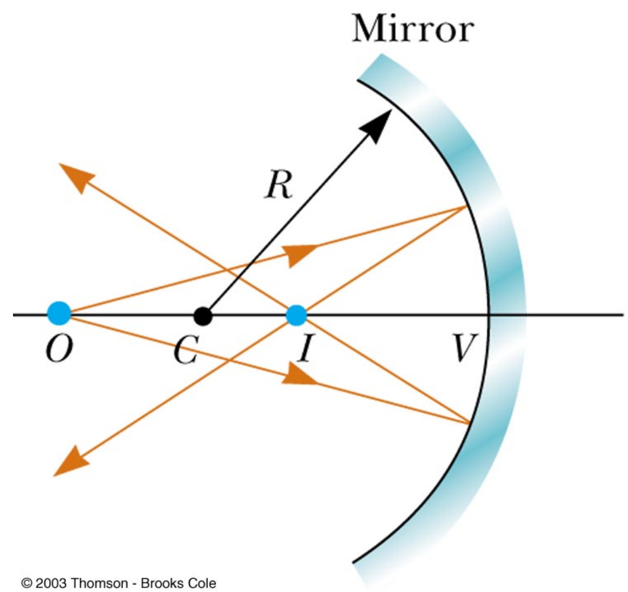
Physics 294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **36.73 hand-in problem for next Wed**
- Quizzes by iclicker (sometimes hand-written)
- Average on 2nd exam (so far)=71/120
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

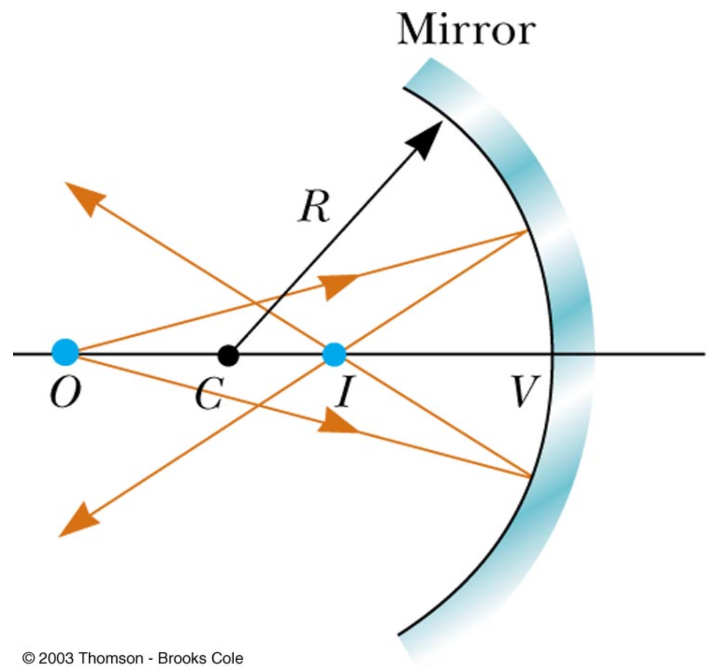
Spherical mirrors

- Spherical mirror has the shape of a segment of a sphere
  - can be either concave, as mirror on right, or convex
  - alas, again many definitions
  - radius of curvature is R; center of curvature is C
  - line drawn from C to V is called the principal axis



Spherical mirrors

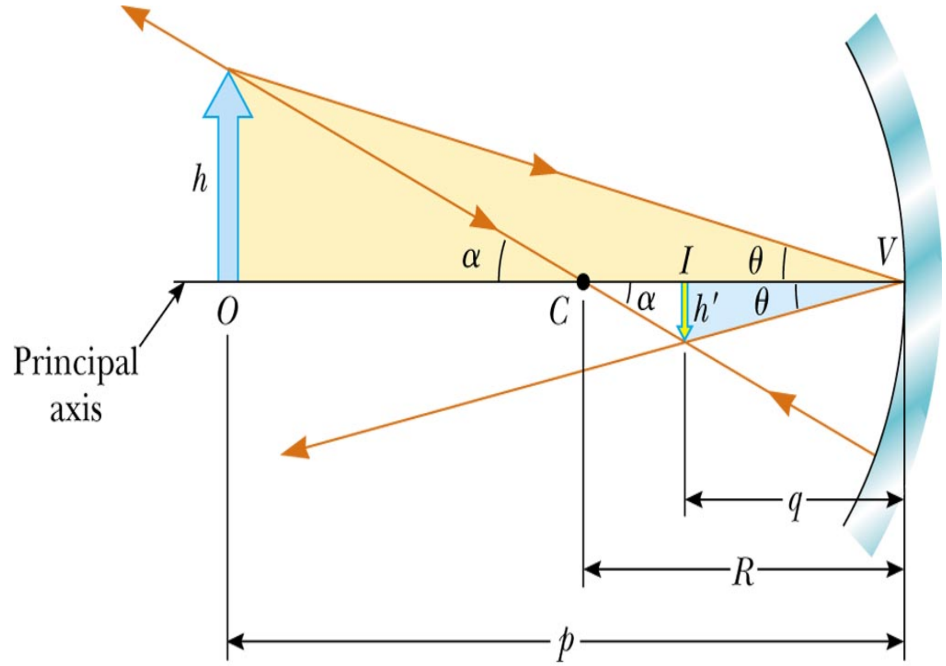
- Consider a point source of light placed at position O
- Draw rays outward from O and look at rays reflected from mirror surface
- Rays converge to meet at location I
- I is called the image point; a *real* image is formed there, i.e. it actually exists



We'll assume that the angles involved are small; for larger angles have to worry about spherical aberration

Image from a spherical mirror

- Use ray tracing
  - ray through C reflects back on itself
  - ray through V reflects at angle θ
- Image forms at I
  - $\tan \theta = h/p$
  - $\tan \theta = -h'/q$
- With a magnification
  - $M = -h'/h = -q/p$
- More geometry
  - $\tan \alpha = h/(p-R)$
  - $\tan \alpha = -h'/(R-q)$
  - $h'/h = -(R-q)/(p-R)$
  - $(R-q)/(p-R) = q/p$



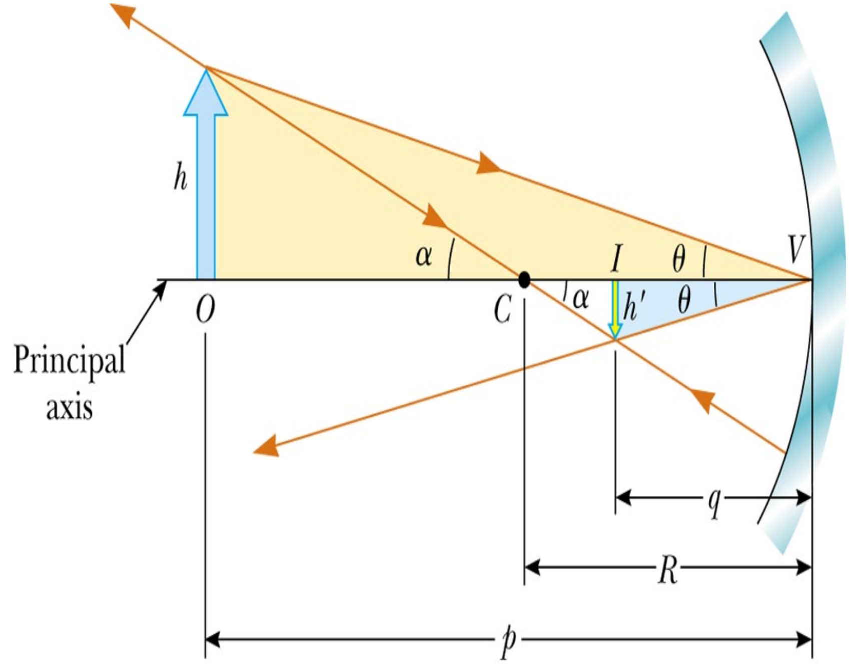
after some algebra

$$1/p + 1/q = 2/R$$

mirror equation

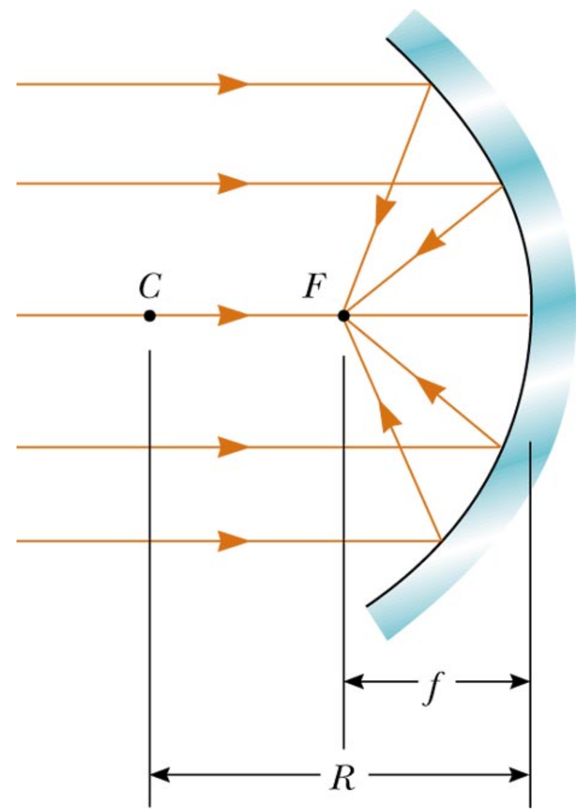
Spherical mirror

- Image has a magnification less than 1, is real and is inverted



Rays from infinity

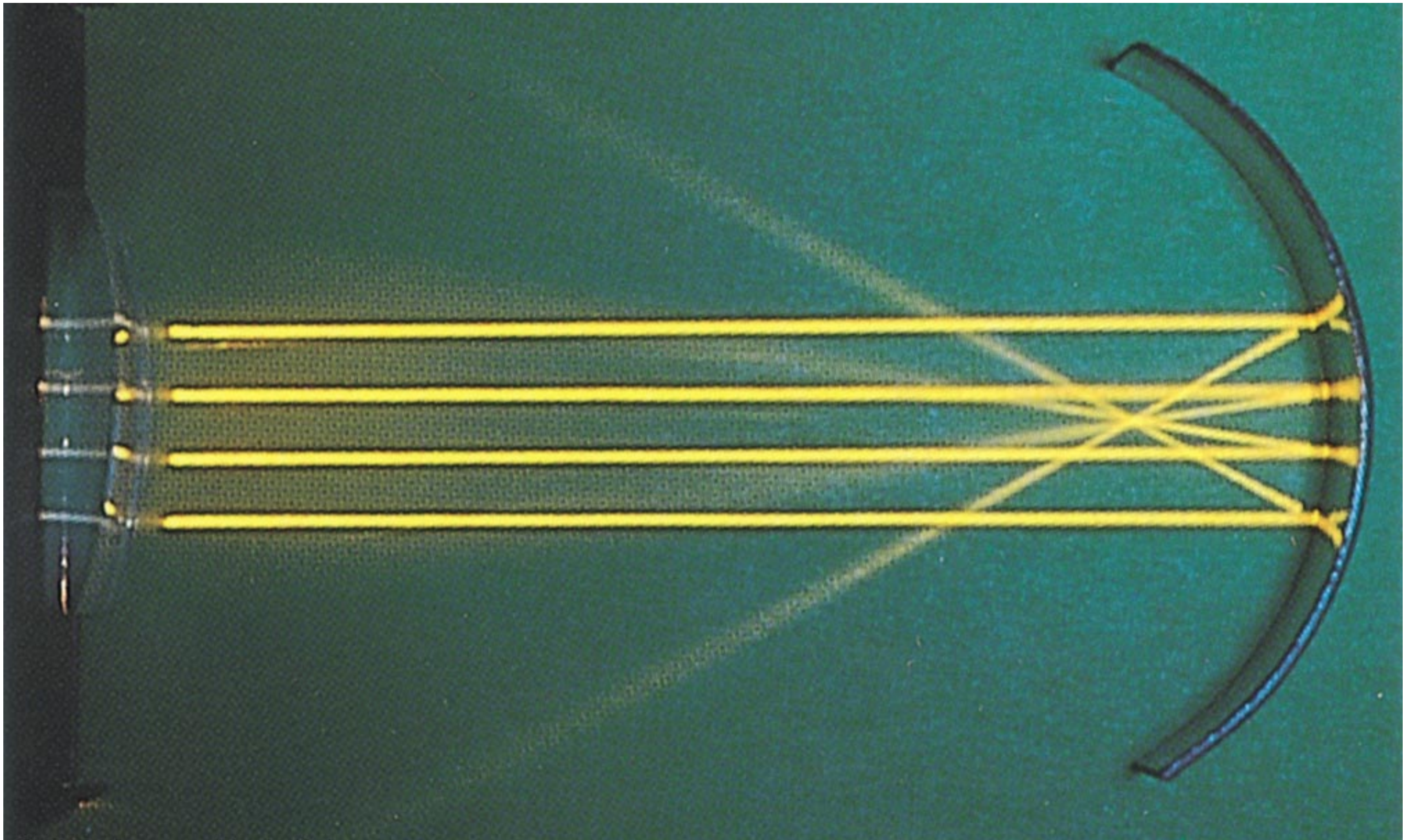
- Consider rays coming in from infinity (the object is very far away)
- The rays are parallel to the optical axis
- After reflection, they converge on point F
  - 1/p + 1/q = 2/R
  - If p=infinity, q=R/2=the focal length f



(a)

So we can rewrite the mirror equation as
1/p + 1/q = 1/f

Example



Hubble space telescope

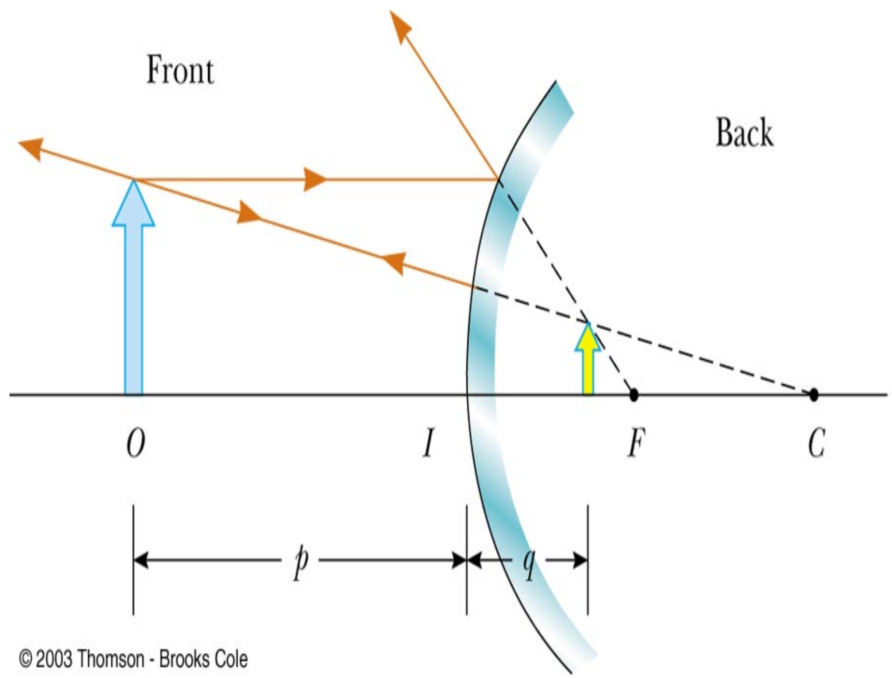
The mirror for the Hubble suffered from spherical aberration. The surface was ground very precisely, within 10 nm, but to the wrong curvature. Luckily, since it was ground so precisely, some corrective optics were installed that allowed the full resolution to be restored.

Hubble before/after pictures

Example of Hubble with right optics: Orion nebula

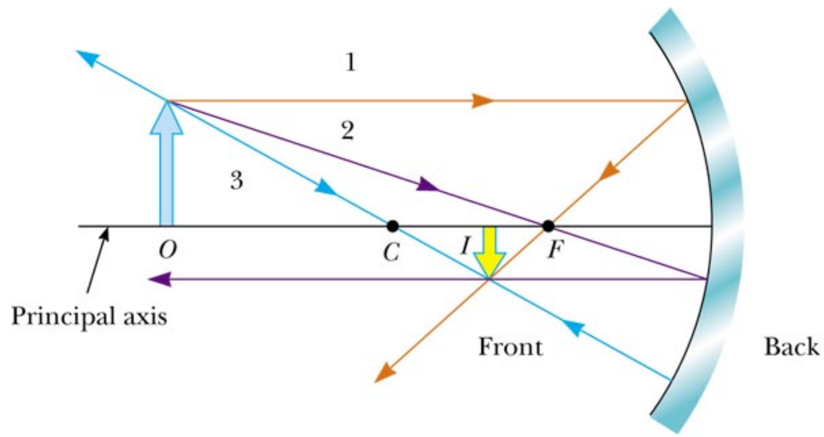
A spherical convex mirror

- Again, we do the ray-tracing thing
- Note that the rays appear to diverge from a point behind the mirror
- So it's a virtual (and upright) image being formed
- Mirror equation still applies



Ray diagrams

- It's convenient to draw 3 particular rays to determine the position and magnitude of an image
  - Ray 1 is drawn parallel to the principal axis and is reflected back through the focal point F
  - Ray 2 is drawn through the focal point. Thus, it is reflected parallel to the principal axis
  - Ray 3 is drawn through the center of curvature C and is reflected back on itself



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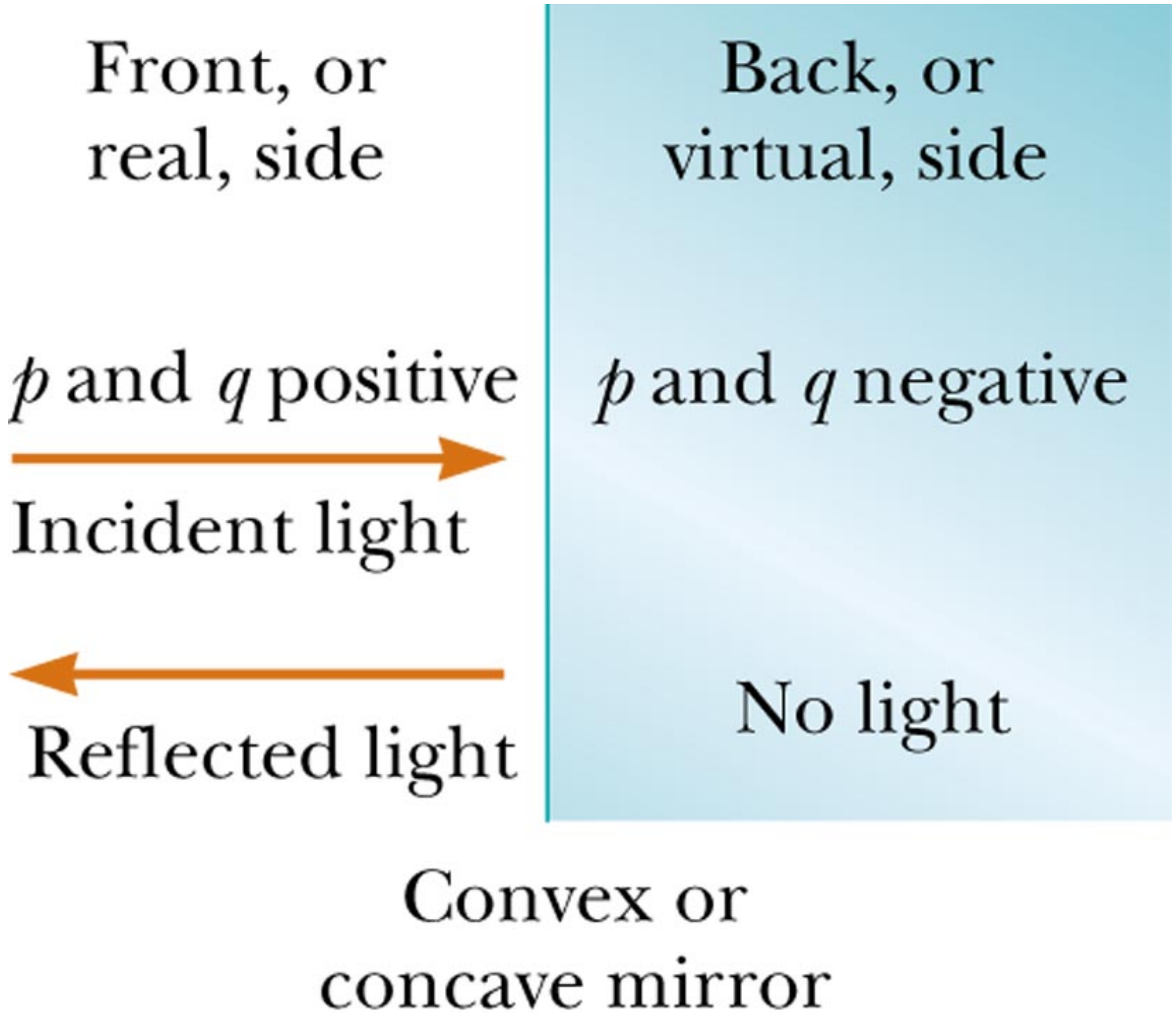
Definitions for mirrors



More definitions

TABLE 23.1 **Sign Conventions for Mirrors**

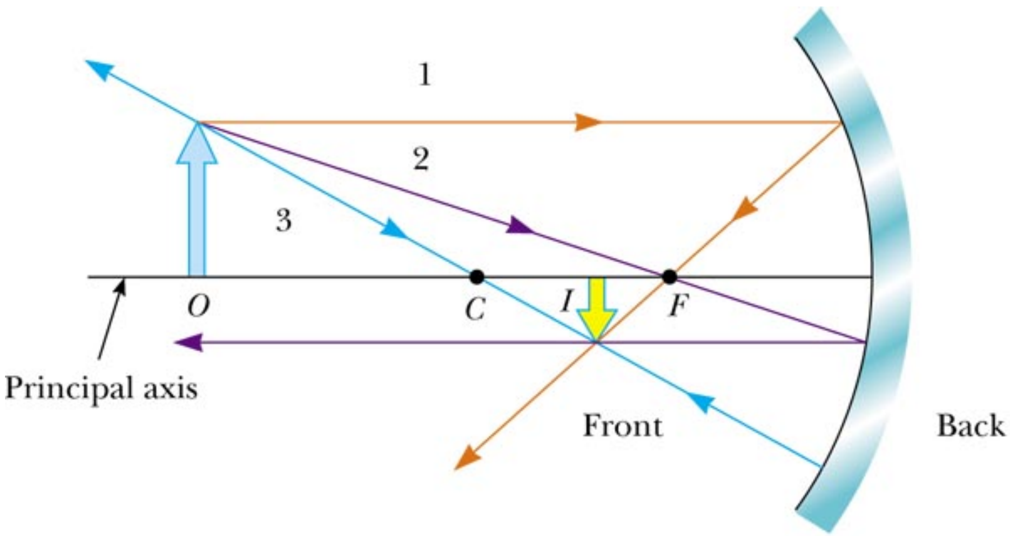
Quantity	Positive When	Negative When
Object location (p)	Object is in front of mirror	Object is behind mirror
Image location (q)	Image is ~~behind~~ in front of mirror	Image is ~~in front of~~ behind mirror
Image height (h')	Image is upright	Image is inverted
Focal length (f) and radius (R)	Mirror is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

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

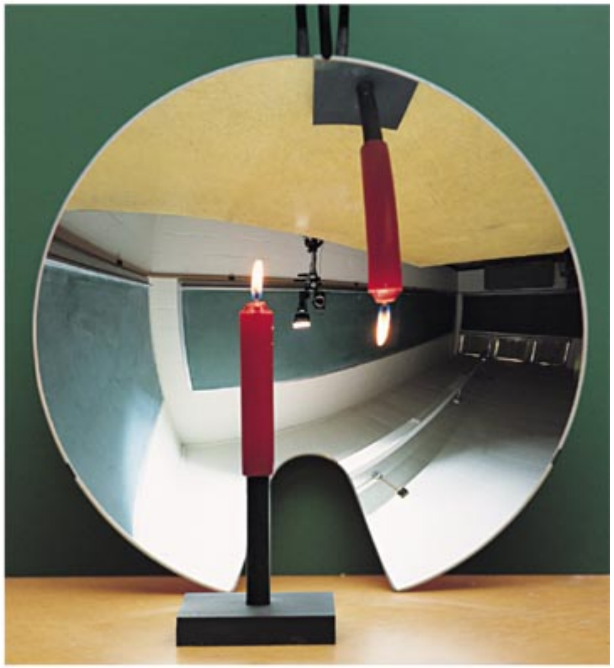
Note: no standard nomenclature for object/image distances.
p=o=s; q=i=s’

Case 1

Object is outside center of curvature of concave mirror



(a)



p is +; q is + (and smaller than p)

m = -q/p is negative and <1

Image is real, reduced and inverted

Case 2

Object is inside focal point of concave mirror

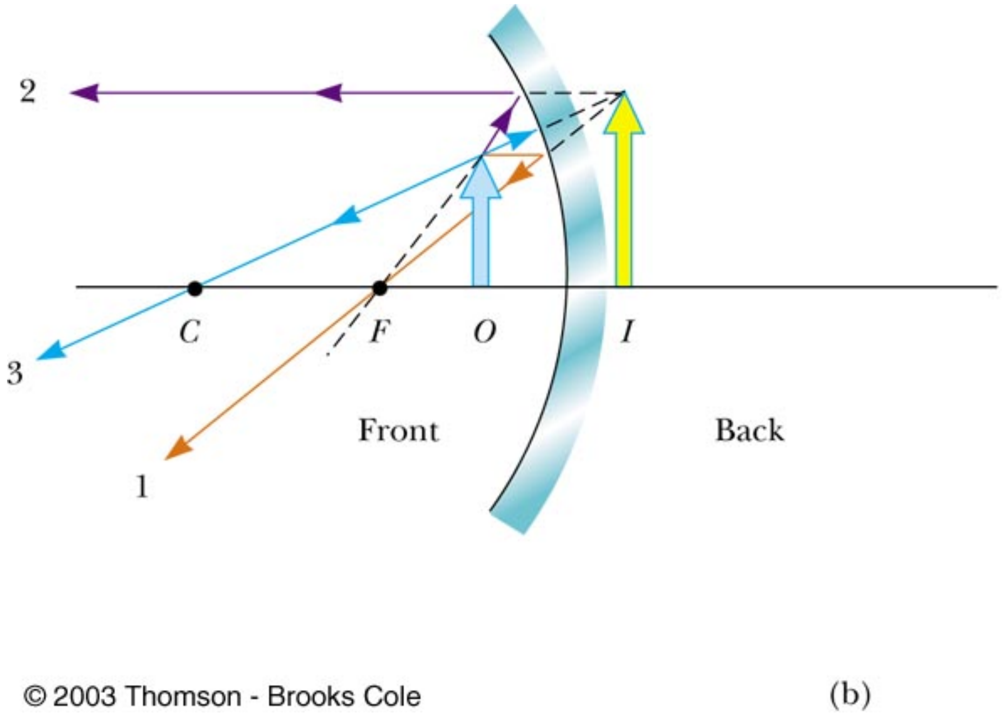
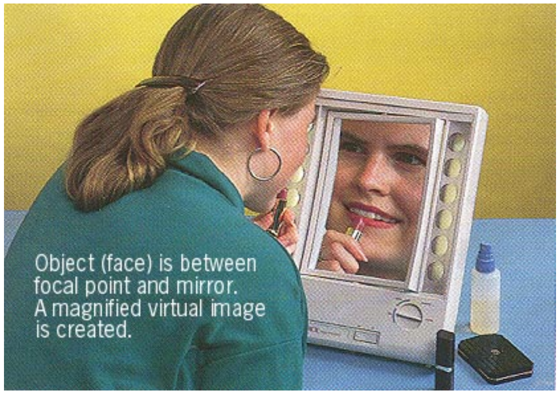


Image is virtual, upright and magnified.

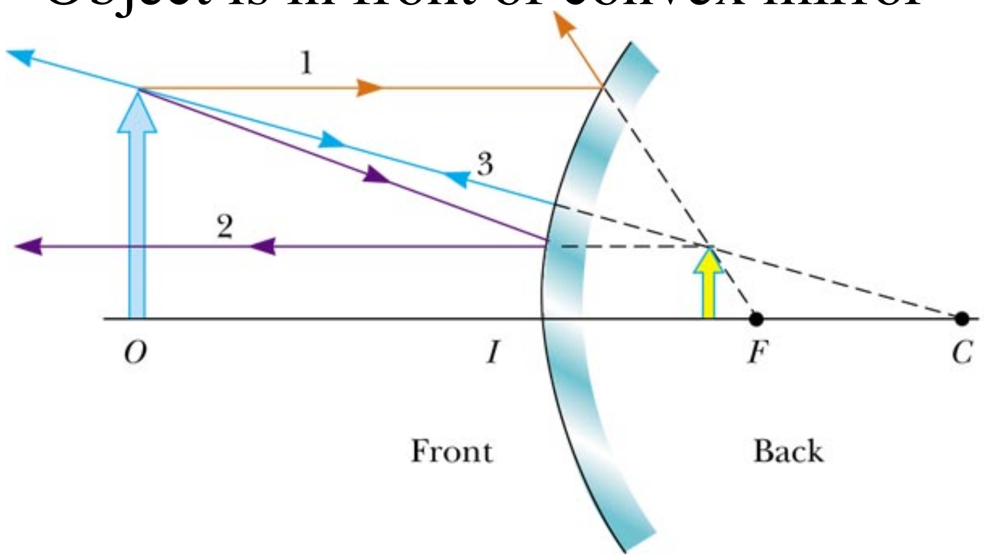
p is +; q is -

M = + and >1



Case 3

Object is in front of convex mirror



(c)

Image is virtual, upright and reduced in size

p is +; q is -

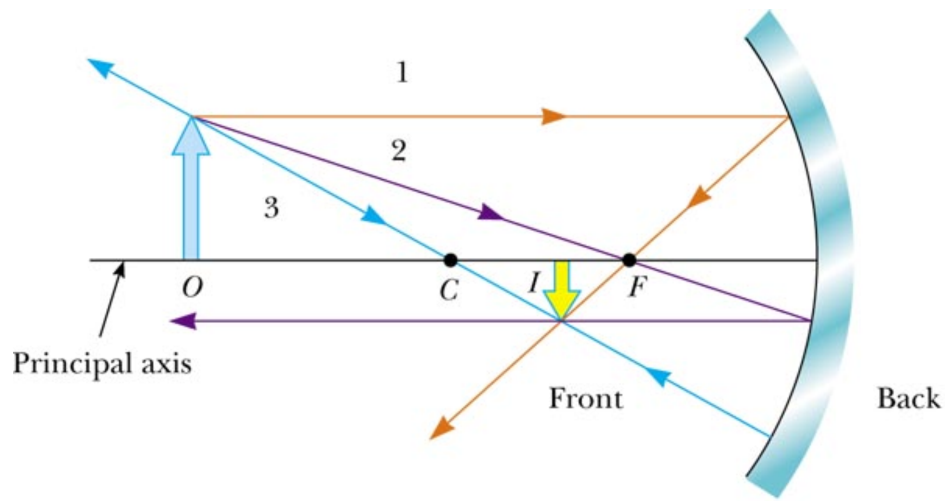
and < p

M = + and <1


OBJECTS IN MIRROR ARE
CLOSER THAN THEY APPEAR

Example

- A dime 40 cm away from, and on the optical axis of, a concave, spherical mirror produces an image 10 cm away from the mirror.
- If the dime is moved on the axis to 20 cm from the mirror, where will the image move? How large is the radius of curvature of the mirror?



You see an upright, magnified image of your face when you look into magnifying “cosmetic mirror.” The image is located

A. In front of the mirror’ s surface.
B. On the mirror’ s surface.
C. Behind the mirror’ s surface.
D. Only in your mind because it’ s a virtual image.

You see an upright, magnified image of your face when you look into magnifying "cosmetic mirror." The image is located

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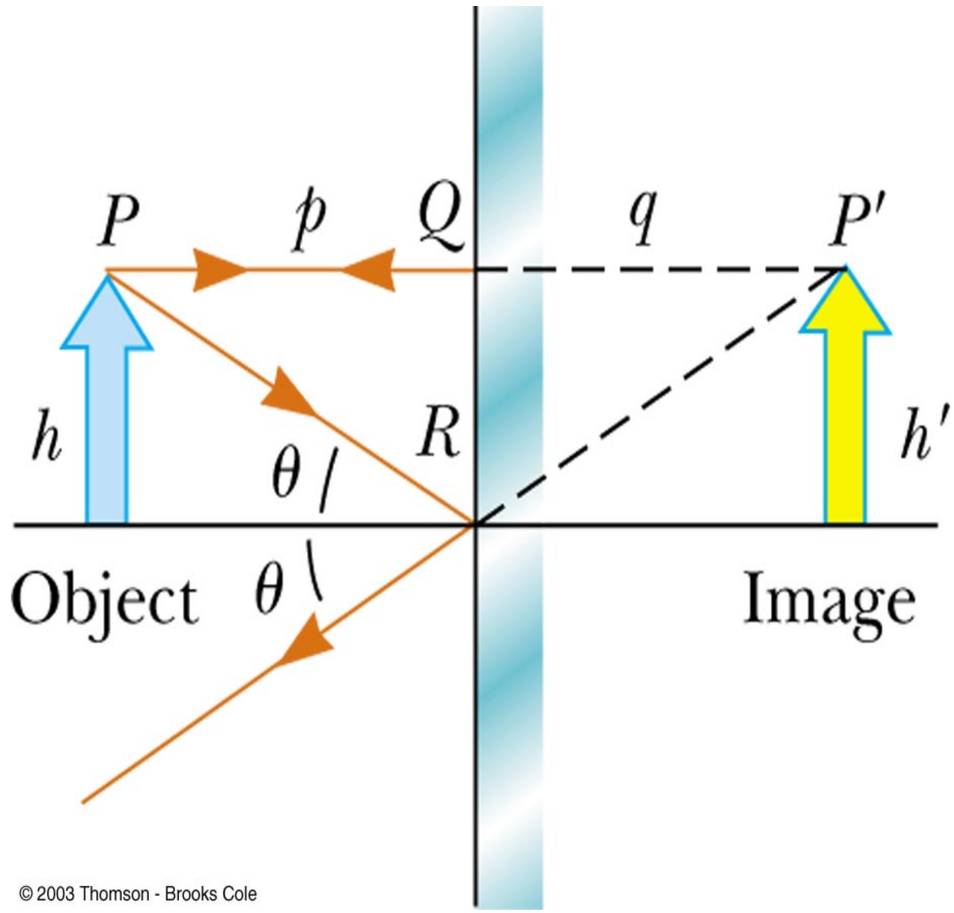
B. On the mirror' s surface.
✔ **C. Behind the mirror' s surface.**
D. Only in your mind because it' s a virtual image.

Flat mirror

- What about with a flat mirror?

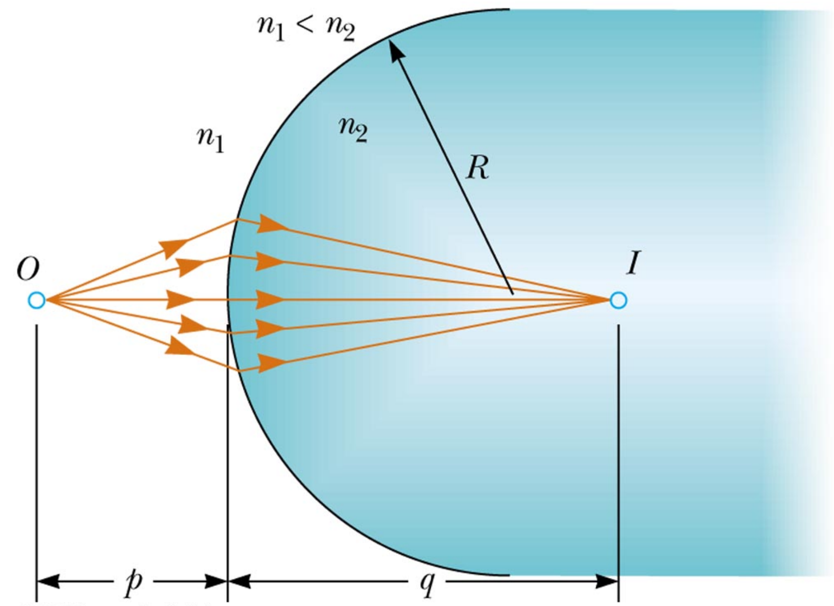
$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$

- In that case, f=infinity, 1/f=0, and q=-p



Refraction

- Suppose I have an interface between two media of indices of refraction n_1 and n_2
- Medium 2 (for example, glass) has the larger index of refraction and a spherical surface of radius R
- Consider the rays originating from point source O
- They are refracted at the interface and converge at the image point I
- Mirrors change the direction of light rays and create real or virtual images of objects
- Ditto with refraction
- Law of reflection is enough to derive the formulae for mirrors; Snell's law will do it for refracting surfaces



Focal point of a refracting surface

- Consider Ray 1 coming in parallel to the axis
- It refracts at the surface
- Snell's law is obeyed
  - $n_1 \sin\theta_1 = n_2 \sin\theta_2$
  - and since θ_1 and θ_2 are small

$$n_1\theta_1 \approx n_2\theta_2$$

Some geometry

$$\phi_1 = \theta_1$$

$$\phi_2 = \theta_1 - \theta_2$$

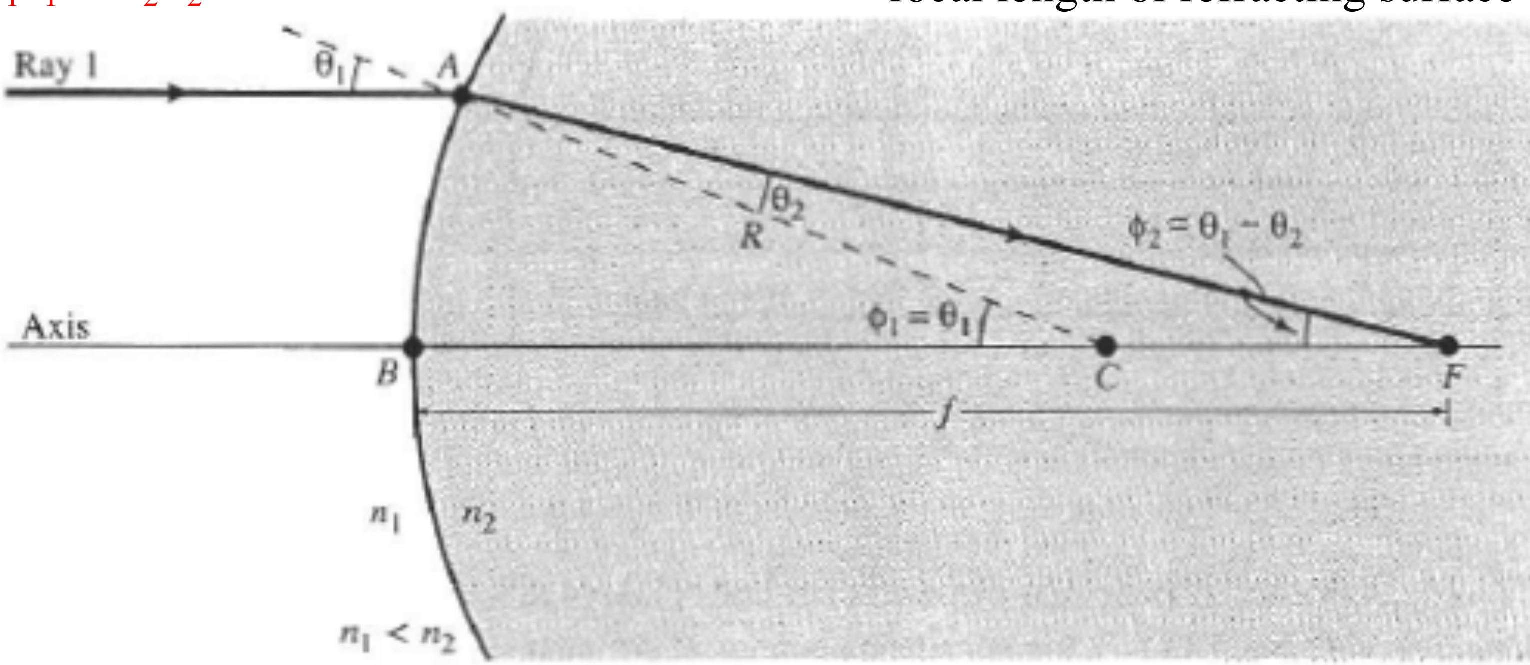
$$BF(\theta_1 - \theta_2) \approx AB$$

$$AB \approx R\theta_1$$

$$BF \approx \frac{R\theta_1}{\theta_1 - \theta_2} \approx \frac{Rn_2}{n_2 - n_1}$$

$$f = \left(\frac{n_2}{n_2 - n_1}\right) R$$

focal length of refracting surface



Relation between object, image and focal length

- Some simple geometry

$$\theta_2 = \beta - \alpha$$
$$\theta_1 = \beta + \gamma$$

- So

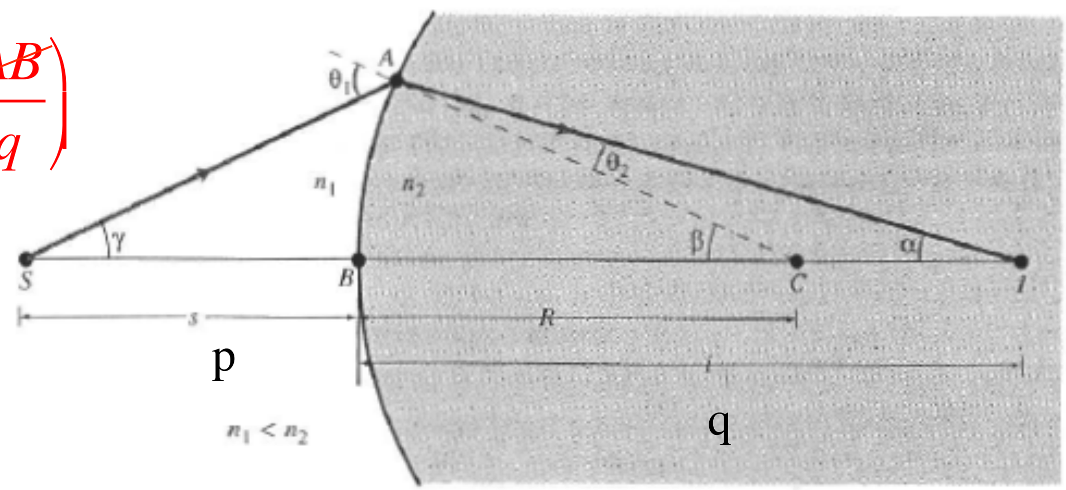
$$n_1(\beta + \gamma) = n_2(\beta - \alpha)$$

- AB=Rβ and AB=pγ=qα; thus

$$n_1\left(\frac{\cancel{AB}}{R} + \frac{\cancel{AB}}{p}\right) = n_2\left(\frac{\cancel{AB}}{R} - \frac{\cancel{AB}}{q}\right)$$

- So we can write

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

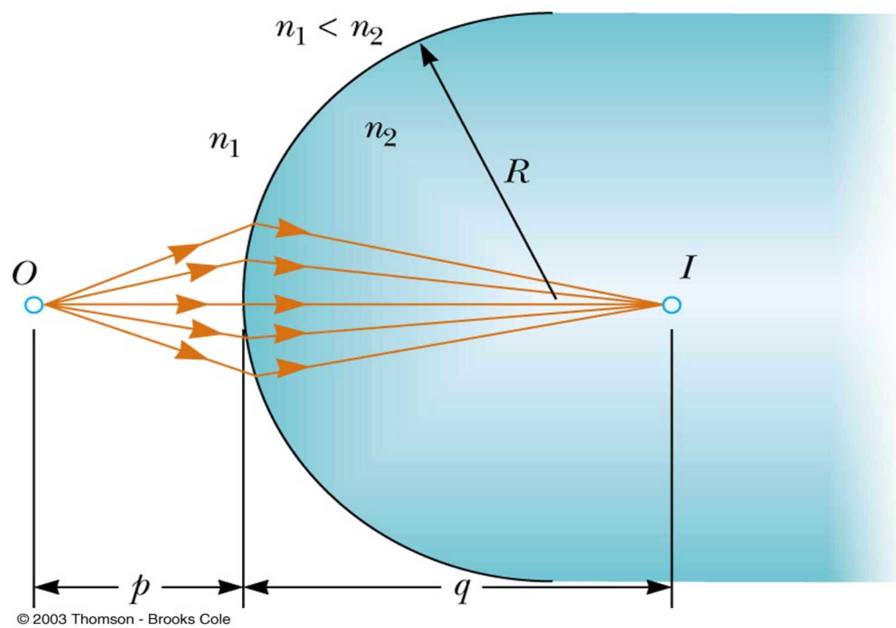


Please, not more sign conventions!

TABLE 23.2 Sign Conventions for Refracting Surfaces

Quantity	Positive When	Negative When
Object location (p)	Object is in front of surface	Object is in back of surface
Image location (q)	Image is in back of surface	Image is in front of surface
Image height (h')	Image is upright	Image is inverted
Radius (R)	Center of curvature is in back of surface	Center of curvature is in front of surface

Note that real images are formed on the opposite side from which the light comes (opposite of the case for mirrors)
So sign conventions are opposite as well.
Sorry.



Flat refracting surfaces

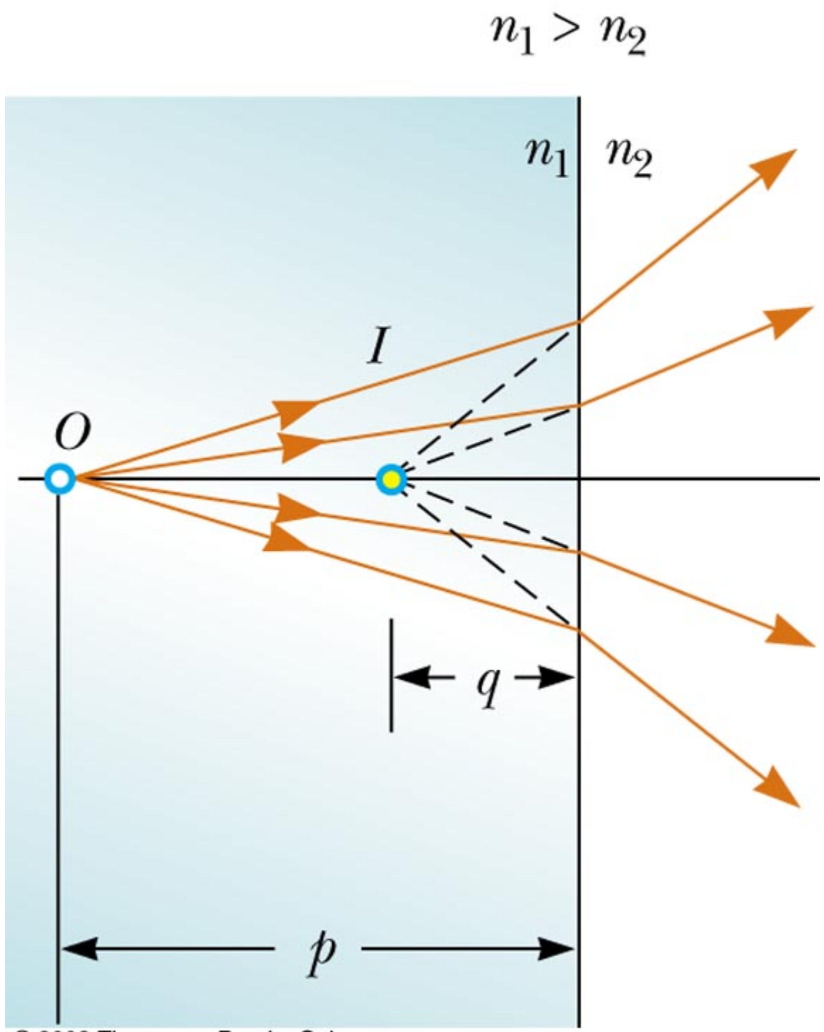
- If the refracting surface is flat, then R approaches infinity

$$\frac{n_1}{p}+\frac{n_2}{q} = \frac{n_2-n_1}{R}$$

$$\frac{n_1}{p} =- \frac{n_2}{q}$$

$q = -n_2/n_1\ p$

- The image of a flat refracting surface is on the same side of the surface and the image distance is smaller than the object distance



A fish in water

- Apparent depth of fish in water is less than real depth
  - $n_1 = 1.33$; $n_2 = 1$
  - $q = d$
  - $q = -n_2/n_1\ p$
  - $q = -1/1.33\ d = -0.752d$