Chapter 9: Reflection

Dual Nature of Light

Light is said to have a dual nature. This means that we can consider light to be a wave and we can consider it to be a particle. Light has the properties of both a WAVE and a PARTICLE.

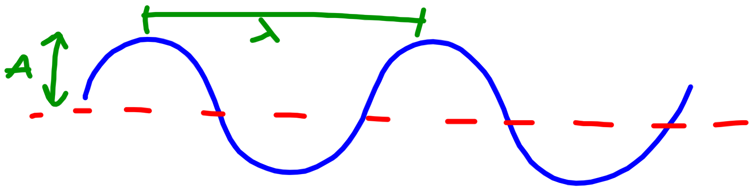
Light as a Particle

A light particle is called a photon. Although it doesn't have mass, it does have momentum!

The speed of light, c, is 3.0×10^8 m/s.

Light as a Wave

If we consider light to be a wave, then the wave propagates at the speed of light (3.0×10^8 m/s).



Amplitude (A): half of max to min
→ related to intensity of light

Frequency (f): number of oscillations per second
high f: ~~~~ low f: ~~~

Wavelength (λ): distance from max to max (period)
→ related to the colour of light

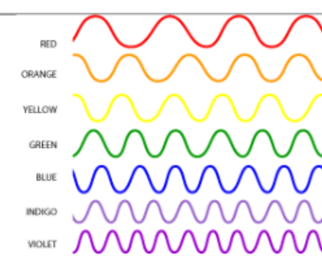
f : hertz → Hz = 1/s "per sec"
λ : nanometers = 1×10^{-9} m

Remember that for all colours of light $c = f\lambda$.

Wavelengths of Different Colours of Light

Visible spectrum

R	- red	650 nm
O	- orange	590 nm
Y	- yellow	570 nm
G	- green	510 nm
B	- blue	475 nm
I	- indigo	445 nm
V	- violet	400 nm



← lower f
← higher f

Examples:

1. What is the frequency of yellow light if it has a wavelength of 570 nm?

$c = f \cdot \lambda$ $\Rightarrow 570 \times 10^{-9}$ m

$f = \frac{c}{\lambda} = \frac{3.0 \times 10^{8} \text{ m/s}}{570 \times 10^{-9} \text{ m}} = 5.26 \times 10^{14} \frac{1}{s} = 5.26 \times 10^{14}$ Hz

2. What is the colour of light that has a frequency of 6.316×10^{14} Hz?

$c = f \cdot \lambda$

$\lambda = \frac{c}{f} = \frac{3.0 \times 10^{8} \text{ m/s}}{6.316 \times 10^{14} \frac{1}{s}} = 4.75 \times 10^{-7} \text{ m} \times \frac{1 \text{ nm}}{10^{-9} \text{ m}} = 475$ nm

= blue!

3. How long does it take for light to travel a distance of 6.0 km?

$\Delta d = v \Delta t$ * light travels at constant speed!

$\Delta t = \frac{\Delta d}{v}$

$= \frac{6000 \text{ m}}{3.0 \times 10^{8} \frac{m}{s}}$

$= 2 \times 10^{-5}$ s

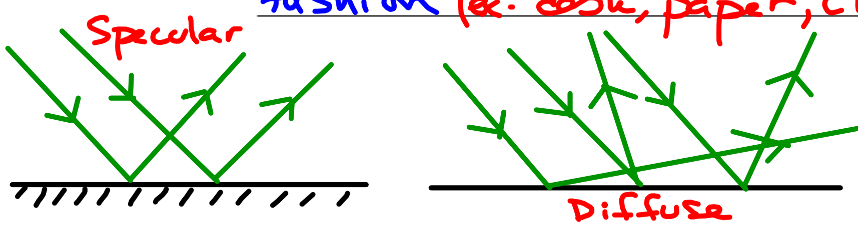
Reflection

Definitions

Reflection: light "bounces" off a surface

* Specular Reflection: light rays are reflected at same angle as incident ray (ex: mirrors)

Diffuse Reflection: light rays are reflected in a random fashion (ex: desk, paper, chair)



Incident ray: ray that approaches the surface (towards)

Reflected ray: ray that leaves the surface (away from)

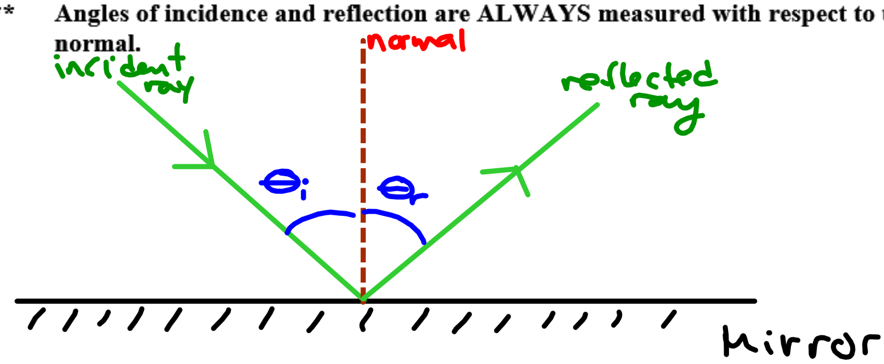
Point of incidence: where the incident ray hits the surface

Normal: imaginary line, perpendicular to the surface at the point of incidence

Angle of incidence (θ_i): between normal and incident ray

Angle of reflection (θ_r): between normal and reflected ray

*** **Angles of incidence and reflection are ALWAYS measured with respect to the normal.**



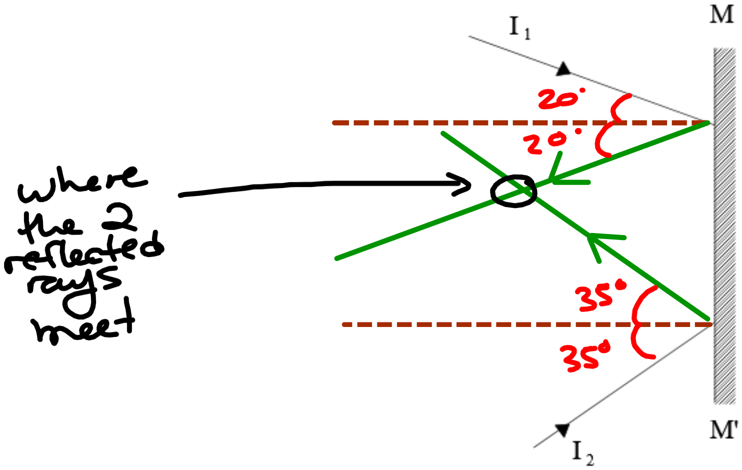
Laws of Reflection

First law: The angle of incidence is equal to the angle of reflection. ($\theta_i = \theta_r$)

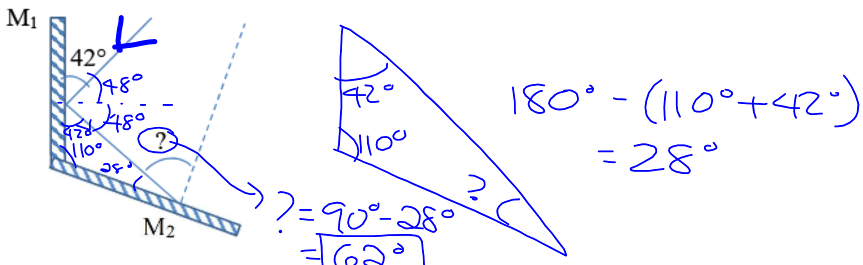
Second law: The normal, the incident ray and the reflected ray all lie on the same plane.

Examples:

1. Two light rays, I_1 and I_2, hit a plane mirror. Draw the reflected rays, and find the point where they meet.



2. Two mirrors, M_1 and M_2, form an angle of 110°.



Light ray R_1 hits M_1 and is reflected. It hits M_2 and is again reflected.

What is the angle of reflection of light ray R_2?

Curved Mirrors

Vertex (V): geometrical center of the mirror

Center of curvature (C): center of the sphere from which the mirror was cut out

Radius of curvature (R): radius of the sphere from which the mirror was cut out (From C to V)

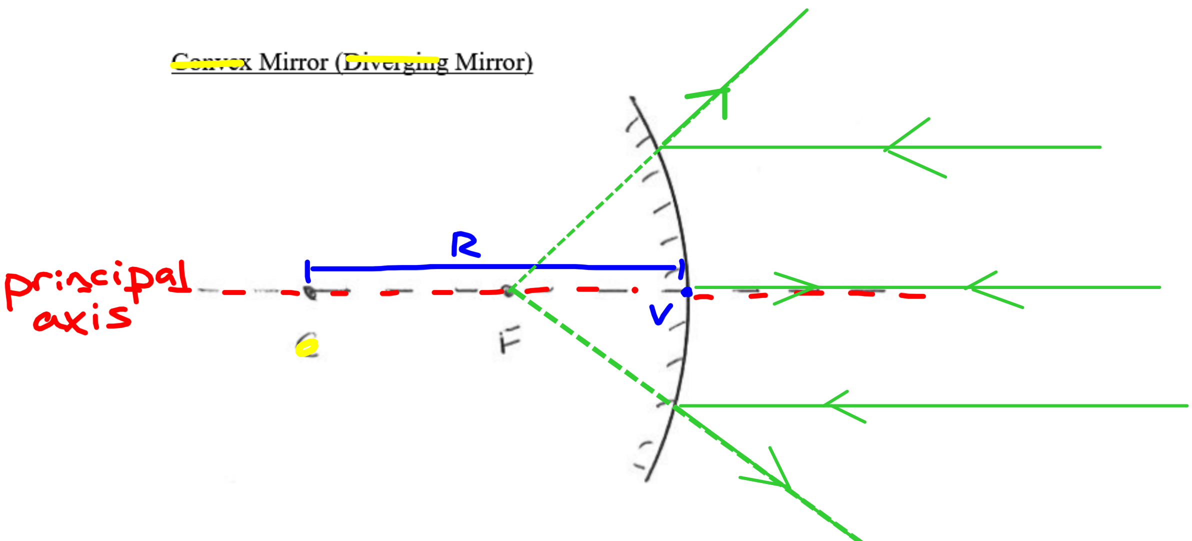
Focal point (F): point where rays parallel to the principal axis converge (converging mirror)
point from where diverging rays appear to come from (diverging mirror)

Note: The focal point is located halfway between the vertex and the center of curvature

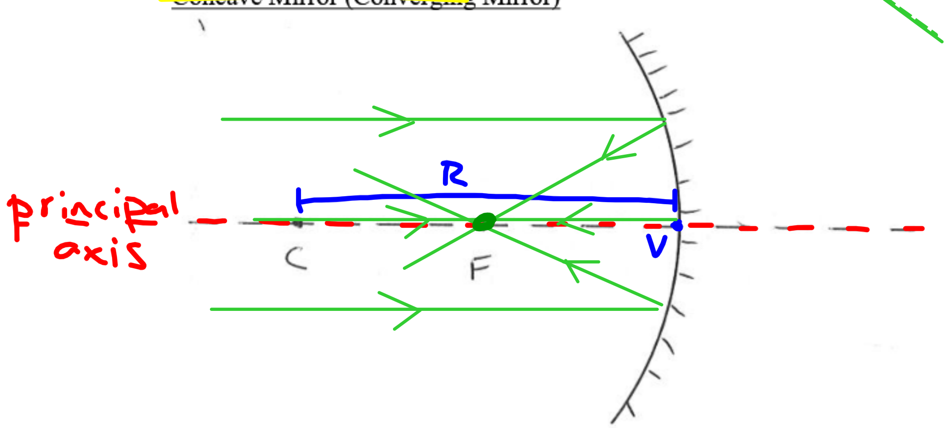
Principal axis: axis that joins the vertex, focal point and center of curvature

Curved mirrors can be spherical, parabolic, etc.

Convex Mirror (Diverging Mirror)



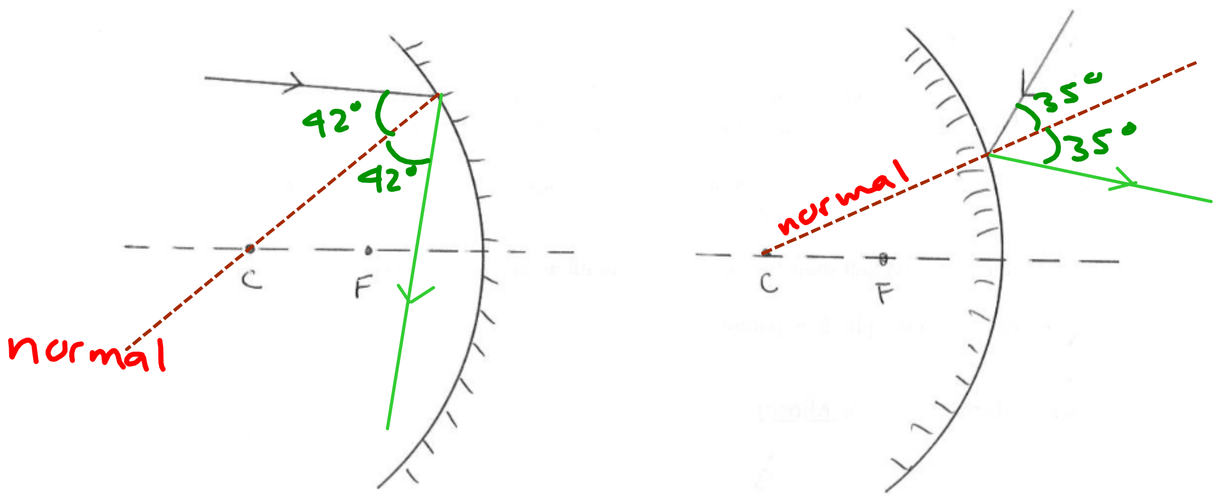
Concave Mirror (Converging Mirror)



Drawing Normals to Curved Mirrors

The normal is drawn as a continuation of the radius, at the point of incidence.

→ from C to point of incidence



Field of Vision

Field of vision: area that can be seen by looking in a mirror

* depends on location of observer

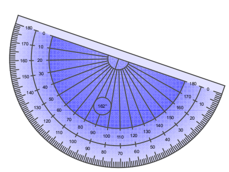
Steps:

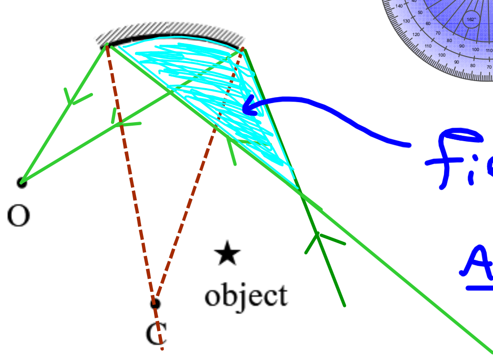
working backwards

1. Draw rays from edges of mirror to observer. (These are the reflected rays.)
2. Draw the normal at each edge of the mirror.
3. Draw the incident rays corresponding to the reflected ones.
4. The field of vision is the area located BETWEEN the INCIDENT rays.

Examples:

1. Can the observer see the object in the mirror?



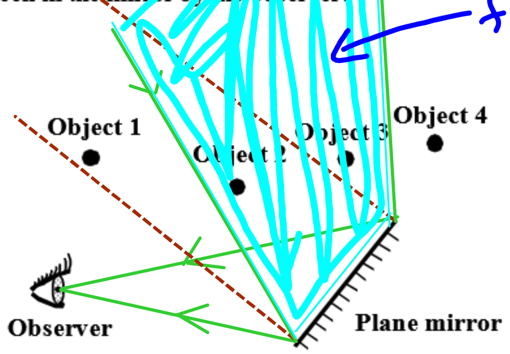


field of vision

Ans: no, because it is not in the field of vision

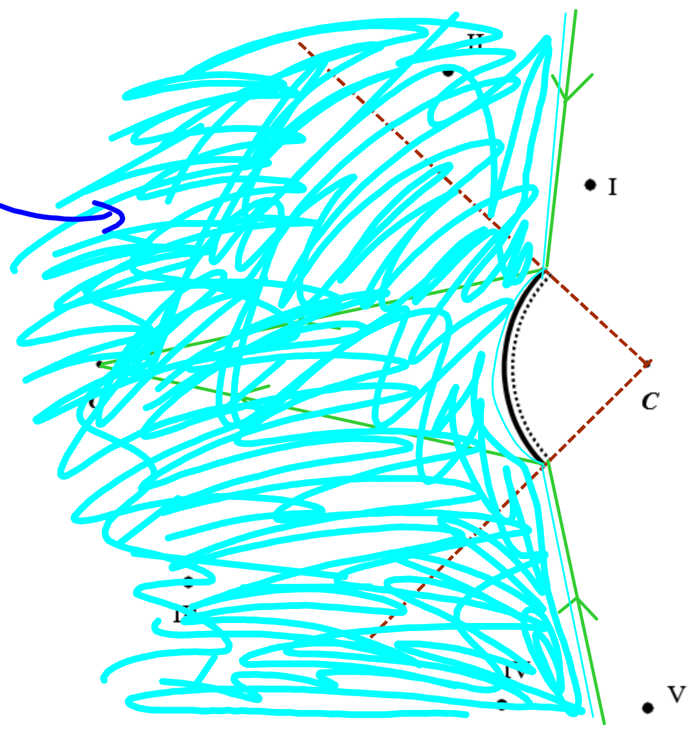
2. Which objects can be seen in the mirror by the observer?

Ans: 2, 3



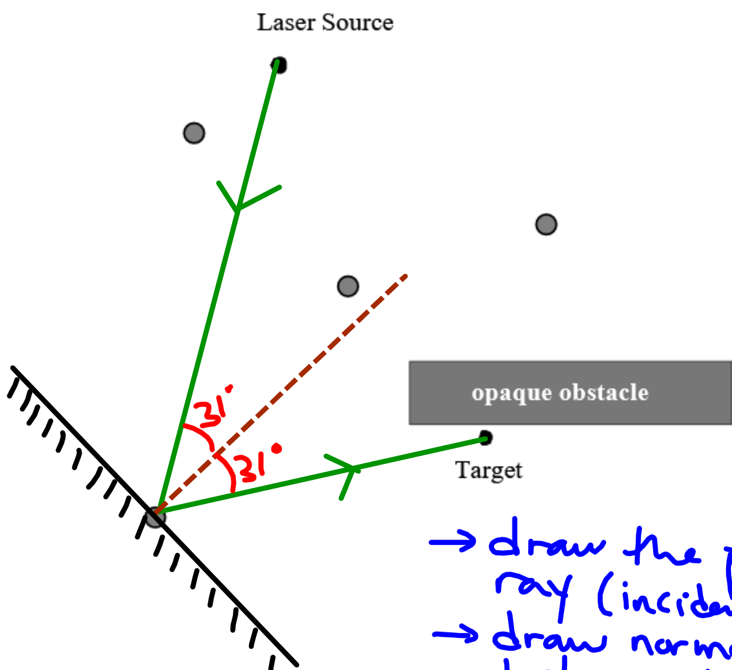
3. Which regions can be seen in the mirror by the observer?

Ans: II, III, IV



Directing a light ray using mirrors

Ex: You have to use a laser to hit the target shown in the diagram below. Several objects are placed throughout the area between the laser and the target. A plane mirror is attached to one of the objects.
Draw the path of a ray of light that would strike the target. The mirror must be accurately placed and the angle of reflection measured.



→ draw the path of light ray (incident + reflected)

→ draw normal (bisect angle between incident + reflected)

→ draw mirror ⊥ to normal

Principal rays on curved mirrors: (You don't need a protractor!)

There are 3 principle rays on curved mirrors

1. Parallel to principal axis:

Converging (concave) mirror
The ray is reflected through the focal point

opposite ↕

Diverging (convex) mirror
The ray is reflected "as if" it came from the focal point

2. Through/to the focus: (focal point)

Through the focal point (converging mirror)
The ray is reflected parallel to the principal axis

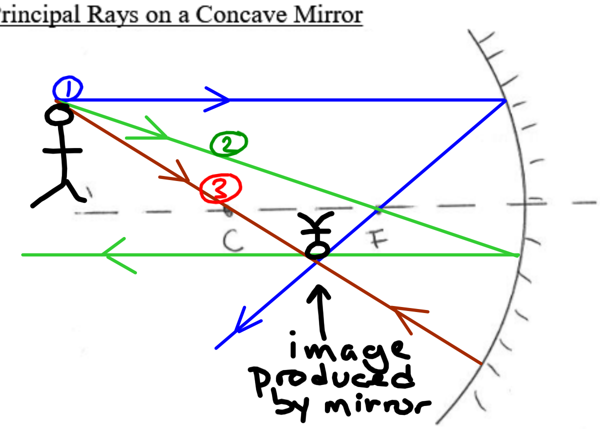
Towards the focal point (diverging mirror)
The ray is reflected parallel to the principal axis

3. Through/to center of: Curvature (on top of normal)

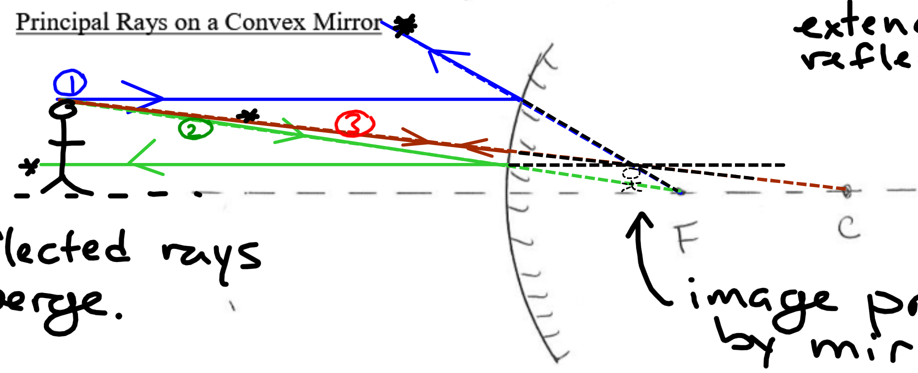
Through the center of curvature (converging mirror)
The ray is reflected back on itself.

Towards the center of curvature (diverging mirror)
The ray is reflected back on itself.

Principal Rays on a Concave Mirror



Principal Rays on a Convex Mirror



extend the reflected rays back!

Reflected rays diverge.

Images Formed by Mirrors

The image of an object is located "where the object appears to be" when we see it through the mirror.

Images can be:

Real:	Produced by the convergence of "actual" reflected light rays. Real images can be picked-up on a screen.
Virtual:	Generated by the extension of reflected light rays. Virtual images can not be picked-up on a screen.
Upright: (Erect)	The image has the same orientation as the object
Inverted:	The image has an orientation that is opposite to that of the object.

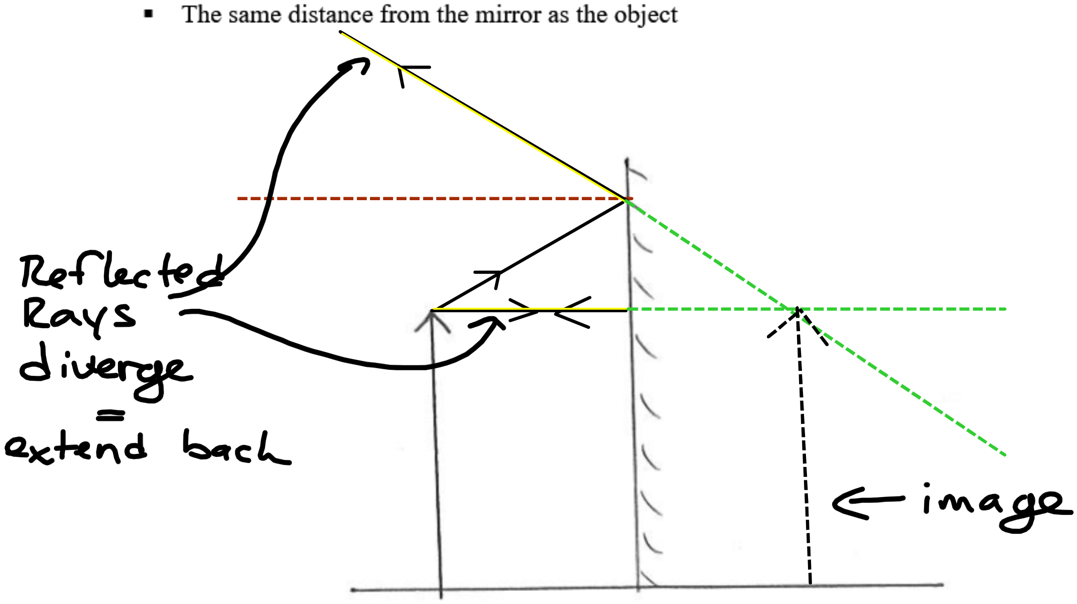
Smaller than the object

Bigger than the object

Images formed by plane mirrors

Images formed by plane mirrors are always:

- Virtual
- Upright (but inverted laterally)
- The same size as the object
- The same distance from the mirror as the object

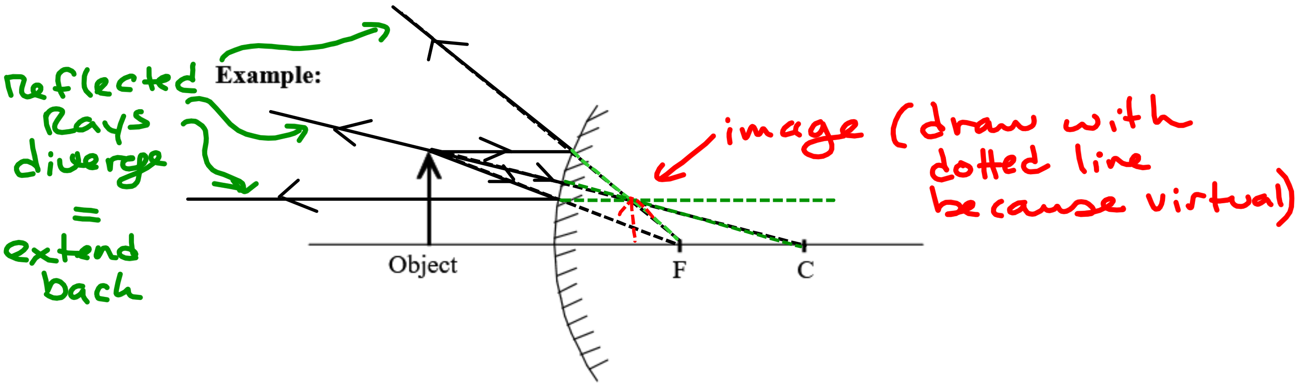


Images formed by convex mirrors

The images formed by a convex mirror are always:

- Virtual
- Upright
- Smaller than object
- Located between F and V

Example:



Images formed by concave mirrors

Concave mirrors can form many kinds of different images, depending where the object is located.

	IMAGE			
OBJECT	**Real or Virtual?**	**Upright or Inverted?**	**Smaller or bigger than object?**	**Where?**
Far beyond C	Real	Inverted	Smaller	At F
Beyond C	Real	Inverted	Smaller	Between C and F
At C	Real	Inverted	Same size	At C
Between C and F	Real	Inverted	Larger	Beyond C
At F	NO IMAGE FORMED			
Between F and V	Virtual	Upright	Larger	Behind Mirror

Examples:

Reflected rays converge!

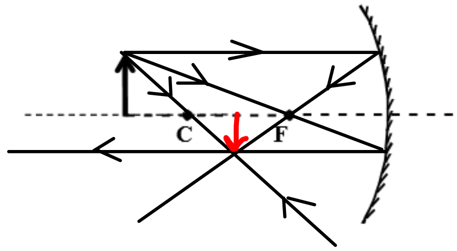


Image:
- inverted
- smaller
- real
- between C and F

Reflected rays converge!

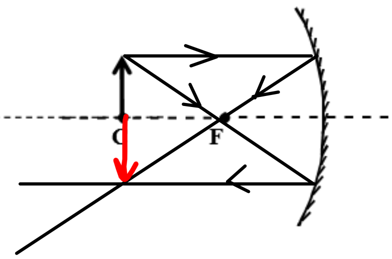


Image:
- real
- Same size as object
- Inverted
- at C

reflected rays converge!

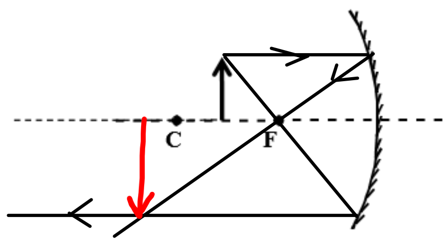
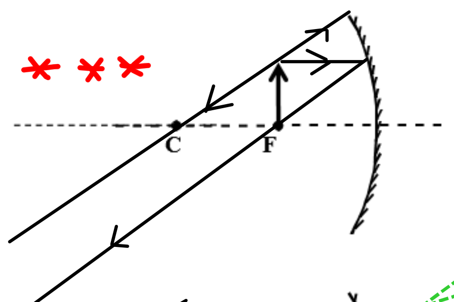


Image:
- real
- inverted
- bigger
- beyond C

Reflected rays are parallel!

***



NO IMAGE!

Reflected rays diverge!

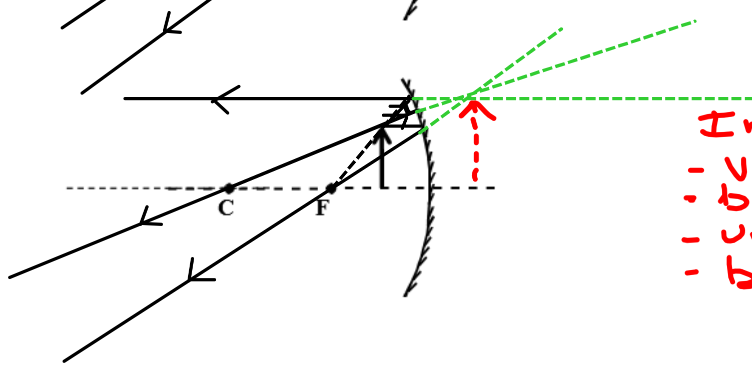


Image:
- Virtual
- bigger
- upright
- behind mirror

Locating images using formulas

It is possible to locate the image formed by a mirror, even without drawing a ray diagram.

M: Magnification (factor by which size of object is enlarged/reduced to form image)

Note: *If M is positive, the image is upright.*

If M is negative, the image is inverted.

M < smaller image

M > larger image

h_o: height of the object

h_i: height of the image

Note: *If h_i and h_o have the same sign, the image is upright.* ↑↑ or ↓↓

If h_i and h_o have opposite sign, the image is inverted. ↑↓ or ↓↑

d_o: distance between the object and the mirror

d_i: distance between the image and the mirror

Note: *We will deal with real objects, therefore d_o will always be positive.*

sign convention

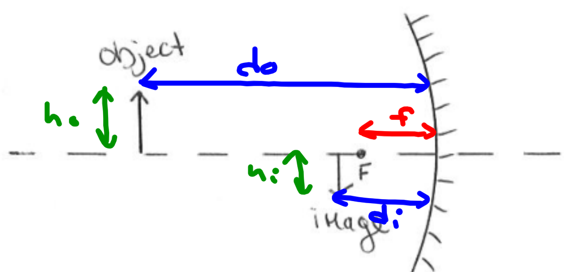
If d_i is positive, the image is real. Real images can be picked up on screens. They are generated by the convergence of light rays.

If d_i is negative, the image is virtual. Virtual images cannot be picked up on screens. They are generated by the extension of light rays.

f: focal length of the mirror (distance between focal point and vertex)

Note: *If f is positive, the mirror is converging (concave).*

If f is negative, the mirror is diverging (convex). } by ♡



Formulas for curved mirrors: ↑ for consistency of signs!

$$M = \frac{h_i}{h_o} \qquad M = -\frac{d_i}{d_o} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o} \qquad \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

(similar triangles)

Formulas for plane mirrors:

$$M = 1 \qquad d_o = -d_i \qquad h_o = h_i$$

Examples:

1. An object 2.0 cm high is placed 5.0 cm in front of a concave mirror of focal length 10.0 cm. Where is the image of this object located?

f ⊕

$h_o = 2.0\,cm$
$d_o = 5.0\,cm$
$f = 10.0\,cm$
$d_i = ?$

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

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

$\frac{1}{d_i} = \frac{1}{10.0\,cm} - \frac{1}{5.0\,cm}$

commn denominator!

$\frac{1}{d_i} = \frac{1}{10.0\,cm} - \frac{2}{10.0\,cm}$

$\frac{1}{d_i} = -\frac{1}{10.0\,cm}$

$d_i = \ominus 10.0\,cm$ → virtual image!

Ans: image is 10.0cm behind mirror!

2. An object is located 15.0 cm in front of a convex mirror of focal length 10.0 cm. What is the magnification?

f ⊖

$d_o = 15.0\,cm$
$f = -10.0\,cm$
$M = ?$
$d_i = ?$

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

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

$\frac{1}{d_i} = \frac{1}{-10.0\,cm} - \frac{1}{15.0\,cm}$

$\frac{1}{d_i} = \frac{-3}{30.0\,cm} - \frac{2}{30.0\,cm}$

$\frac{1}{d_i} = \frac{-5}{30.0\,cm}$

$-5d_i = 30.0\,cm$

$d_i = -6.0\,cm$

② $M = \frac{-d_i}{d_o}$

$M = \frac{-(-6.0\,cm)}{15.0\,cm}$

$M = 0.4$

3. An object is placed 20.0 cm in front of a concave mirror. The image produced is half the size of the object, and inverted. What is the focal length of this mirror?

$d_o = 20.0\text{cm}$

$M = -\frac{1}{2}$

$f = ?$

① Find d_i

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

$-d_i = M d_o$

$d_i = -M d_o$

$= -\left(-\frac{1}{2}\right)(20.0\text{cm})$

$d_i = 10.0\text{cm}$

② $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{f} = \frac{1}{20.0\text{cm}} + \frac{1}{10.0\text{cm}}$

$\frac{1}{f} = \frac{1}{20.0\text{cm}} + \frac{2}{20.0\text{cm}}$

$\frac{1}{f} = \frac{3}{20.0\text{cm}}$

$f = \frac{20.0\text{cm}}{3}$

$f = 6.67\text{cm}$

*** 4. A concave mirror (f ⊕) of focal length 10.0 cm produces an image that is inverted and 4 times smaller than the object. How far from the mirror is the object located?

$f = 10.0\text{cm}$

$M = -\frac{1}{4}$

$d_o = ?$

"system"

① expression for d_i

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

$d_i = -M d_o$

$d_i = -\left(-\frac{1}{4}\right) d_o$

$d_i = \frac{d_o}{4}$

② $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{10.0\text{cm}} = \frac{1}{d_o} + \frac{1}{\frac{d_o}{4}}$

$\frac{1}{10.0\text{cm}} = \frac{1}{d_o} + \frac{4}{d_o}$

$\frac{1}{10.0\text{cm}} = \frac{5}{d_o}$

$d_o = 50.0\text{cm}$

5. When an object is placed 4.0 cm in front of a convex mirror, its image is located 2.4 cm behind the mirror. What would be the magnification provided by this mirror if an object was placed 8.0 cm in front of the mirror?

* No Ratios!!! (Rational function!)
* 2 separate set-ups! (Same f for both)

① Set-up #1 (d_o=4.0cm)

$d_o = 4.0\text{cm}$

$d_i = -2.4\text{cm}$ ← behind mirror (virtual)

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

$$\frac{1}{f} = \frac{1}{4.0\text{cm}} + \frac{1}{-2.4\text{cm}}$$

$$\frac{1}{f} = \frac{2.4}{9.6\text{cm}} - \frac{4.0}{9.6\text{cm}}$$

$$\frac{1}{f} = \frac{-1.6}{9.6\text{cm}}$$

$$f = \frac{9.6\text{cm}}{-1.6}$$

$$f = -6.00\text{cm}$$

② Set-up #2 (d_o=8.0cm)

$d_o = 8.0\text{cm}$ (moved)

$f = -6.00\text{cm}$ (same mirror)

$d_i = ?$ new!

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

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

$$\frac{1}{d_i} = \frac{1}{-6.0\text{cm}} - \frac{1}{8.0\text{cm}}$$

$$\frac{1}{d_i} = \frac{-4}{24\text{cm}} - \frac{3}{24\text{cm}}$$

$$\frac{1}{d_i} = \frac{-7}{24\text{cm}}$$

$$d_i = -3.43\text{cm}$$

③ Answer!

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

$$= -\frac{(-3.43\text{cm})}{8.0\text{cm}}$$

M = 0.43