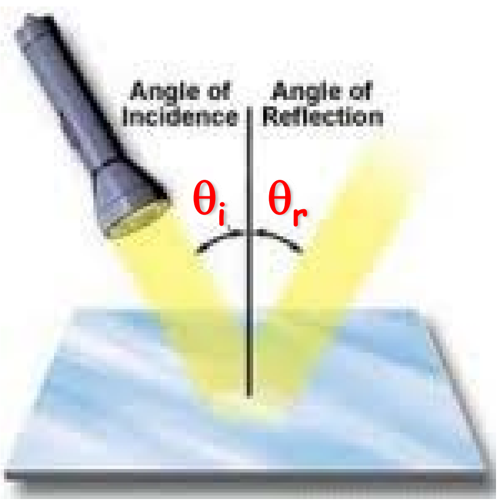
LOUISIANA STATE UNIVERSITY
Department of Physics & Astronomy

Algebra-based Physics II

Oct 18th: Chap 25. 1-4

You need: Geometry + trigonometry

- Wave front and ray
- Law of reflection: $\theta_r = \theta_i$
- Plane mirror
- Spherical mirror



Ch. 25 The Reflection of Light

25.1 Wave fronts and rays

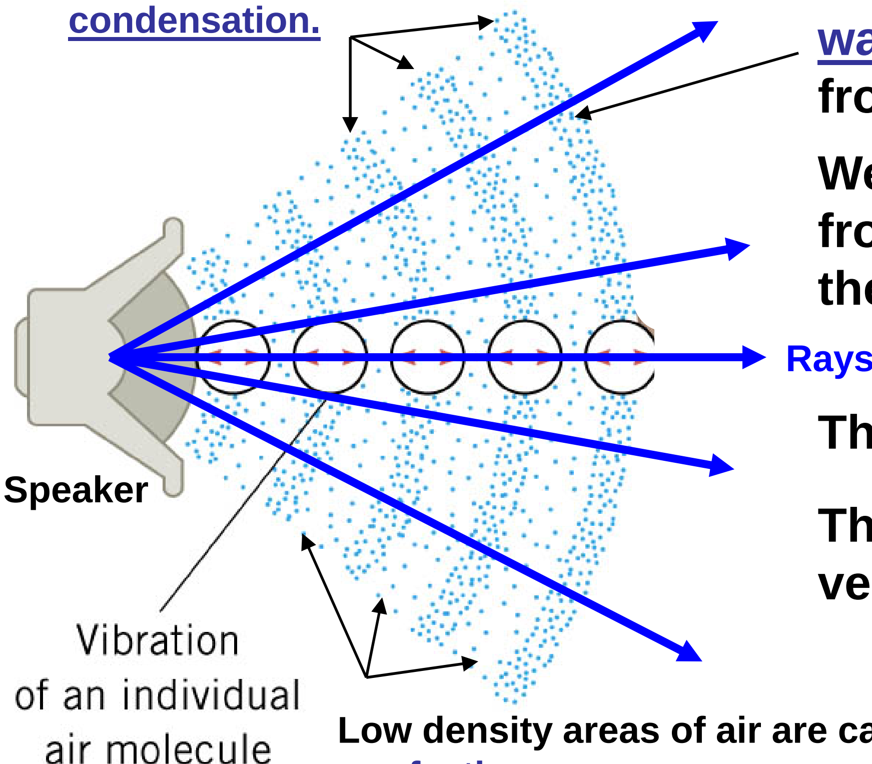
We are all familiar with mirrors.

We see images because some light is reflected off the surface of the mirror and into our eyes.

In order to describe the reflection process in some detail, we need to define a few things:

Consider again sound waves:

High density areas of air are called condensation.



Low density areas of air are called rarefaction.

The areas of condensation are also called wave fronts, and they propagate out away from the source.

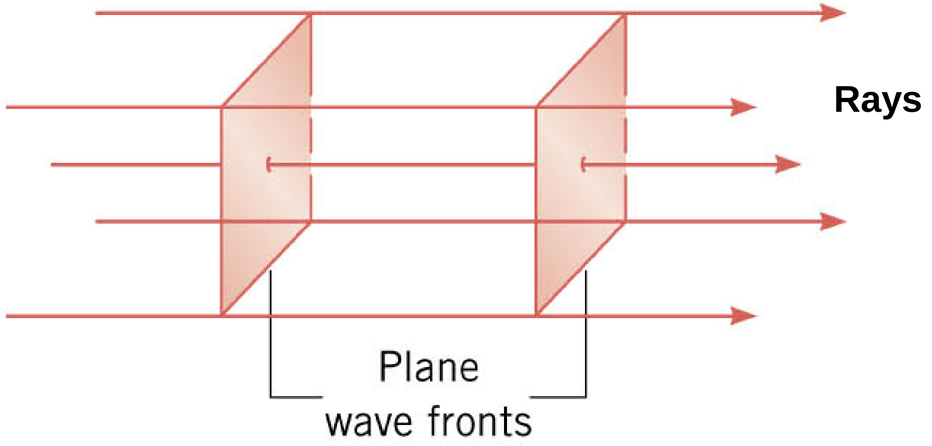
We can draw in radial lines which point out from the source and are perpendicular to the wave fronts.

These are called wave rays, or just rays.

The rays point in the direction of the wave velocity.

Think of the ray as a narrow beam of light showing the direction of the light's path.

We could also have plane wave fronts:



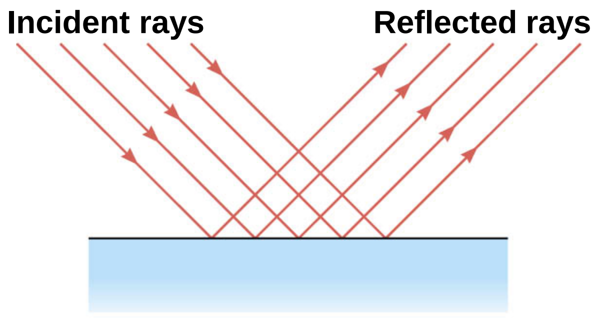
In plane waves, the rays are all parallel to each other!

25.2 The Reflection of Light

Most objects will reflect at least a portion of the light that hits them.

How the light is reflected depends largely on the condition of the object's surface.

If the surface is flat and smooth, then the reflected rays are all parallel:



(*a*) Specular reflection

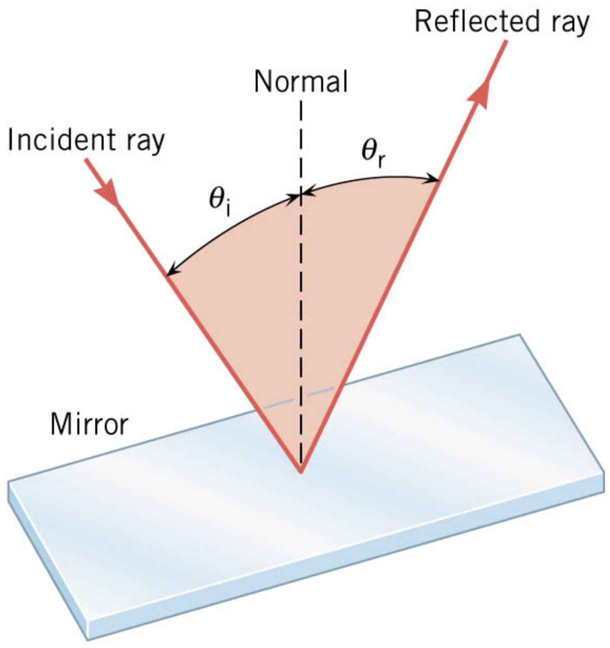
This is called specular reflection.

If the surface is rough, like wood or paper, then the reflected rays point in random directions.

This is called diffuse reflection.

Let's look at specular reflection from a smooth flat surface.

If the incident ray, the reflected ray, and the normal to the surface all reside in the same plane, then the angle of incidence = the angle of reflection.



This is called the Law of Reflection.

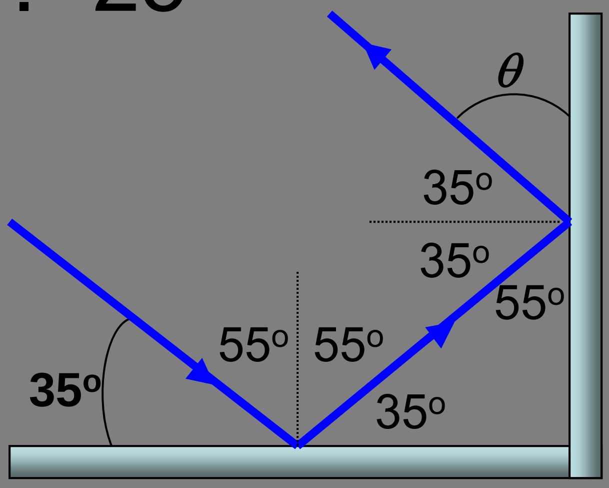
Incident angle $$\theta_i = \theta_r$$ Reflected angle

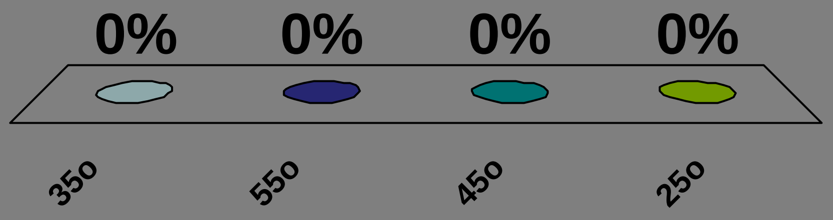
<u>*Note:</u> The incident and reflected angles are both measured <u>relative to the normal to the surface.</u>

Clicker Question 25 - 1

A light beam strikes two perpendicular mirrors as shown. What is the value of θ?

1. 35°
2. ✓ 55°
3. 45°
4. 25°

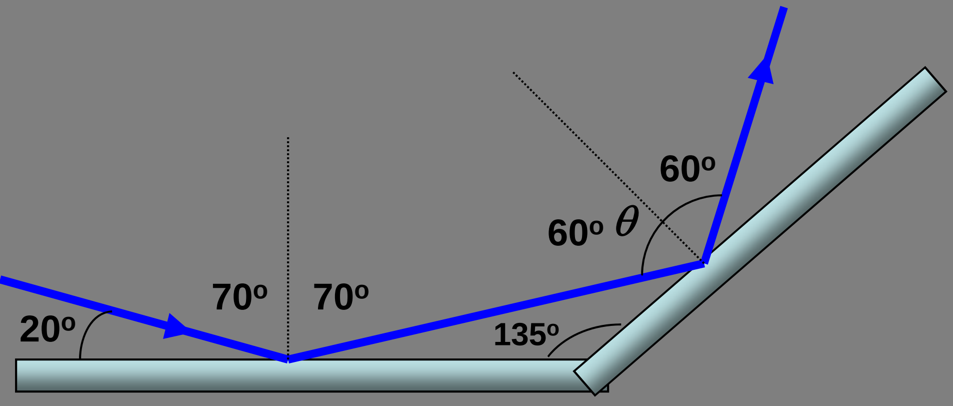


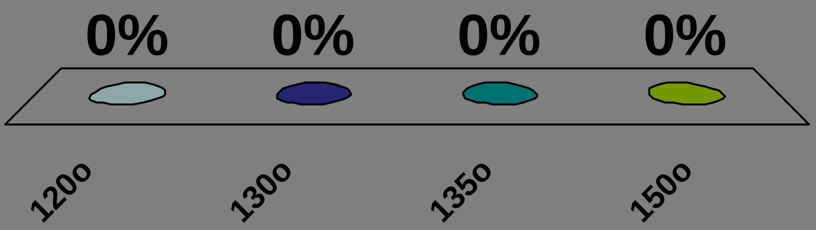


Clicker Question 25 - 2

A light beam strikes the two mirrors as shown below. What is the value of θ?

1. 120º
2. 130º
3. 135º
4. 150º





25.3 Plane Mirrors

Look into a plane mirror. What are the properties of the image you see?

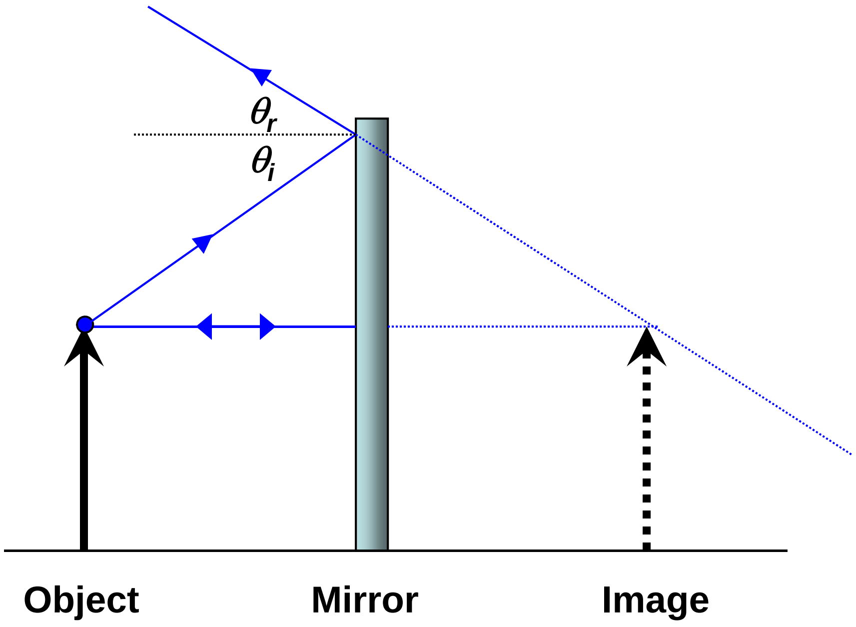
1. The image is upright.

2. The image is the same size as the object.

3. The image is located as far behind the mirror as the object is located in front of it.

4. The image is reversed from left to right.

Let's see how an image is formed with a plane mirror:



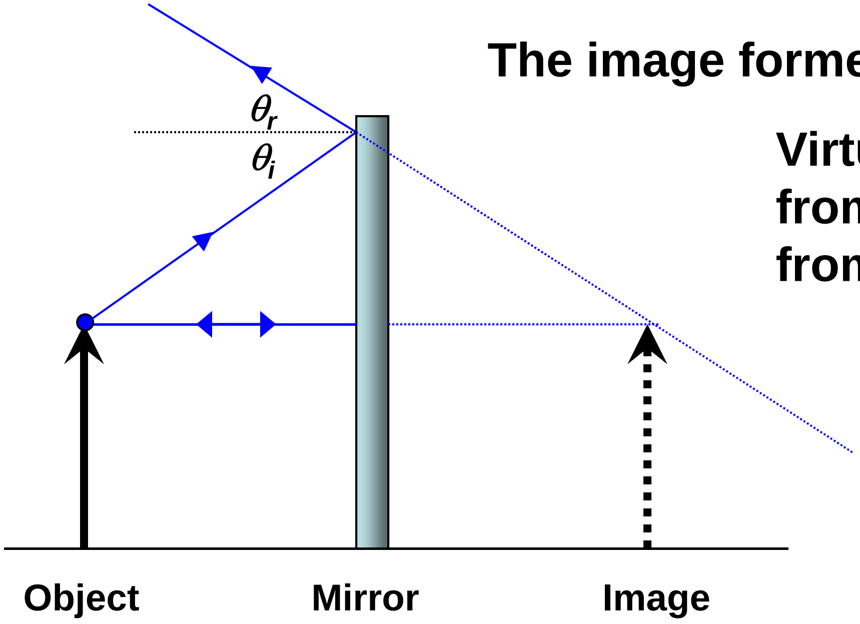
First, I can use a ray that goes straight over and reflects straight back.

Now use a second ray which comes up from the object at some angle.

Extrapolate the second ray back behind the mirror.

The two extrapolated rays intersect at the image.

The image formed by a plane mirror is called a virtual image.

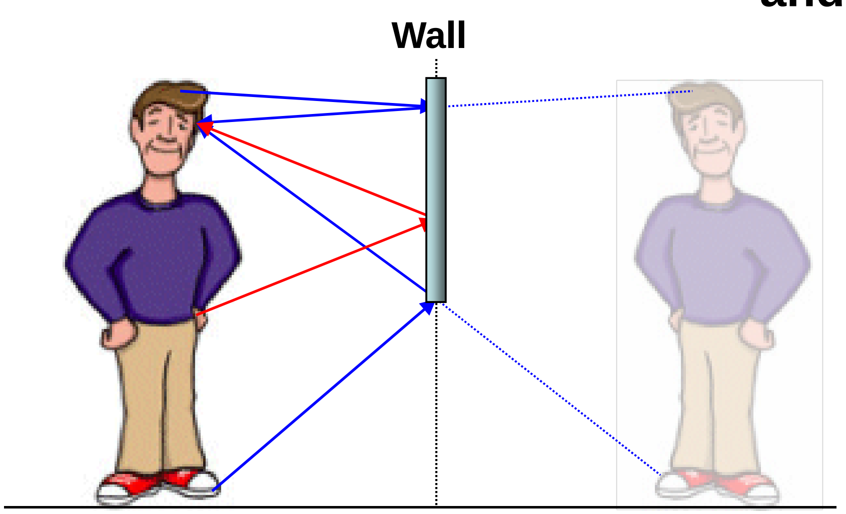


Virtual, since the light rays only appear to come from the image, but they do not actually emanate from there.

Question: I want to use a plane mirror to see my entire body. How long does the mirror have to be?

A ray from the top of my head will strike the mirror and enter my eyes as shown.

And, a ray from my foot can strike the mirror and enter my eyes as well.



Extrapolating these rays back will show the location of the image.

Any other ray from above my foot, like from my waist, would have to strike the mirror above the point where the ray from my foot did.

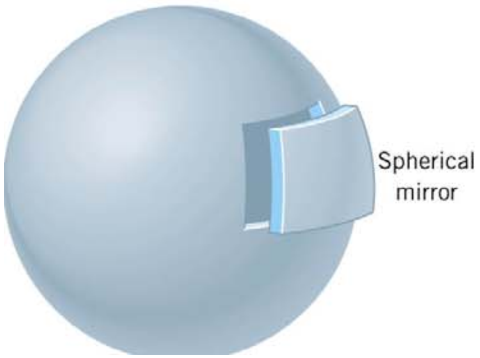
Thus, to see my entire body, I only need a mirror that is ½ my height.

Note: It doesn't matter how far I am from the mirror either!

25.4 Spherical Mirrors

So plane mirrors are flat, but what if the mirror is curved?

Let's go ahead and cut a small section out of a spherical surface:



We can make two different types of spherical mirrors, depending on which side we put the reflective coating:

If the inside is reflective, then we call this a <u>concave mirror</u>.

If the outside is reflective, then we call this a <u>convex mirror</u>.

C **is the <u>center</u> of the mirror, and** ***R*** **is the <u>radius of curvature</u>.**

A line that runs thru the center of the mirror is called the <u>principle axis.</u>

Parallel light rays that are close to the principle axis are called <u>paraxial rays</u>.

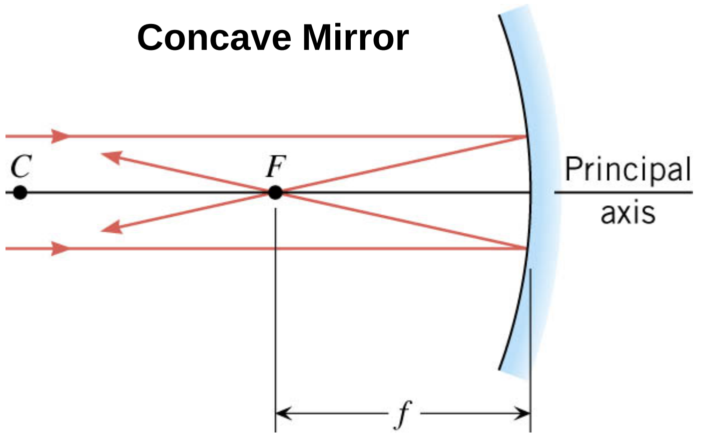
Paraxial rays that strike a concave mirror are reflected toward the principle axis.

Paraxial rays that strike a convex mirror are reflected away from the principle axis.

If an object is very, very far away, then all of the rays coming from it are parallel, i.e. they will be paraxial rays.

All paraxial rays get reflected thru the same point, called the <u>focal point (*F*):</u>

Concave Mirror



For the concave mirror, the parallel rays get reflected thru the focal point.

→ The image is <u>Real</u> (rays come from the image)

For the convex mirror, the parallel rays get reflected away from the principle axis, but if you extrapolate them back, it looks like they emanate from the focal point.

→ The image is <u>Virtual.</u>

It can be shown that $f = \frac{1}{2}R$ **for concave mirrors, and** $f = -\frac{1}{2}R$ **for convex mirrors.**

Since R is a positive number, f will be <u>positive for concave</u> mirrors and <u>negative for convex</u> mirrors.

Algebra-based Physics II

Oct 20th: Chap 25. 4-6

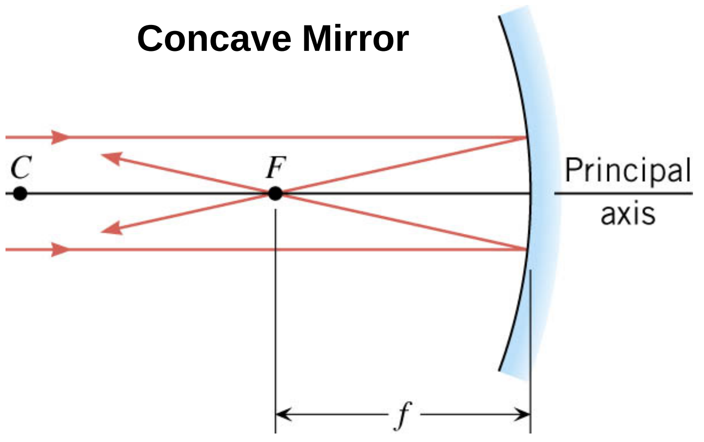
You need: Geometry + trigonometry

- Spherical mirrors
- Images of spherical mirrors
- Mirror equation

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

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

All paraxial rays get reflected thru the same point, called the focal point (F):



For the concave mirror, the parallel rays get reflected thru the focal point.

$\rightarrow$ The image is Real (rays come from the image)

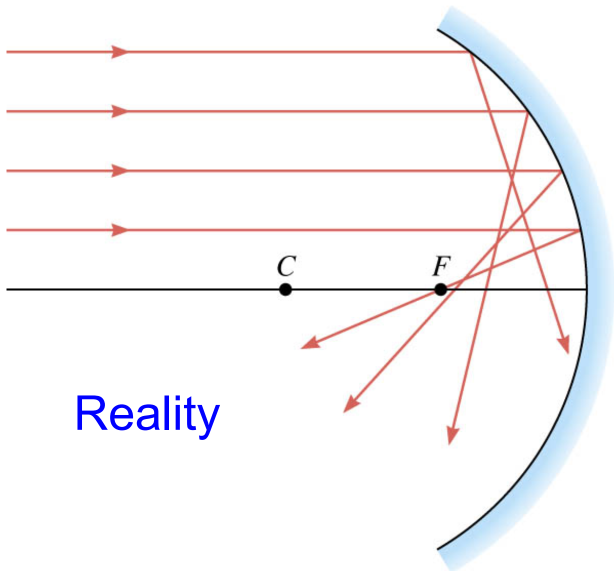
For the convex mirror, the parallel rays get reflected away from the principle axis, but if you extrapolate them back, it looks like they emanate from the focal point.

$\rightarrow$ The image is Virtual.

It can be shown that $f = \frac{1}{2}R$ **for concave mirrors, and** $f = -\frac{1}{2}R$ **for convex mirrors.**

Since R is a positive number, f will be positive for concave mirrors and negative for convex mirrors.

As the rays get farther and farther away from the principle axis, they no longer pass thru the focal point.

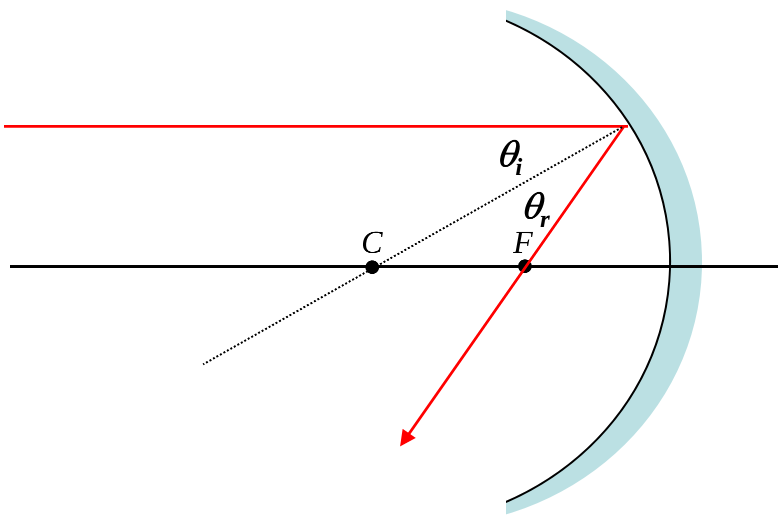


This is called spherical abberation, and the image looks fuzzy.

We could correct this problem by using a parabolic mirror instead of a spherical one.

All parallel rays, not just paraxial rays, into a concave parabolic mirror get reflected thru the focal point.

Before we start forming images with spherical mirrors, let's look more closely at the surface of the mirror where a light ray strikes:



When a paraxial ray comes in, it reflects off the surface and pass thru F.

Where it strikes the mirror's surface, the Law of Reflection is obeyed.

$$\theta_i = \theta_r$$

25.5 Images from Spherical Mirrors

We will now use the techniques of ray tracing to determine the position, size, and orientation of images formed by spherical mirrors.

For concave mirrors, we will use three special rays:

1. A paraxial ray from the object. It passes thru the focal point upon reflection.

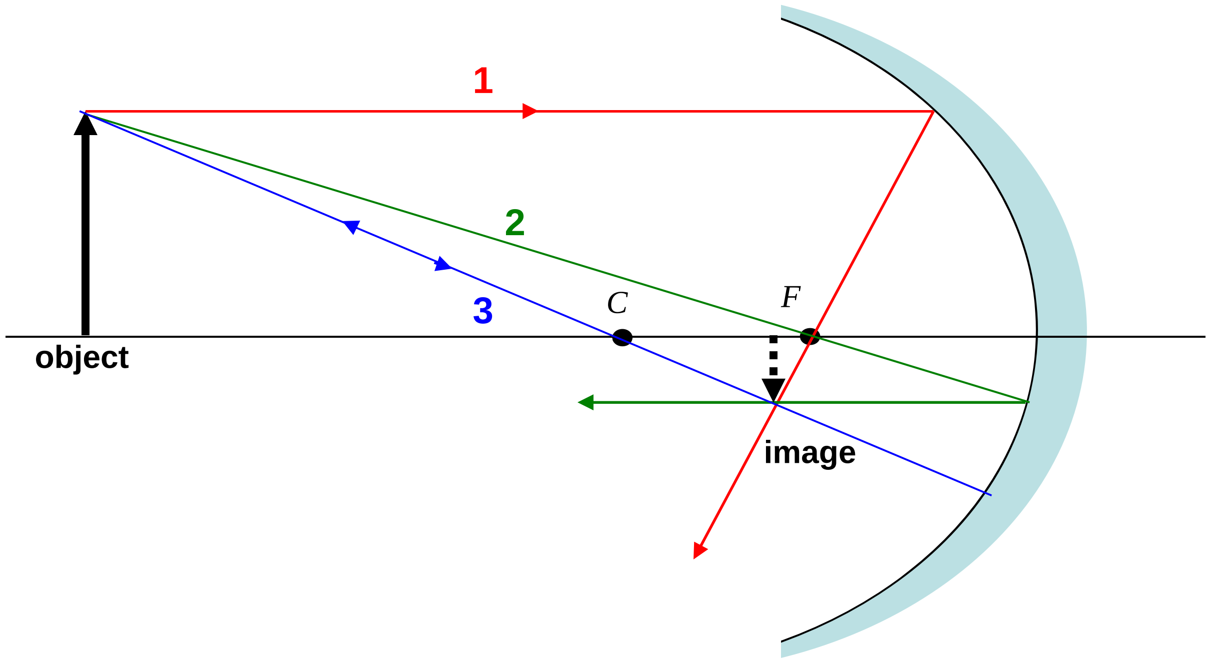
2. A ray from the object that passes thru F and then strikes the mirror. Upon reflection it leaves parallel to the principle axis.

3. A ray from the object that passes thru C and then strikes the mirror. Upon reflection it retraces its original path.

The location and properties of the image depends on where the object is located with respect to F and C.

There are three distinct cases for a concave mirror. We will take them one at a time.

Case 1: The object is located beyond *C*.



So now I can see where the image is located – at the intersection of the reflected rays!

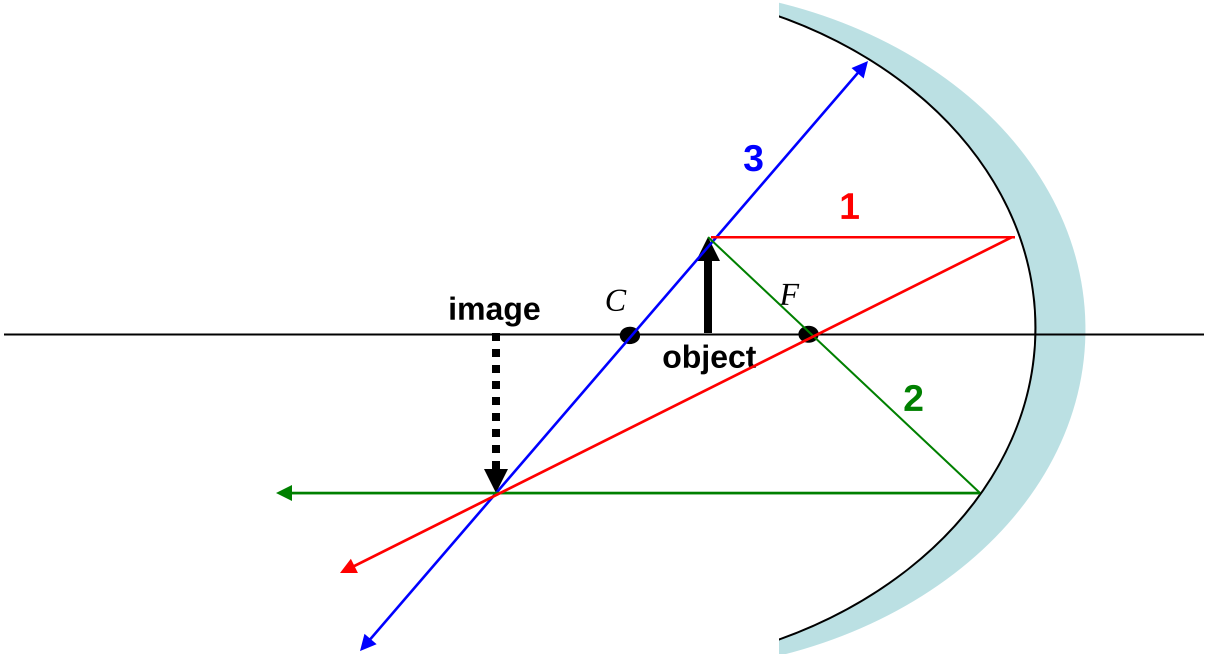
So for this case, what are the image properties:

1. The image is real.

2. The image is inverted with respect to the object.

3. The image is reduced with respect to the object.

Case 2: The object is located between *C* and *F*.



Now we can see where the image is located.

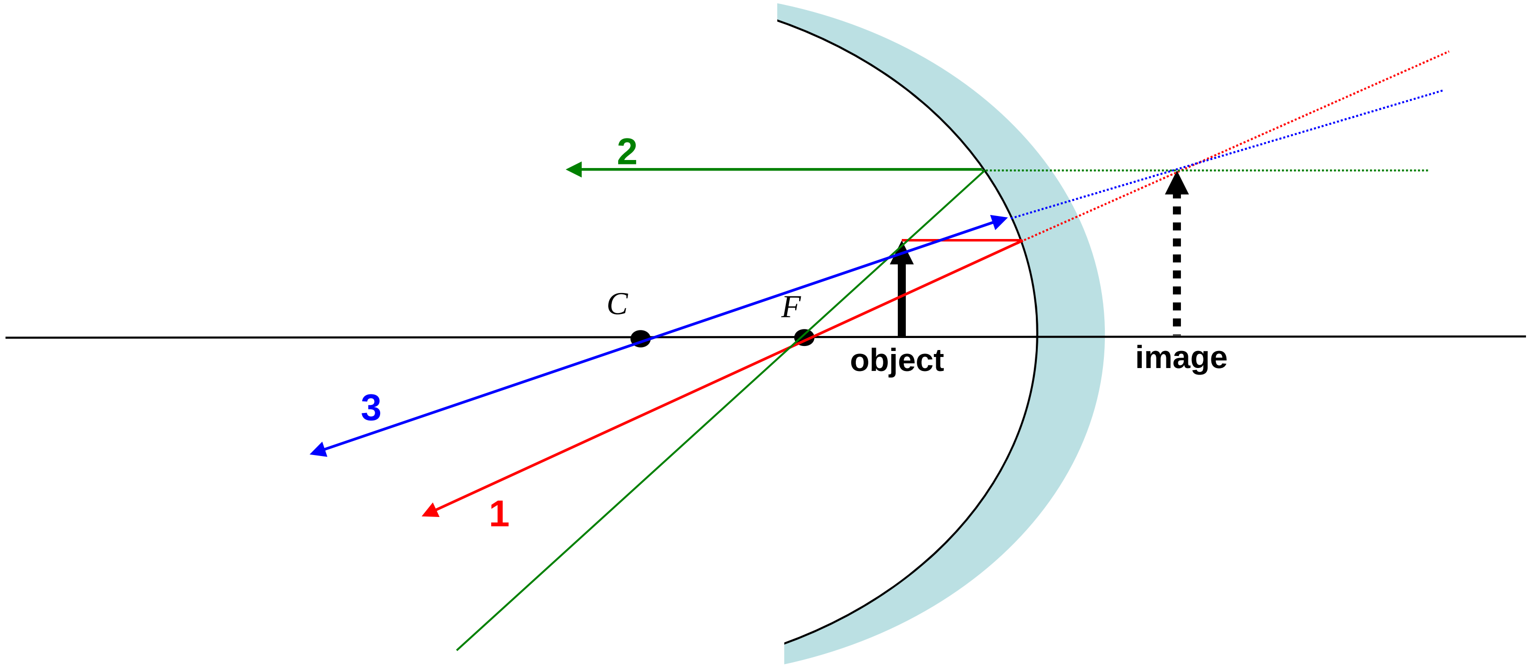
Image properties?

1. The image is real.

2. The image is inverted with respect to the object.

3. The image is enlarged with respect to the object.

Case 3: The object is located inside of *F*.



We see that the reflected rays don't intersect.

Thus, we must extrapolate the reflected waves back.

Now we see where the image is formed. **Image properties?**

1. The image is virtual.

2. The image is upright with respect to the object.

3. The image is enlarged with respect to the object.

Image formed by a convex spherical mirror (only one case)

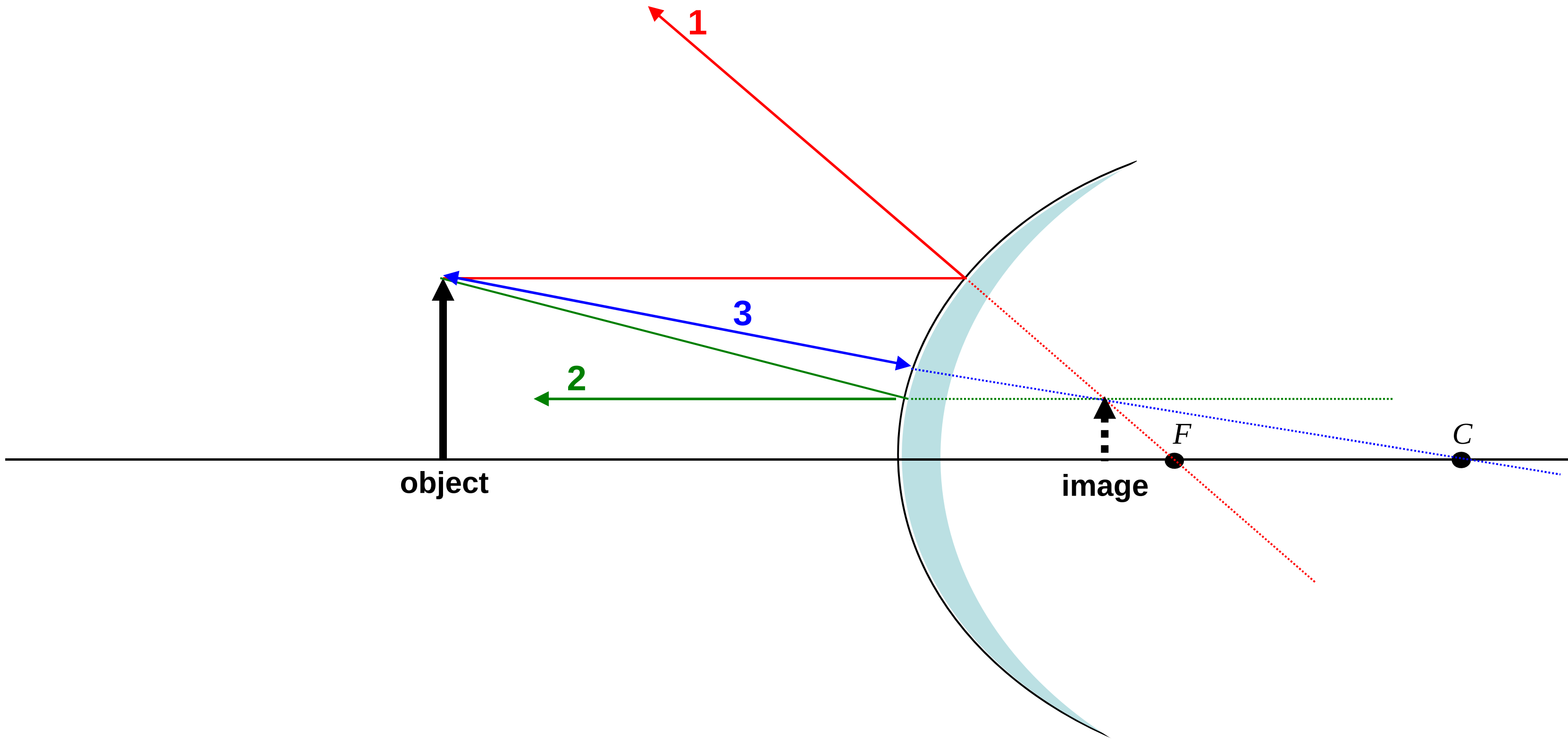
For a convex mirror, we will use 3 slightly different rays:

1. A paraxial ray from the object reflects as if originating from F.

2. A ray from the object that heads toward F gets reflected parallel to the principle axis.

3. A ray from the object that heads toward C gets reflected back along the same path as if originating from C.

There is only one case to consider for convex mirrors, since there is only one location for the object relative to F and C.



Now we can see where the image is formed.

<u>Image properties?</u>

1. The image is virtual.

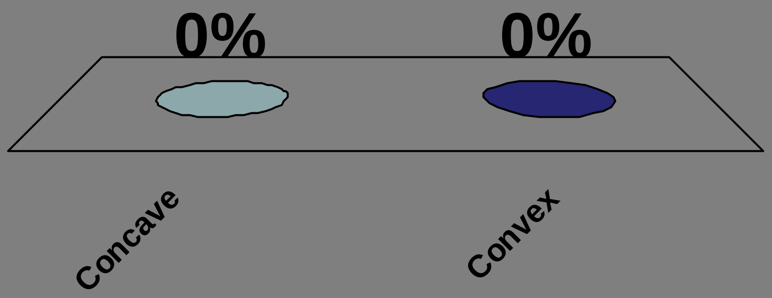
2. The image is upright with respect to the object.

3. The image is reduced with respect to the object.

Clicker Question 25 - 3

Let's say you wanted to try and use a spherical mirror to start a fire with sunlight. Which type of mirror should you use?

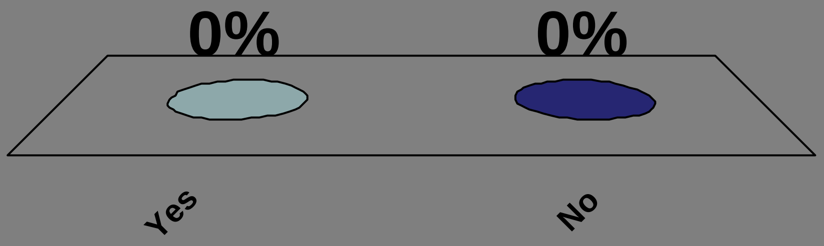
1. Concave
2. Convex



Clicker Question 25 - 4

Can the image formed by a concave mirror ever be projected directly onto a screen?

1. ✓ Yes
2. No



25.6 Mirror and Magnification Equations

Let's define the following quantities:

- f = the focal length of the mirror
- d_o = the object distance from mirror
- d_i = the image distance from mirror
- m = the mirror magnification
- h_o = the object height
- h_i = the image height

We can use a little geometry and properties of similar triangles to show that the following relationships are true:

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

The mirror equation

$$m = \frac{\text{Image height}}{\text{Object height}} = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

The magnification equation

These two equations provide a complete description of the images formed by mirrors: (1) The location of the object and image, (2) The size of the object and image, and (3) Whether the object is upright or inverted.

From the magnification equation, we see that:

If $m > 1$, the image is enlarged.

If $m < 1$, the image is reduced.

If m is positive, the image is upright with respect to the object.

If m is negative, the image is inverted with respect to the object.

Sign Conventions

Focal Length

f is positive for concave mirrors

f is negative for convex mirrors

Object Distance

d_o is positive if the object is in front of the mirror

d_o is negative if the object is behind the mirror

Image Distance

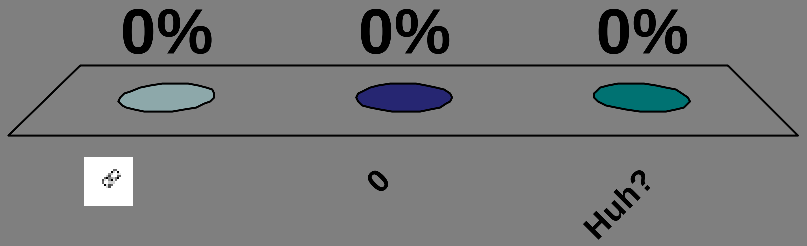
d_i is positive if the image is in front of the mirror (real image)

d_i is negative if the image is behind the mirror (virtual image)

Clicker Question 25 - 5

Based on the mirror equation, what is the focal length of a plane mirror?

1. ∞ ✓
2. 0
3. Huh?



Example

A spherical mirror is used to reflect light from an object that is 66 cm in front of the mirror. The focal length of the mirror is -46 cm. Find the location of the image and its magnification.

Solution

What we know:

d_o **= 66 cm** f **= - 46cm** **Mirror is convex**

What we need to find:

d_i m

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \Rightarrow \frac{1}{d_i}=\frac{1}{f}-\frac{1}{d_o} \Rightarrow \frac{1}{d_i}=\frac{1}{-46}-\frac{1}{66} \Rightarrow \frac{1}{d_i}=-0.036891$$

$$\Rightarrow \boxed{d_i=-27.1\,\text{cm}}$$

So, the image is virtual, located 27.1 cm behind the mirror.

$$m=\frac{-d_i}{d_o} \Rightarrow m=\frac{-(-27.1)}{66} \Rightarrow \boxed{m=0.41}$$

The image is reduced and upright wrt the object.