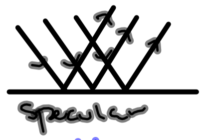
Chapter 9: Reflection

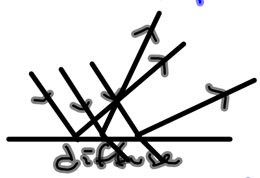
Definitions

Reflection: when light bounces off a surface

* Specular Reflection: parallel rays are still parallel after reflection (ex: mirror, lake, window) see image

Diffuse Reflection: parallel rays are no longer parallel after reflection (paper, shirt) don't see image





Incident ray: ray that approaches the surface (incoming)

Reflected ray: " " leaves " " (outgoing)

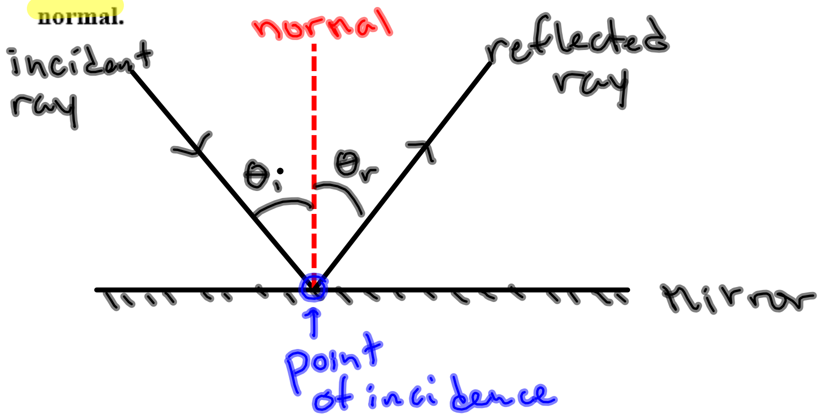
Point of incidence: point where the ray hits the surface

Normal: "line" perpendicular to the surface at the point of incidence

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

Angle of reflection (θ_r): " " reflected " " normal

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



Laws of Reflection

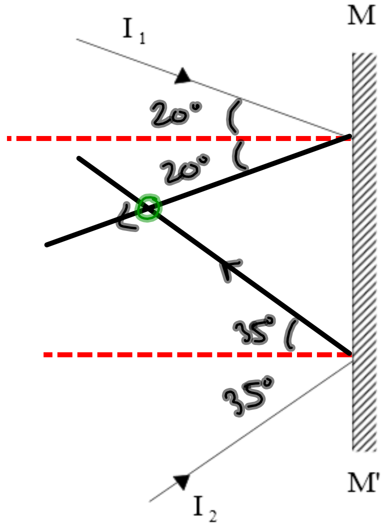
First law: The angle of incidence is equal to the angle of reflection. ($\theta_i = \theta_r$)

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

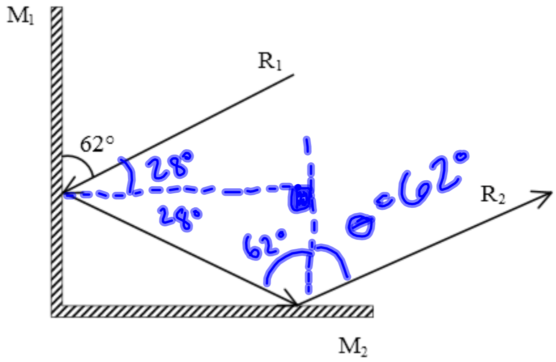
(no weird 3D effects)

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, are placed perpendicular to each other as shown in the diagram below:



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? 62°

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

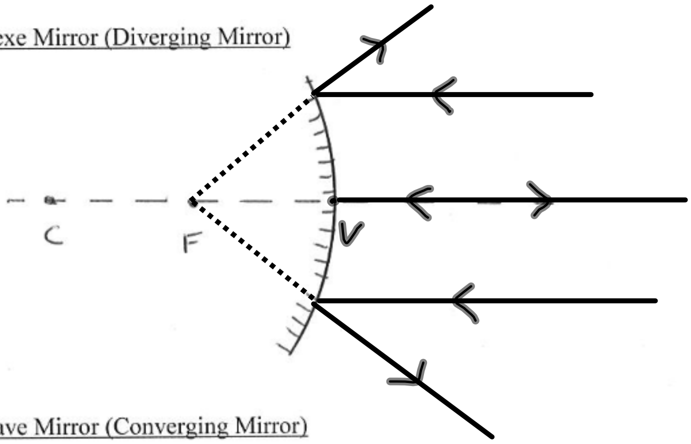
Focal point (F): point where rays parallel to the principal axis converge (converging mirror)
point from where diverging rays appear to come from (diverging mirror)

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

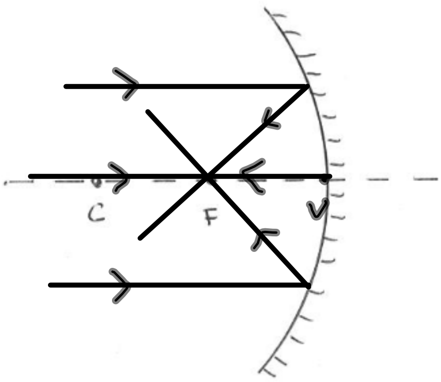
Principal axis: axis that joins the vertex, focal point and center of curvature

Curved mirrors can be spherical, parabolic, etc.

Convexe Mirror (Diverging Mirror)

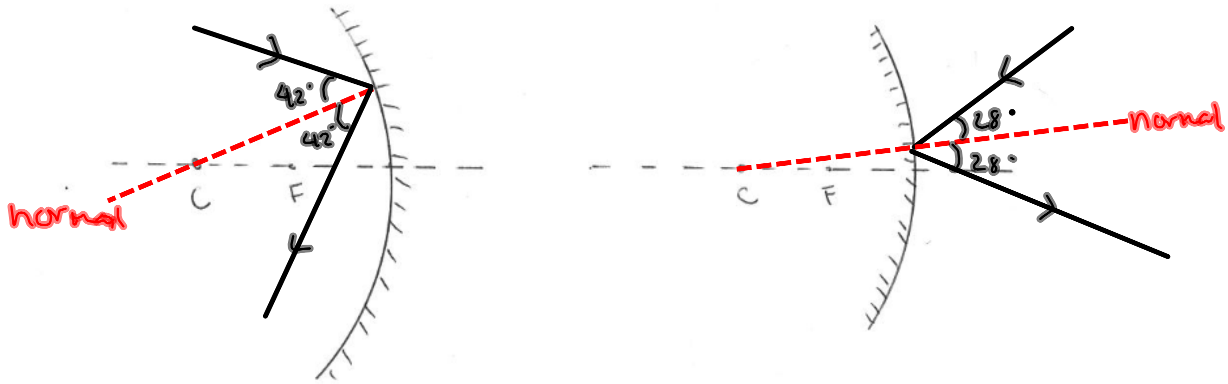


Concave Mirror (Converging Mirror)



Drawing Normals to Curved Mirrors

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



Non-parallel rays on curved mirrors

THREE PRINCIPLE RAYS:

① Parallel to principal axis: *Converging (concave) mirror*
The ray is reflected through the focal point

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

② Through/to the focus: *Through the focal point (converging mirror)*
The ray is reflected parallel to the principal axis

(to: as if going)

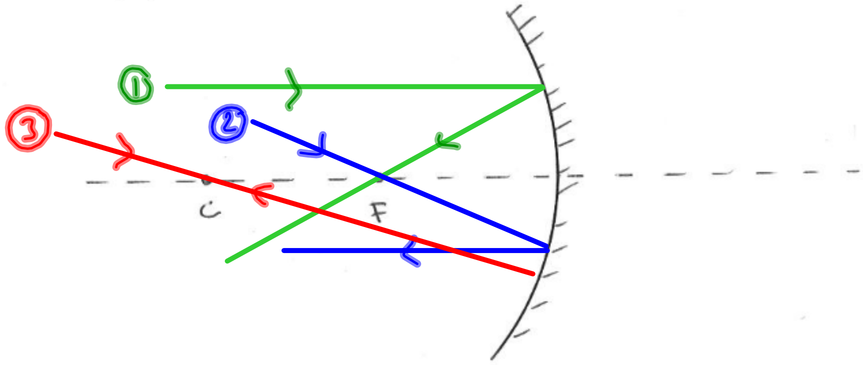
Towards the focal point (diverging mirror)
The ray is reflected parallel to the principal axis

③ Through/to center of: Curvature *Through the center of curvature (converging mirror)*
The ray is reflected back on itself.

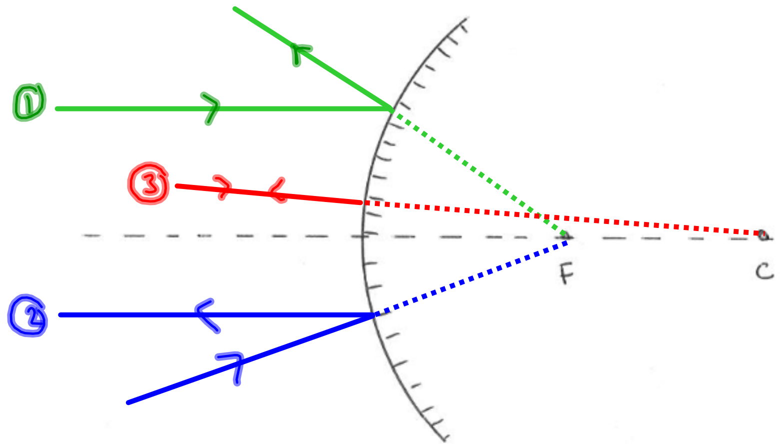
(to: as if going)

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

Non-Parallel Rays on a Concave Mirror



Non-Parallel Rays on a Convex Mirror



Field of Vision

Field of vision: area that can be seen by an observer in mirror

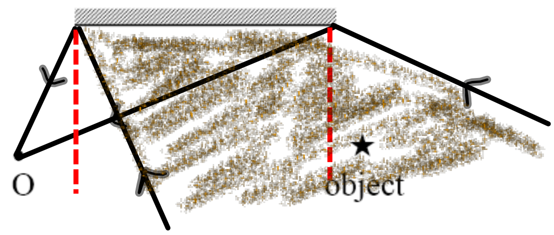
Steps:

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:

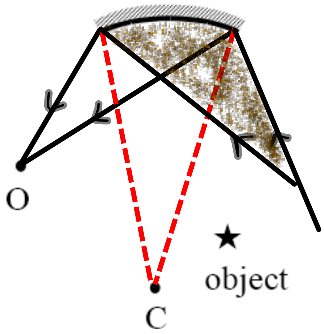
1. Can the observer see the object?

a.



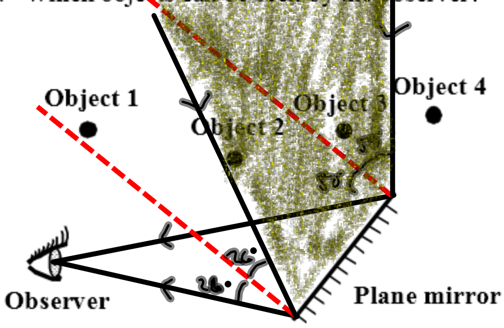
Yes!

b.



No!
(small field of vision)
concave/converging

2. Which objects can be seen by the observer?

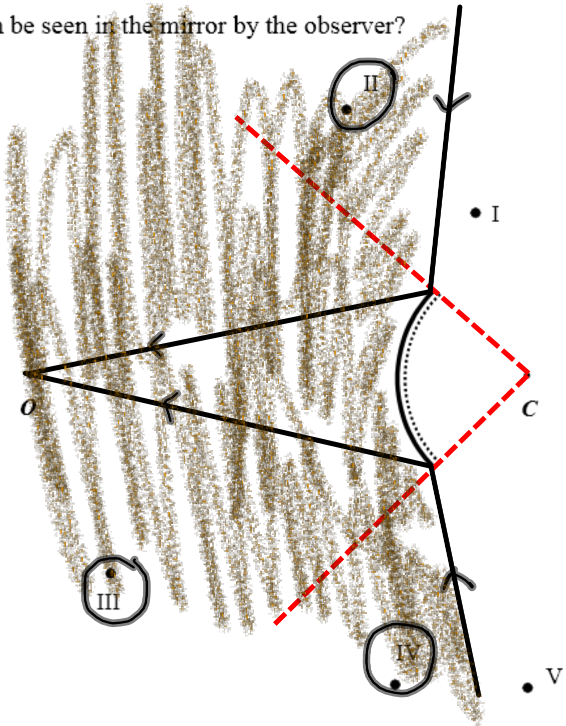


2, 3 can be seen in mirror

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

II, III, IV

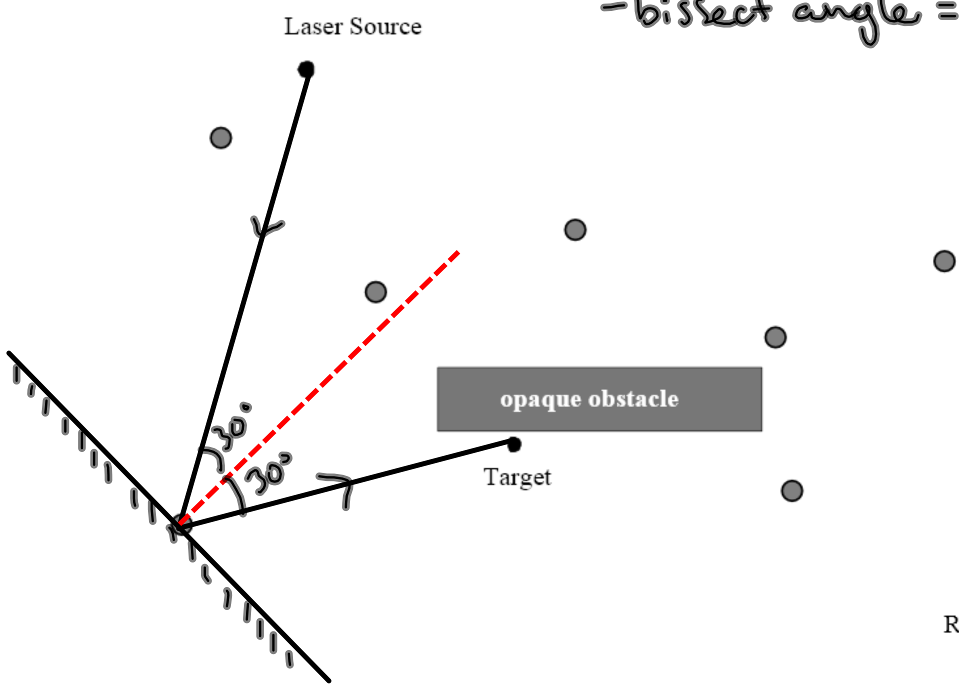
(large field of vision)



4. 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.

-bissect angle = normal



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.

or

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

or

Inverted: The image has an orientation that is opposite to that of the object.

Smaller than the object

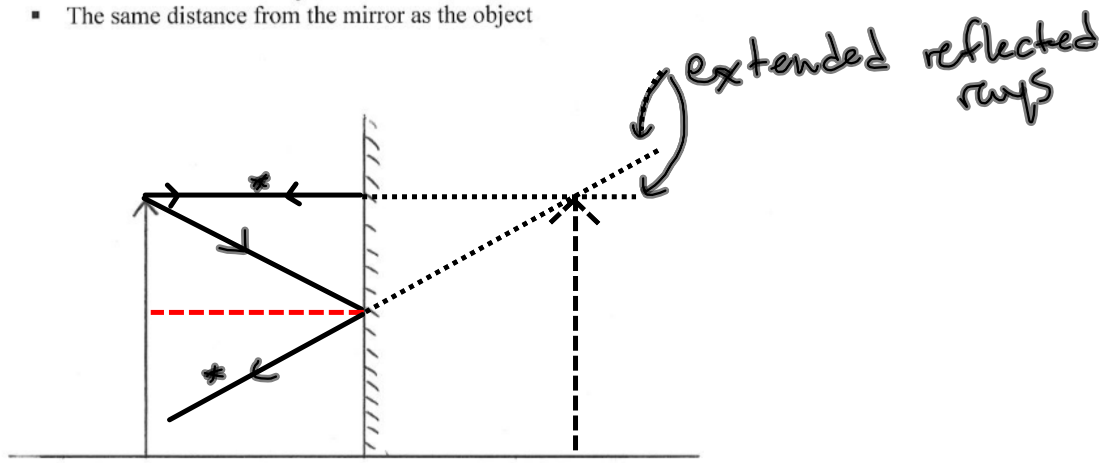
or

Bigger than the object
(larger)

Images formed by plane mirrors

Images formed by plane mirrors are always:

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

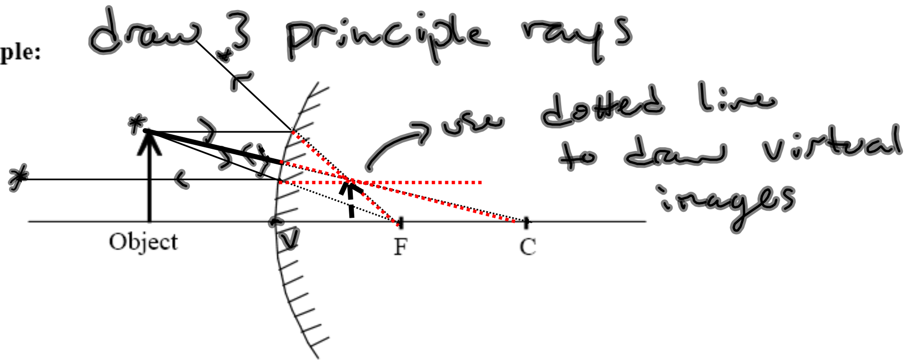


Images formed by convex mirrors

The images formed by a convex mirror are always:

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

Example:



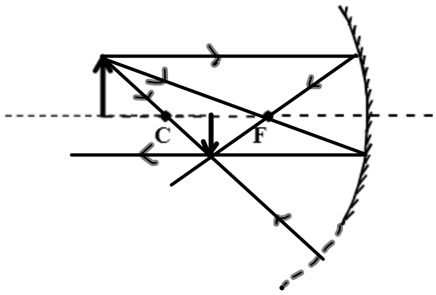
Images formed by concave mirrors

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

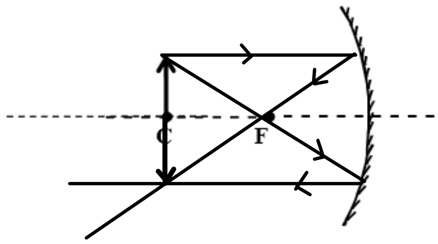
object	Real or Virtual?	Upright or Inverted?	Smaller or bigger than object?	Where? Image
Far beyond C	Real	Inverted	Smaller	At F
Beyond C	Real	Inverted	Smaller	Between C and F
At C	Real	Inverted	Same size	At C
Between C and F	Real	Inverted	Larger	Beyond C
At F	NO IMAGE FORMED			
Between F and V	Virtual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

* Real images are always inverted!

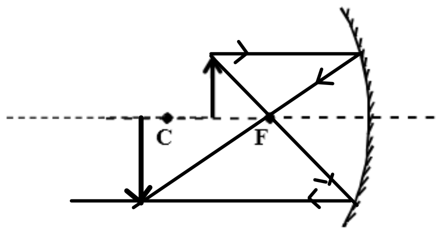
Examples:



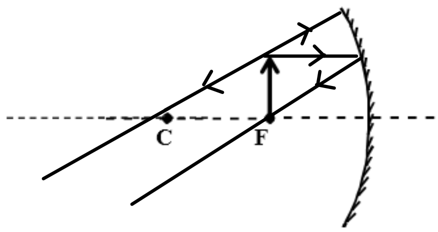
inverted
smaller
real
between C and F



inverted
same size
real
at C

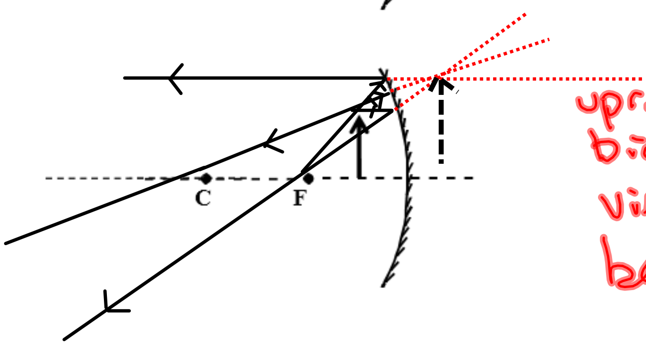


inverted
larger
real
beyond C



reflected rays are parallel

* NO IMAGE is formed!



upright
bigger
virtual
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

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

If M is negative, the image is inverted.

$|M| < 1 \rightarrow$ smaller

$|M| > 1 \rightarrow$ larger

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.*

If they have opposite sign, the image is inverted.

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.*

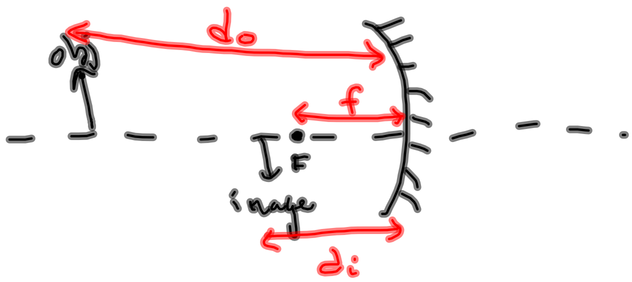
If d_i *is positive, the image is real. Real images can be picked up on screens. They are generated by the convergence of light rays.*

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

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

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

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



Formulas for curved mirrors:

$$M = \frac{h_i}{h_o}$$

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

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

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

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. Find the height of the image.

$f = +10.0\text{cm}$

$f = 10.0\text{cm}$
$h_o = 2.0\text{cm}$
$d_o = 5.0\text{cm}$
$h_i = ?$

① Find d_i

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$
$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$
$$\frac{1}{d_i} = \frac{1}{10\text{cm}} - \frac{1}{5\text{cm}}$$
$$\frac{1}{d_i} = \frac{1}{10\text{cm}} - \frac{2}{10\text{cm}}$$
$$\frac{1}{d_i} = -\frac{1}{10\text{cm}}$$
$$d_i = -10\text{cm}$$ ← virtual

② Find h_i

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$
$$h_i = -\frac{d_i h_o}{d_o}$$
$$= -\frac{(-10\text{cm})(2\text{cm})}{5\text{cm}}$$
$$h_i = 4.0\text{cm}$$
→ larger
→ upright

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

$f < 0$

$f = -10.0\text{cm}$
$d_o = 15.0\text{cm}$
$M = ?$

① Find d_i

$$\frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{f}$$
$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$
$$\frac{1}{d_i} = \frac{1}{-10\text{cm}} - \frac{1}{15\text{cm}}$$
$$\frac{1}{d_i} = \frac{-3}{30\text{cm}} - \frac{2}{30\text{cm}}$$
$$\frac{1}{d_i} = \frac{-5}{30\text{cm}}$$
$$d_i = \frac{30\text{cm}}{-5}$$
$$d_i = -6.0\text{cm}$$

② Find M

$$M = -\frac{d_i}{d_o}$$
$$= -\frac{(-6.0\text{cm})}{15.0\text{cm}}$$
$$= 0.4$$

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?

$f = ?$

$d_o = 20.0\text{cm}$

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

① Find d_i

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

$d_i = -m d_o$

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

$d_i = 10.0\text{cm}$

② Find f

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

$\frac{1}{f} = \frac{1}{20\text{cm}} + \frac{1}{10\text{cm}}$

$\frac{1}{f} = \frac{1}{20\text{cm}} + \frac{2}{20\text{cm}}$

$\frac{1}{f} = \frac{3}{20\text{cm}}$

$f = \frac{20\text{cm}}{3} = 6.67\text{ cm}$

4. A convex mirror has a radius of curvature of 30.0 cm. An object is placed 10.0 cm in front of this mirror. Where is the image of this object located?

$f = \frac{1}{2}(-30\text{cm})$
$= -15.0\text{cm}$

$d_o = 10.0\text{cm}$

$d_i = ?$

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

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

$\frac{1}{d_i} = \frac{1}{-15\text{cm}} - \frac{1}{10\text{cm}}$

$\frac{1}{d_i} = -\frac{2}{30\text{cm}} - \frac{3}{30\text{cm}}$

$\frac{1}{d_i} = \frac{-5}{30\text{cm}}$

$d_i = \frac{30\text{cm}}{-5} = -6.0\text{ cm}$

→ 6.0 cm behind the mirror (virtual)

5. A concave mirror 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?

$f = 10.0\,cm$ System!

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

① $m = -\frac{d_i}{d_o} \rightarrow d_i = -m d_o$

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

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

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

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

$\frac{1}{d_o} = \frac{1}{10cm} - \frac{1}{\left(\frac{d_o}{4}\right)}$

$\frac{1}{d_o} = \frac{1}{10cm} - \frac{4}{d_o}$

$\frac{1}{d_o} + \frac{4}{d_o} = \frac{1}{10cm}$

$\frac{5}{d_o} = \frac{1}{10cm}$

$\frac{d_o}{5} = 10cm$

$d_o = 5(10cm)$

$= 50cm$

6. 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?

Same mirror = same f

Before moving

$d_o = 4.0cm$

$d_i = -2.4cm$

$f = ?$

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

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

$$\frac{1}{f} = \frac{2.4}{9.6cm} + \frac{-4}{9.6cm}$$

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

$$f = \frac{9.6cm}{-1.6} = -6.0cm$$

After moving

$f = -6.0cm$

$d_o = 8.0cm$

$M = ?$

① Find d_i

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

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

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

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

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

$$d_i = \frac{24cm}{-7} = -3.43cm$$

② $M = -\frac{d_i}{d_o}$

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

$$M = 0.43$$