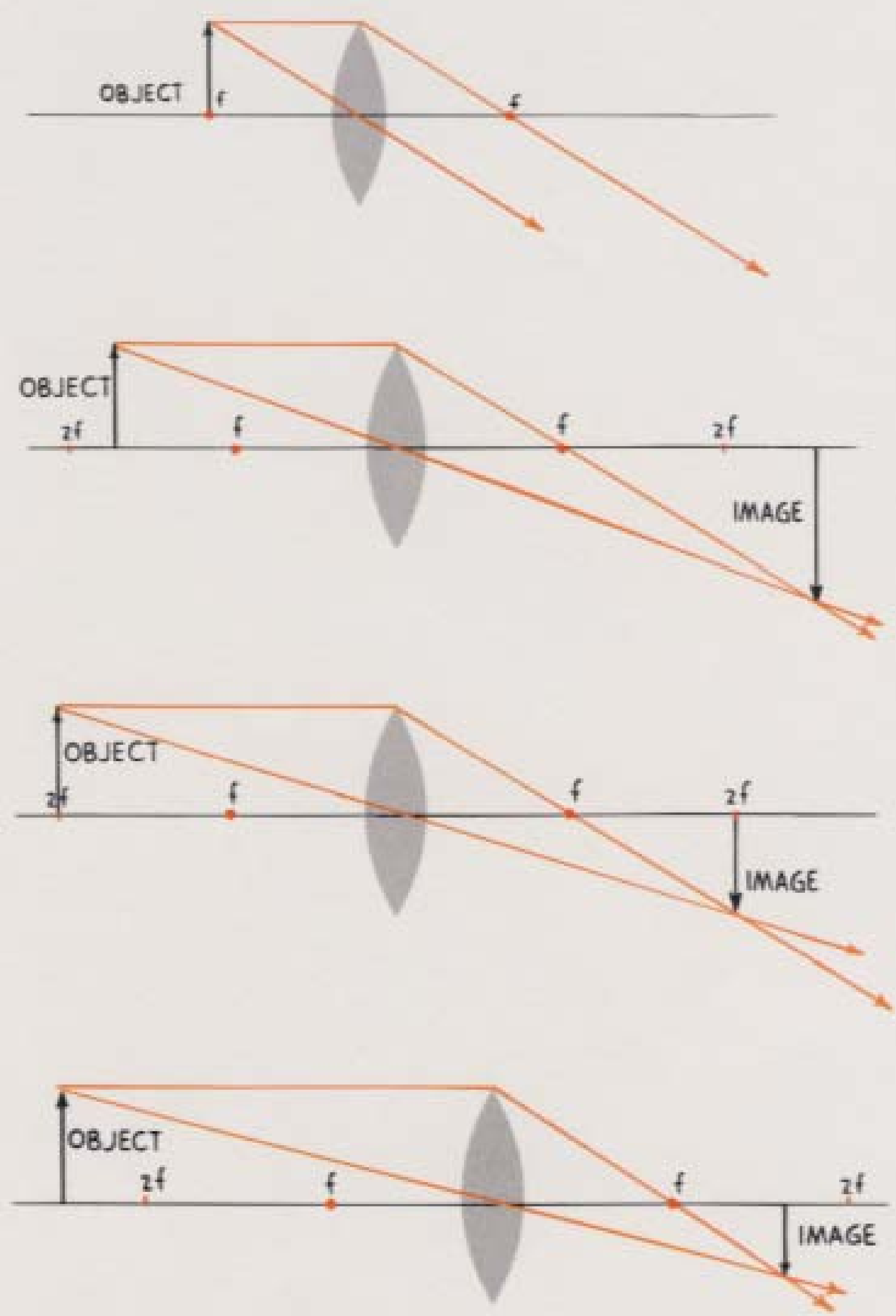


5. What happens when the object is between the focal point and the lens?



6. What happens when an object is placed the same distance from two different lenses?

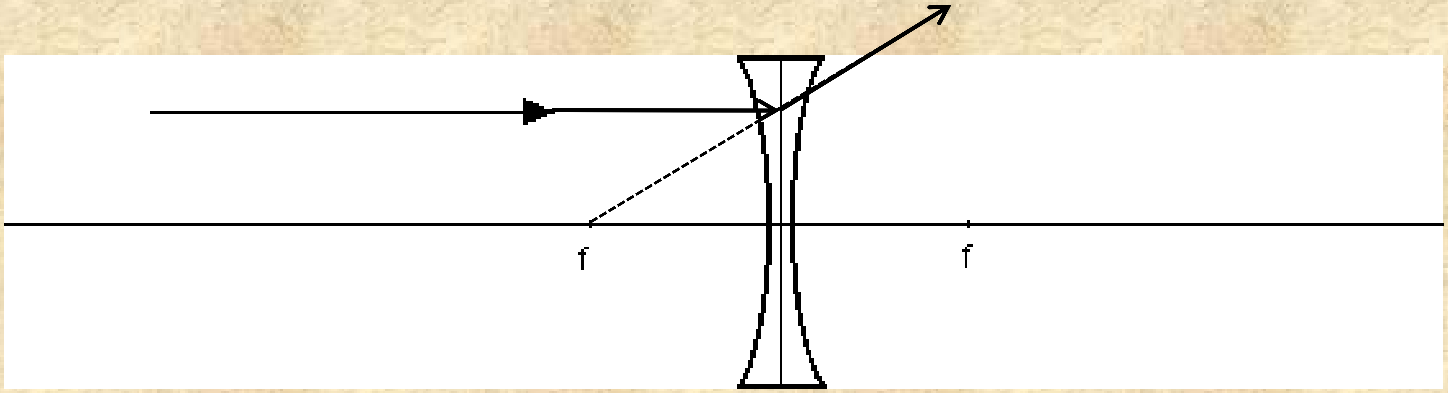



OBJECT
f
f
OBJECT
2f
f
f
2f
IMAGE
OBJECT
2f
f
f
2f
IMAGE
OBJECT
2f
f
f
2f
IMAGE

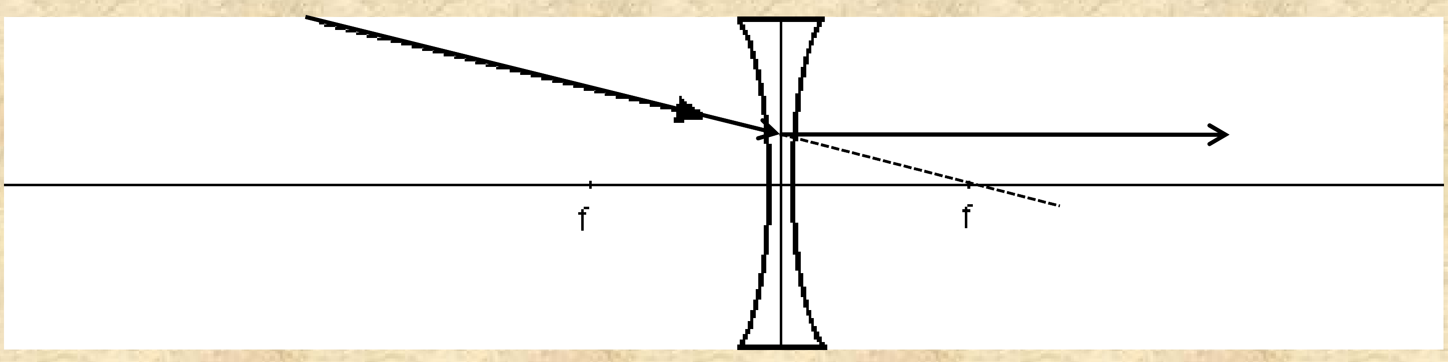
7. Now let us summarize what we have learned so far about the images formed by converging lenses.

Object Location	Image Location	Image size relative to object size	Type of image
beyond “2f” from the lens	between “2f” and “f”	Smaller	Real
at “2f”	at “2f”	Same size	Real
between “2f” and “f”	beyond “2f”	Larger	Real
between “f” and the lens	Same side as object	Larger	Virtual
at the lens	at the lens	Same size	Virtual
at infinity	at “f”	XXXX	XXXX

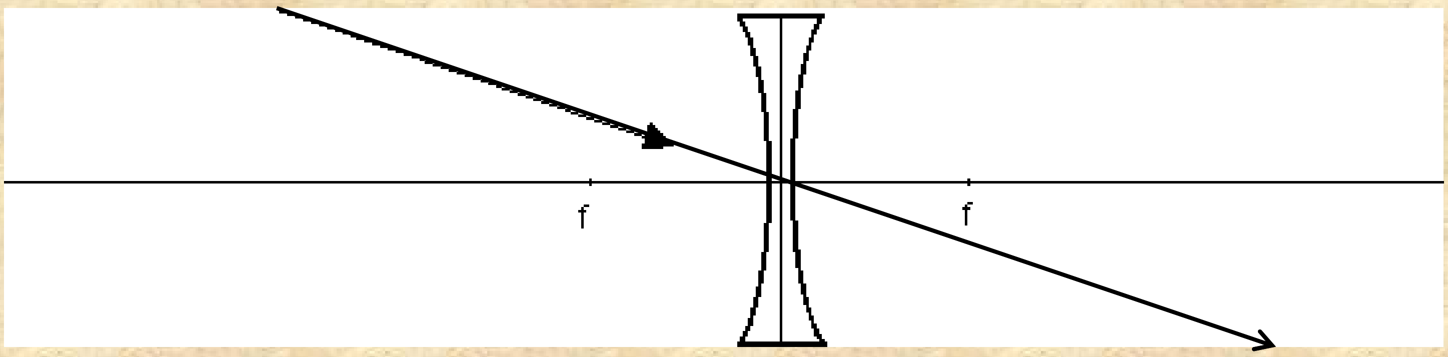
8. A ray of light that approaches the lens **parallel to the principal axis** refracts, diverging as if it came from the first **focal point** (the one on the same side of the lens).



9. A ray of light that is pointing towards the **second focal point** (the one on the other side of the lens) strikes the lens and refracts **parallel to the principal axis**.

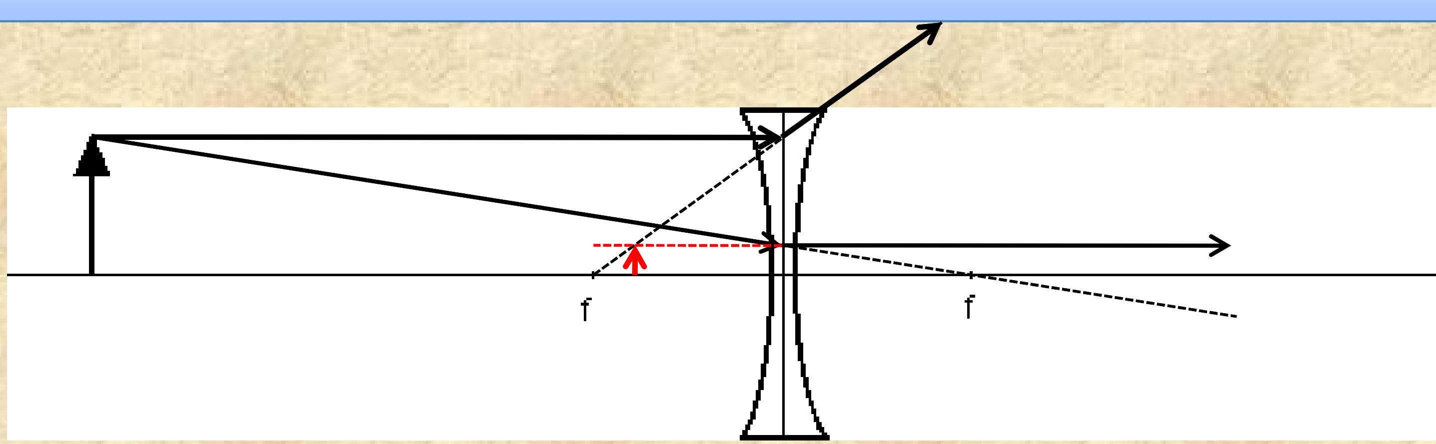


10. A ray of light that passes though the center of the lens is along a **normal** and thus passes **straight through** the lens (does not bend at all).



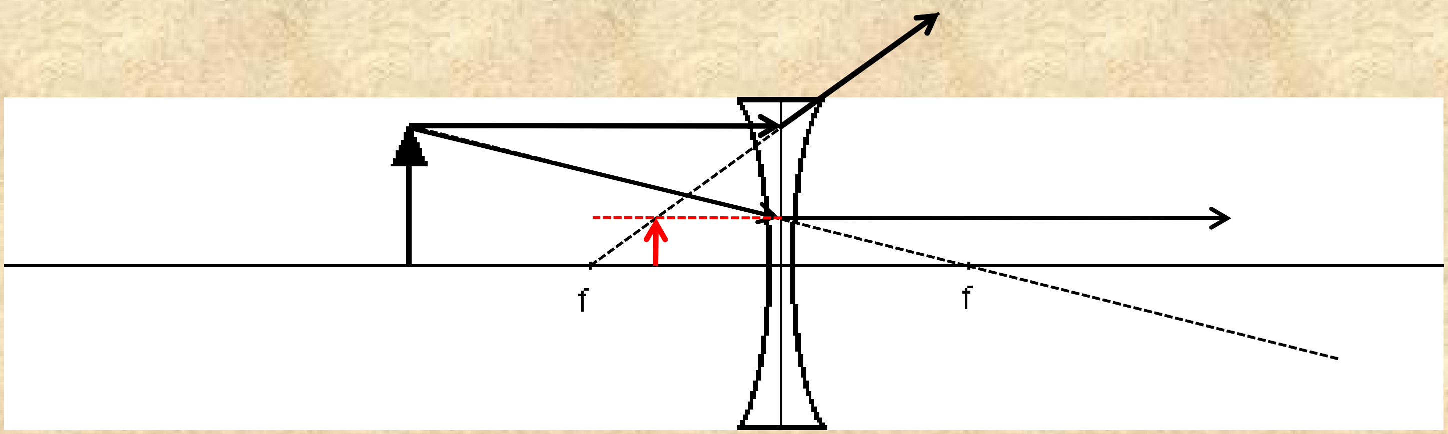
11. Find the images in the following cases where an object is placed in front of a diverging lens.

a)

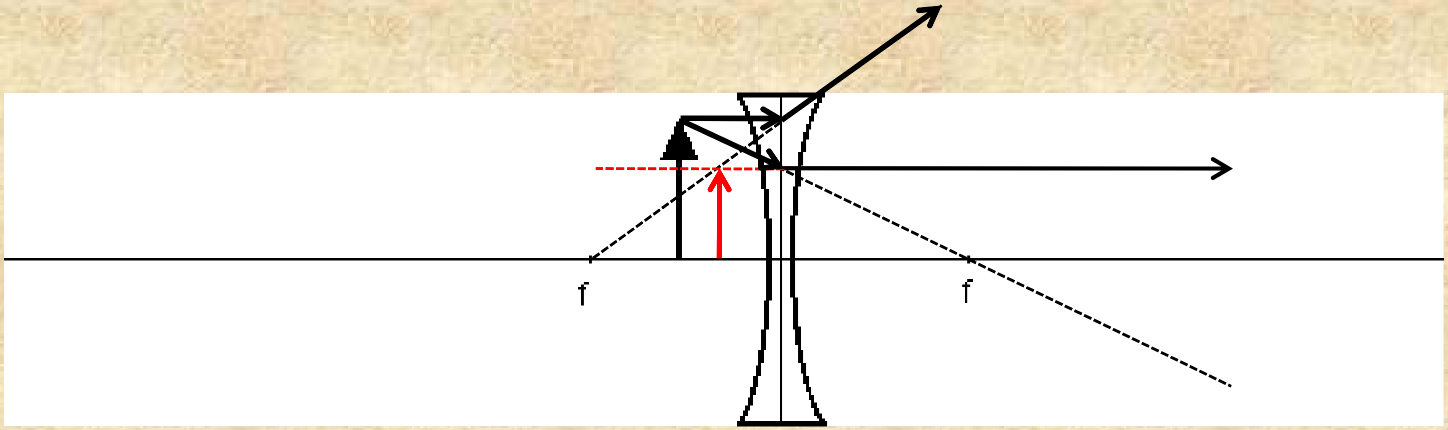


11. Find the images in the following cases where an object is placed in front of a diverging lens.

b)

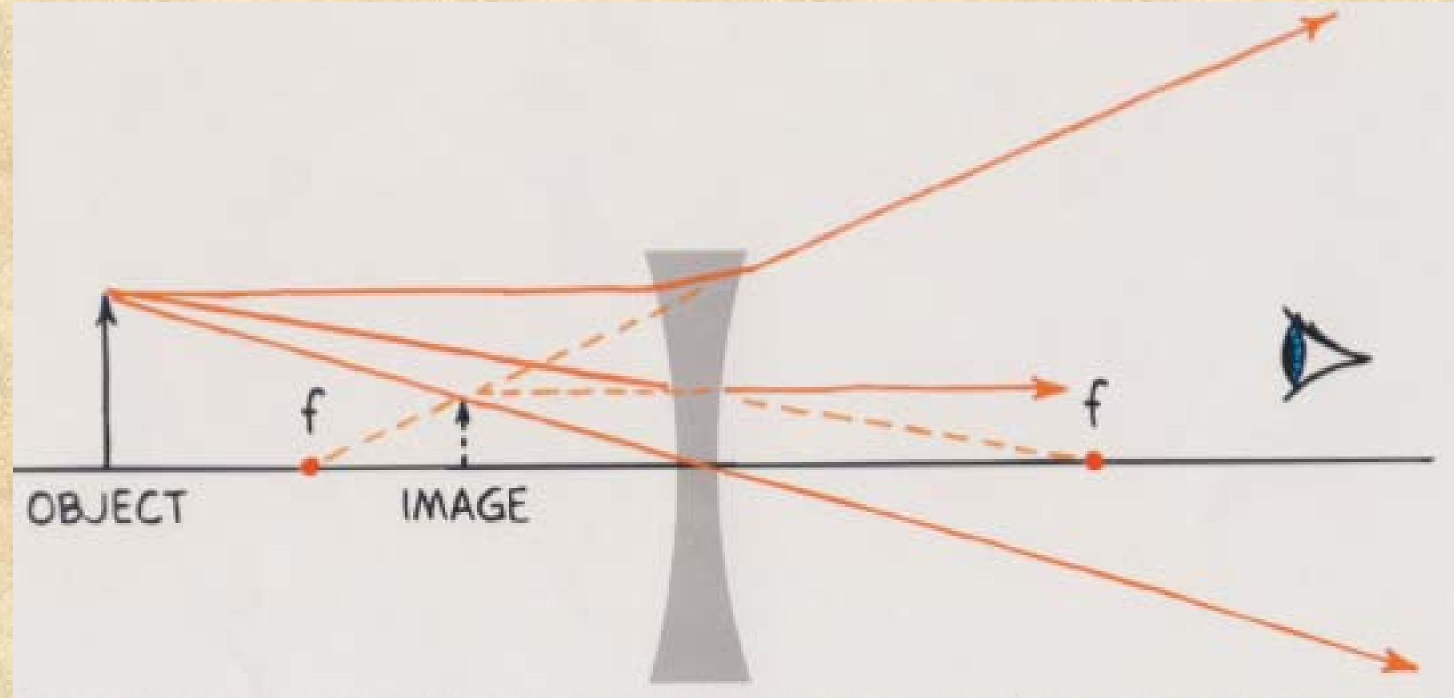


c)



12. What type of image is formed by a diverging lens?

Virtual image that is smaller than the object.



This image is only created by the mind. The refracted light rays do not intersect, so our mind projects them back until the rays intersect forming a virtual image.

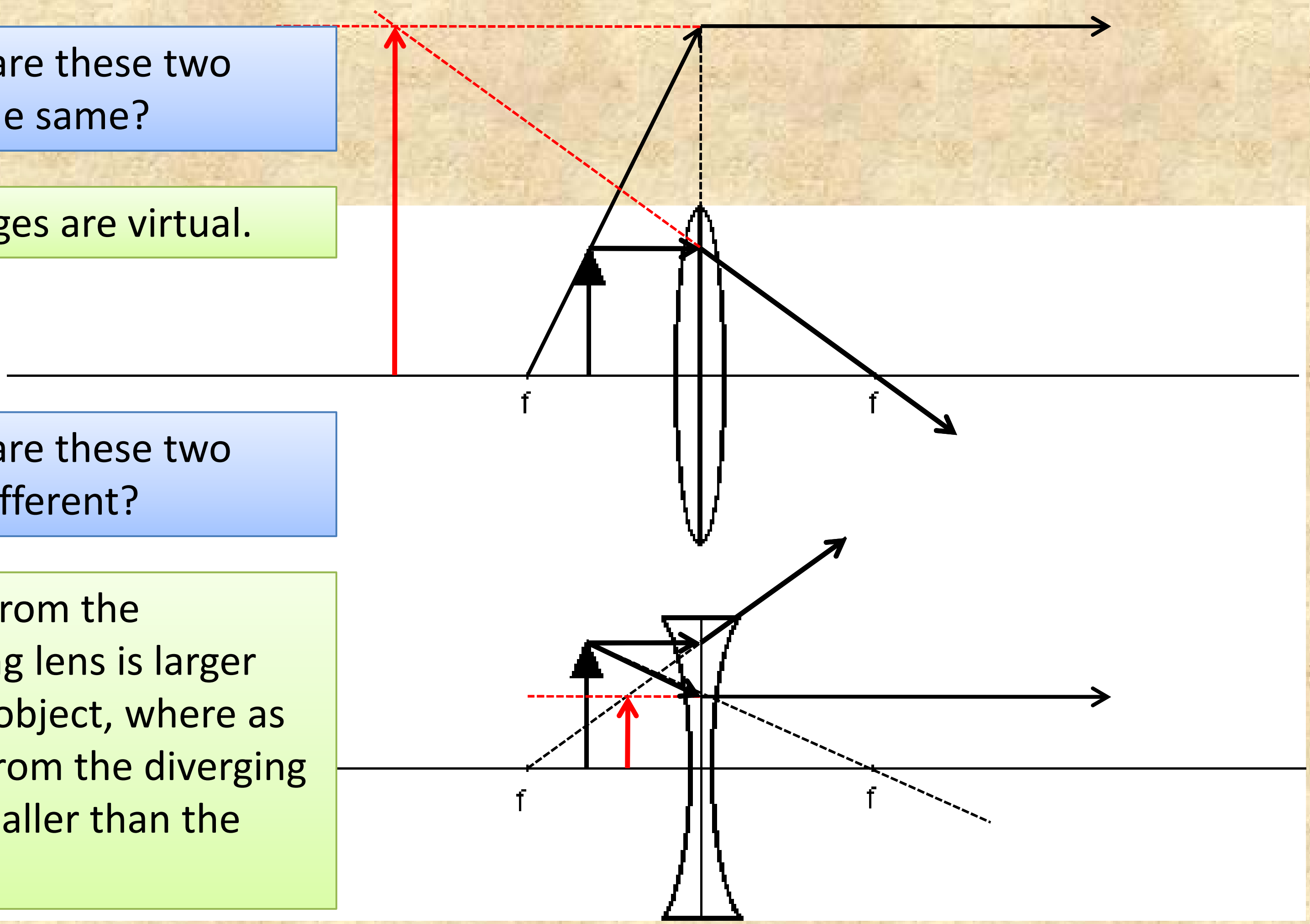
13. Let us compare virtual images formed by a diverging lens with virtual images formed by a converging lens. Find the image in each case.

14. How are these two images the same?

Both images are virtual.

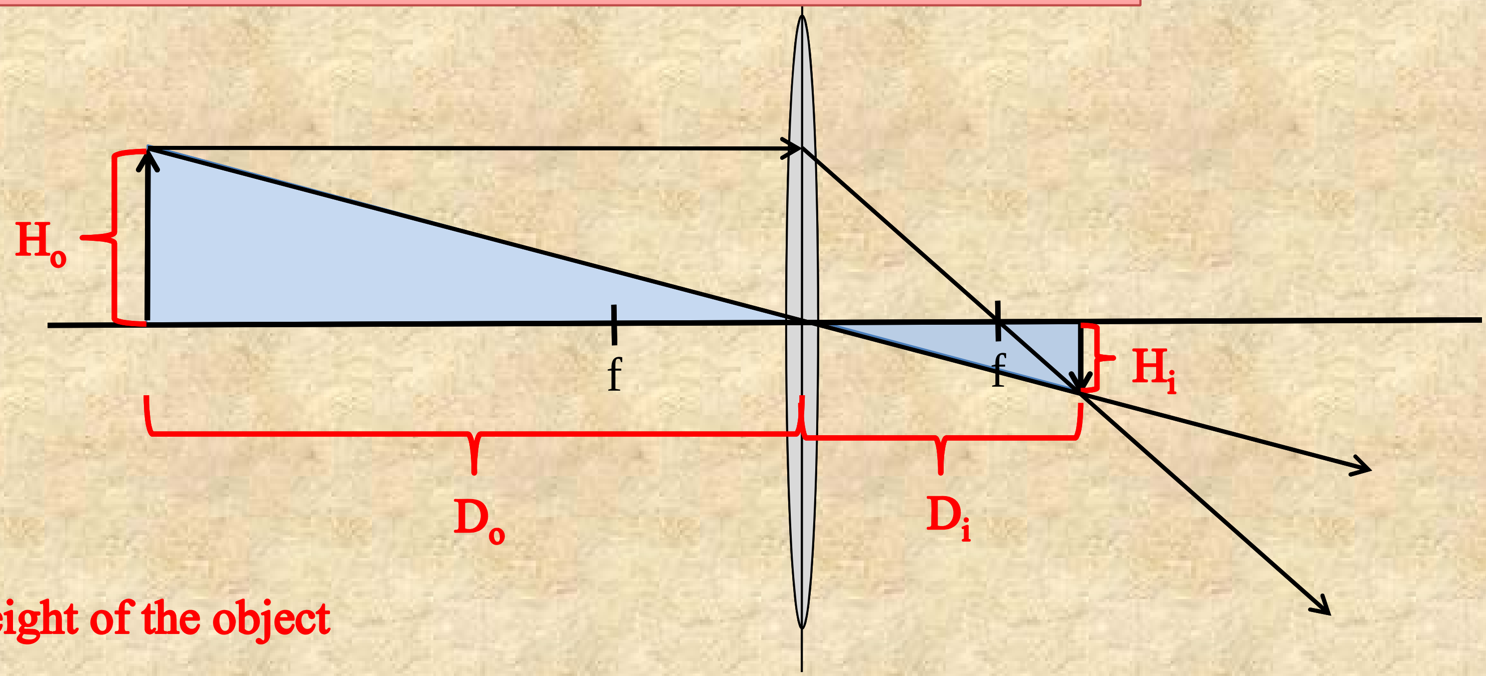
15. How are these two images different?

The one from the converging lens is larger than the object, where as the one from the diverging lens is smaller than the object.



Deriving Lens Equations

We can show that these two triangles are similar



H_o = Height of the object

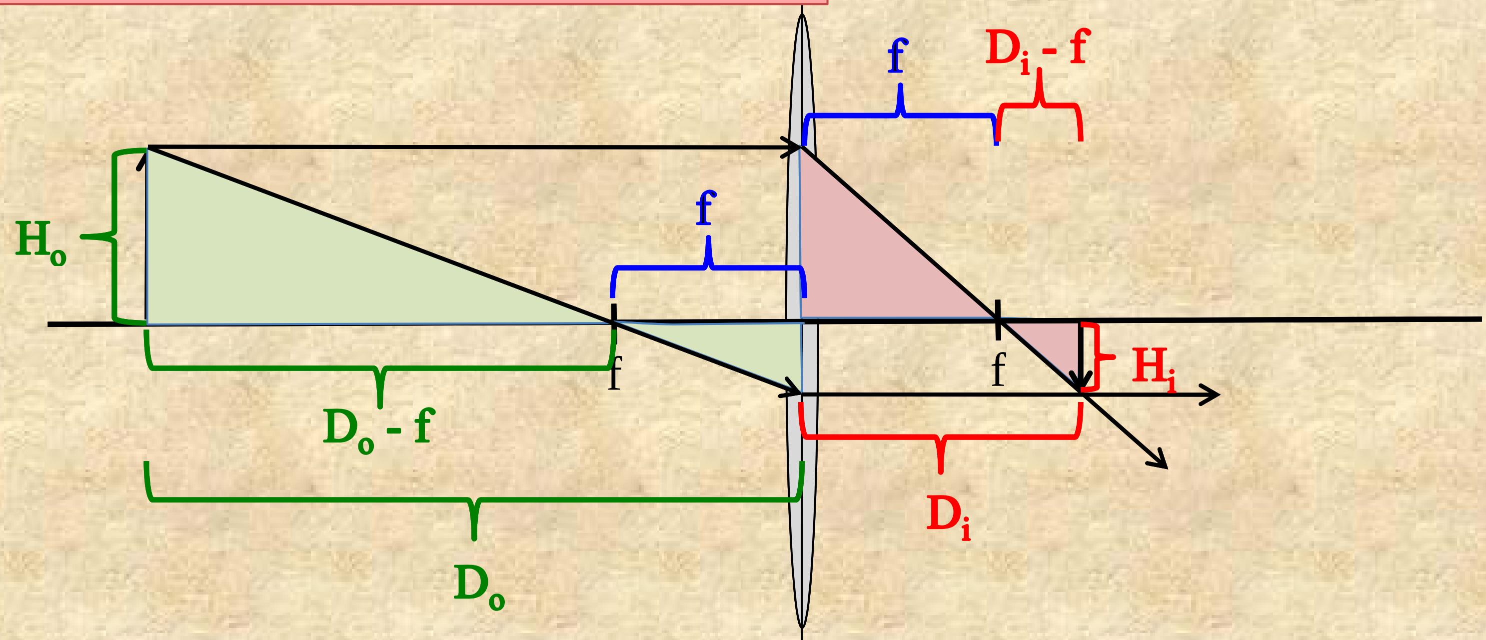
H_i = Height of the image

D_o = Distance of the object to the lens (center)

D_i = Distance of the image to the lens (center)

$$H_i/H_o = D_i/D_o$$

Derive the equation $1/f = 1/D_o + 1/D_i$



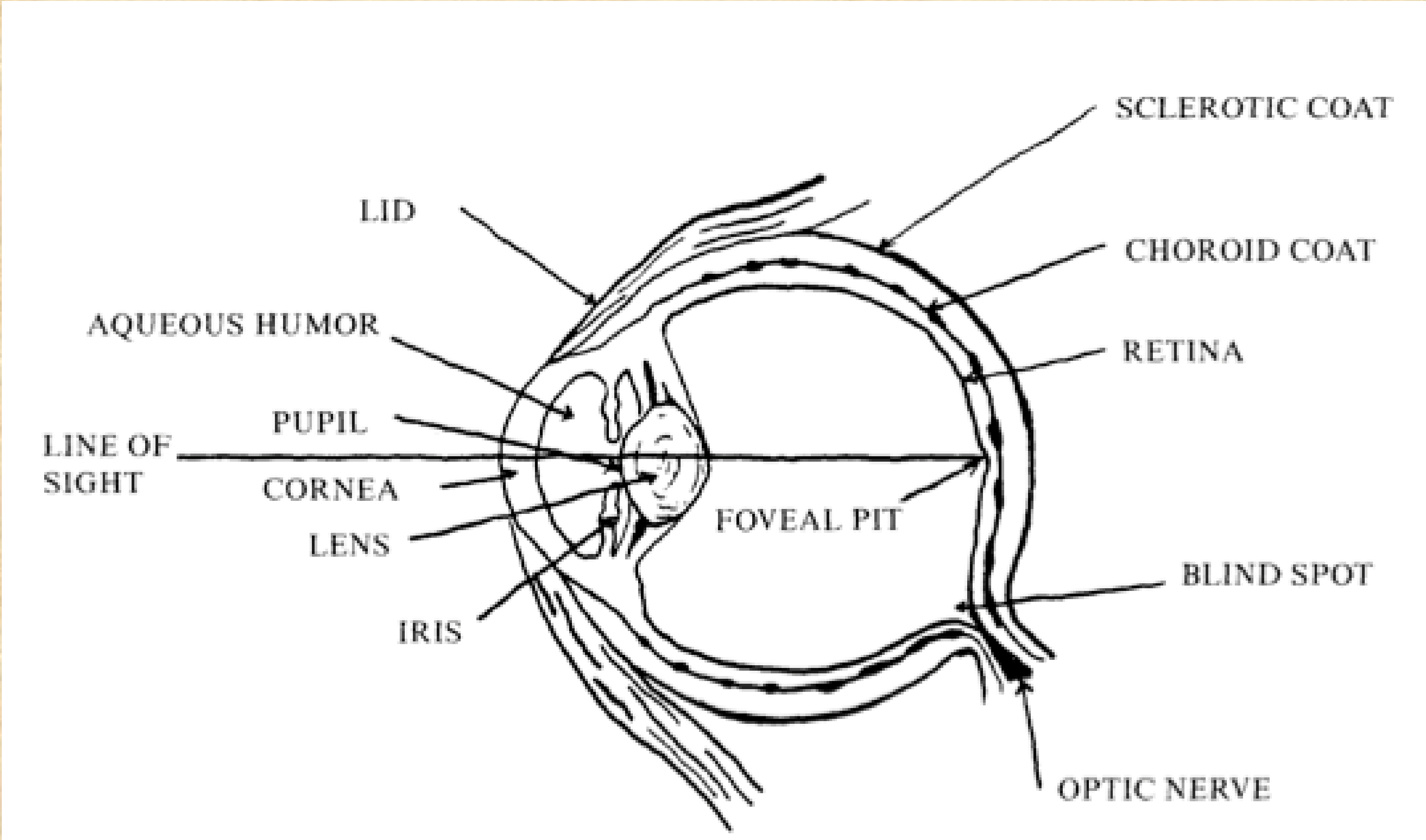
Using the green similar triangles: $H_i/H_o = f/(D_o - f)$

Using the red similar triangles: $H_i/H_o = (D_i - f)/f$

Using our algebra we can show that: $f/(D_o - f) = (D_i - f)/f$

and manipulating the equation we get: $1/f = 1/D_o + 1/D_i$

The Eye and Corrective Lenses


SCLEROTIC COAT
LID
CHOROID COAT
AQUEOUS HUMOR
RETINA
PUPIL
LINE OF
SIGHT
CORNEA
FOVEAL PIT
LENS
BLIND SPOT
IRIS
OPTIC NERVE

The eye

Distant objects. Lens in eye has long focal length.

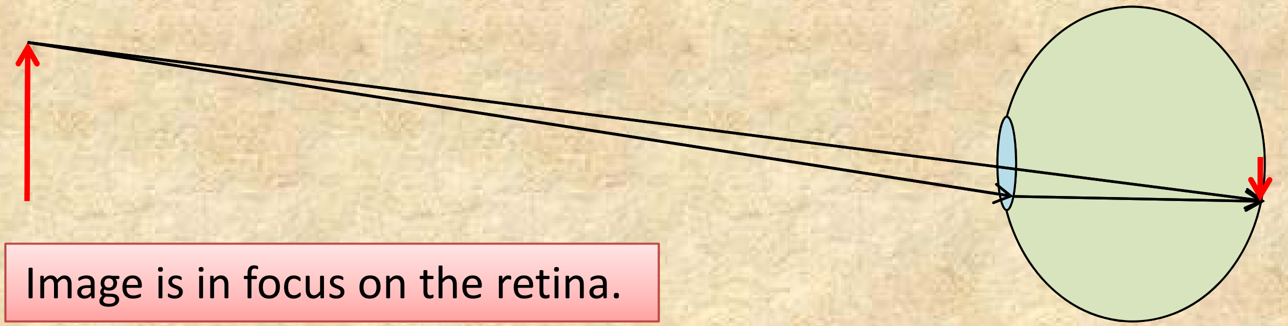


Image is in focus on the retina.

Close objects. Lens in eye has short focal length.

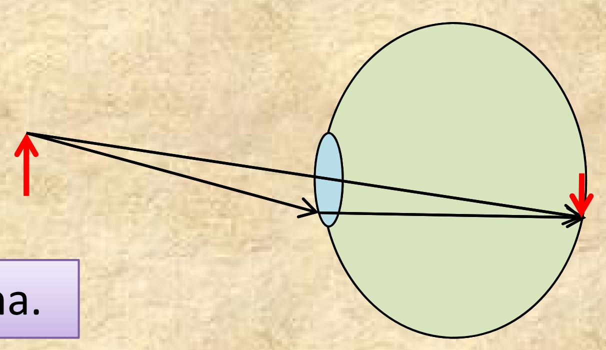


Image is in focus on the retina.

Hyperopia, farsightedness. Can see distant objects.

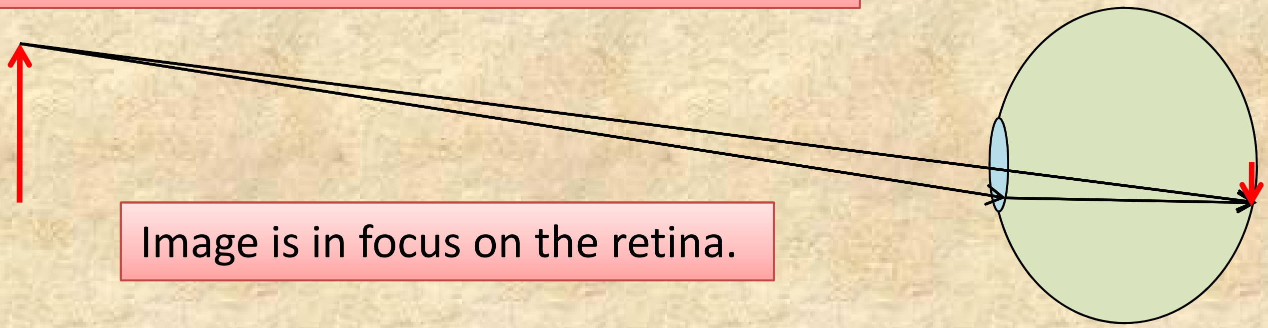
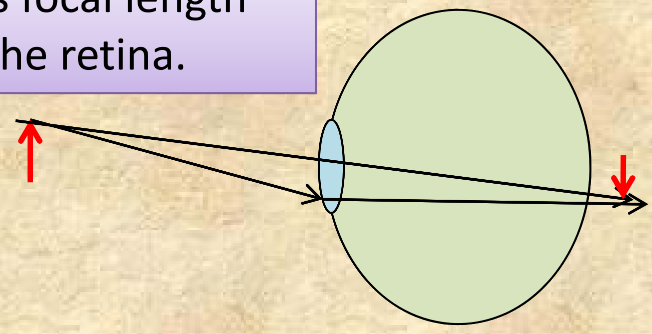
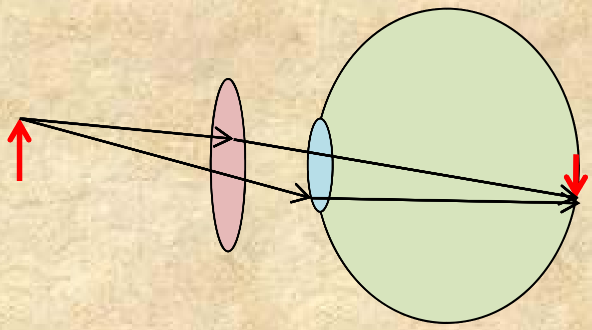


Image is in focus on the retina.

For close objects the lens cannot shorten its focal length enough. Thus the image is in focus behind the retina.



Use a converging lens to make the rays converge sooner and the image to form on the retina.



Myopia, nearsightedness. Can see close objects.

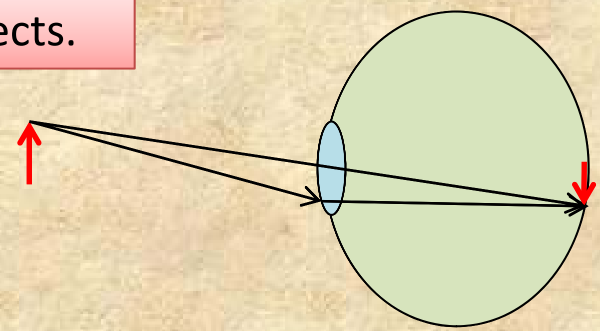
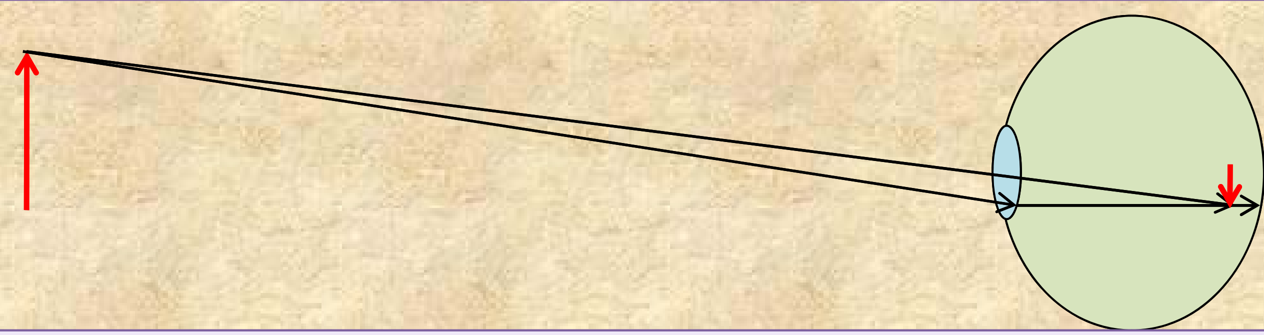


Image is in focus on the retina.

For distant objects the lens cannot lengthen the focal length enough. Thus the image is in focus in front of the retina.



Use a diverging lens to make the rays converge less and the image to form on the retina.

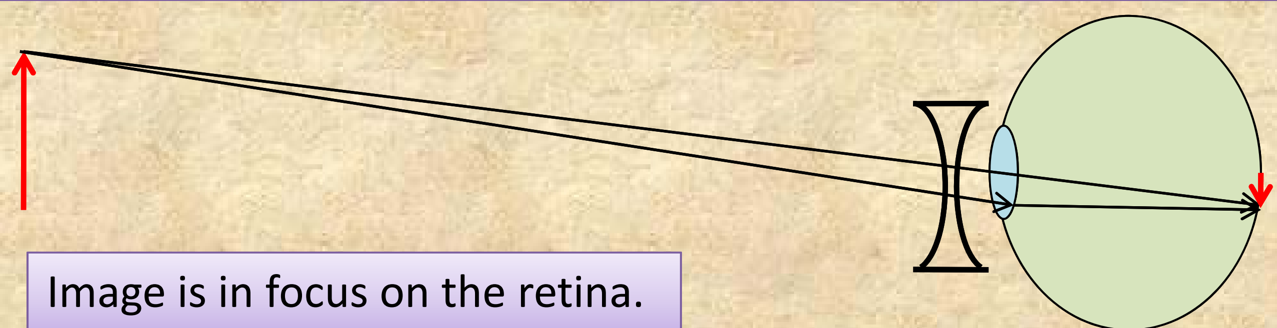
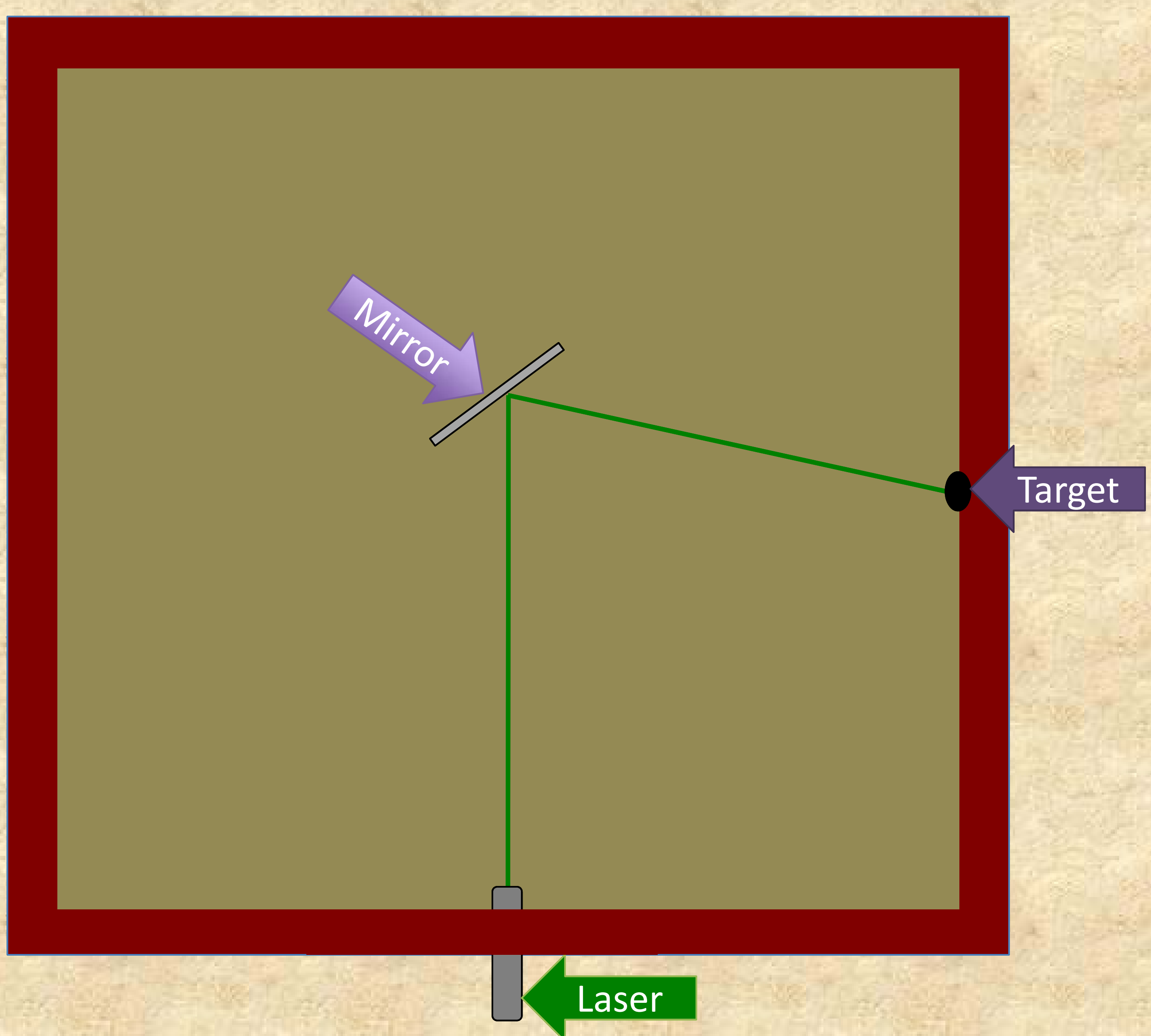


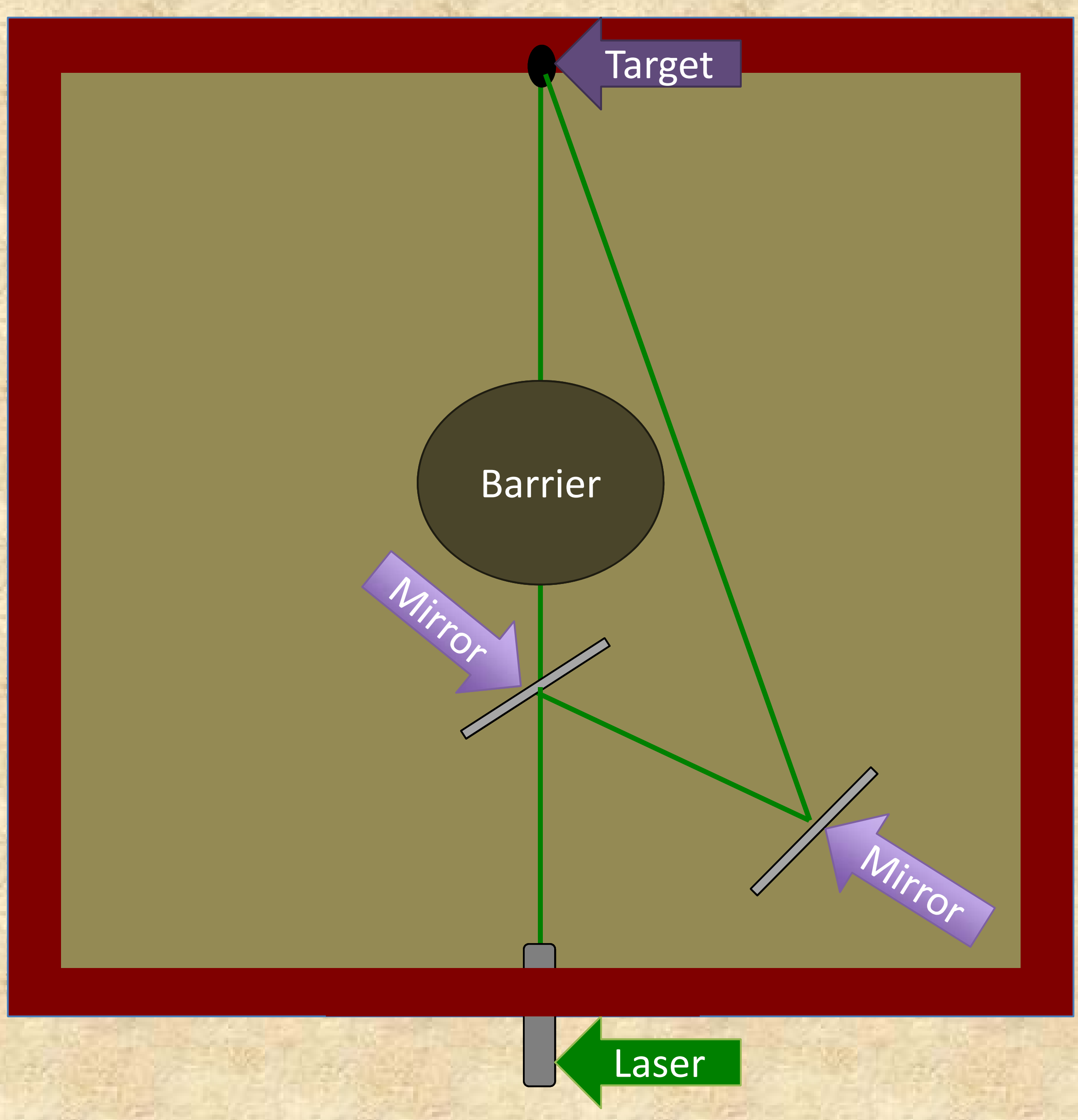
Image is in focus on the retina.

Laser Shoot

Division B: Target on side of frame



Division C: Target behind barrier on back of frame



The End