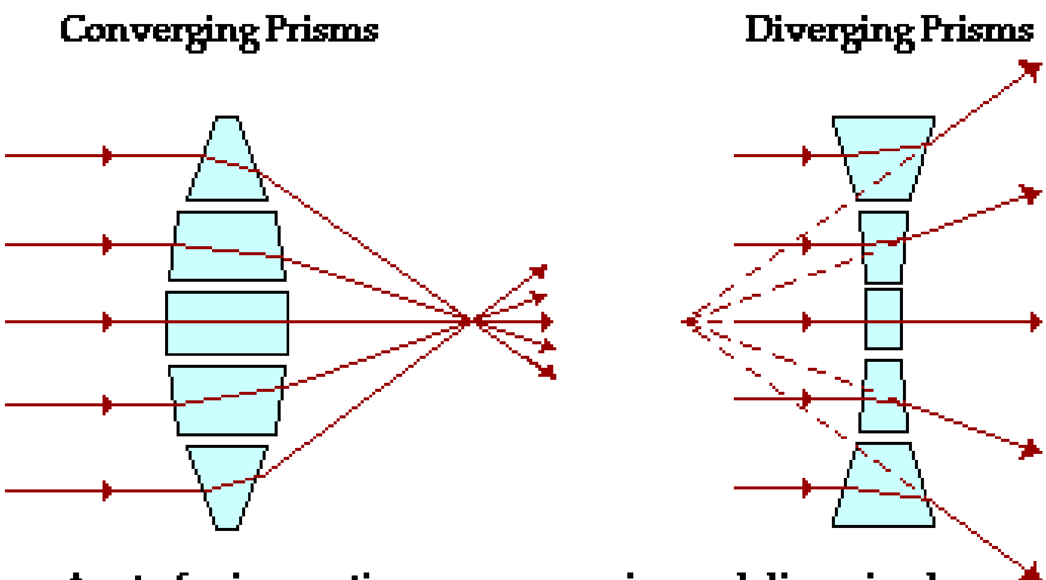
The Anatomy of a Lens

Lens - a carefully ground or molded piece of transparent material which refracts light rays in such as way as to form an image.

Lenses can be thought of as a series of tiny refracting lenses, each of which refracts light to produce their own image. When these prisms act together, they produce a bright enough image focused at a point.



A set of prisms acting as a converging and diverging lens.

Converging lens - a lens which converges rays of light which are traveling parallel to its principal axis

Diverging lens - a lens which diverges rays of light which are traveling parallel to its principal axis..

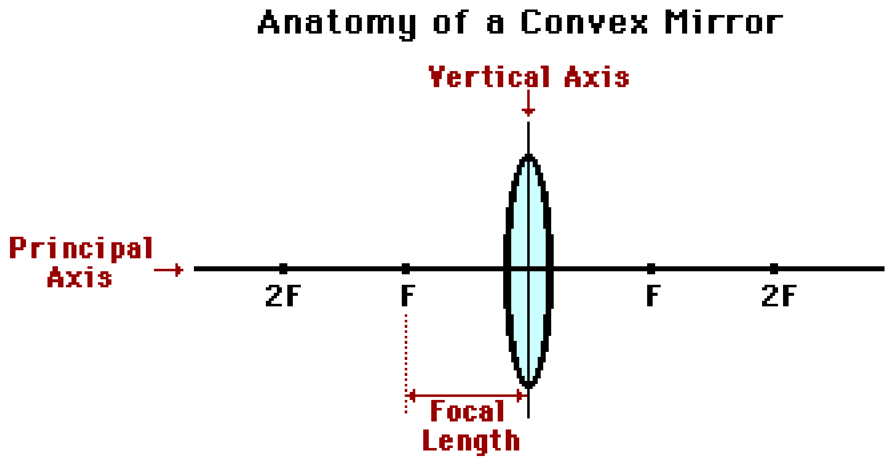
Principal axis - a straight line passing through the very center of the lens and perpendicular to its two surfaces.

Focal Plane - the plane in which all points would focus on.

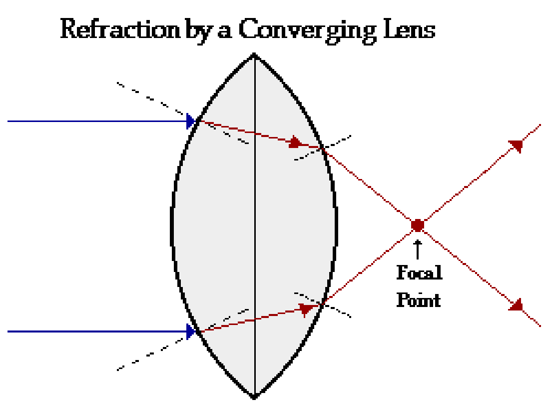
Focal Point (F) - the point that rays parallel to the principle axis focus on after passing through the lens.

Focal Length (f) - distance from the focal point to the center of the lens.

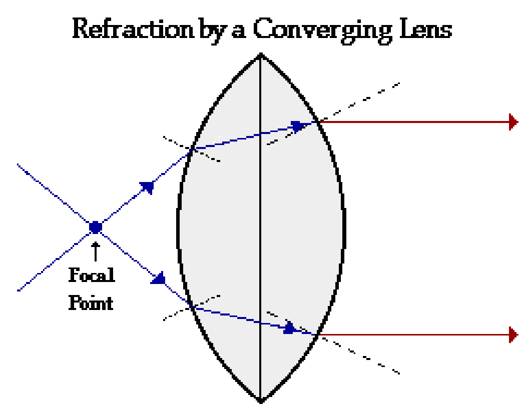
Each lens (converging and diverging) has two focal points - one on each side of the lens.



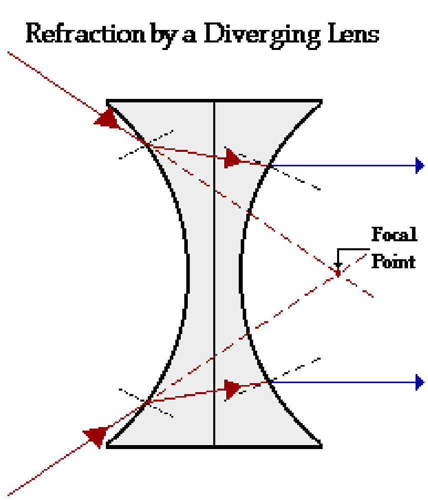
A lens does have an imaginary point which we refer to as the **2F point**. This is the point on the principal axis which is twice as far from the vertical axis as the focal point is.



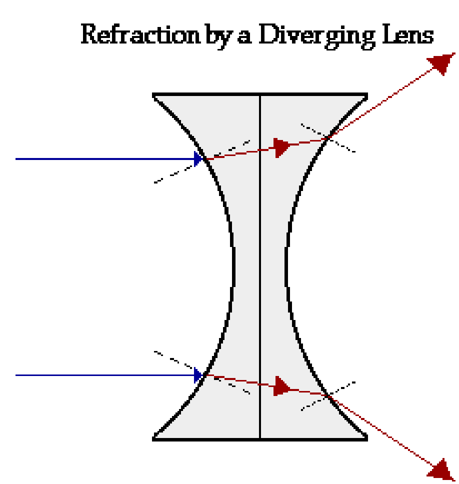
Incident rays which travel parallel to the principal axis will refract through the lens and converge to a point.



Incident rays which travel through the focal point will refract trough the lens and travel parallel to the principal axis.



Incident rays traveling towards the focal point will refract and travel parallel to the principal axis.



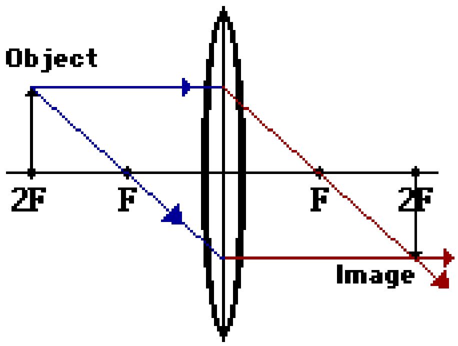
Incident rays traveling parallel to the principal axis will refract through the lens and diverge, never intersecting.

Refraction Rules for a Converging Lens

* Any incident ray traveling parallel to the principal axis of a converging lens will refract through the lens and travel through the focal point on the opposite side of the lens.

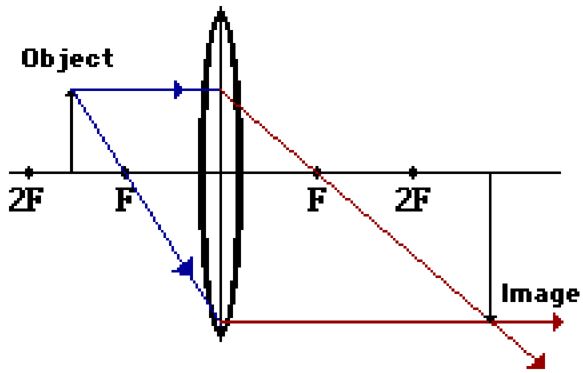
* Any incident ray traveling through the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis.

* An incident ray which passes through the center of the lens will in effect continue in the same direction that it had when it entered the lens.



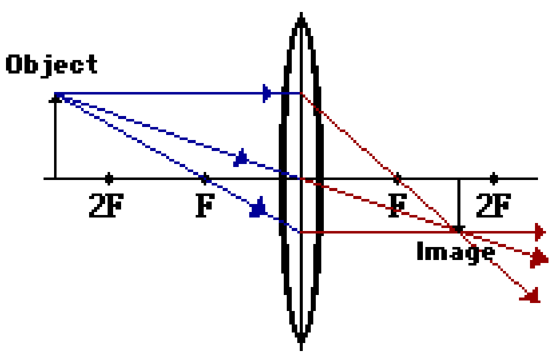
Ray Diagram for Object Located at 2F

Inverted, Same Size, Real

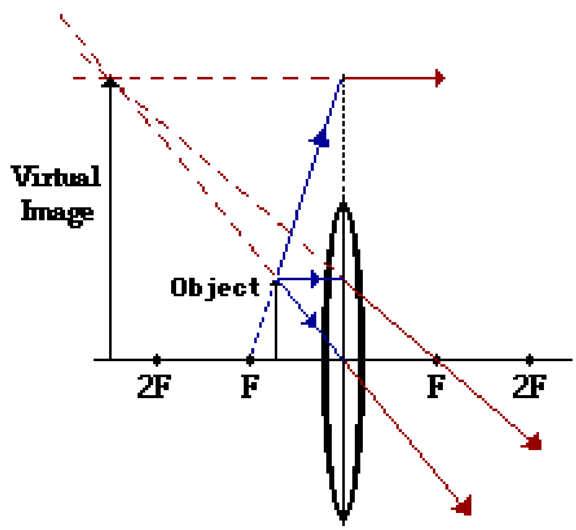


Ray Diagram for Object Located Between F and 2F

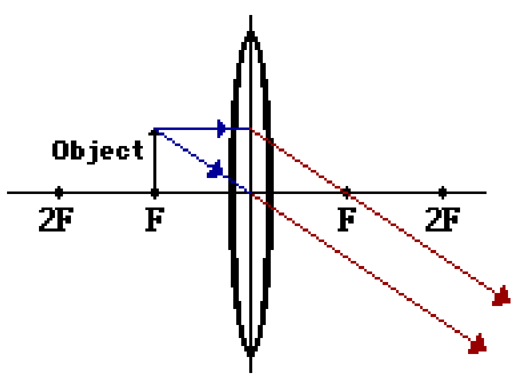
Inverted, Enlarged, Real



Ray Diagram for Object Located beyond F
Inverted, Reduced, Real



Ray Diagram for Object Located in Front of F
Upright, Enlarged, Virtual



Ray Diagram for Object Located at F
(an image is <u>not</u> formed)

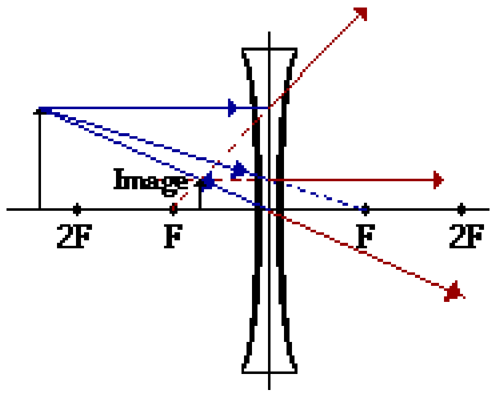
Refraction Rules for a Diverging Lens

* Any incident ray traveling parallel to the principal axis of a diverging lens will refract through the lens and travel *in line with* the focal point (i.e., in a direction such that its extension will pass through the focal point).

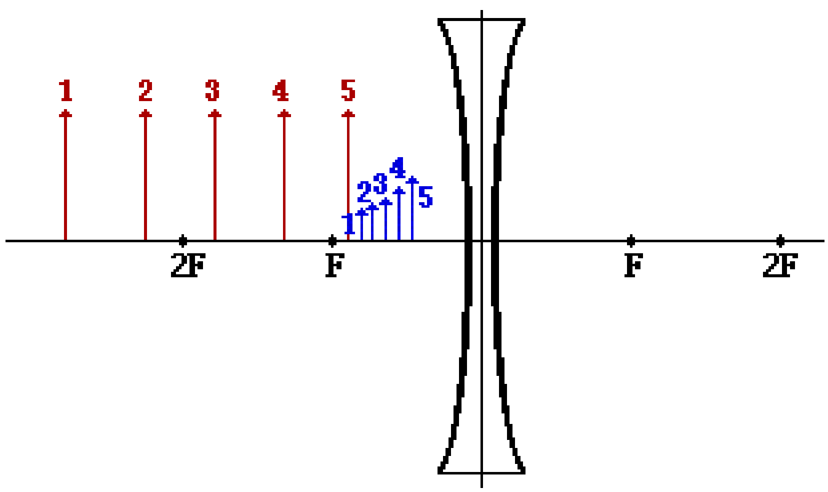
* Any incident ray traveling towards the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis.

* An incident ray which passes through the center of the lens will in effect continue in the same direction that it had when it entered the lens.

For a Diverging Lens, no matter where the object is placed the image will **always** be
Upright, Reduced, Virtual



Another characteristic of the images of objects formed by **diverging lenses** pertains to how a variation in object distance effects the image distance and size. The diagram below shows five different object locations and their corresponding image locations.



The diagram shows that as the object distance is decreased, the image distance is decreased and the image size is increased.

Lens Equations

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

The lens equation expresses the quantitative relationship between the object distance (do), the image distance(di), and the focal length (f).

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

The Magnification equation relates the ratio of the image distance and object distance to the ratio of the image height (hi) and object height (ho).

The sign conventions for the given quantities in the lens equation and magnification equations are as follows:

* f is + if the lens is a double convex lens (converging lens)
* f is - if the lens is a double concave lens (diverging lens)
* di is + if the image is a real image and located on the opposite side of the lens.
* di is - if the image is a virtual image and located on the object's side of the lens.
* hi is + if the image is an upright image (and therefore, also virtual)
* hi is - if the image an inverted image (and therefore, also real)

Sample Problem

A 4.0-m tall light bulb is placed a distance of 45.7 m from a **double convex lens** having a focal length of 15.2 m. Determine the image distance and the image size.

Like all problems in physics, begin by the identification of the unknown information.

ho = 4.0 m   di = ???

do = 45.7 m   hi = ???

f = 15.2 m

To determine the image distance, the lens equation will have to be used. The following lines represent the solution to the image distance; substitutions and algebraic steps are shown.

1/f = 1/do + 1/di

1/(15.2 m) = 1/(45.7 m) + 1/di

0.0658 = 0.0219 + 1/di

0.0439 = 1/di

di = 22.8 m

To determine the image height, the magnification equation is needed. Since three of the four quantities in the equation (disregarding the M) are known, the fourth quantity can be calculated.

hi/ho = - di/do

hi /(4.0 m) = - (22.8 m)/(45.7 m)

hi = - (4.0 m) * (22.8 m)/(45.7 m)

hi = -1.99 m

The negative values for image height indicate that the image is an inverted image.

Sample Problem

A 4.0-m tall light bulb is placed a distance of 35.5 m from a **diverging lens** having a focal length of -12.2 m. Determine the image distance and the image size.

Like all problems in physics, begin by the identification of the unknown information.

ho = 4.0 m	di = ???
do = 35.5 m	hi = ???
f = -12.2 m	

To determine the image distance, the lens equation will have to be used. The following lines represent the solution to the image distance; substitutions and algebraic steps are shown.

1/f = 1/do + 1/di

1/(-12.2 m) = 1/(35.5 m) + 1/di

-0.0820 = 0.0282 + 1/di

-0.110 = 1/di

di = -9.08 m

To determine the image height, the magnification equation is needed. Since three of the four quantities in the equation (disregarding the M) are known, the fourth quantity can be calculated.

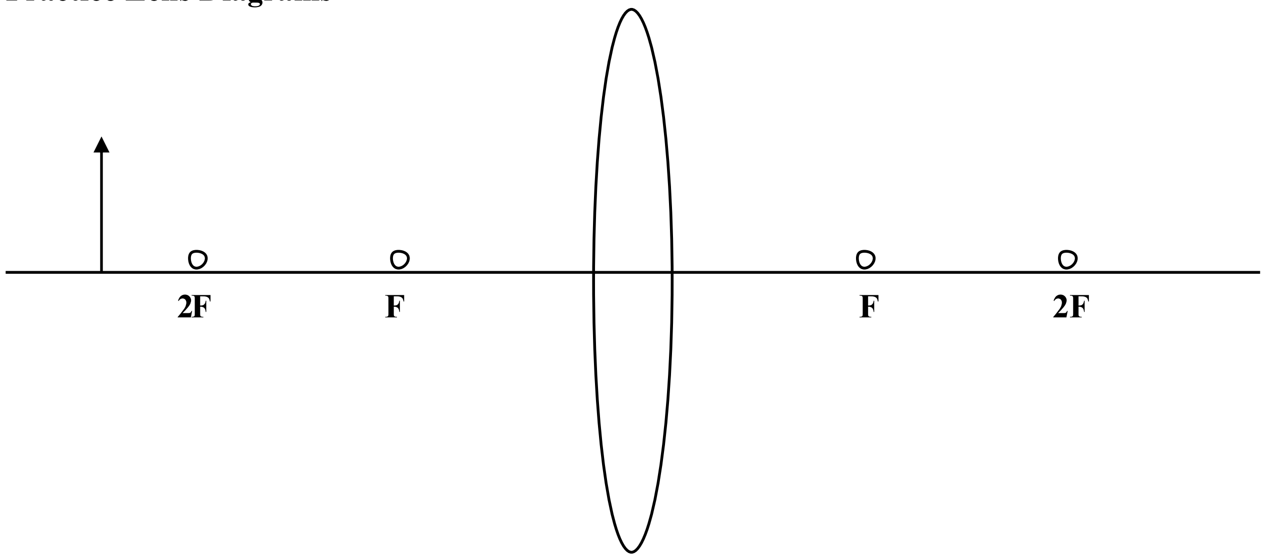
hi/ho = - di/do

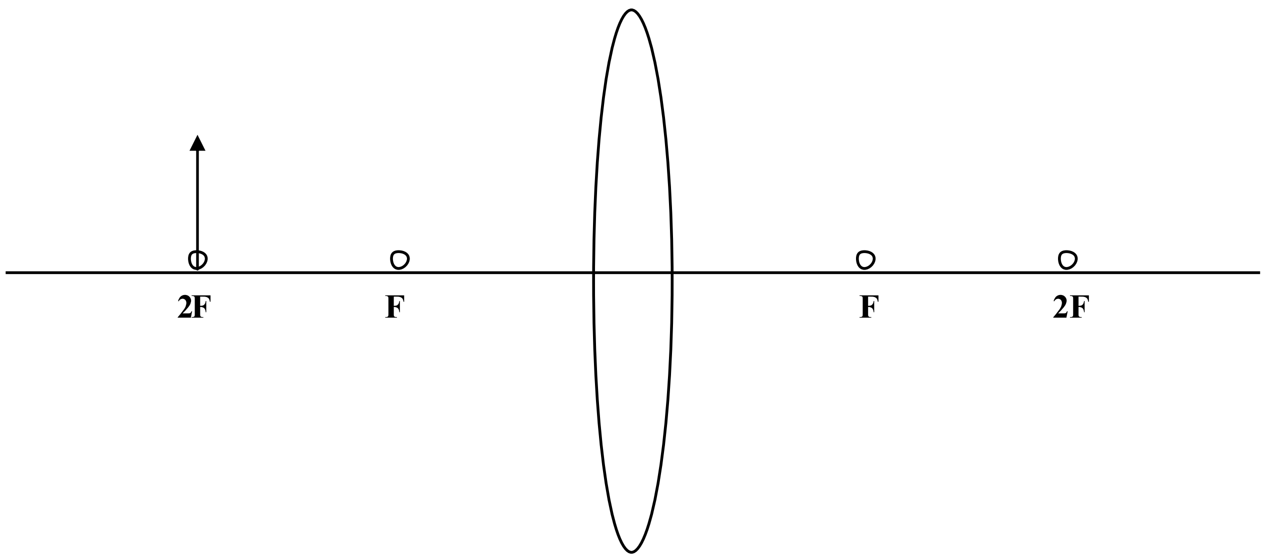
hi /(4.0 m) = - (-9.08 m)/(35.5 m)

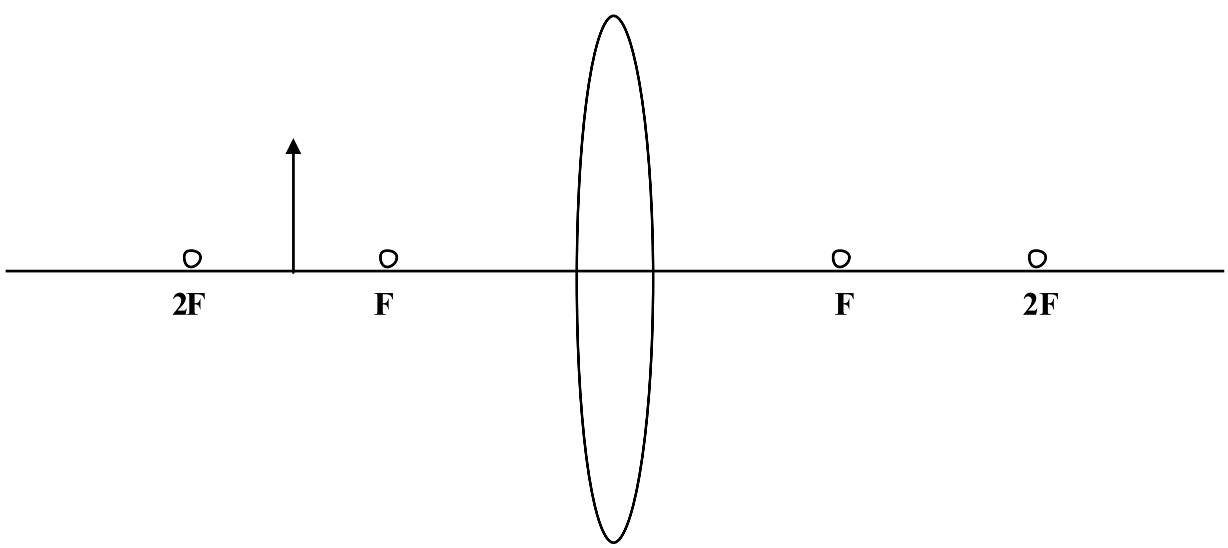
hi = - (4.0 m) * (-9.08 m)/(35.5 m)

hi = 1.02 m

Practice Lens Diagrams







Practice Lens Diagrams