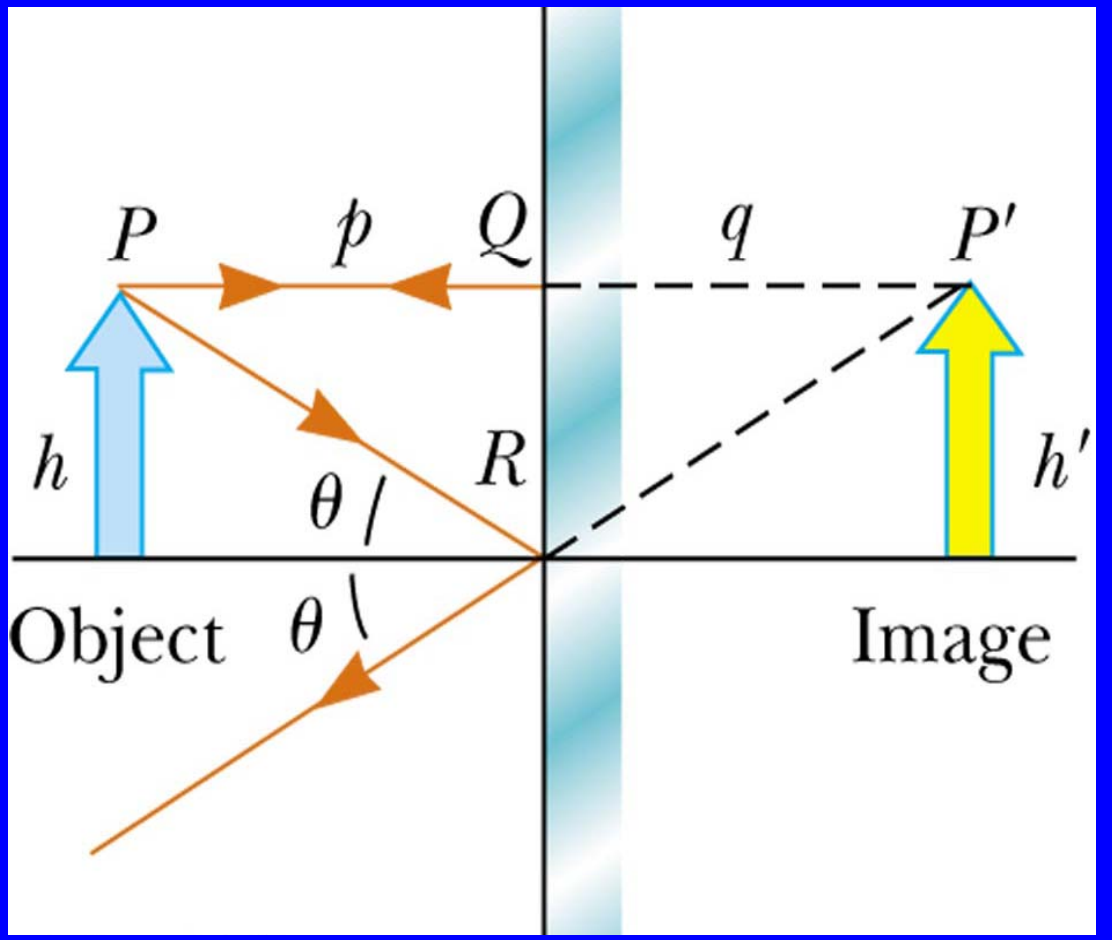
PHYSICS 1442-003
Fall 2011

Lecture 18

MIRRORS AND LENSES

Flat Mirror

- Simplest possible mirror
- Properties of the image can be determined by geometry
- One ray starts at P, follows path PQ and reflects back on itself
- A second ray follows path PR and reflects according to the Law of Reflection



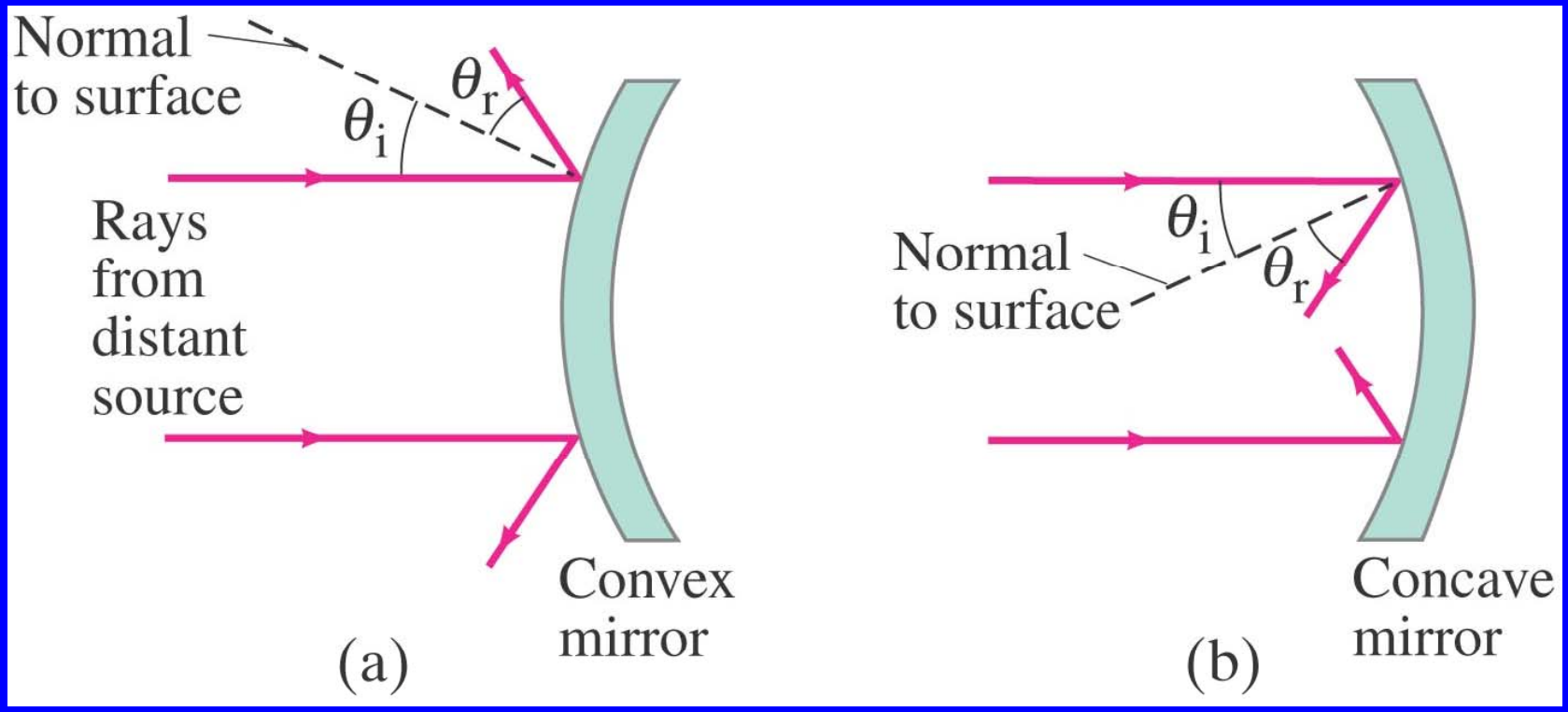
- The image is behind the mirror as the object is in front: q = p
- The image is unmagnified: h′ = h and M = 1

Properties of the Image Formed by a Flat Mirror

- The image is virtual
- The image is upright
  - It has the same orientation as the object
- There is an apparent left-right reversal in the image

Formation of Images by Spherical Mirrors

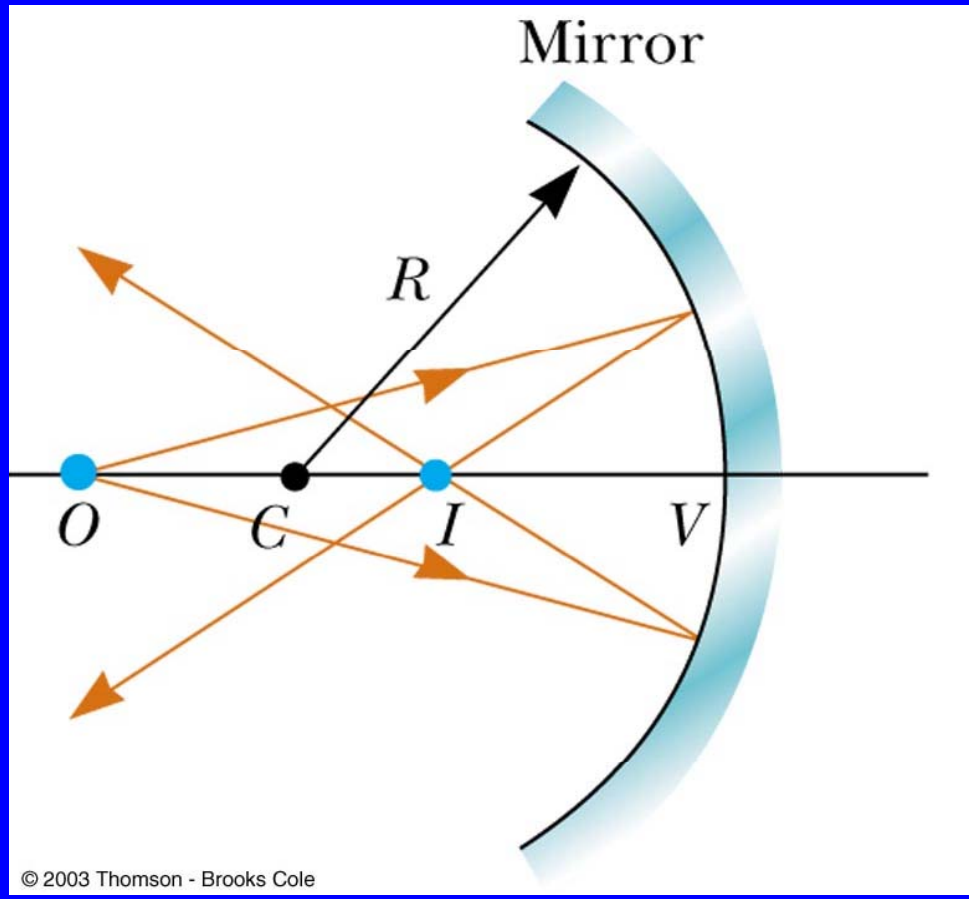
Spherical mirrors are shaped like sections of a sphere, and may be reflective on either the inside (concave) or outside (convex).



Note that $\theta_r = \theta_i$ for each ray

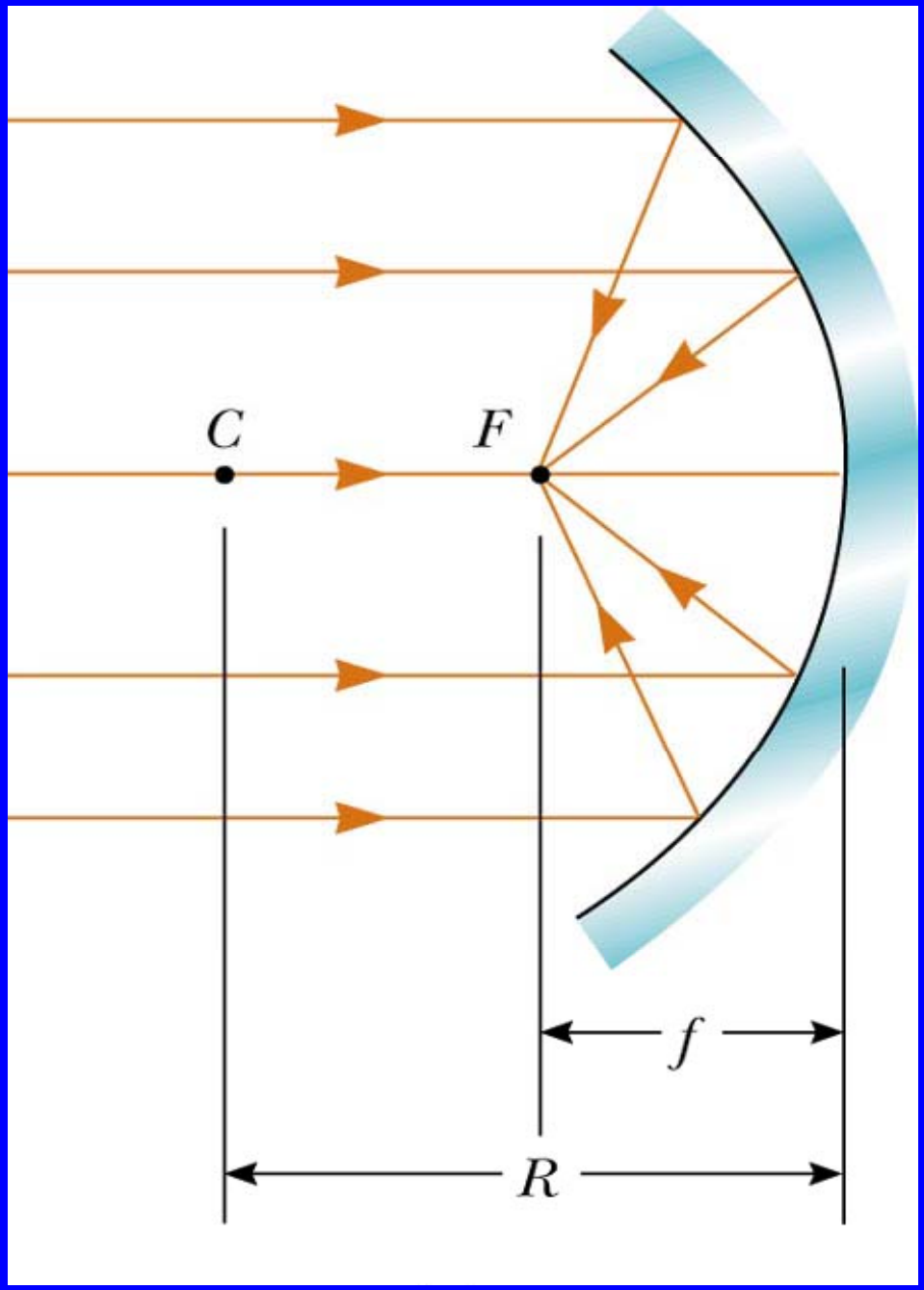
Concave Mirror, Notation

- The mirror has a *radius of curvature* of R
- Its *center of curvature* is the point C
- Point V is the center of the spherical segment
- A line drawn from C to V is called the *principle axis* of the mirror



Focal Length

- If an object is very far away, then $p \to \infty$ and $1/p \to 0$
- Incoming rays are essentially parallel
- In this special case, the image point is called the *focal point*
- The distance from the mirror to the focal point is called the *focal length*
  - The focal length is ½ the radius of curvature



Focal Point and Focal Length

- The focal point is dependent solely on the curvature of the mirror, not by the location of the object
- $f = R / 2$
- The mirror equation can be expressed as

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

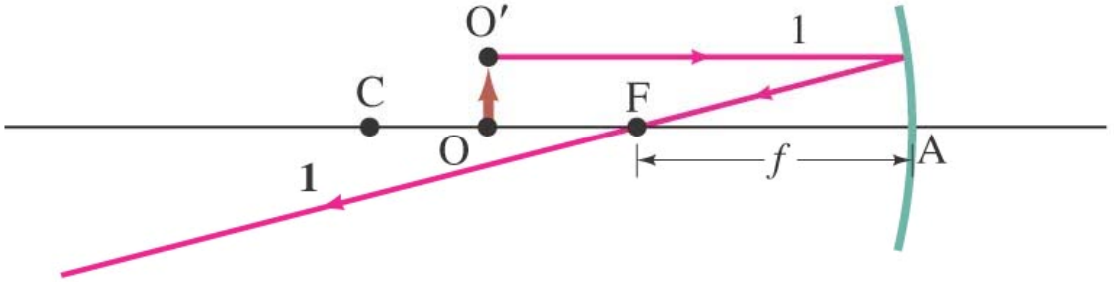
Notation for Mirrors

- The *object distance* is the distance from the object to the mirror or lens
  - Denoted by p or d_0
- The *image distance* is the distance from the image to the mirror or lens
  - Denoted by q or d_i
- The *lateral magnification* of the mirror or lens is the ratio of the image height to the object height
  - Denoted by M

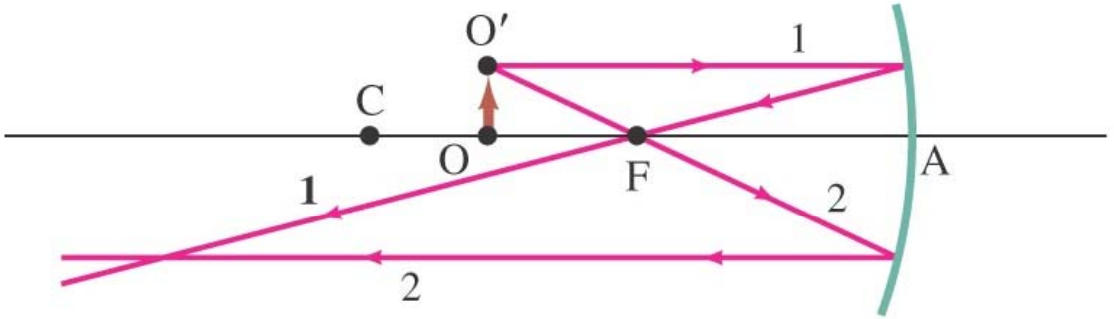
The Rays in a Ray Diagram

- Ray 1 is drawn parallel to the principle axis and is reflected back through the focal point, F
- Ray 2 is drawn through the focal point and is reflected parallel to the principle axis
- Ray 3 is drawn through the center of curvature and is reflected back on itself

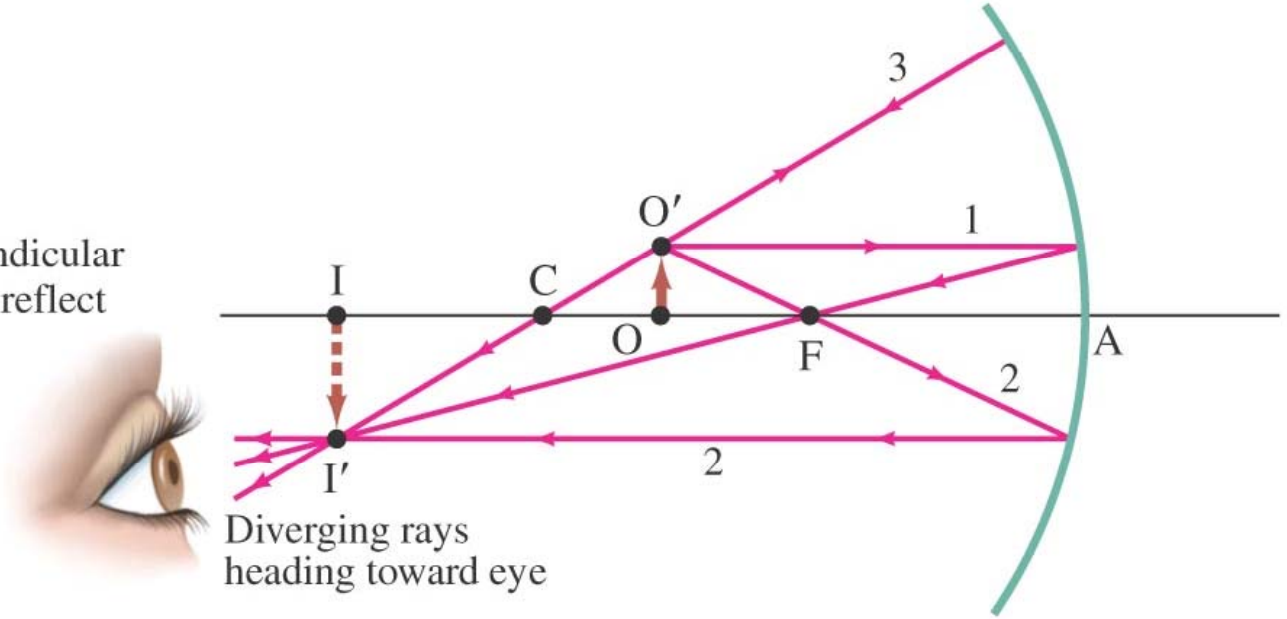
(a) Ray 1 goes out from O′ parallel to the axis and reflects through F.



(b) Ray 2 goes through F and then reflects back parallel to the axis.

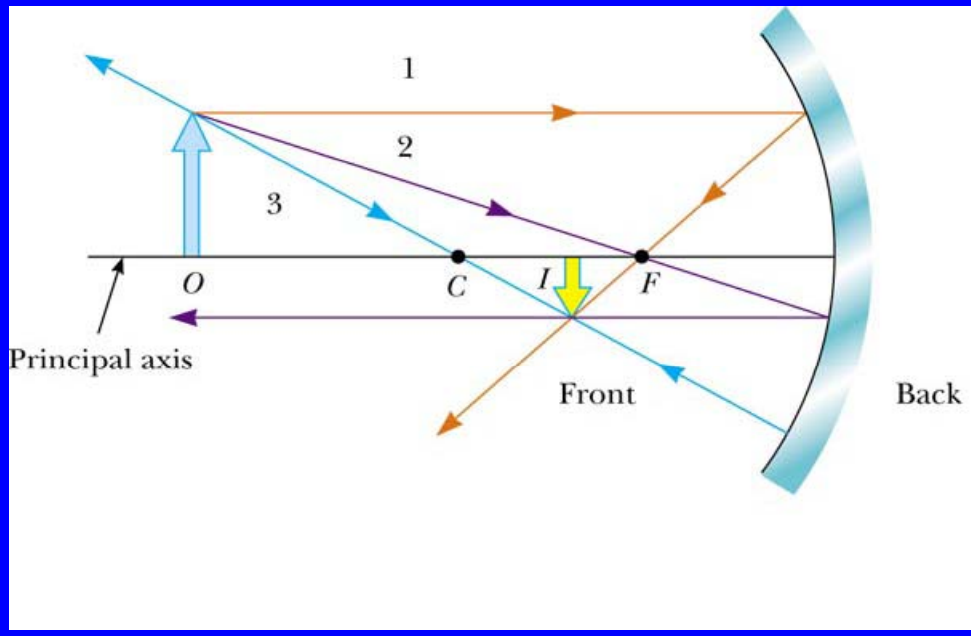


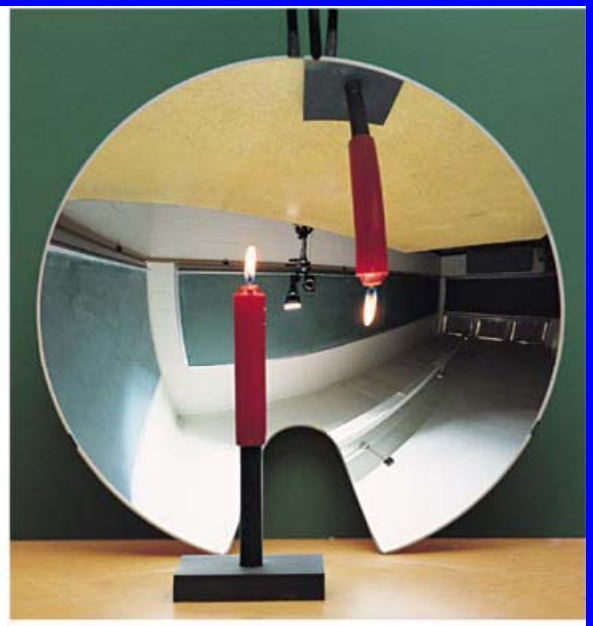
(c) Ray 3 is chosen perpendicular to mirror, and so must reflect back on itself and go through C (center of curvature).



The intersection of these three rays gives the position of the image of that point on the object. To get a full image, we can do the same with other points (two points suffice for may purposes).

Ray Diagram for Concave Mirror, p > R



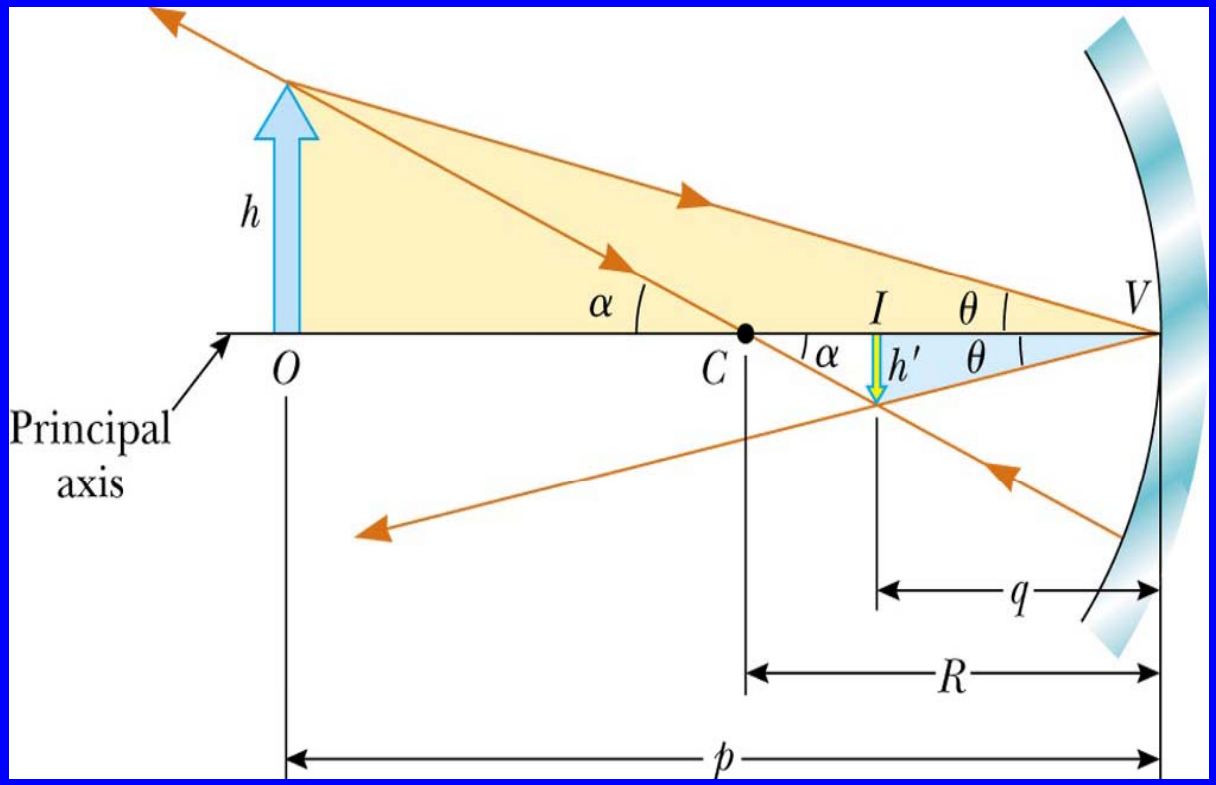


- The object is outside the center of curvature of the mirror
- The image is real
- The image is inverted
- The image is smaller than the object

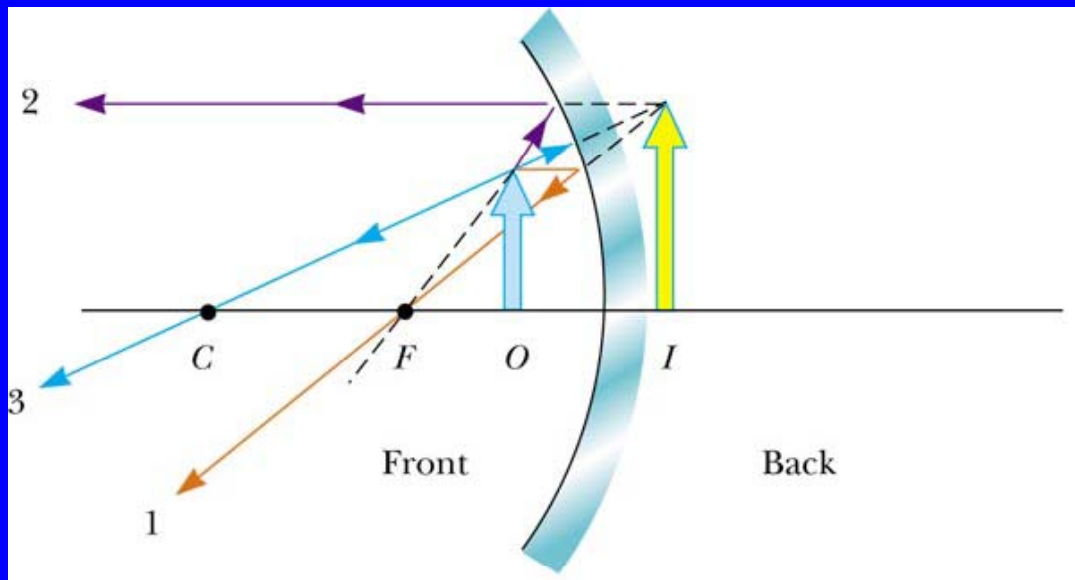
Image Formed by a Concave Mirror

- Geometry shows the relationship between the image and object distances

$$\frac{1}{p}+\frac{1}{q}=\frac{2}{R}$$



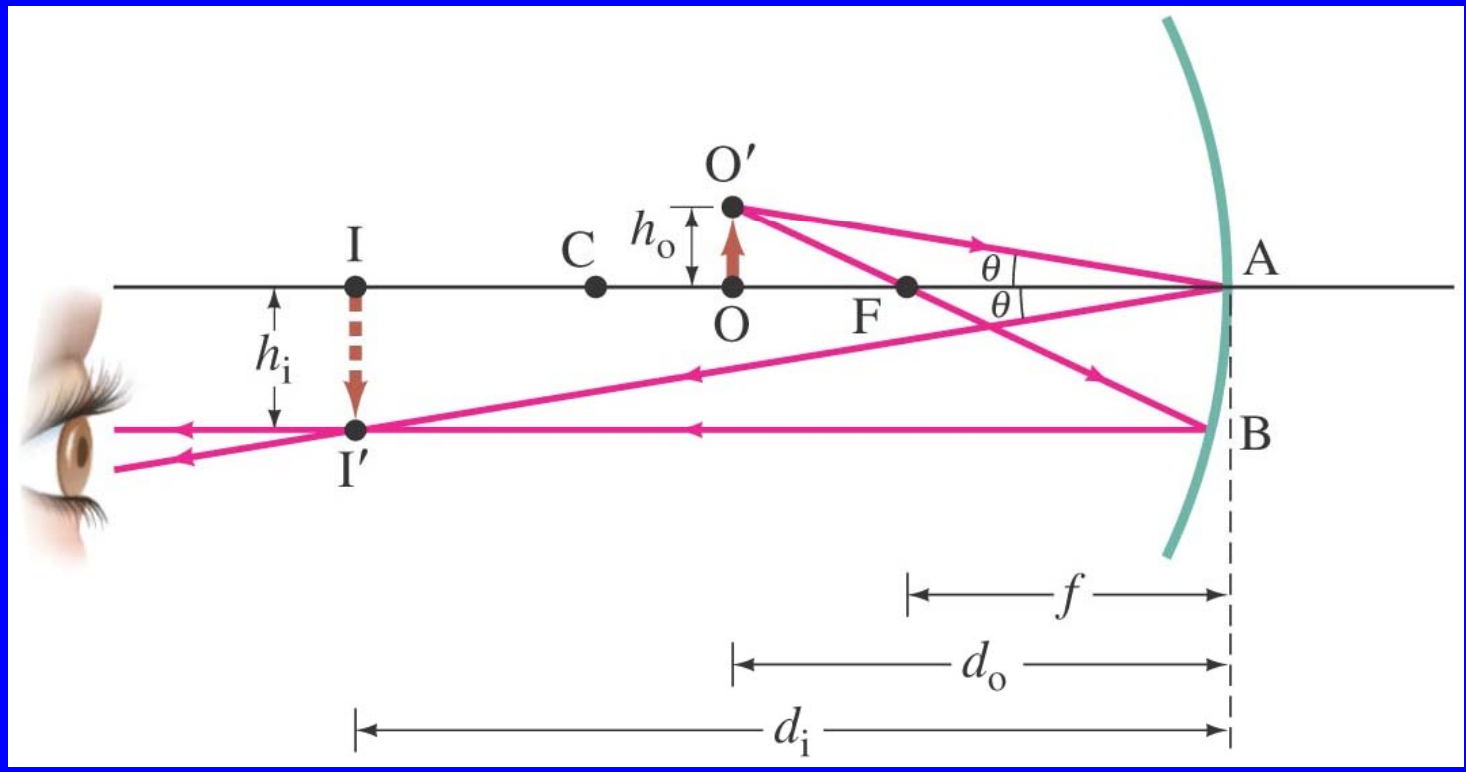
Ray Diagram for a Concave Mirror, p < f



- The object is between the mirror and the focal point
- The image is virtual
- The image is upright
- The image is larger than the object

Geometrically, we can derive an equation that relates the object distance, image distance, and focal length of the mirror:

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



We can also find the magnification (ratio of image height to object height):

$$m = \frac{h_\mathrm{i}}{h_\mathrm{o}} = -\frac{d_\mathrm{i}}{d_\mathrm{o}}.$$

The negative sign indicates that the image is inverted. This object is between the center of curvature and the focal point, and its image is larger, inverted, and real.

Image Formed by a Concave Mirror

- Geometry can also be used to determine the magnification of the image

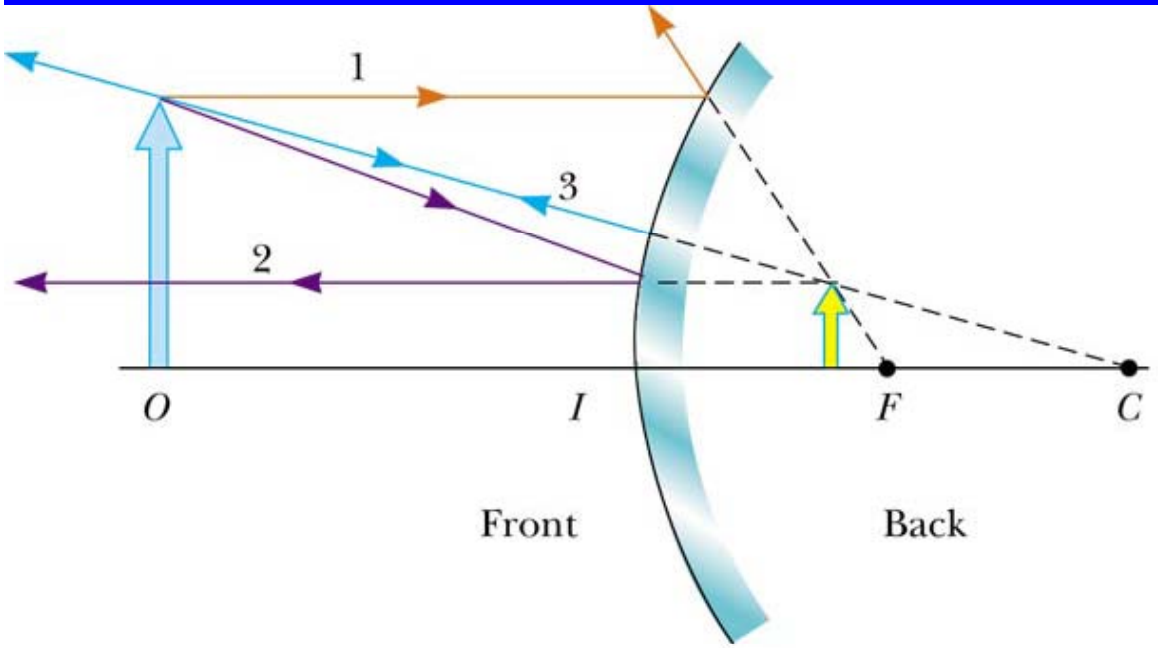
$$M = \frac{h'}{h} = -\frac{q}{p}$$

  - h’ is negative when the image is inverted with respect to the object

Convex Mirrors

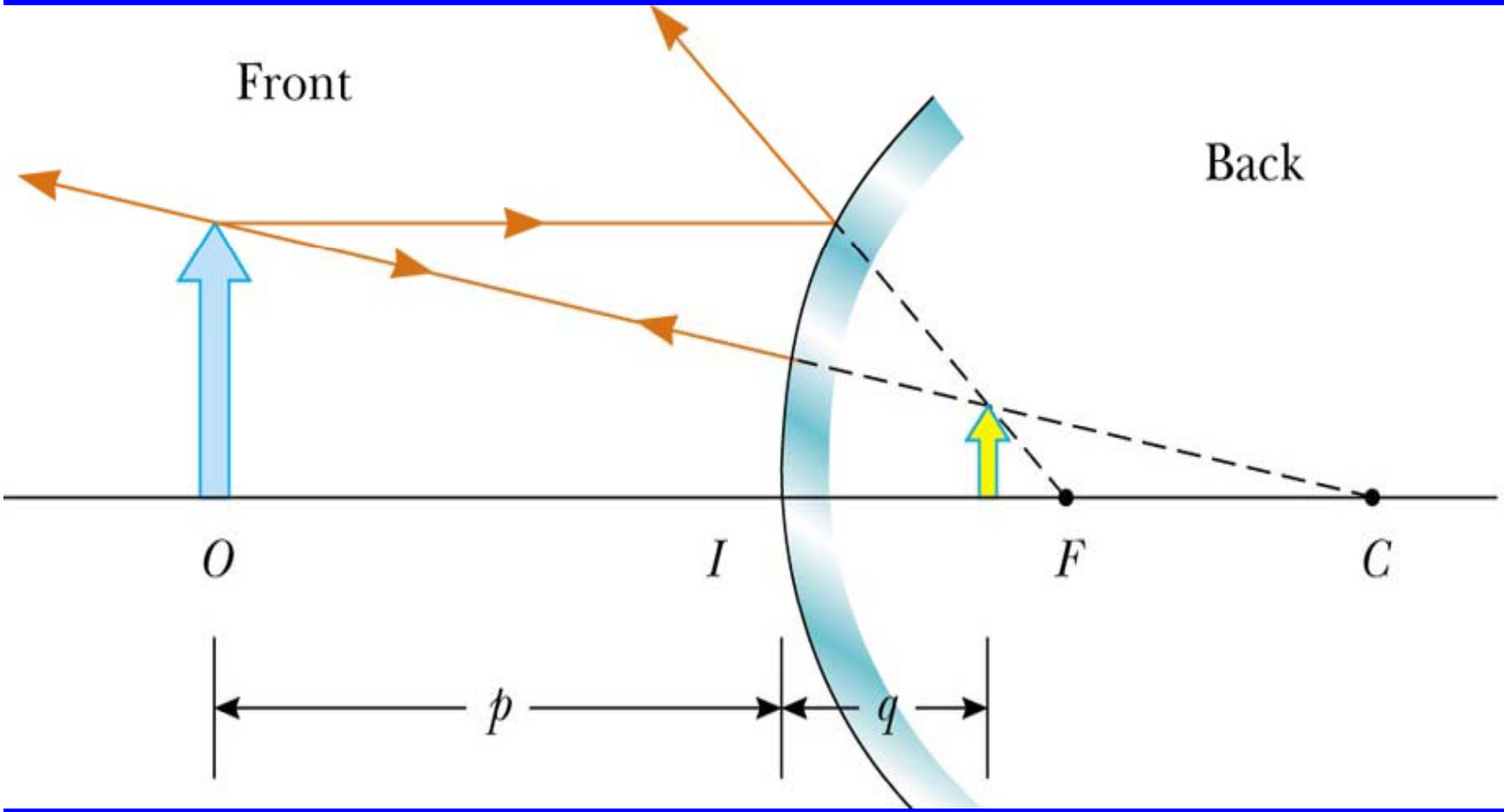
- A convex mirror is sometimes called a *diverging* mirror
- The rays from any point on the object diverge after reflection as though they were coming from some point behind the mirror
- The image is virtual because it lies behind the mirror at the point where the reflected rays appear to originate
- In general, the image formed by a convex mirror is upright, virtual, and smaller than the object

Ray Diagram for a Convex Mirror



- The object is in front of a convex mirror
- The image is virtual
- The image is upright
- The image is smaller than the object

Image Formed by a Convex Mirror



Notes on Images

- With a concave mirror, the image may be either real or virtual
  - When the object is outside the focal point, the image is real
  - When the object is at the focal point, the image is infinitely far away
  - When the object is between the mirror and the focal point, the image is virtual
- With a convex mirror, the image is always virtual and upright
  - As the object distance increases, the virtual image gets smaller

Sign Conventions for Mirrors

Quantity	*Positive When*	*Negative When*
Object location (p)	Object is in front of the mirror	Object is behind the mirror
Image location (q)	Image is behind mirror	Image is in front of mirror
Image height (h′)	Image is upright	Image is inverted
Focal length (f) and radius (R)	Mirror is concave	Mirror is convex
Magnification (M)	Image is upright	Image is inverted