Image Formation: Lens and Mirrors (Sec. 23.9-10)

- Using the ray approximation of geometric optics, we can now study how images are formed with mirrors and lens
- Then we can apply these principles to practical optical devices: the eye, telescopes, …
- First consider the common flat mirror to make some definitions
- We will call the source of light, the **object** (O). The object will be a point source with rays radiating in all directions (spherical waves).

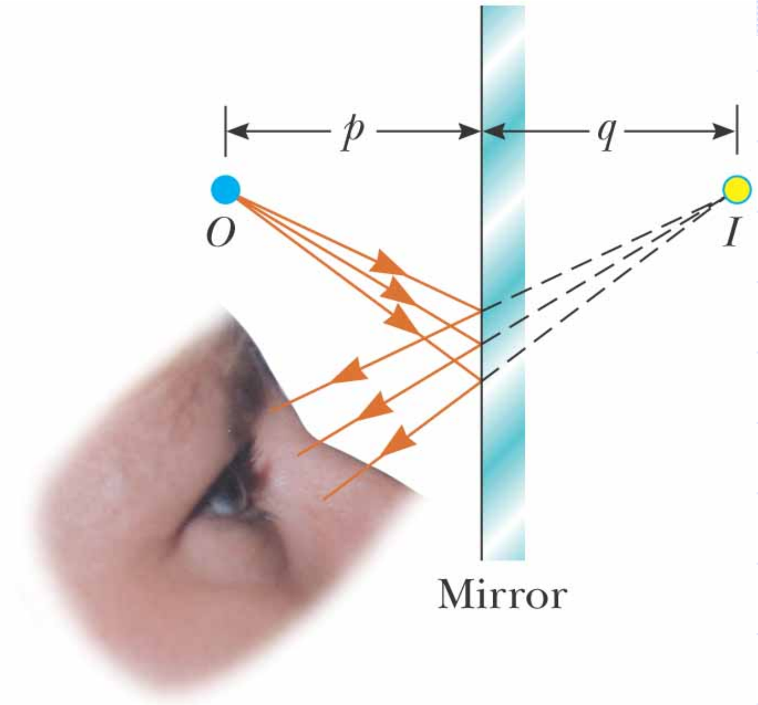
Flat Mirror

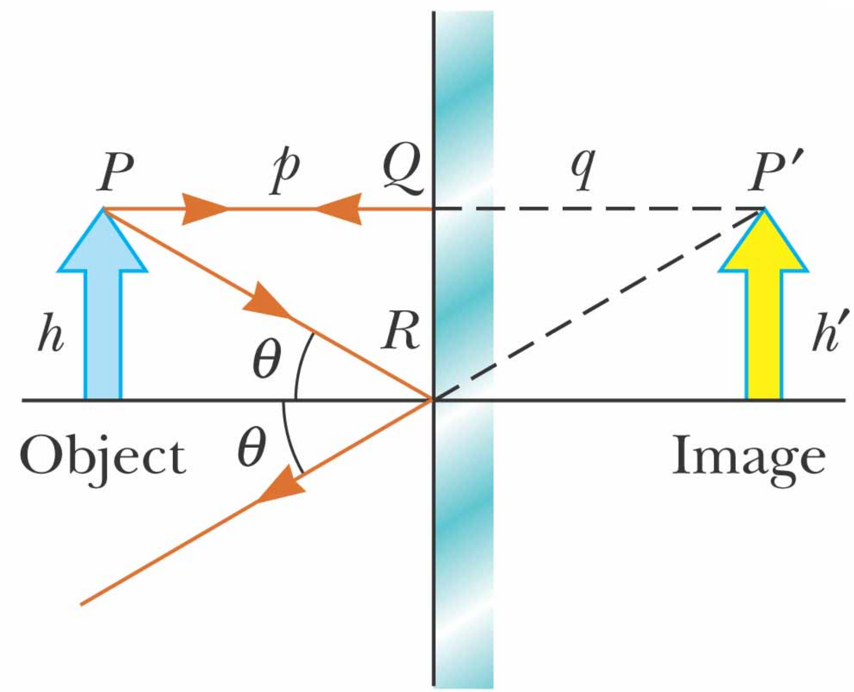
- Light rays strike the surface, reflect following the law of reflection, and thus diverge

p = distance from object to surface (s or s_O)

q = distance from image to surface (s’ or s_I)

- Extend the diverging light rays to a point where they meet to obtain the location of the image



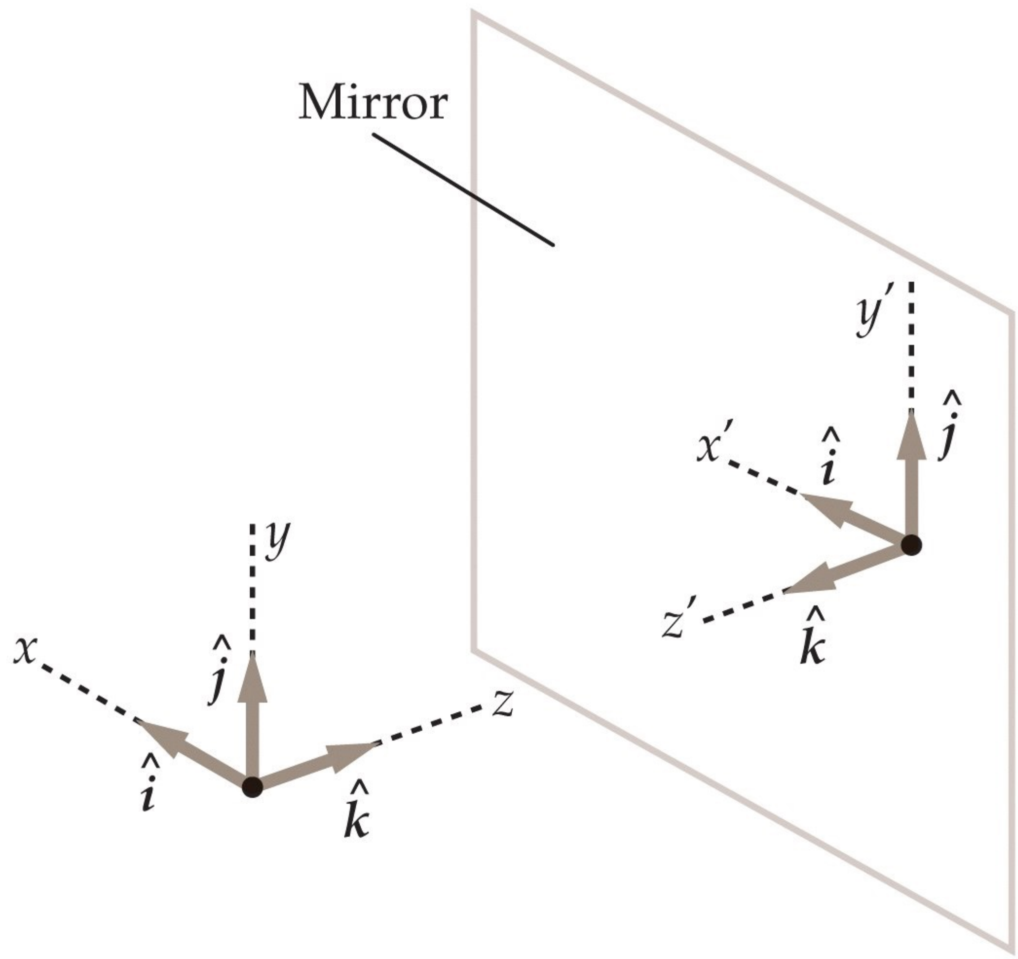


- Since the rays do not pass through the mirror, the image is a virtual image
- A real image forms when actual light rays converge onto the image point (and then diverge)
- For the flat mirror, |p|=|q| and the image appears to be behind the mirror (virtual)
- What about the size of the image compared to the object?
- From the ray diagram, we see that the two right triangles PQR and P’QR are congruent. Lengths PQ=P’Q and the heights h=h’
- The image height equals the object height

- Define the Lateral Magnification
  M ≡ (image height)/(object height) = h'/h
- For the flat mirror, M=1

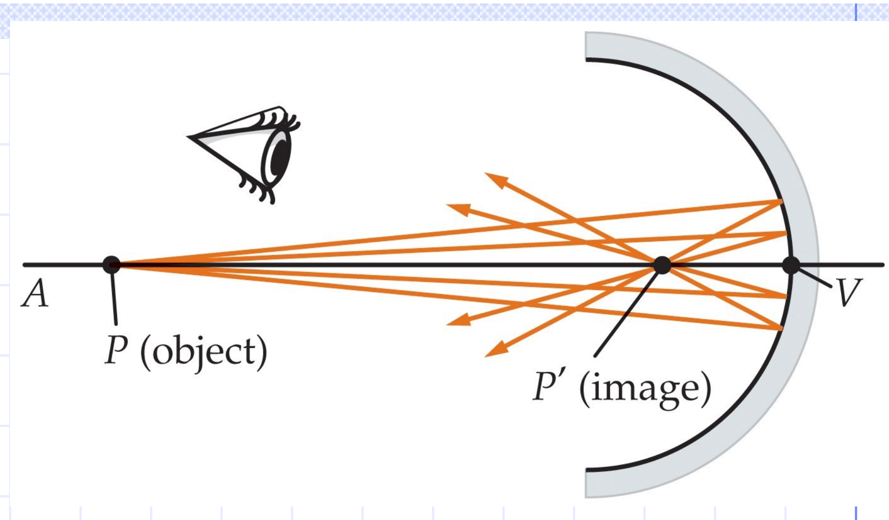
Front-back reversal

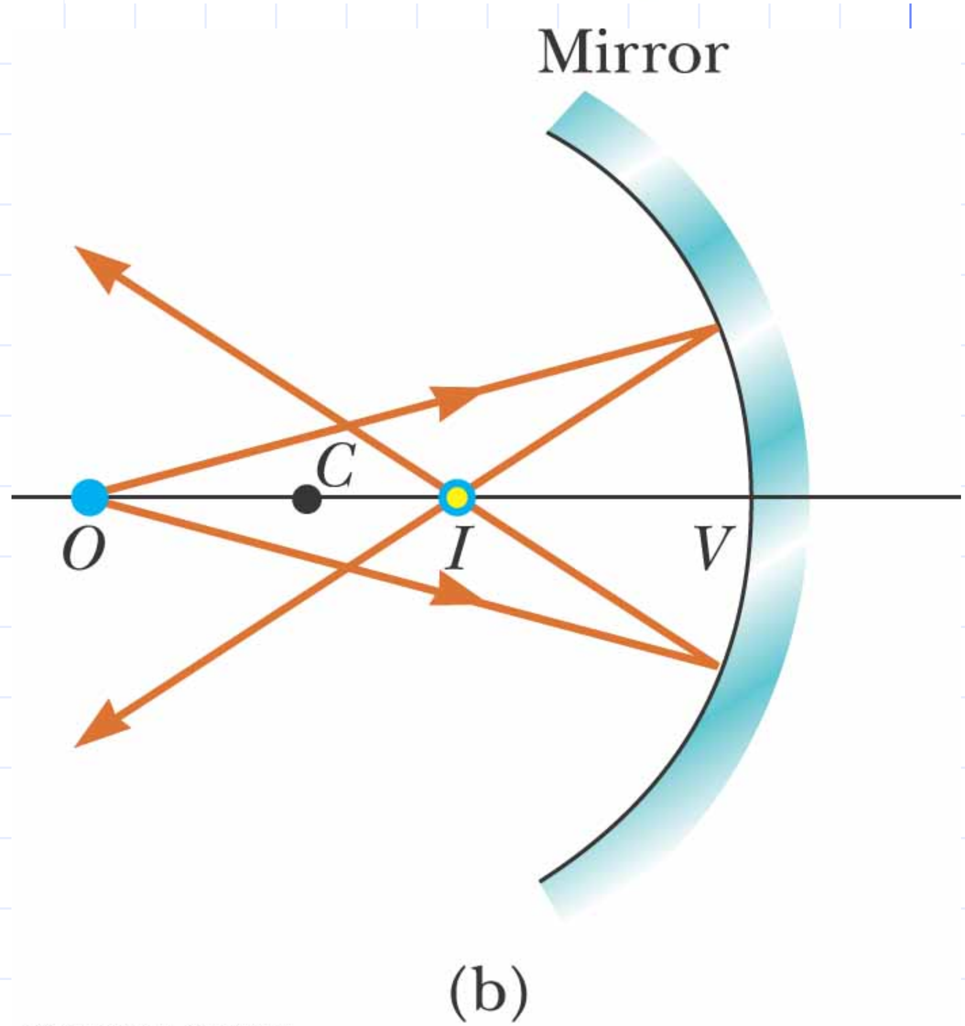
- We commonly think that a flat mirror provides a left-right reversal
- The unit vectors demonstrate it is actually a front-back reversal



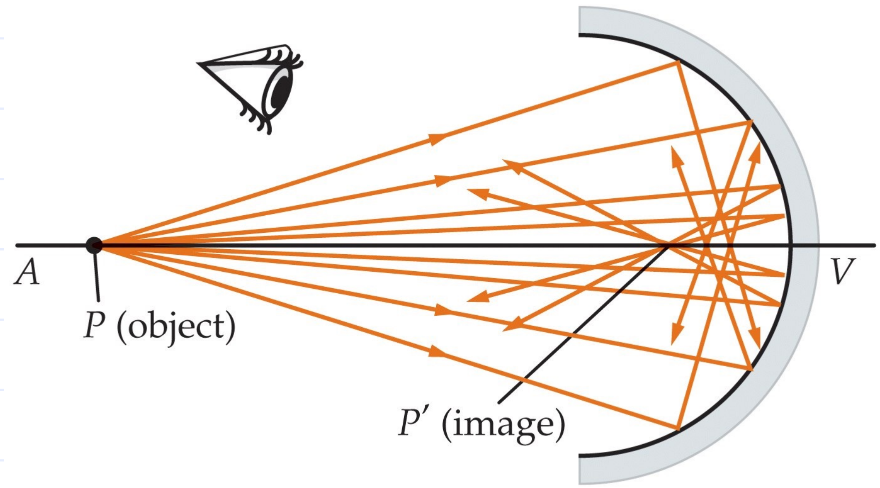
Concave Spherical Mirrors

- Consider a spherical mirror with radius of curvature R (from C)
- Point C is the center
- Let p>R (p is at O)
- Define the principal axis as the horizontal line through points O, C, and I
- p is distance from object to mirror

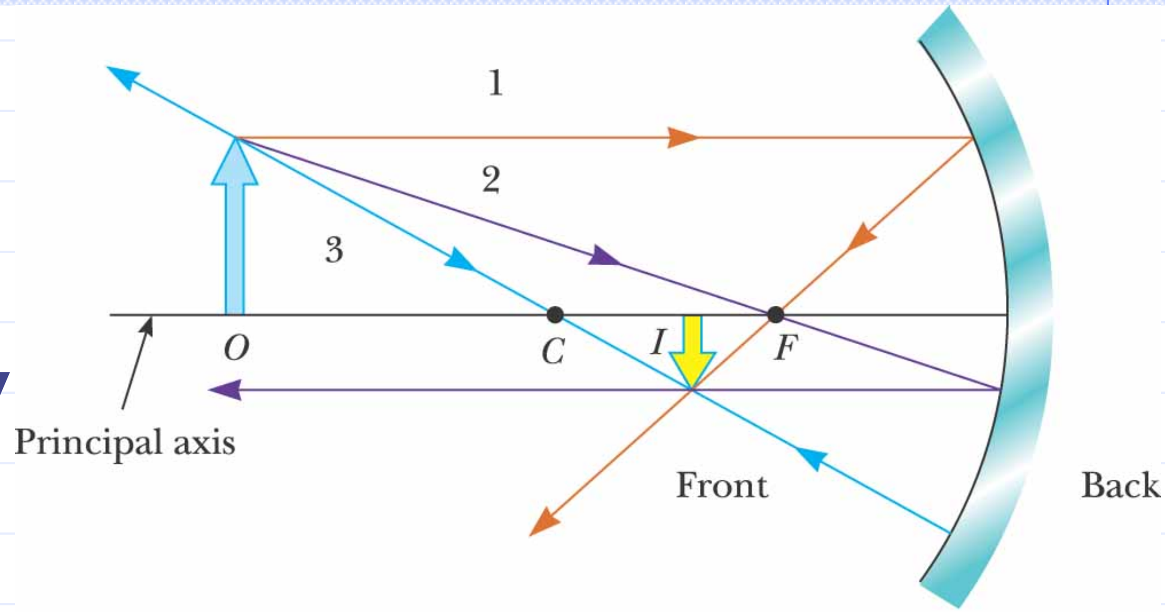




- As for the flat mirror, we will draw rays from the object to the mirror and follow their reflection
- However, the angle of the incident rays (w.r.t the principal axis) must be "small".
- For a spherical mirror, only small angle rays, called paraxial rays, reflect and converge to I
- "Large" angle rays converge to other points resulting in spherical aberration – a blurring of the image



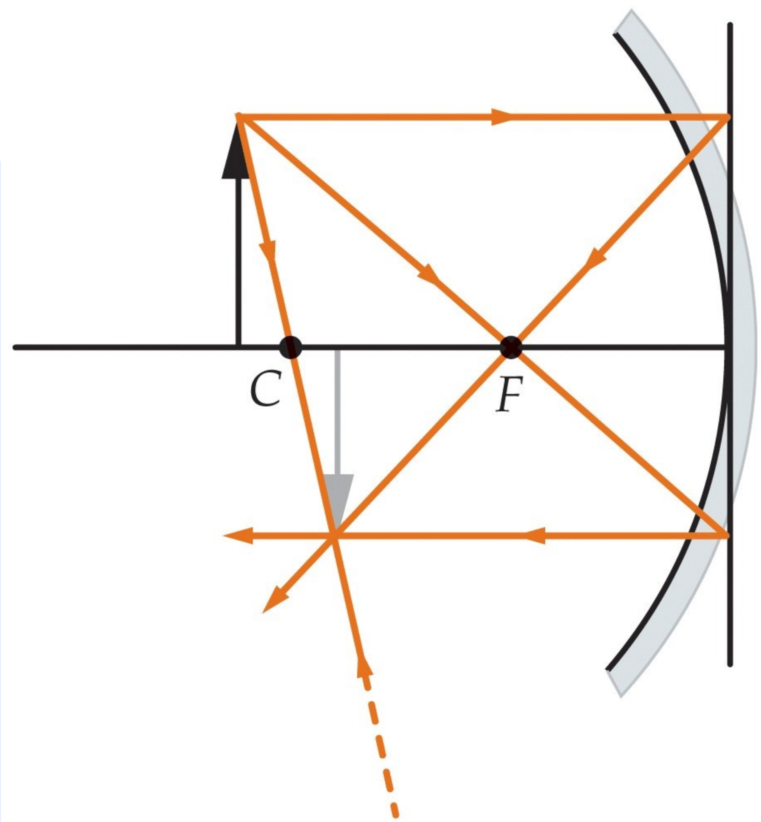
- Draw ray diagram for p>R. Usually, 3 rays are useful.
- With this geometry, we can derive two useful equations
- q is distance from mirror to image



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

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

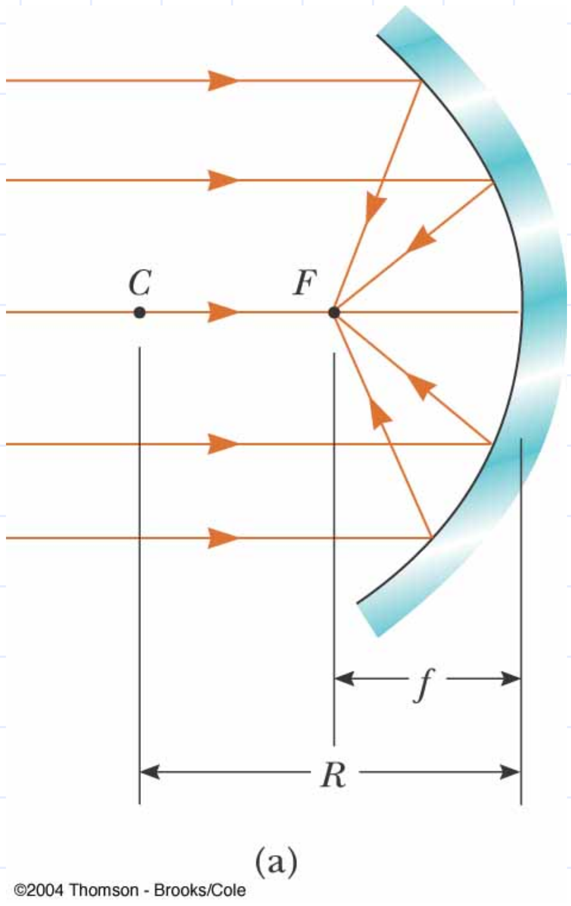
Mirror equation



- Let p>>R ($p \to \infty$), so $1/p \approx 0$
- Therefore, from the mirror equation, we see that q=R/2
- Now define the focal length $f = R/2$
- F is the focal point
- The mirror equation becomes

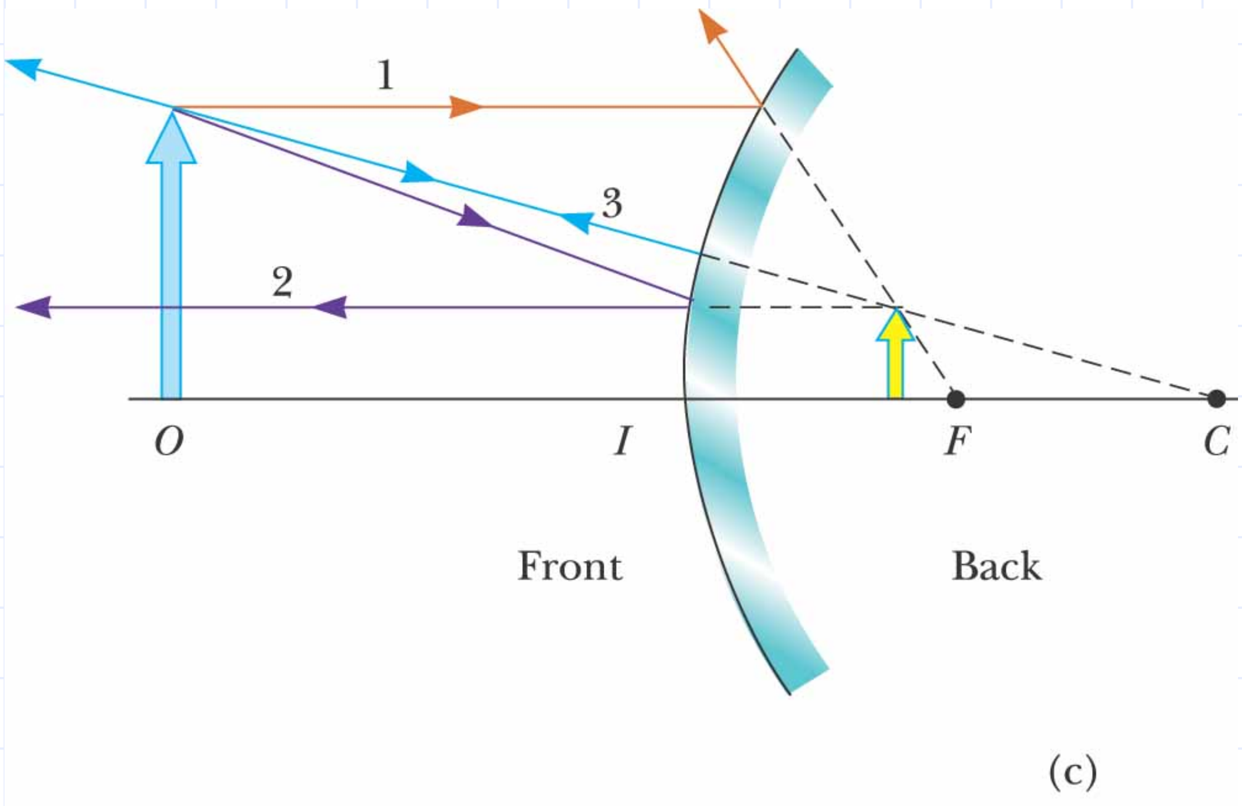
$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

- Notice since the rays reflect, there is no dependence on the mirror materials, only the radius of curvature R

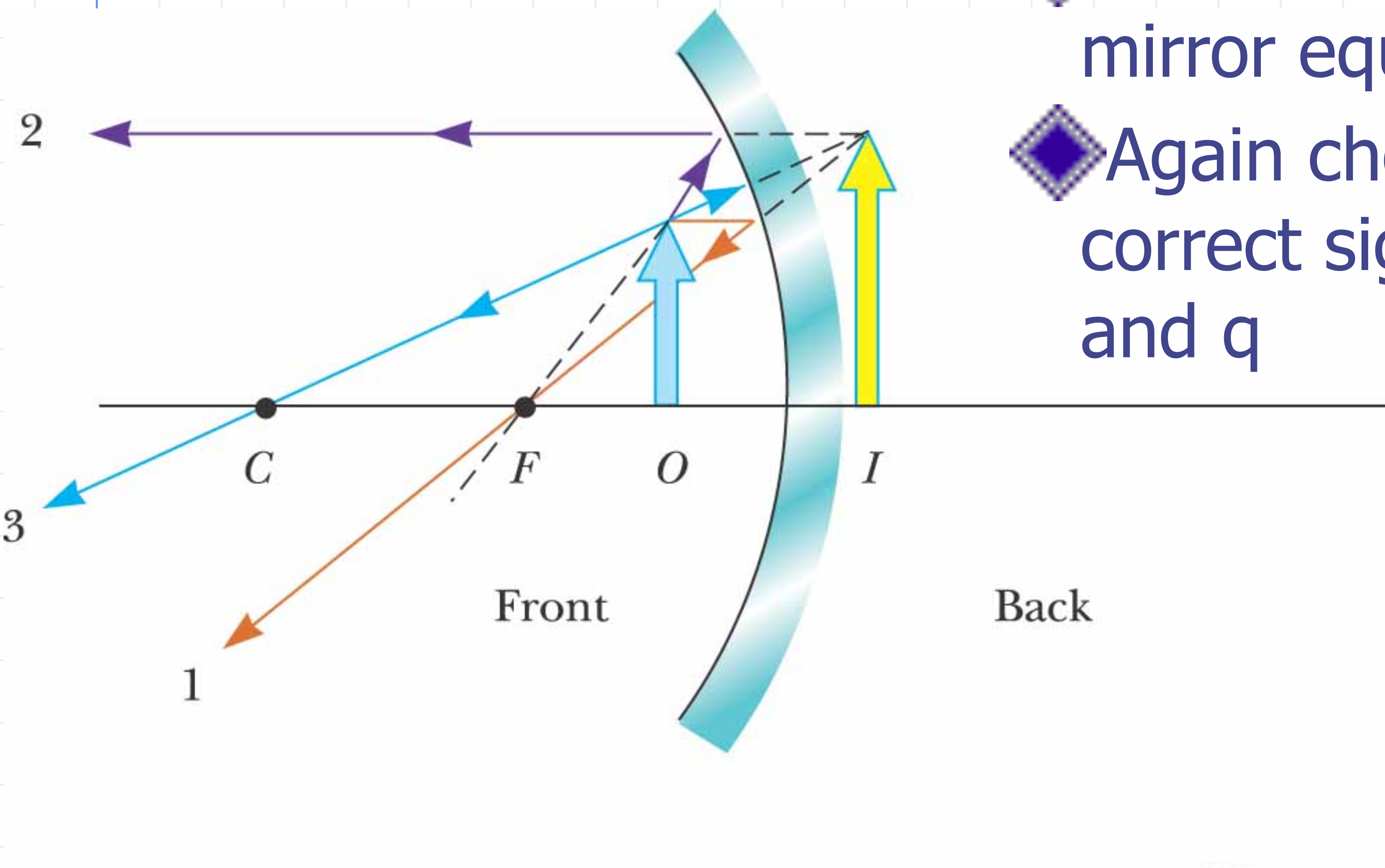


Convex Spherical Mirrors

- Light reflects from the outer convex surface
- Only a virtual image is formed
- Same mirror equations hold, but must be careful about signs of q (and p)



Concave Mirror Revised (Object Inside F)



- Only virtual image is formed
- Also can use same mirror equation
- Again choose correct signs for p and q