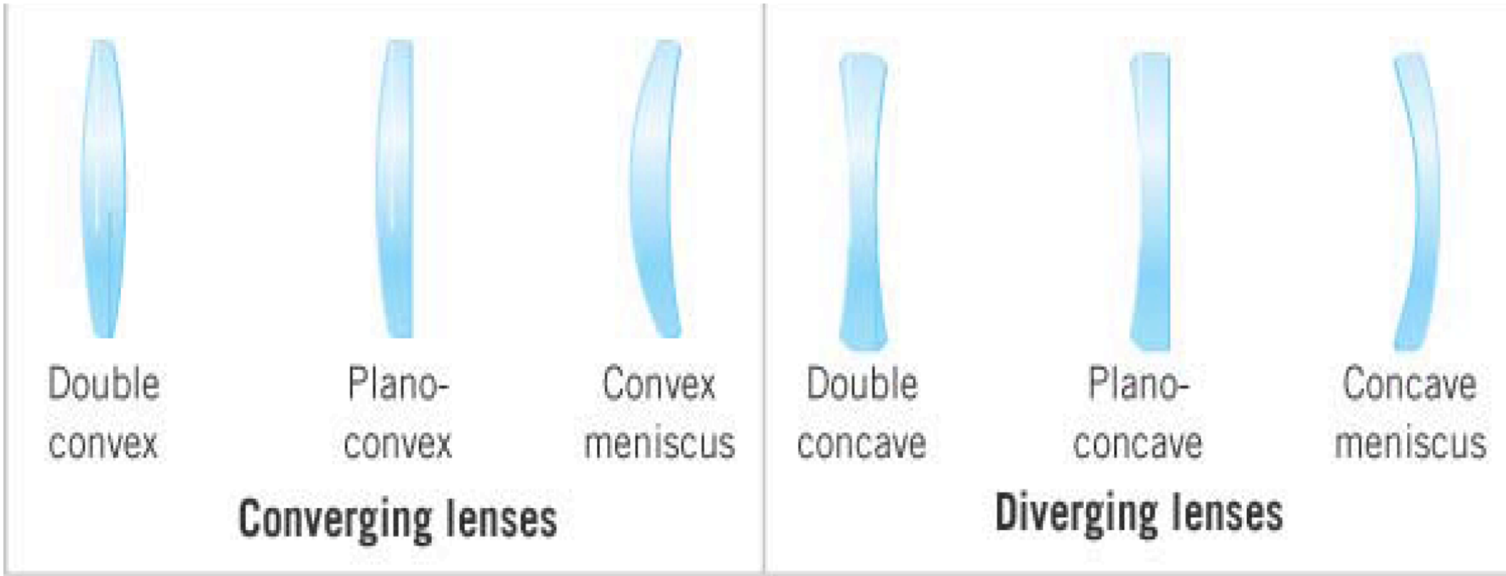
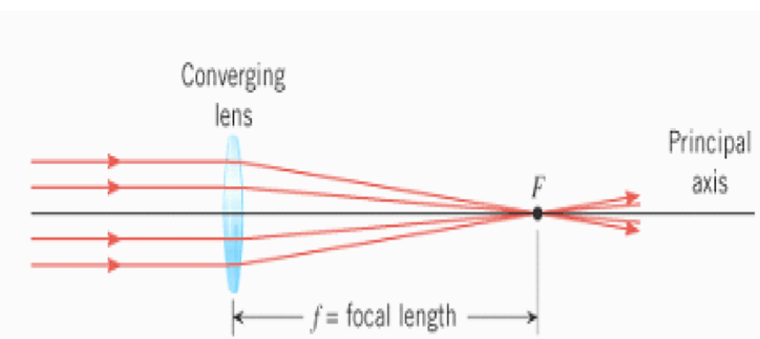
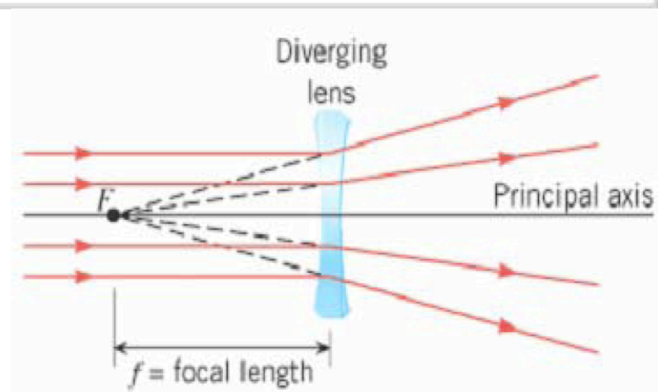
Lenses

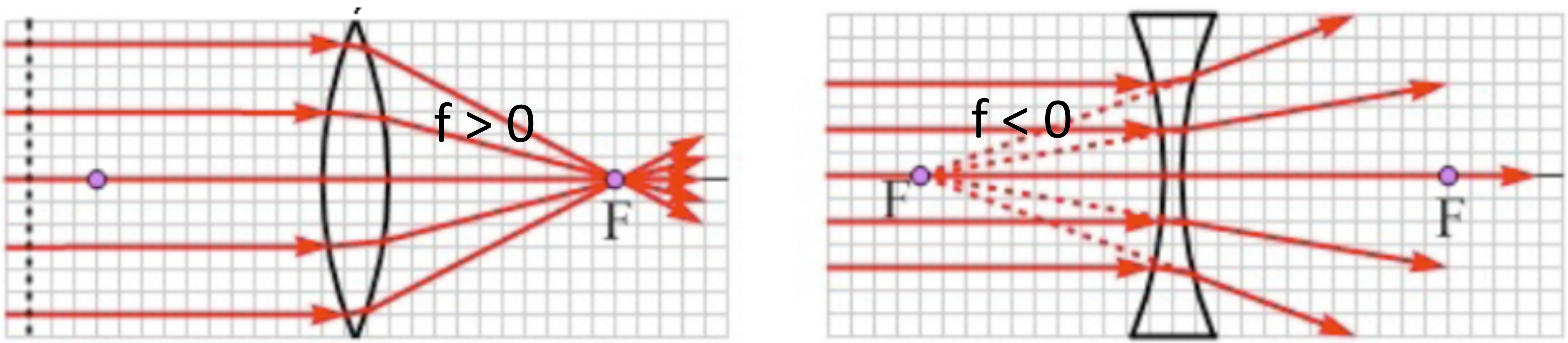
Lenses are optical devices for bending light rays (beams)







Focus, focal point, focal distance



Converging lens **Diverging lens**

Diopters

This is a measure of the refractive power of the lens, which is the inverse of the focal length.

$$D = \text{refractive power in diopters} = \frac{1}{f},$$

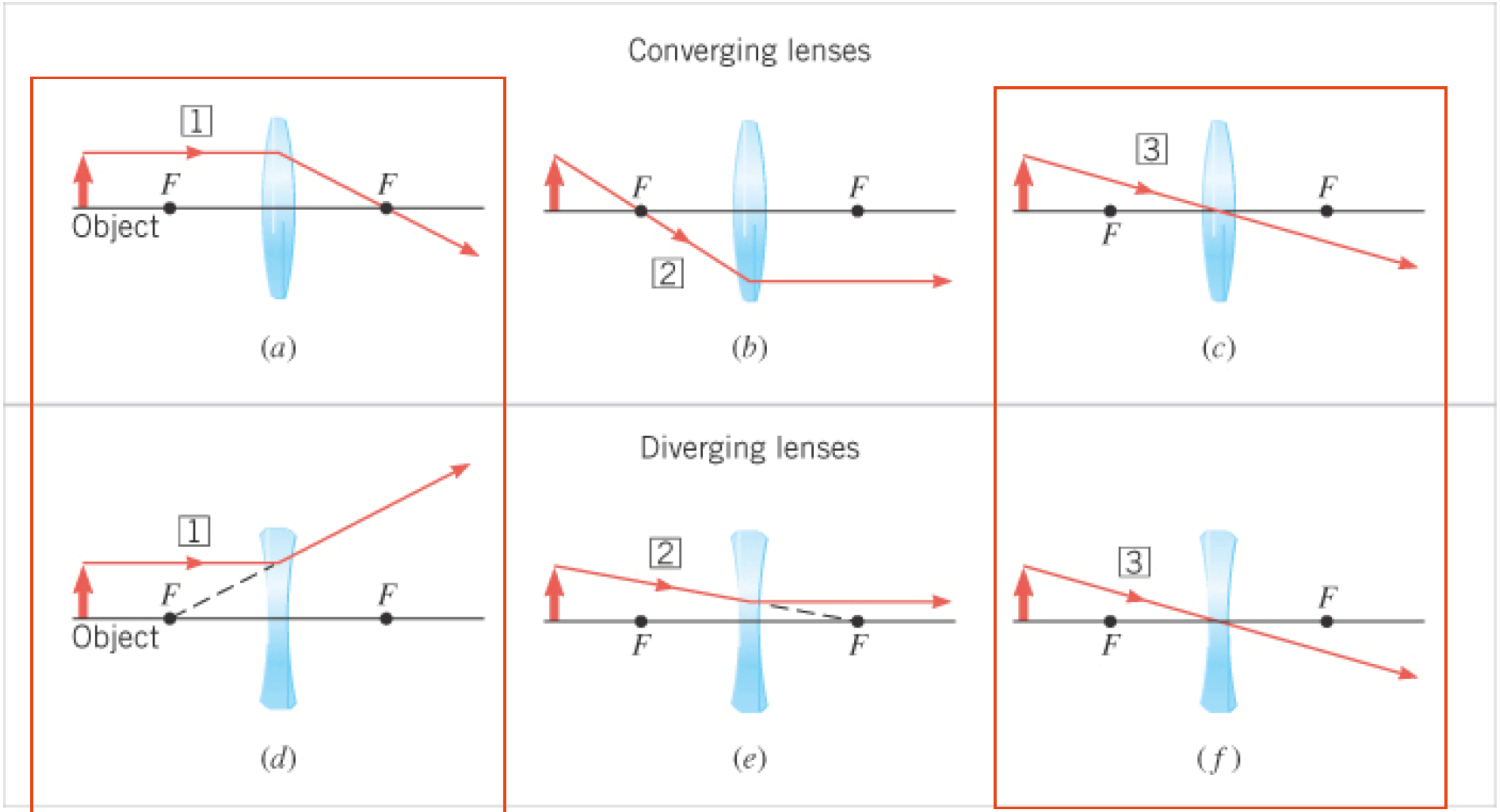
$$\frac{1}{D} = f$$

where f is in meters.

A diopter has units of 1 / m .

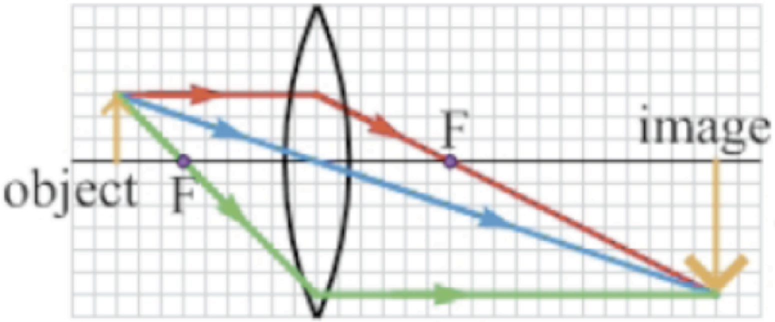
Larger D means shorter f (stronger refraction)

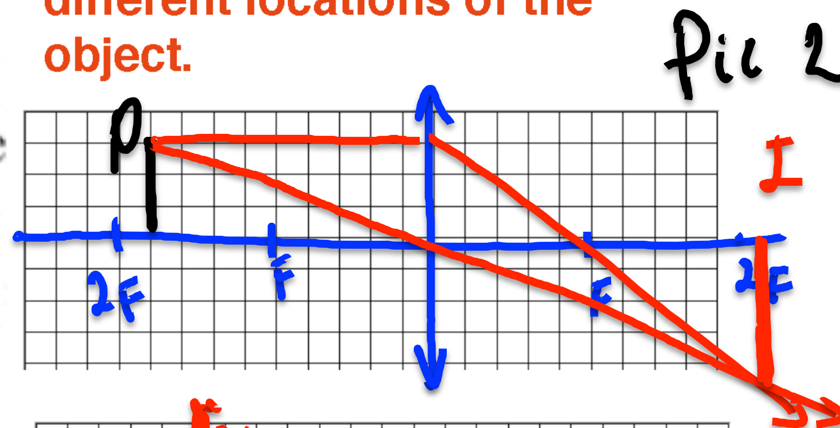
RAY DIAGRAMS

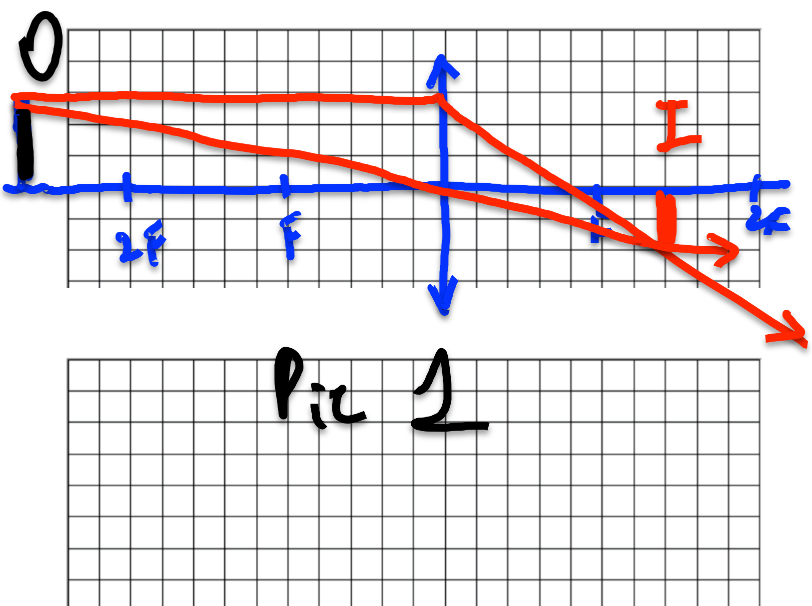


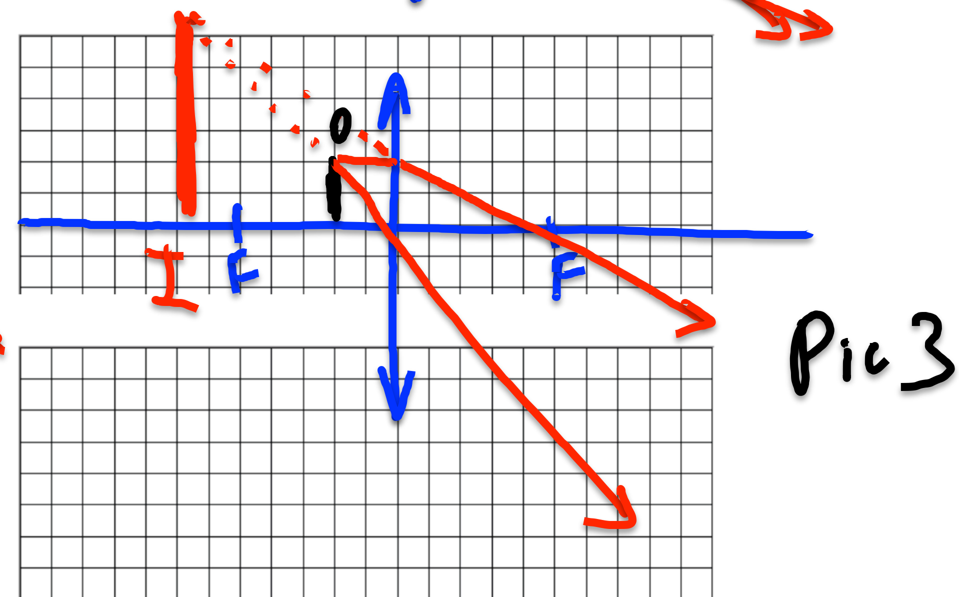
we need just two the most convenient rays!

Draw ray diagrams for different locations of the object.





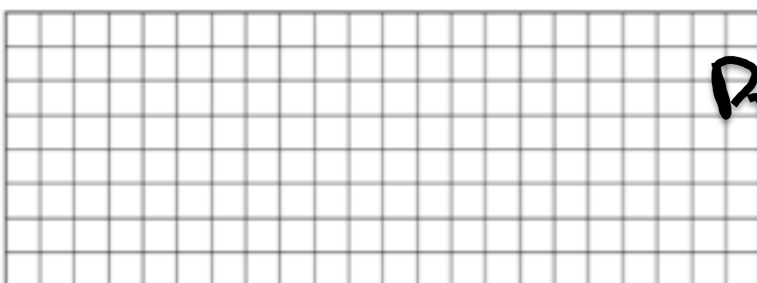




Properties of an image formed by a converging lens

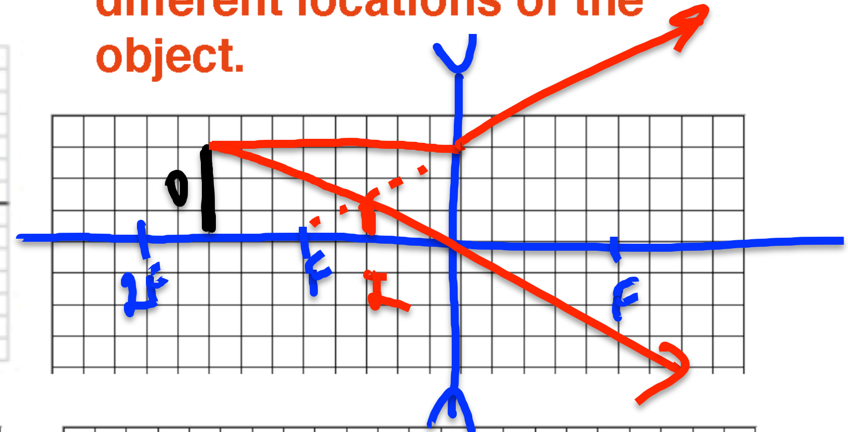
Pic 1 R ; Sm ; Inv

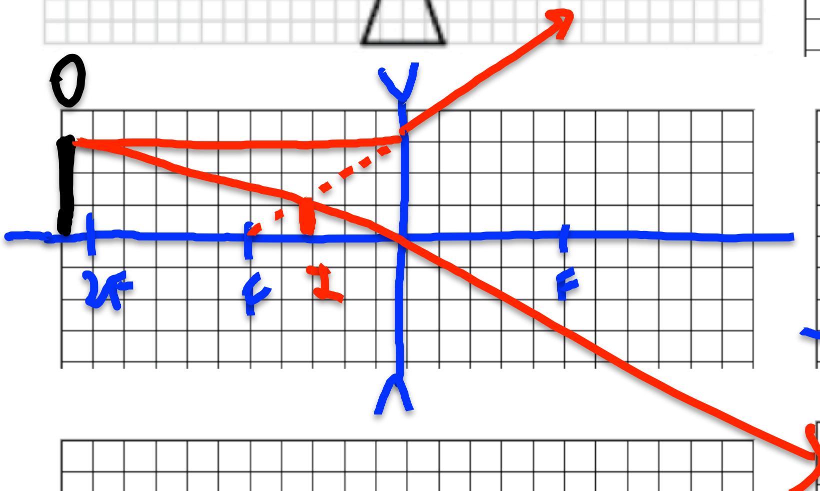
Pic 2 R ; Lag ; Inv

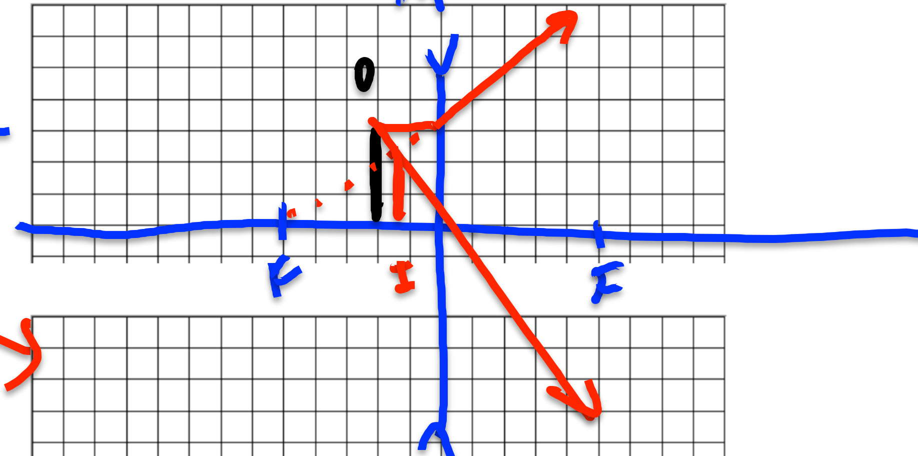


Pic 3 V ; L ; Upr

Draw ray diagrams for different locations of the object.







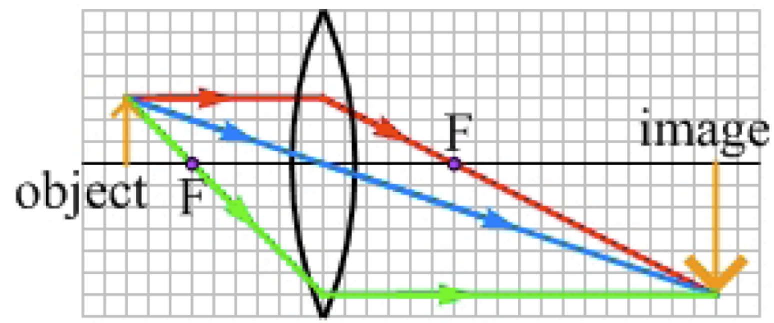
Properties of an image formed by a diverging lens

V, Sm, Upr

The sign convention

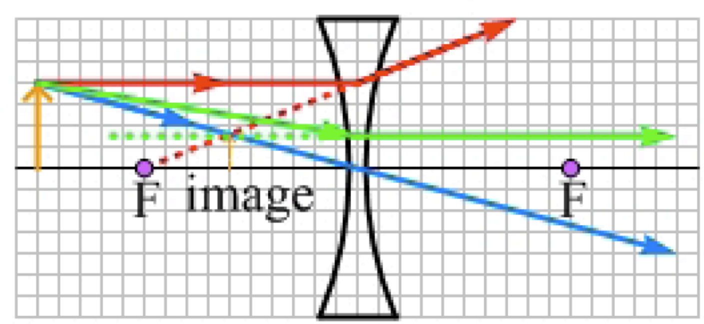
When the image distance is positive, the image is on the opposite side of the lens as the object, and it is real and inverted.

$d_i > 0$

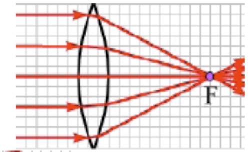


When the image distance is negative, the image is on the same side of the lens as the object, and the image is virtual and upright.

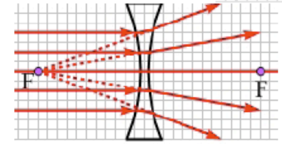
$d_i < 0$



Summary of Sign Conventions for Lenses

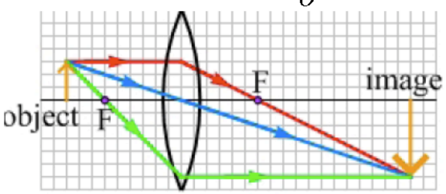


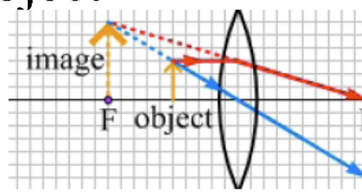
f is + for a converging lens.

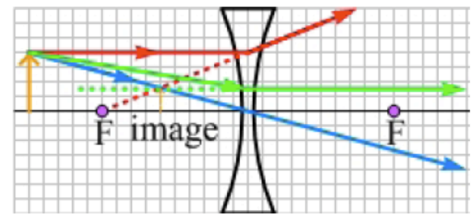


f is – for a diverging lens.

d_o is + for the object







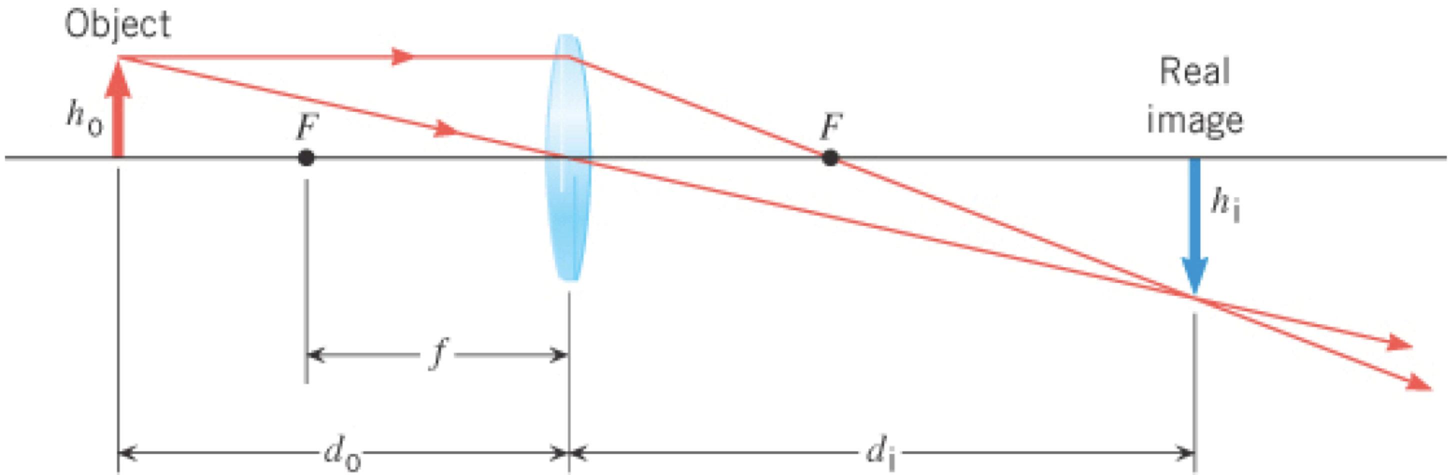
d_i is + for an image formed **by light rays** (real image).

d_i is – for an image formed **by extensions** (virtual image).

$h_{o,i}$ is + for an upright object/image.

$h_{o,i}$ is - for an inverted object/image.

The Thin-Lens Equation and the Magnification Equation



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

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

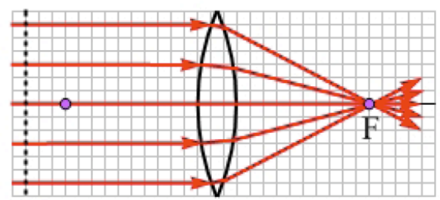
Definition

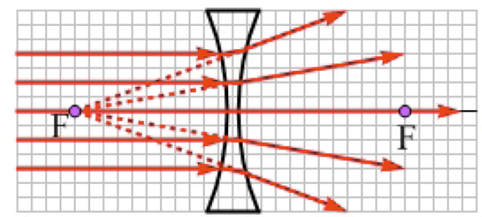
Geometry

The thin-lens equation

Drawing a ray diagram is a great way to get an idea of what is going on. We can also calculate distances and heights precisely using the thin-lens equation, which is derived from the geometry of similar triangles.

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





This can be written:

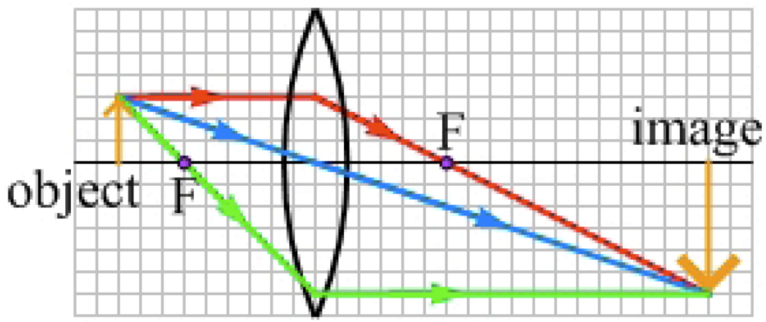
$$d_i = \frac{d_o \times f}{d_o - f}$$

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

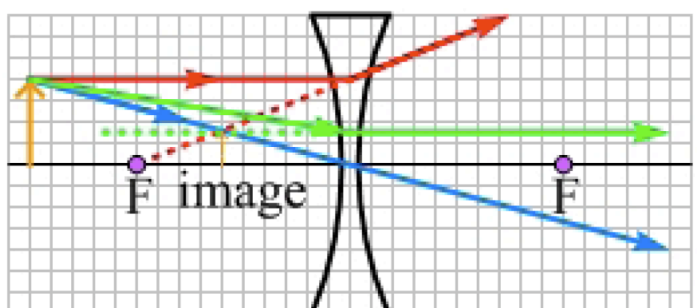
d_o = object distance, d_i = image distance

The sign convention

A negative *m* means that the image is inverted.



A positive *m* means an upright image.

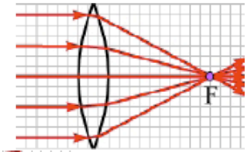


Summary of Sign Conventions for Lenses

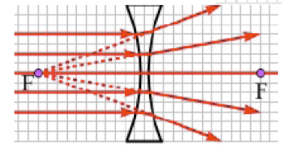
$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$$

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

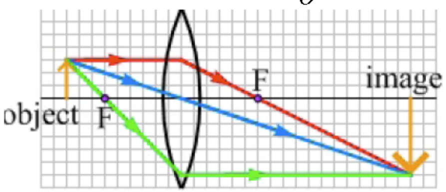
f is + for a converging lens.

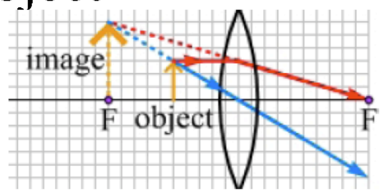


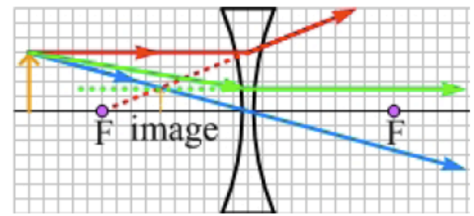
f is – for a diverging lens.



d_o is + for the object







d_i is + for an image formed **by light rays** (real image).

d_i is – for an image formed **by extensions** (virtual image).

m is + for an upright image. m is – for an inverted image.

(assuming the object is upright)

$h_{o,i}$ is + for an upright object/image.

$h_{o,i}$ is - for an inverted object/image.

A method for analyzing lens problems

Solving a lens problem means determining where the image is, and determining what kind of image it is (real or virtual, upright or inverted).

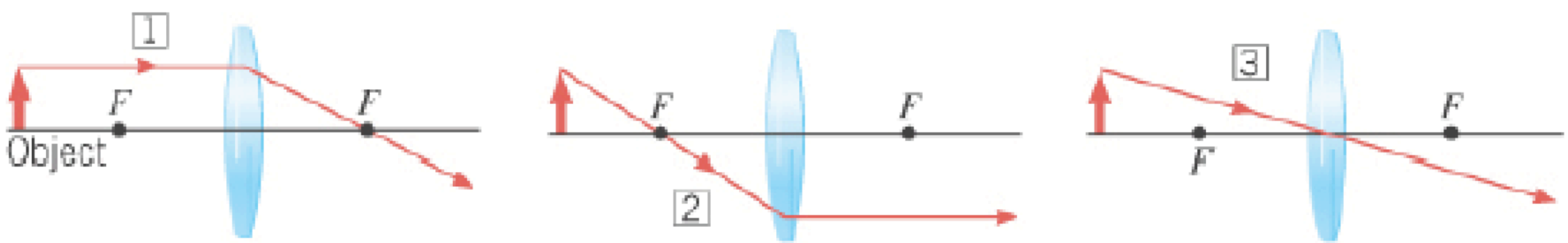
1. Draw a ray diagram. The more careful you are in drawing it, the more accurately you will know where the image is.

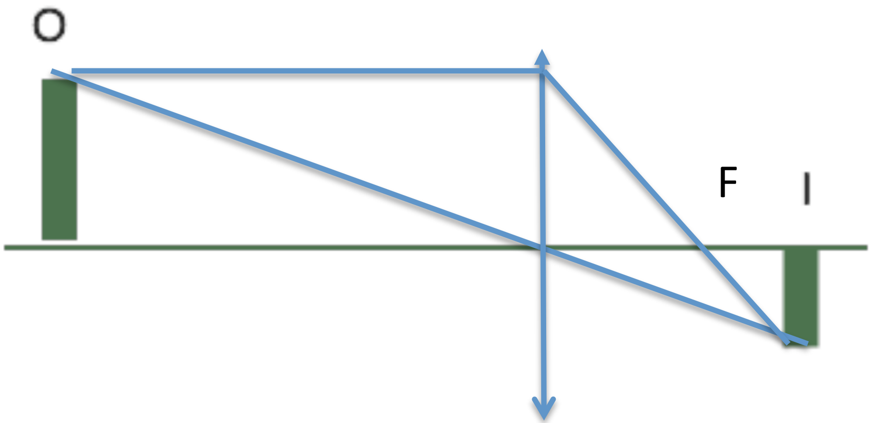
2. Apply the thin-lens equation to determine the image distance. (Or to find the object distance, or the focal length, depending on what is given.)

3. Make sure steps 1 and 2 are consistent with each other.

The picture to the left shows an object, its image in a certain lens and the central axis of the lens.

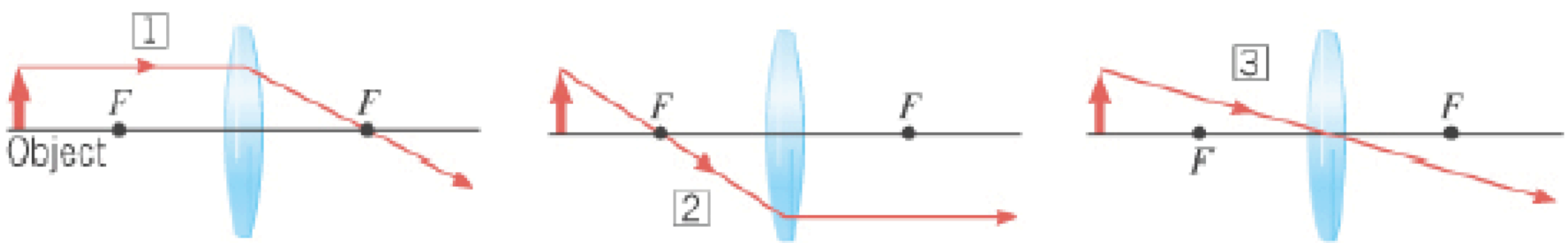
Find (draw) the location of the lens and its focal points.
If the image is a half of the object and 3 m away from it, find the focal distance of the lens.

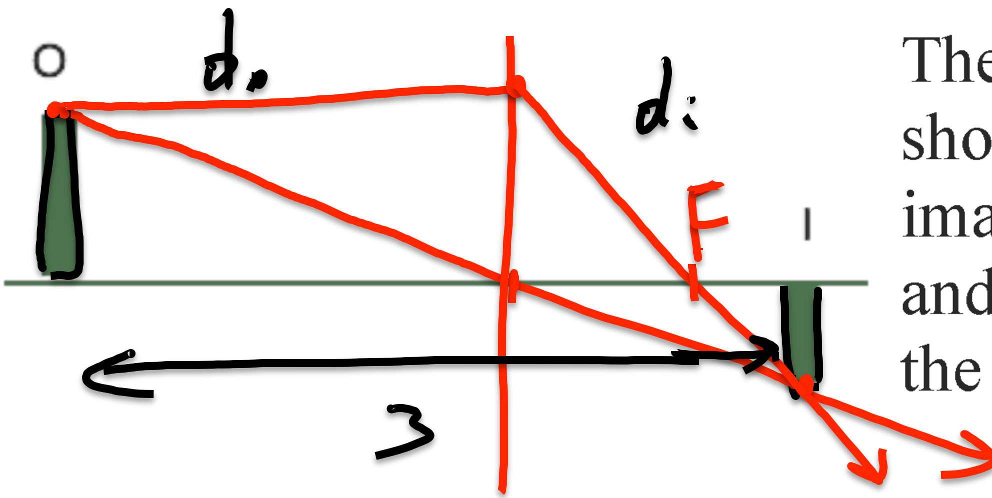




The picture to the left shows an object, its image in a certain lens and the central axis of the lens.

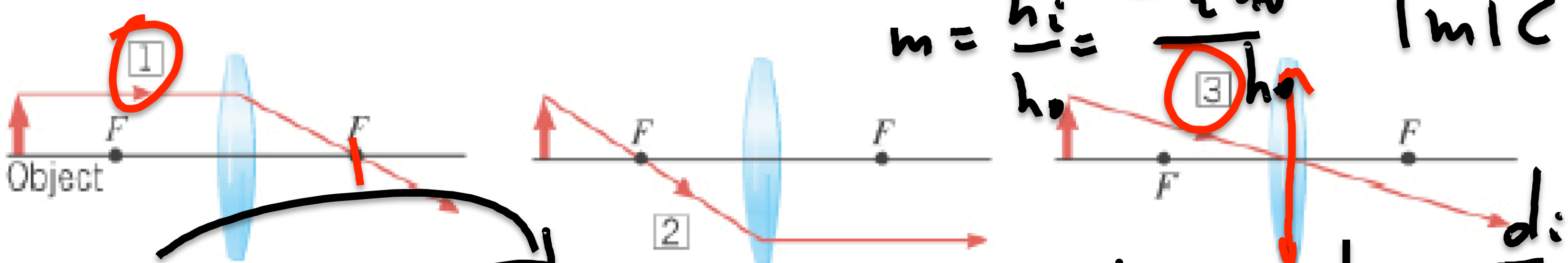
Find (draw) the location of the lens and its focal points.
If the image is a half of the object and 3 m away from it, find the focal distance of the lens.





The picture to the left shows an object, its image in a certain lens and the central axis of the lens.

Find (draw) the location of the lens and its focal points. If the image is a half of the object and 3 m away from it, find the focal distance of the lens.



Example

A Star Wars action figure, 15 cm tall, is placed 75 cm in front of a converging lens that has a focal length of +30 cm.

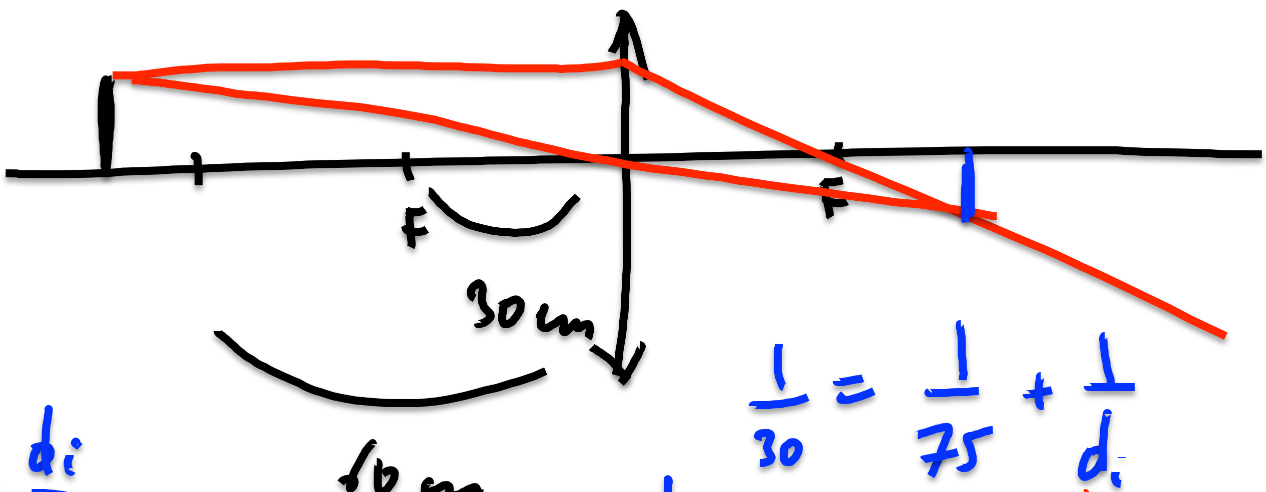
Where is the image?

How tall is the image?

What are the characteristics of the image?

A Star Wars action figure, 15 cm tall, is placed 75 cm in front of a converging lens that has a focal length of +30 cm.

A Star Wars action figure, 15 cm tall, is placed 75 cm in front of a converging lens that has a focal length of +30 cm.



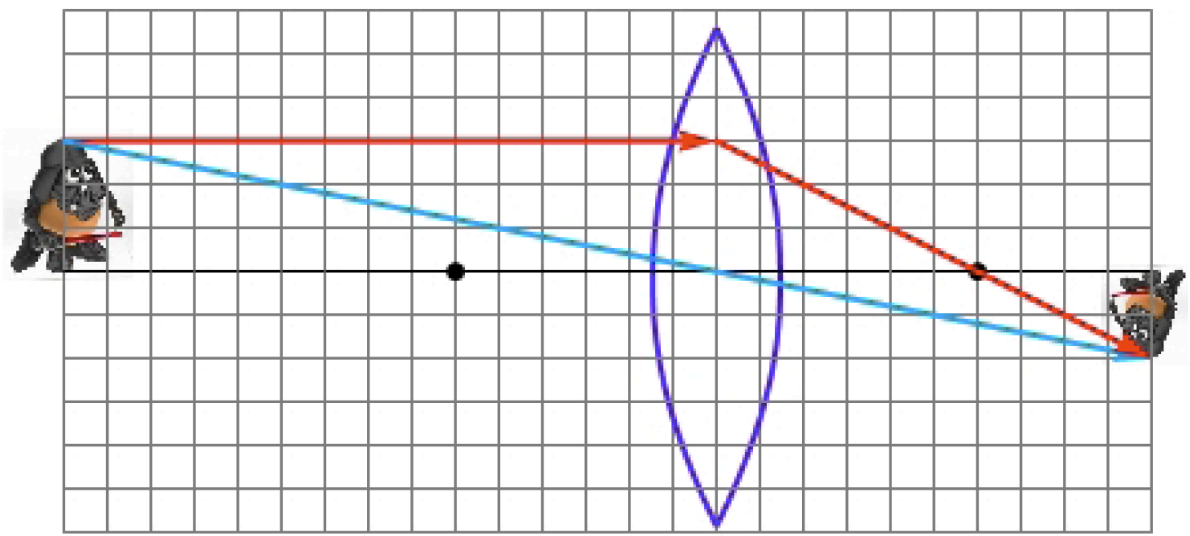
$$\frac{1}{30} = \frac{1}{75} + \frac{1}{d_i}$$

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \rightarrow h_i = 15 \cdot \frac{-d_i}{75}$$

Example

First, sketch a ray diagram.

1 grid unit = 5 cm.



Example

A Star Wars action figure, 15 cm tall, is placed 75 cm in front of a converging lens that has a focal length of +30 cm.

Where is the image?

$$d_o = 75 \text{ cm}, \; f = +30 \text{ cm}$$

$$d_i = \frac{d_o \times f}{d_o - f}$$

$$= \frac{(75 \text{ cm}) \times (30 \text{ cm})}{(75 \text{ cm}) - (30 \text{ cm})}$$

$$= +50 \text{ cm}$$

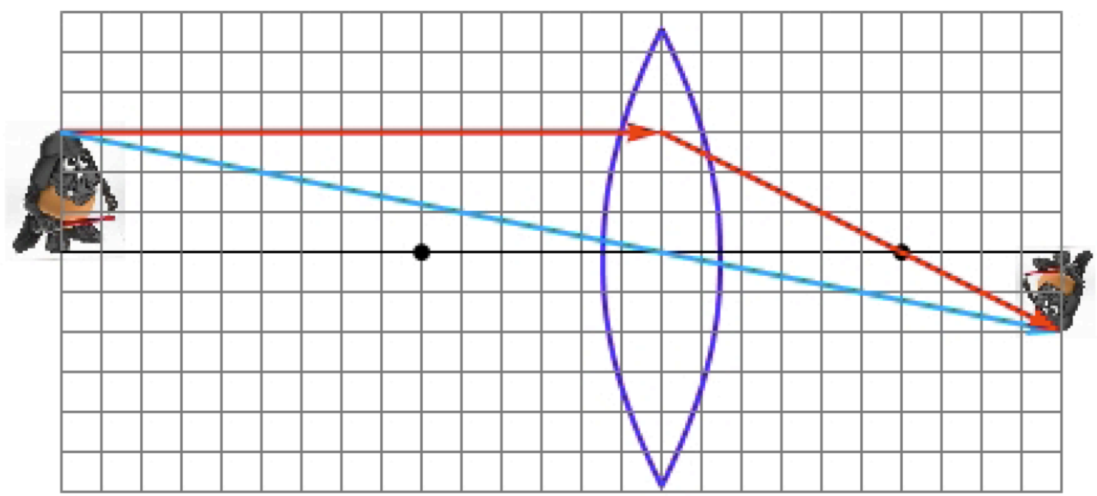
Example

A Star Wars action figure, 15 cm tall, is placed 75 cm in front of a converging lens that has a focal length of +30 cm.

Where is the image?

$$d_o = 75 \text{ cm}, \;\; d_i = +50 \text{ cm}$$

This agrees with the ray diagram



Example

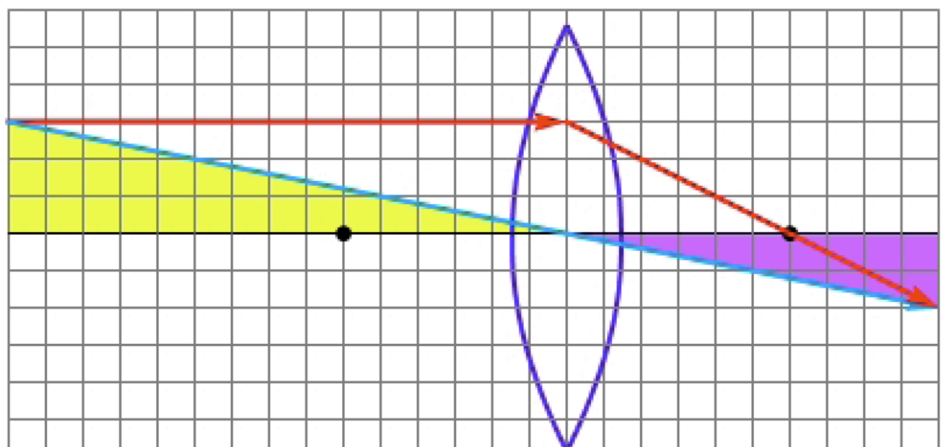
How tall is the image?

$$d_o = 75\text{ cm},\ \ d_i = 50\text{ cm},\ h_o = 15\text{ cm}$$

We can find the image height from the similar triangles or from the magnification equation.

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

$$h_i = -10\text{ cm}$$



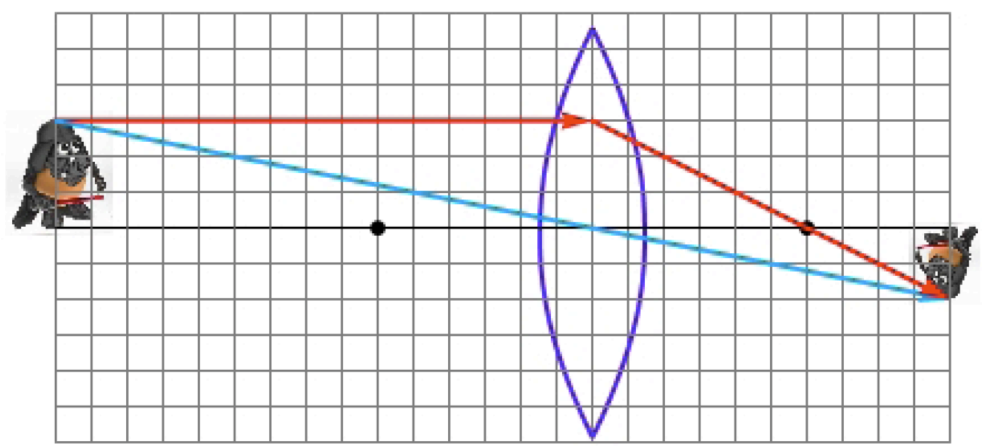
Example

A Star Wars action figure, 15 cm tall, is placed 75 cm in front of a converging lens that has a focal length of +30 cm.

What are the image characteristics?

The image is:

- real
- inverted
- smaller than the object



Example

A Star Wars action figure, 15 cm tall, is placed 60 cm in front of a diverging lens that has a focal length of -30 cm.

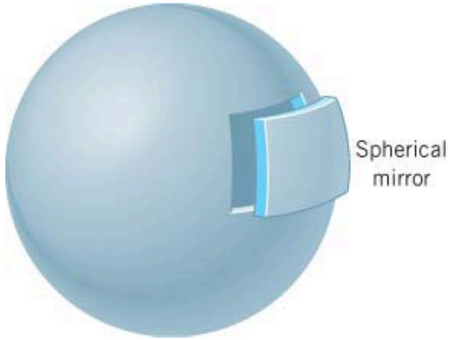
Where is the image?

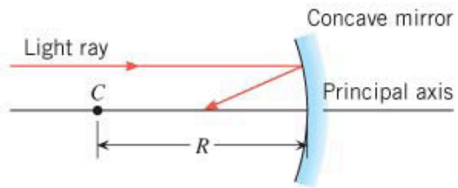
How tall is the image?

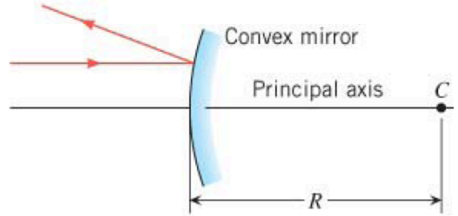
What are the characteristics of the image?

A Star Wars action figure, 15 cm tall, is placed 60 cm in front of a diverging lens that has a focal length of -30 cm.

Spherical Mirrors







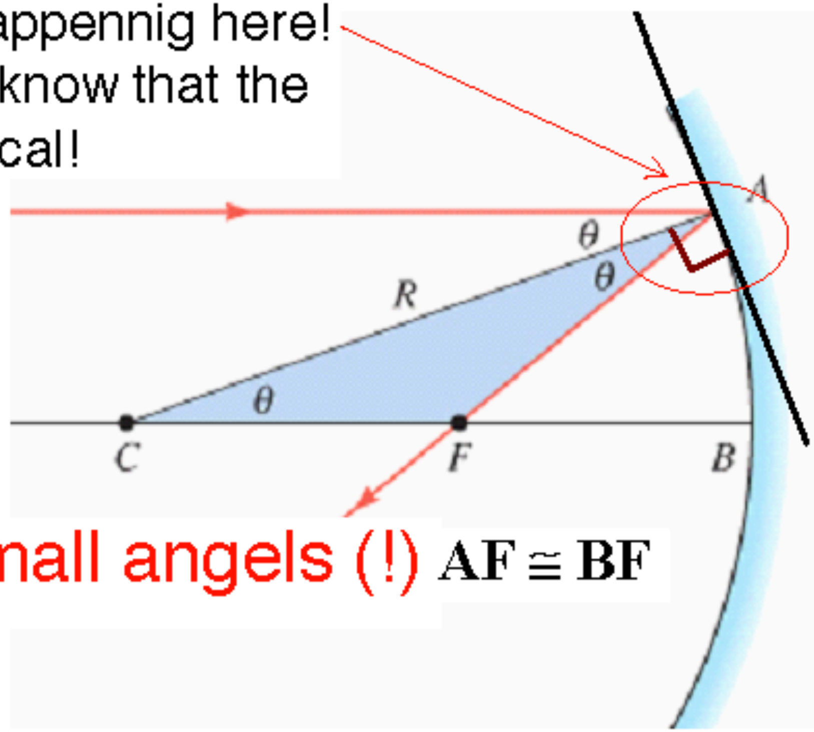
If the inside surface of the spherical mirror is polished, it is a ***concave mirror.***

If the outside surface is polished, is it a ***convex mirror.***

The law of reflection applies, just as it does for a plane mirror.

The ***principal axis*** of the mirror is a straight line drawn through the center and the midpoint of the mirror.

Reflection is happennig here!
Light does not know that the
mirror is spherical!



for small angels (!) $\mathbf{AF \cong BF}$

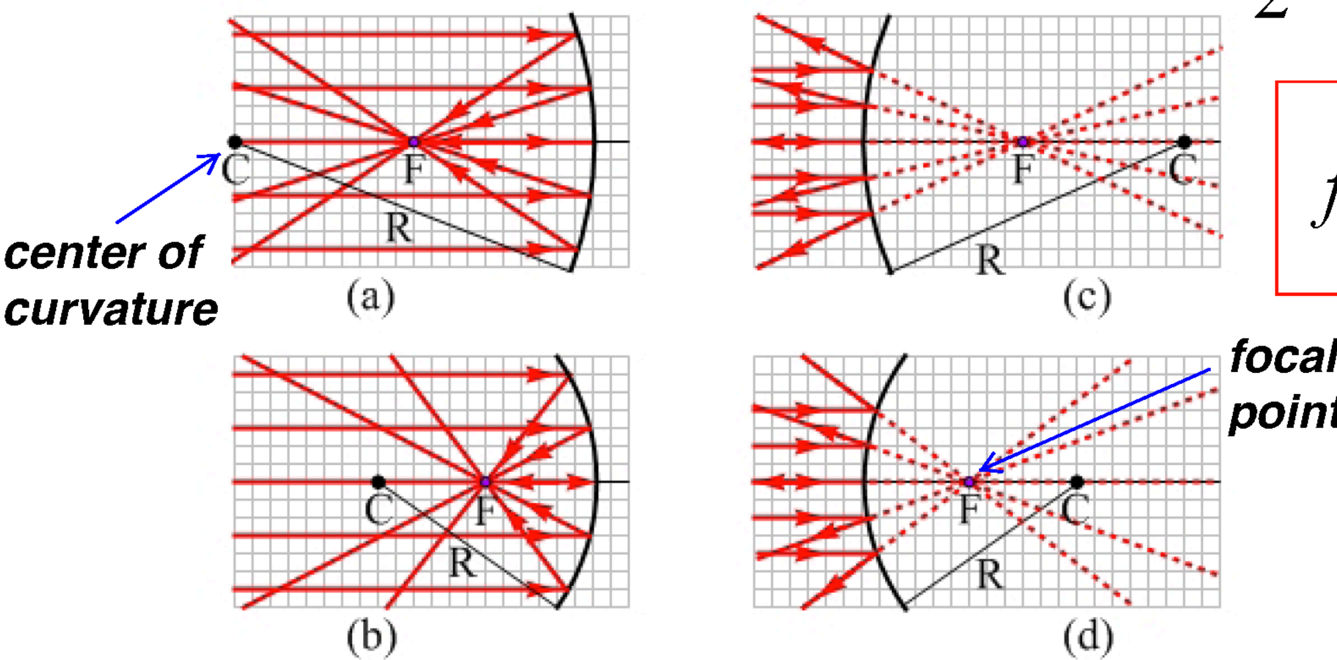
The focal point of a concave mirror is halfway between the center of curvature of the mirror C and the mirror at B.

$$|f| = \frac{1}{2}R$$

for small angels (!)

Spherical mirrors

The focal length of a spherical mirror : $|f| = \frac{R}{2}$



$$f = \pm\frac{R}{2}$$

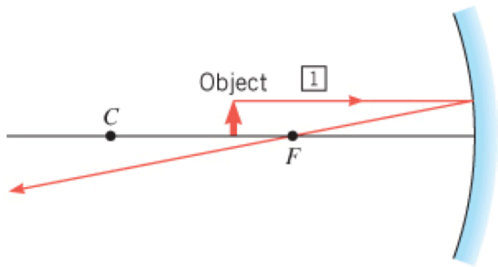
Concave

(positive *f*)

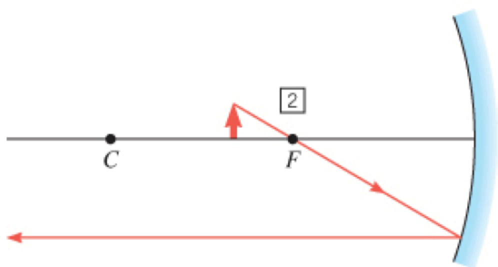
Convex

(negative *f*)

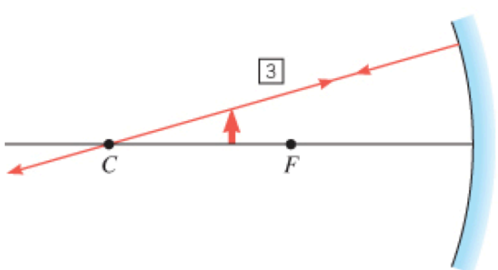
CONCAVE MIRRORS



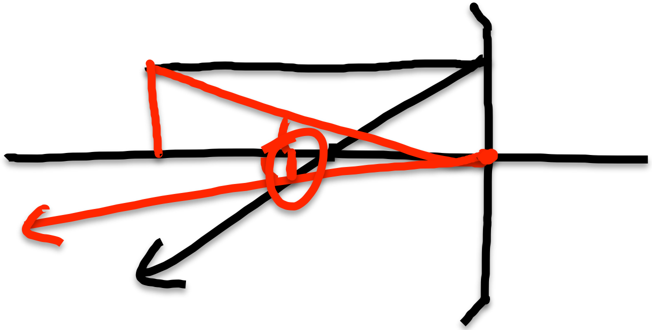
This ray is initially parallel to the principal axis and passes through the focal point.

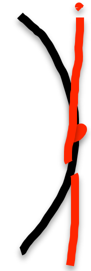


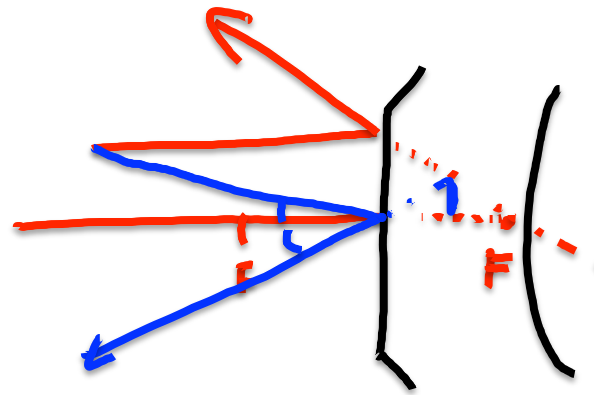
This ray initially passes through the focal point, then emerges parallel to the principal axis.



This ray travels along a line that passes through the center.






F