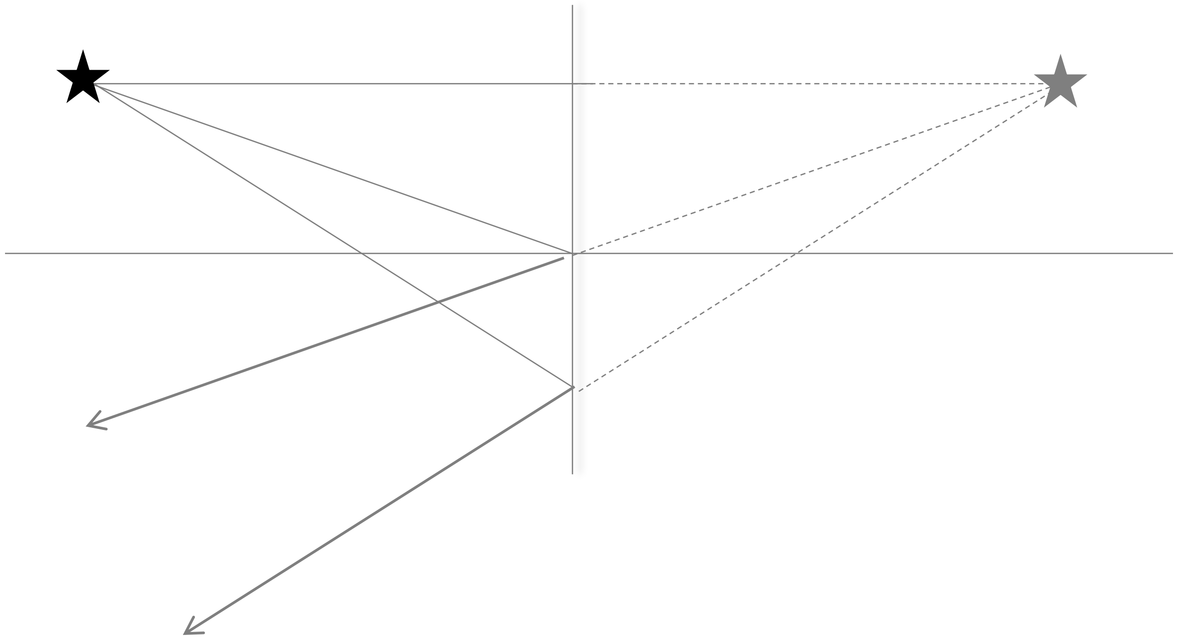
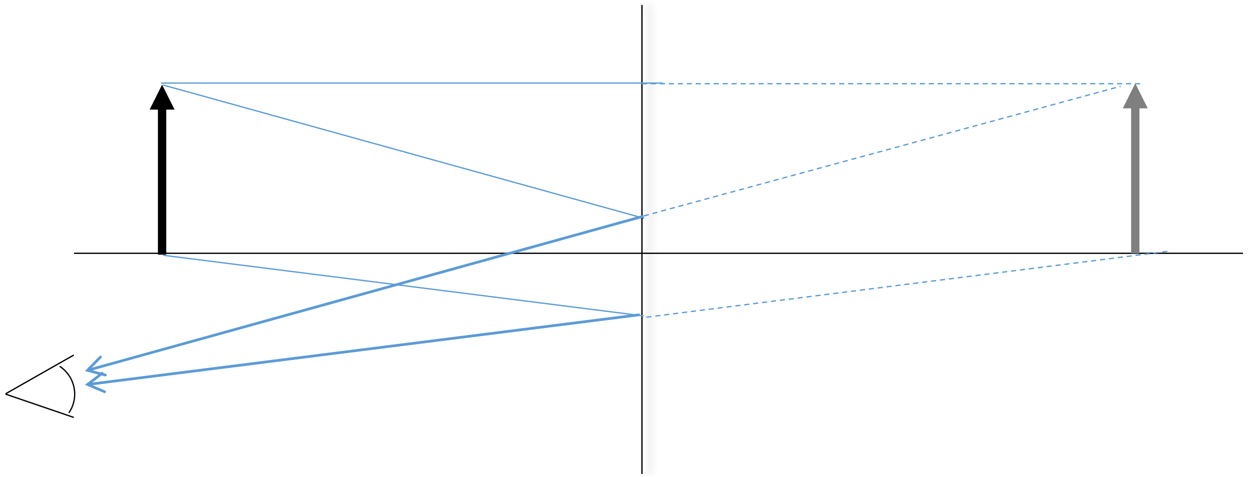
Geometrical (Ray) Optics

Plane (Flat) Mirrors…

Always produce **virtual** images regardless of the location of the object.

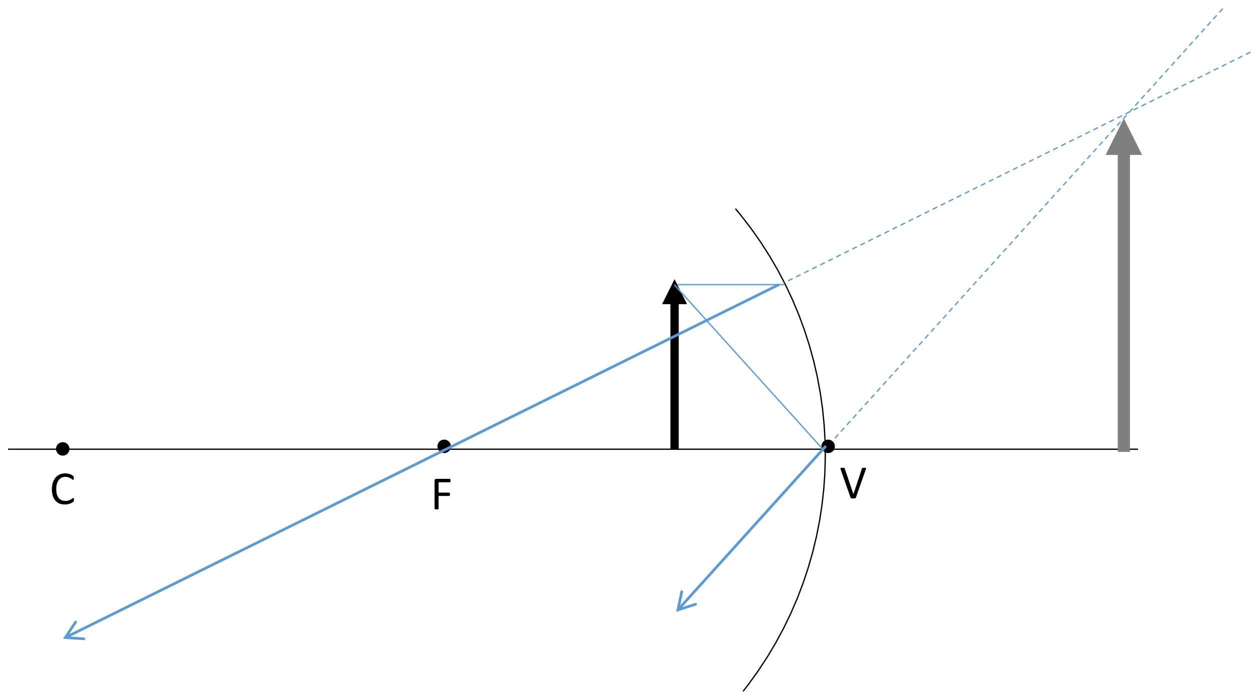
These **virtual** images are always upright (erect) and just as far behind the mirror as the object is in front of the mirror.



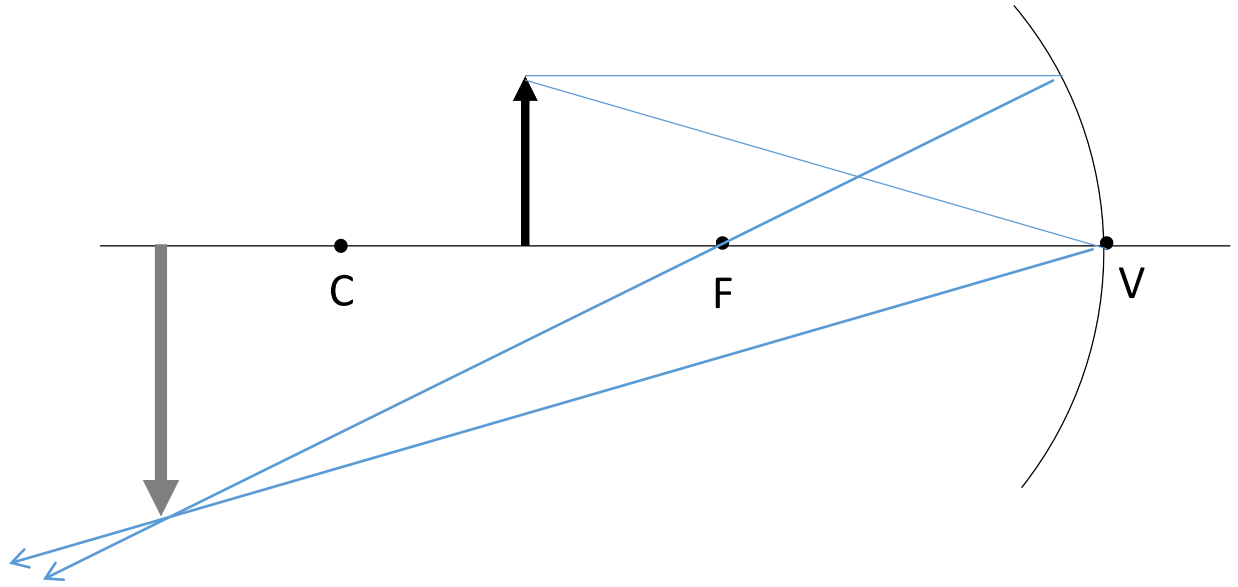


Concave Mirrors…

produce enlarged **virtual** images when the object is within the focal length ($d_o < f$),

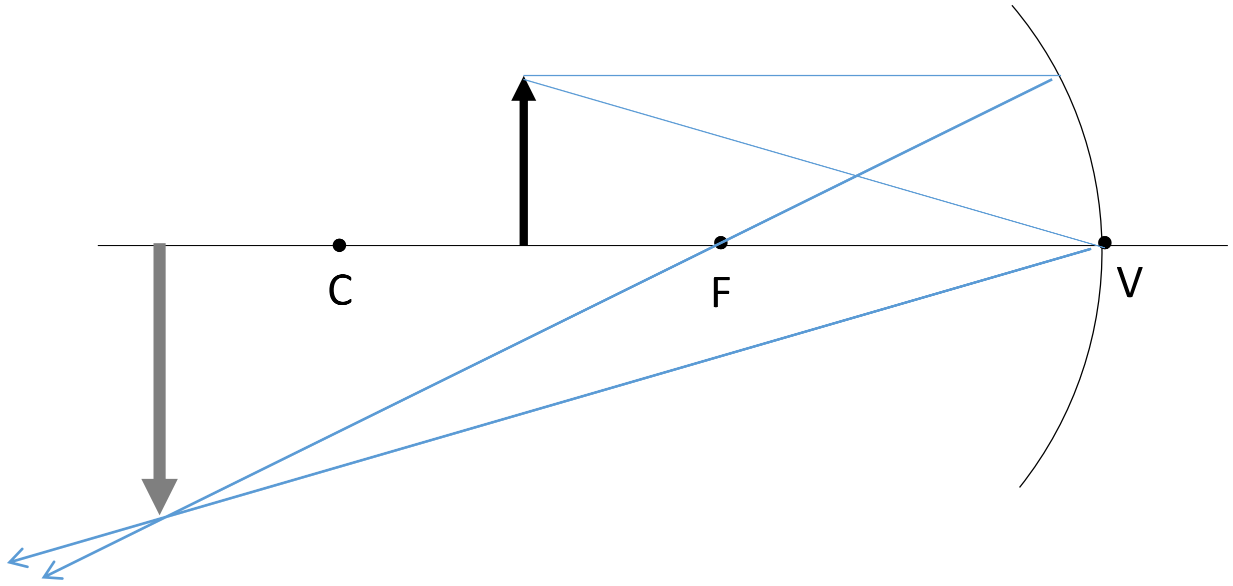


and inverted **real** images when the object is beyond the focal length ($d_o > f$).

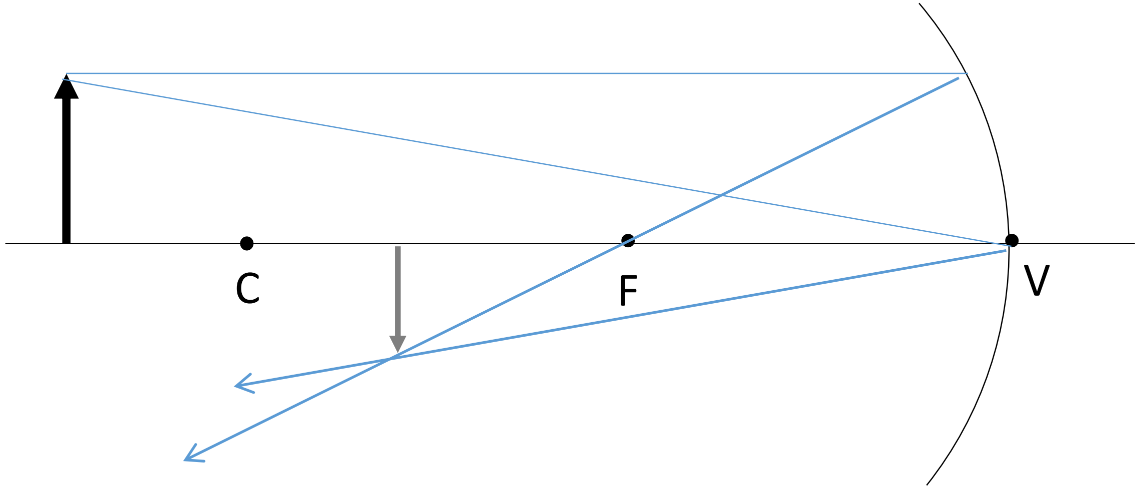


Regarding Concave Mirrors…

The size of the inverted real images of concave mirrors can be larger or smaller than the object depending on how far beyond the focus the object is placed.

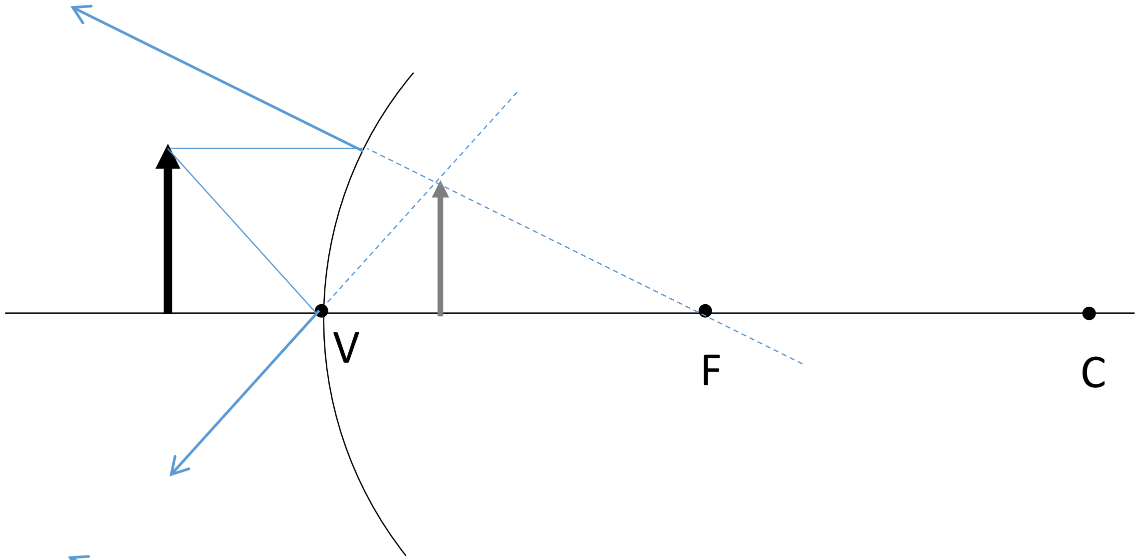


If ($f < d_o < r$), the image is larger than the object. If ($d_o > r$), the image is smaller than the object.

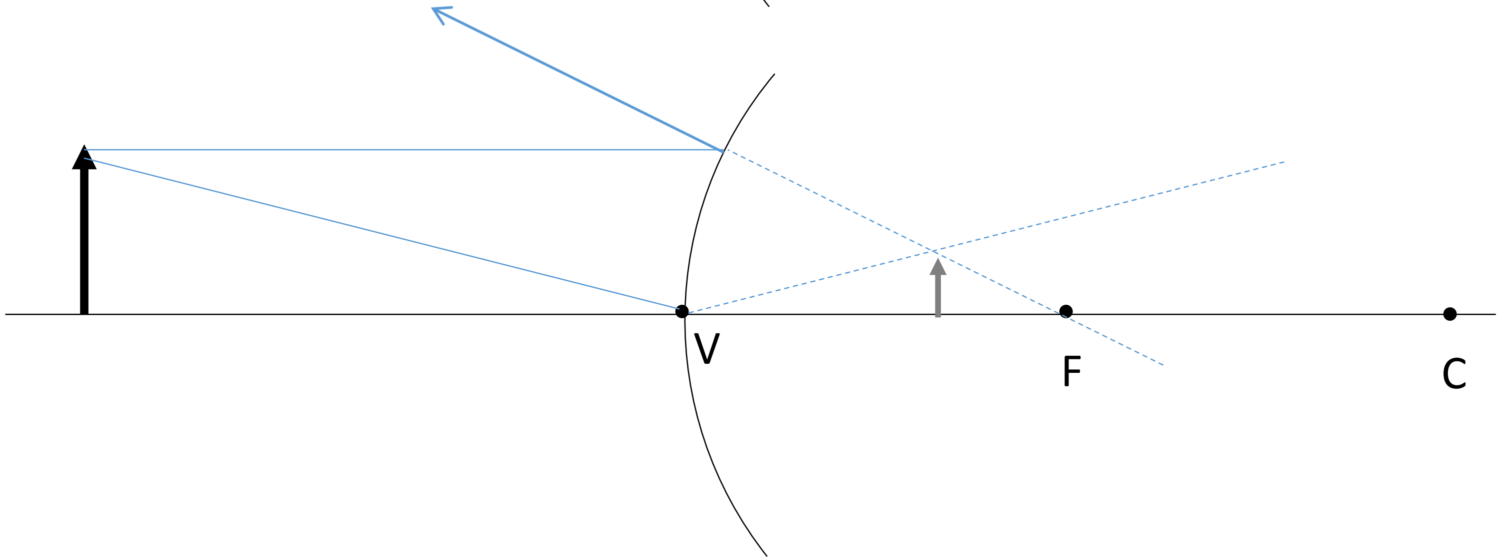


Convex Mirrors…

always produce smaller upright virtual images regardless of the location of the object.



The (virtual) image will always be between the vertex and the focus.



Summarizing Plane & Spherical Mirrors

Formulas: $\frac{1}{d_0} + \frac{1}{d_i} = \frac{1}{f}$ $\quad f = \frac{r}{2}$ $\quad m = -\frac{d_o}{d_i}$

$d_o, d_i, f, r > 0$ if in front of mirror; $d_o, d_i, f, r < 0$ if behind mirror.

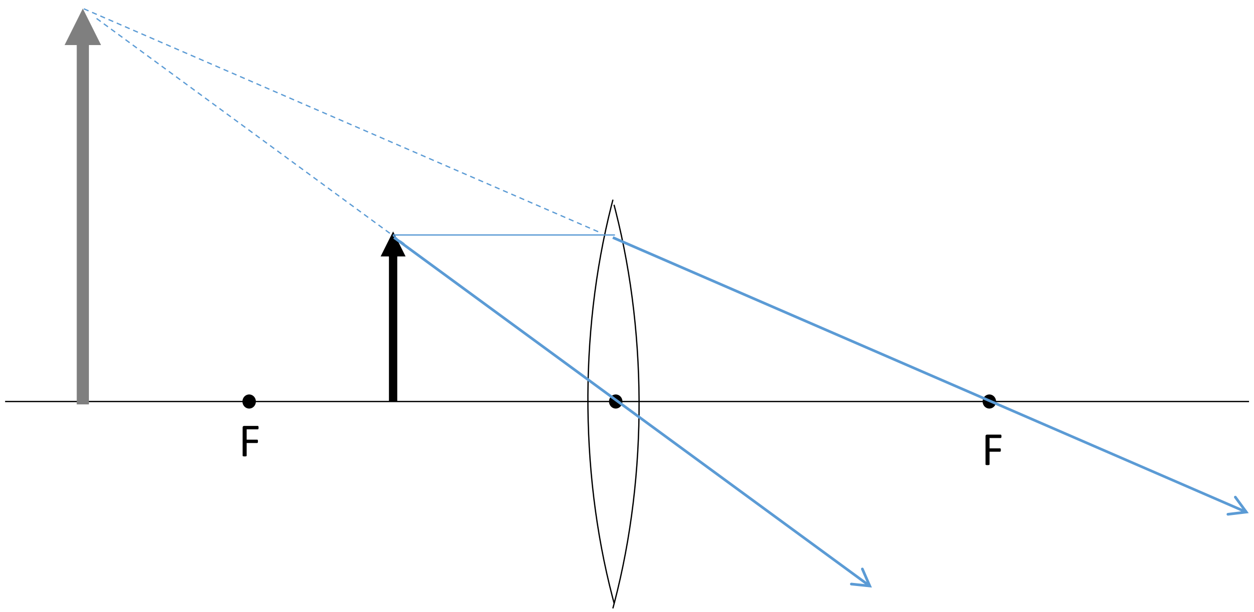
$m > 0$: image is upright (erect); $m < 0$: image is inverted.

$|m| > 1$: image is larger than object; $|m| < 1$: image is smaller than object.

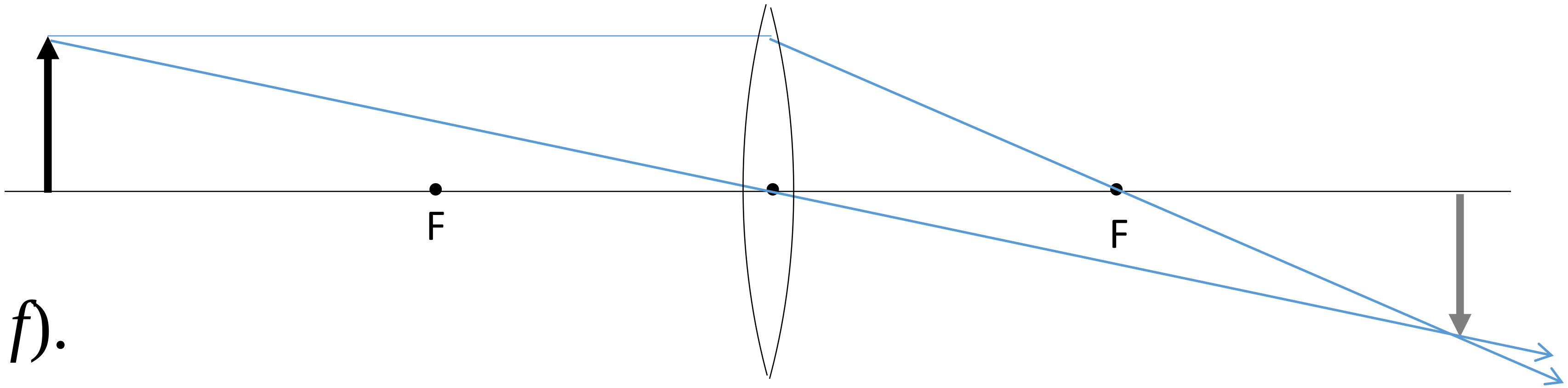
Mirror Type	**Object Location**	**Image Location**	**Image Type**	**Image Orientation**	**Sign of *f***	**Sign of d_i**	**Sign of *m***
Plane	Anywhere	Anywhere	V	Upright	N.A.	–	+
Concave	$d_o < f$	Anywhere	V	Upright	+	–	+
	$d_o > f$	$d_i > f$	R	Inverted	+	+	–
Convex	Anywhere	$\|d_i\| < f$	V	Upright	–	–	+

Converging Lenses…

produce enlarged **virtual** images when the object is within the focal length ($d_o < f$),

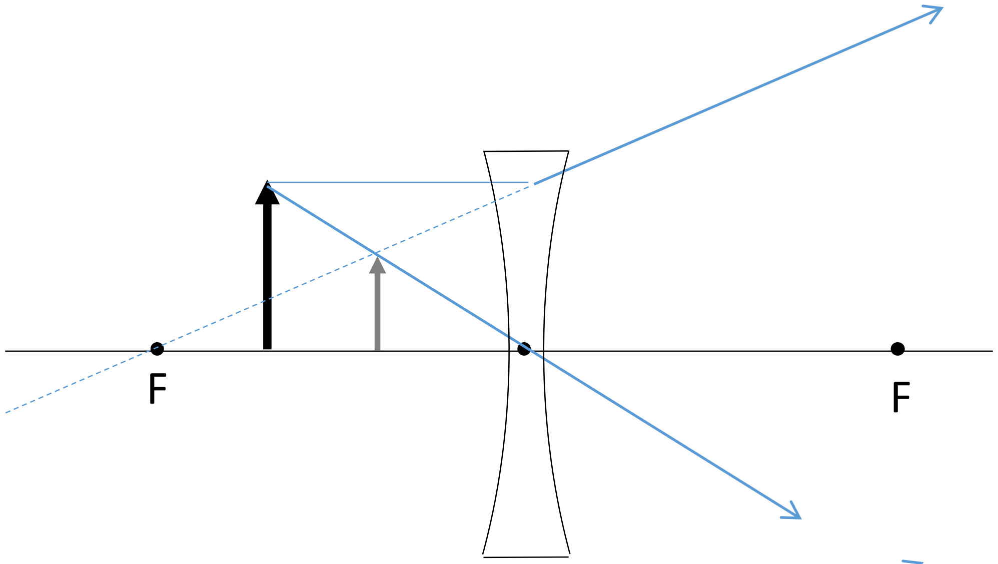


and inverted **real** images when the object is beyond the focal length ($d_o > f$).

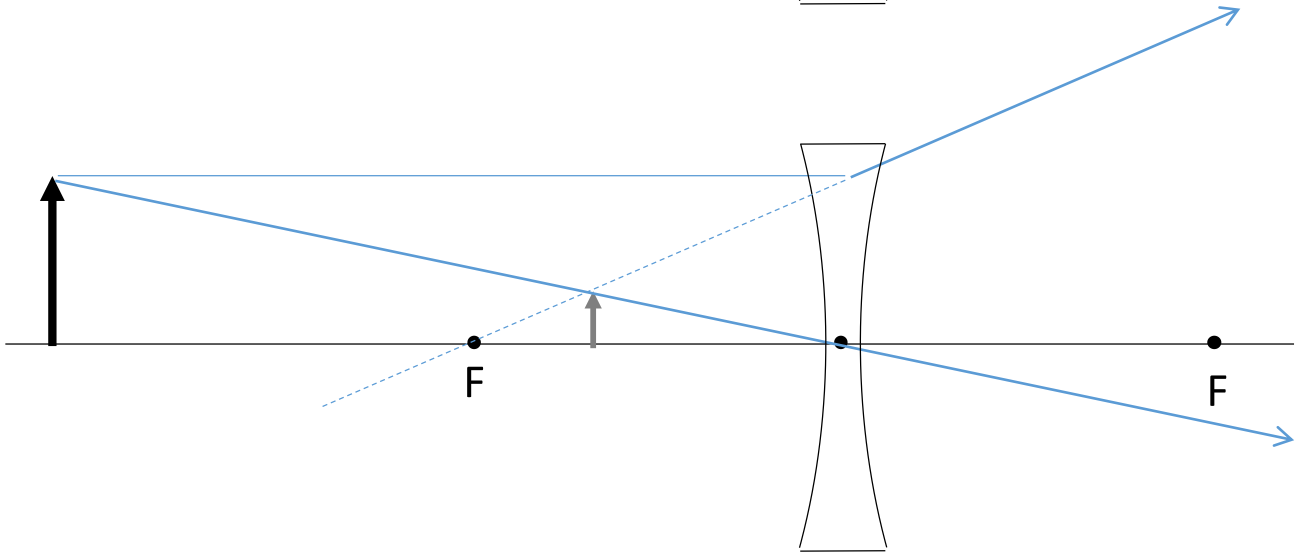


Diverging Lenses…

always produce smaller upright virtual images regardless of the location of the object.



The (virtual) image will always be between the lens and the focus.



Summarizing Thin Lenses

Formulas: $\frac{1}{d_0} + \frac{1}{d_i} = \frac{1}{f}$ $f = \left(\frac{n_{lens}}{n_{med}} - 1\right)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ $m = -\frac{d_o}{d_i}$

d_o, d_i, $r > 0$ if on other side of lens; d_o, d_i, $r < 0$ if on same side as object.

$m > 0$: image is upright (erect); $m < 0$: image is inverted.

$|m| > 1$: image is larger than object; $|m| < 1$: image is smaller than object.

Lens Type	Object Location	Image Location	Image Type	Image Orientation	Sign of f	Sign of d_i	Sign of m
Converging	$d_o < f$	Same side as O	V	Upright	+	–	+
	$d_o > f$	Opposite side	R	Inverted	+	+	–
Diverging	Anywhere	$\|d_i\| < \|f\|$	V	Upright	–	–	+

Multiple-Component Systems

1. Find the image and magnification form the first optical component (ignoring all others).
2. Treat the image of the first component as the object for the second component. If the "new" object is beyond the second component, then the object is virtual and d_{o2} is negative.
3. Find the image and magnification for the second component (ignoring all others) in the usual fashion.
4. Repeat Steps 2 and 3 for each optical component.
5. Overall magnification is $M = m_1 m_2 m_3 \ldots$

Exercise #1

A convex mirror whose radius of curvature is 40 cm produces an image whose distance from the mirror vertex is 4.0 cm.

a) What are the algebraic signs of f and d_i?

b) How far from the vertex is the object that produced this image?

c) Characterize the image:

- Is the image real or virtual?
- Is the image upright or inverted?
- What is the magnification?

Exercise #2

An object is located 100 cm in front of a concave mirror having a radius of 90 cm. Between the object and the concave mirror is a convex mirror placed 60 cm in front of and facing the concave mirror. The radius of the convex mirror is 120 cm. Characterize the final image of this two-mirror optical system:

a) Locate the final image.

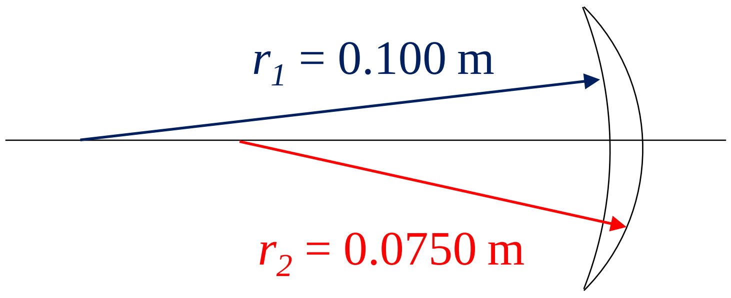
b) Determine the overall magnification.

c) Is the final image real or virtual?

d) Is the final image upright or inverted?

Exercise #3

A lens is constructed of crown glass (n = 1.50) and has surfaces with radii 0.100 m and 0.0750 m. Both centers of curvature are on the same side of the lens as shown.



a) Determine the focal length and *strength* of the lens.

b) Characterize the image produced by this lens if an object is placed 0.800 m in front of the lens: locate the final image, calculate the magnification, and determine whether is the final image real or virtual.

c) Is the final image upright or inverted?

d) Repeat (b) and (c) for an object placed 0.0800 m in front of the lens.

Exercise #4

Two thin lenses having focal lengths f_1 = 10 cm and f_2 = 20 cm are separated by 20 cm. An object is placed 15 cm in front of the first lens.

Characterize the image produced by this two-lens system.