PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 19 (Chapter 36):

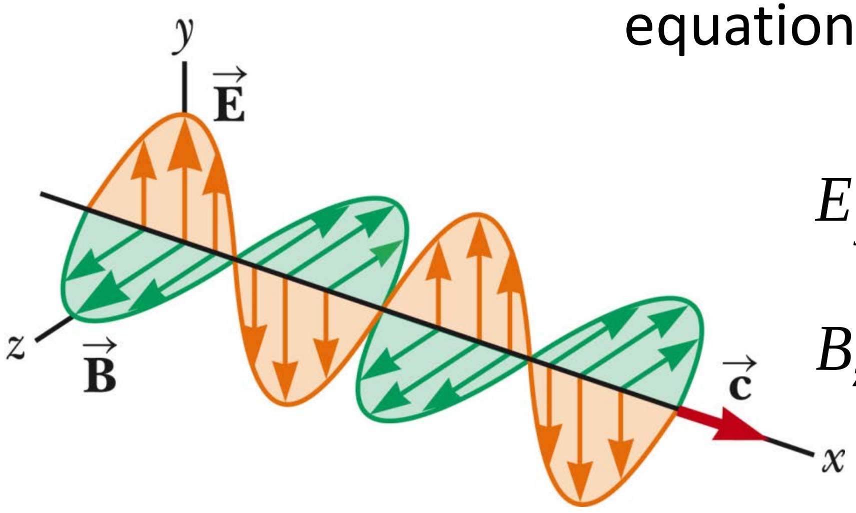
Optical properties of light

1. Mirror reflections

2. Images in flat and spherical mirrors

13	03/08/2012	Faraday's law	31.1-31.5	31.12,31.23,31.40	03/20/2012
	03/13/2012	*No class (Spring Break)*			
	03/15/2012	*No class (Spring Break)*			
14	03/20/2012	Induction and AC circuits	32.1-32.6	32.4,32.20,32.43	03/22/2012
15	03/22/2012	AC circuits	33.1-33.9	33.8,33.24,33.71	03/27/2012
16	03/27/2012	Electromagnetic waves	34.1-34.3	34.3,34.10,34.13	03/29/2012
17	03/29/2012	Electromagnetic waves	34.4-34.7	34.22,34.46,34.57	04/03/2012
18	04/03/2012	Ray optics Evening exam	35.1-35.8	35.20,35.27,35.35	04/10/2012
19	04/05/2012	Image formation Evening exam	36.1-36.4	36.8,36.31,36.42	04/10/2012
20	04/10/2012	Image formation	36.5-36.10	36.52,36.54,36.64	04/12/2012
21	04/12/2012	Wave interference	37.1-37.6		
22	04/17/2012	Diffraction	38.1-38.6		
23	04/19/2012	Quantum Physics	40.1-42.10		

Plane wave solution to Maxwell's equations in dielectric medium with *v=c/n*:



$$E_y = E_y(x,t) = E_{\max}\cos(k(x-vt))$$

$$B_z = B_z(x,t) = \frac{E_{\max}}{v}\cos(k(x-vt))$$

Additional comments:

For this solution, the **y** direction is called the **polarization** direction (the E field orientation)

This is a periodic wave, where $k=2\pi/\lambda$ and λ represents the wavelength and the frequency of the wave is $kc/n=\omega=2\pi f$.

Index of refraction n:

In vacuum:

$$\varepsilon_0$$

$$\mu_0$$

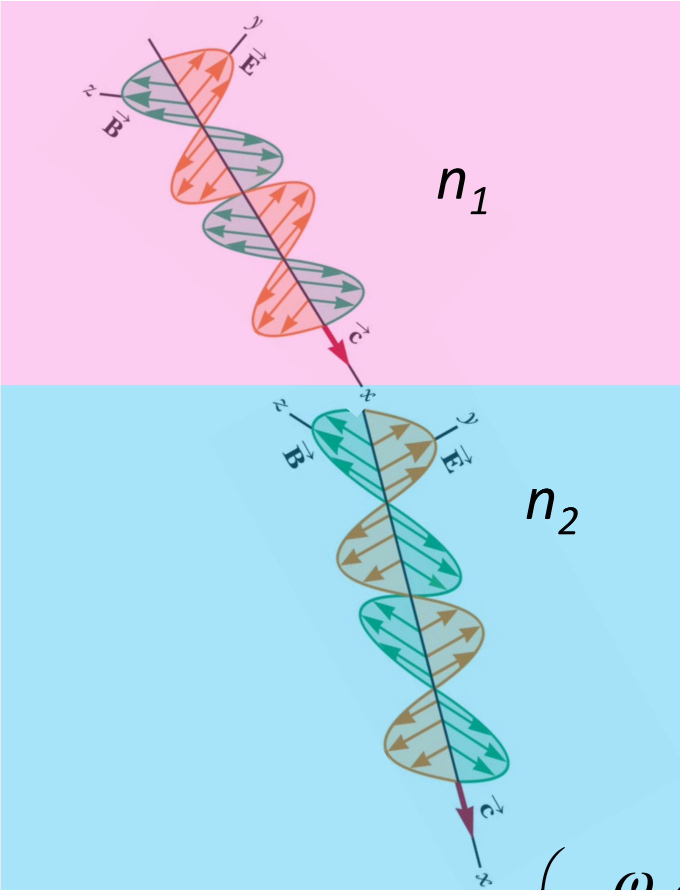
$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

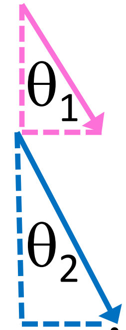
In medium:

$$\varepsilon \geq \varepsilon_0$$

$$\mu \geq \mu_0$$

$$v = \frac{1}{\sqrt{\varepsilon \mu}} \equiv \frac{c}{n}$$





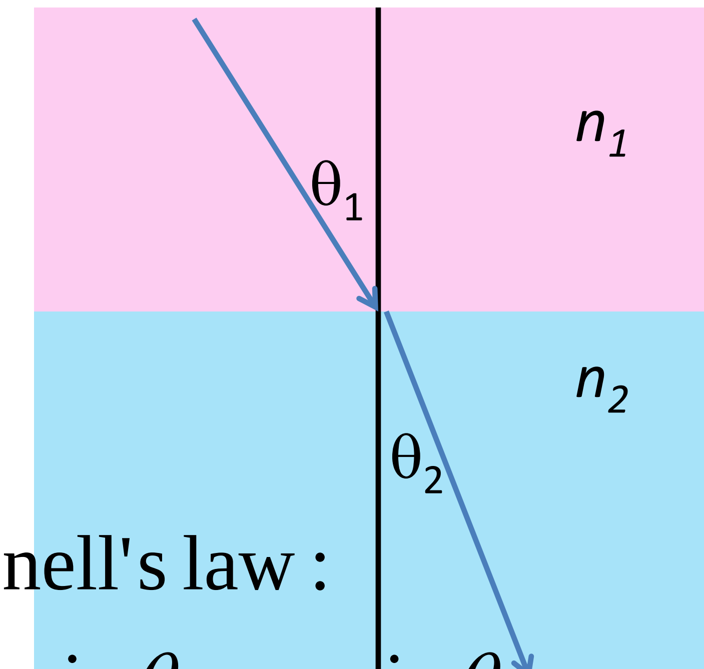
$$n_1 \frac{\omega}{c} \sin\theta_1 =$$

$$n_2 \frac{\omega}{c} \sin\theta_2$$

⇐ **E** and **B** continuous at boundary

$$E_y = E_y(x,t) = E_{\max} \cos\left(n\frac{\omega}{c}(x-ct) \right)$$

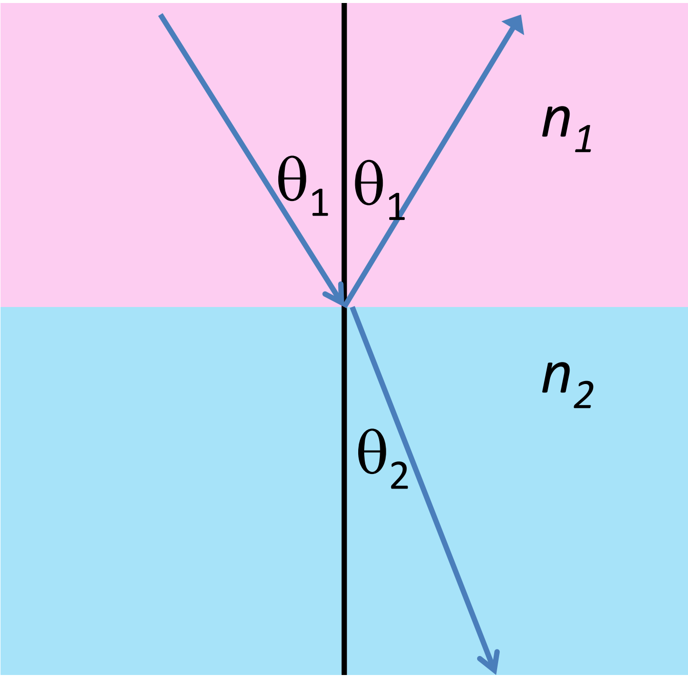
$$B_z = B_z(x,t) = (E_{\max}/c) \cos\left(n\frac{\omega}{c}(x-ct) \right)$$



Snell's law :

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

General case – reflection and refraction



For E polarized in scattering plane

$$\frac{E_2}{E_0} = \frac{2n_1 n_2 \cos\theta_1}{n_2^2 \cos\theta_1 + n_1 n_2 \cos\theta_2}$$

$$\frac{E_{1R}}{E_0} = \frac{n_2^2 \cos\theta_1 - n_1 n_2 \cos\theta_2}{n_2^2 \cos\theta_1 + n_1 n_2 \cos\theta_2}$$

For E polarized out of scattering plane

$$\frac{E_2}{E_0} = \frac{2n_1 \cos\theta_1}{n_1 \cos\theta_1 + n_2 \cos\theta_2}$$

$$\frac{E_{1R}}{E_0} = \frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2}$$

For $\theta_1 = 0 = \theta_2$

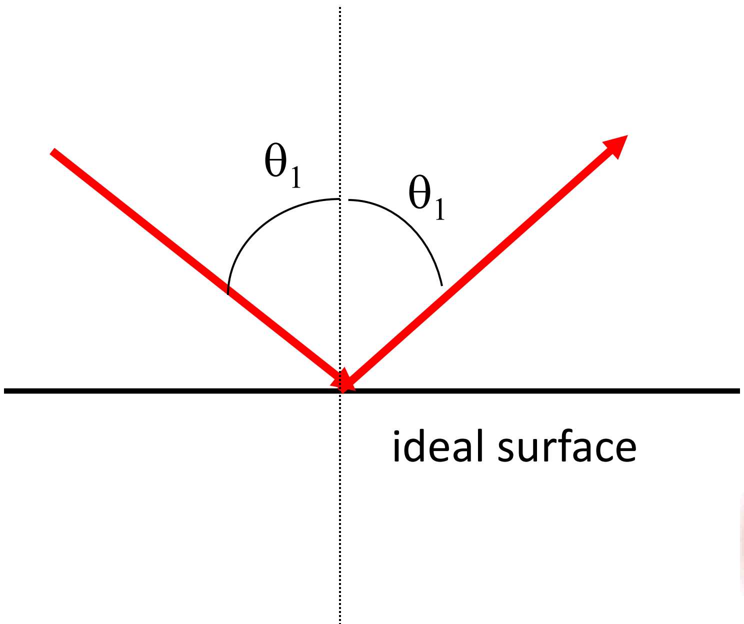
$$\frac{E_2}{E_0} = \frac{2n_1}{n_2 + n_1}$$

$$\frac{E_{1R}}{E_0} = \frac{n_2 - n_1}{n_2 + n_1}$$

If $n_2 \rightarrow \infty$, then:

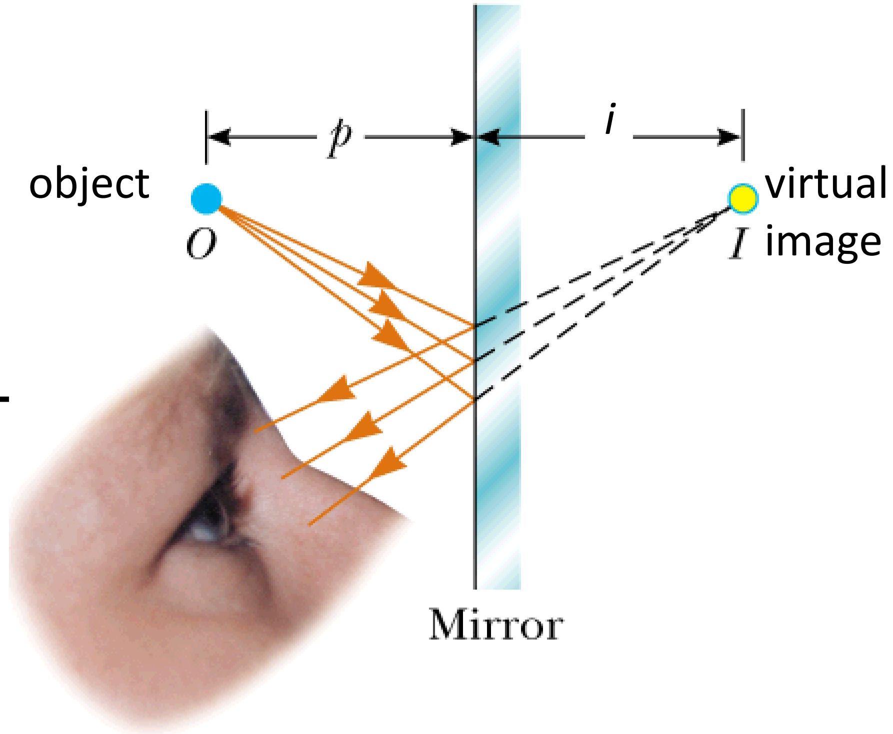
$$\frac{E_2 / E_0}{E_0} \rightarrow 0 \text{ and } \frac{E_{1R} / E_0}{E_0} \rightarrow 1$$

Images formed from reflected light:



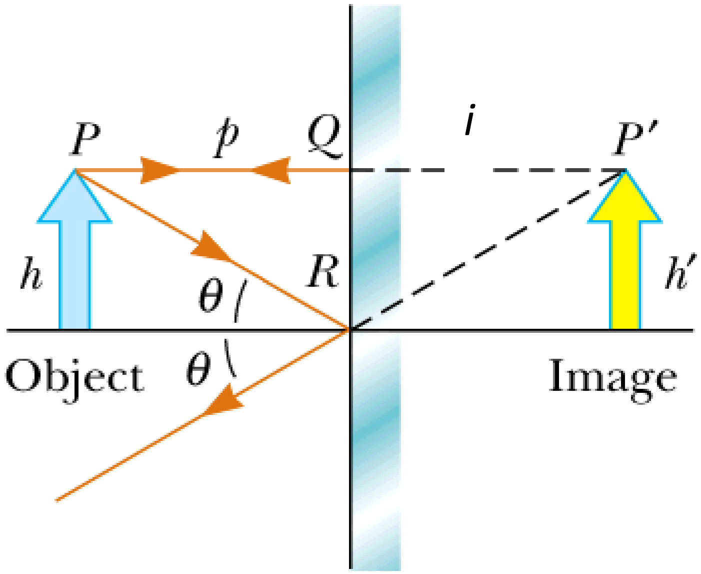
Notation for image position:

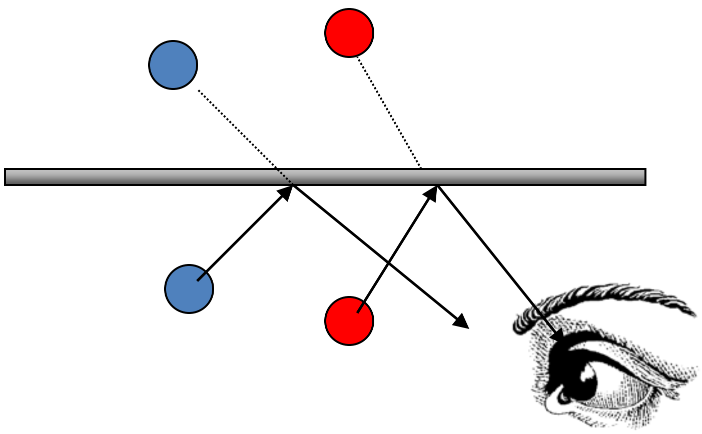
$i \leftrightarrow q$



Analysis of mirror image

Mirror symmetry:





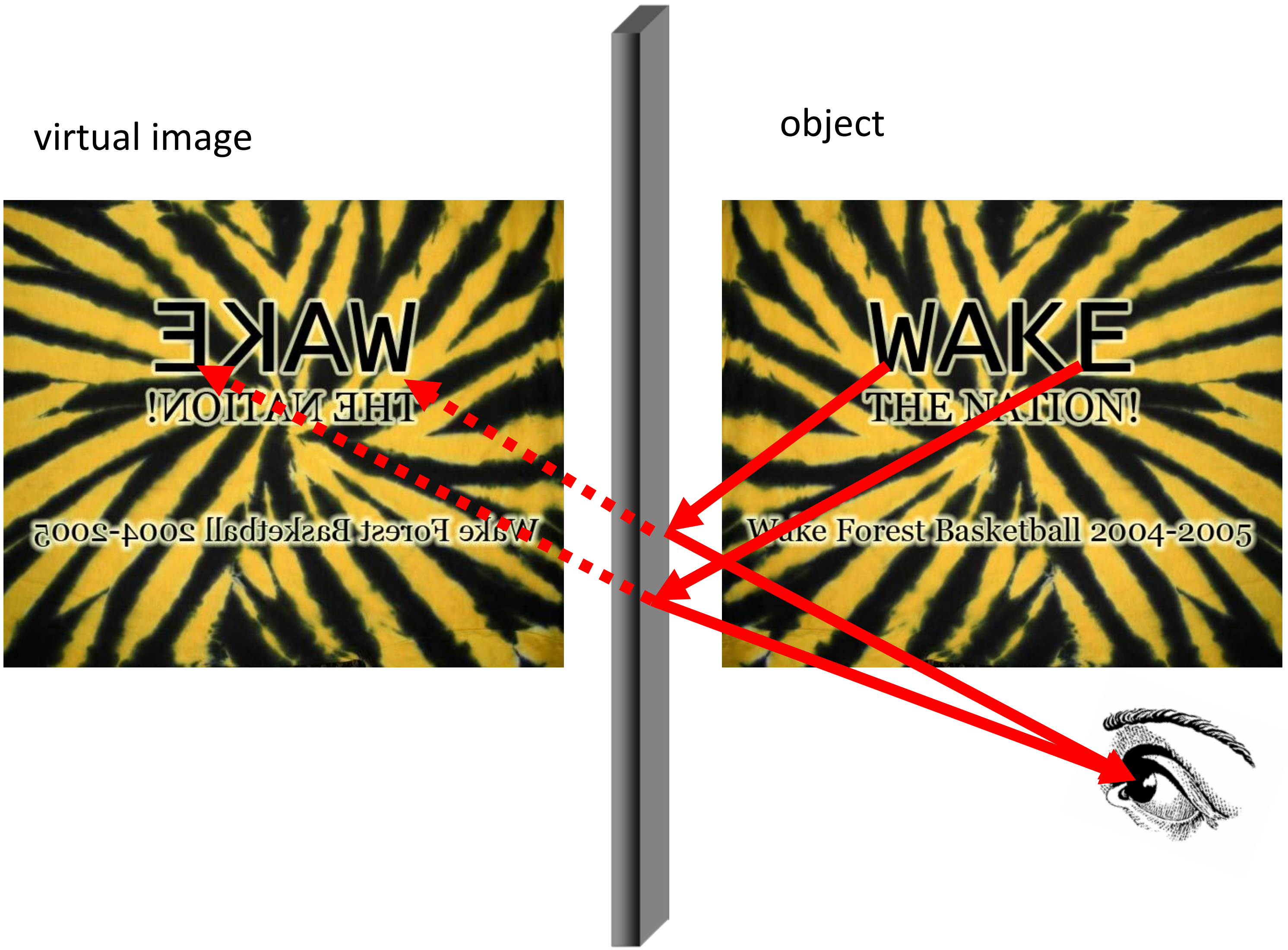
Using geometry:

$i = p \quad h = h'$

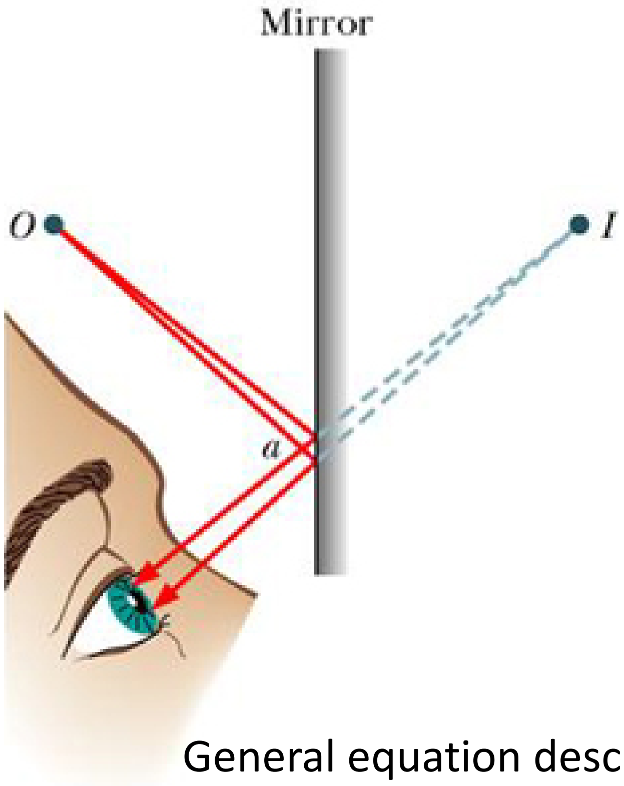
Terminology:

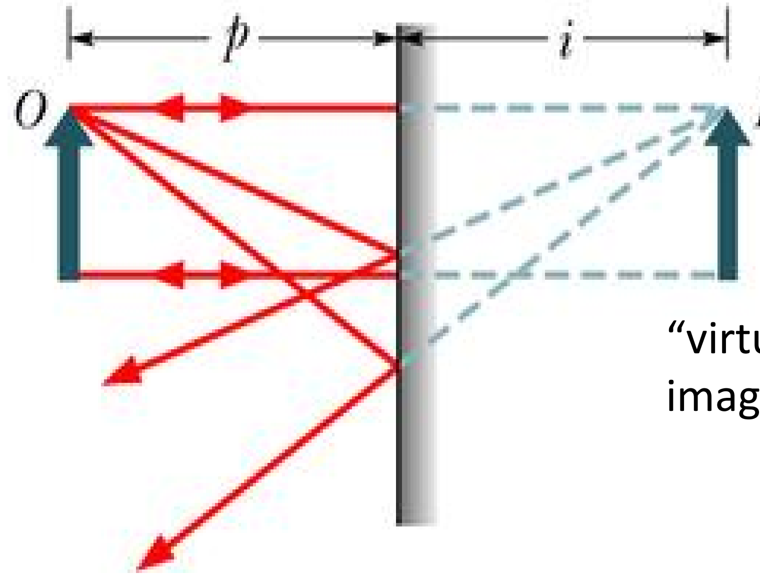
Virtual image -- perceived image but no light can be detected at the location of the virtual image

Real image - - light can detected at the location of the real image


virtual image
object
WAKE

Summary of geometric optics of plane mirror





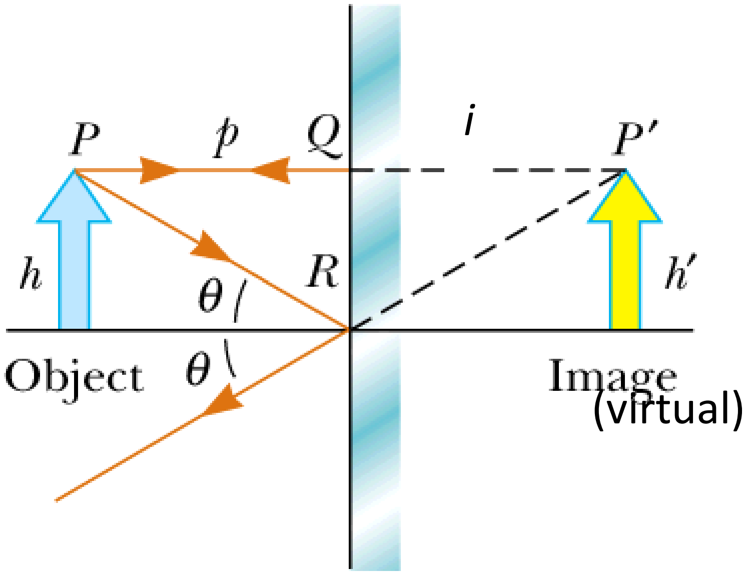
"virtual" image

In this case: $i = -p; \quad f = \infty$

General equation describing object and image positions:

$$\text{Mirror equation:} \quad \frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

Analysis of image from plane mirror



Some details:

By convention,

$i < 0$ for virtual image

$$\frac{1}{i} + \frac{1}{p} = 0 = \frac{1}{\infty}$$

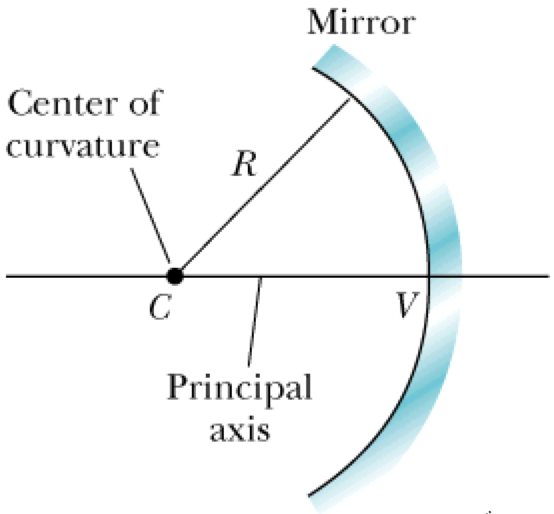
Geometrical relationships

$|i| = p \quad h = h'$

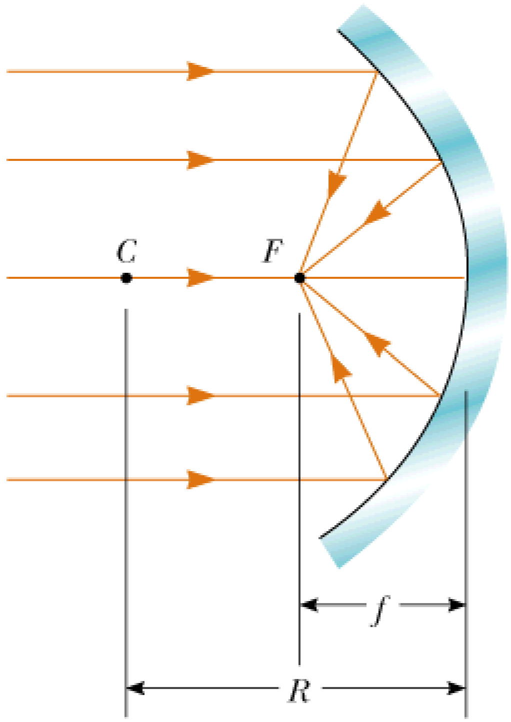
Magnification

$$M \equiv \frac{\text{Image height}}{\text{Object height}} = \frac{h'}{h}$$

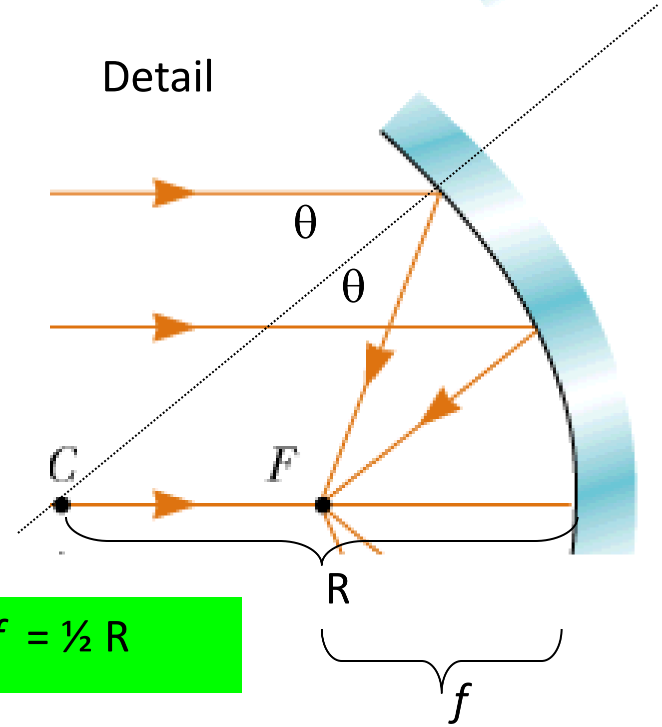
Spherical mirrors -- concave



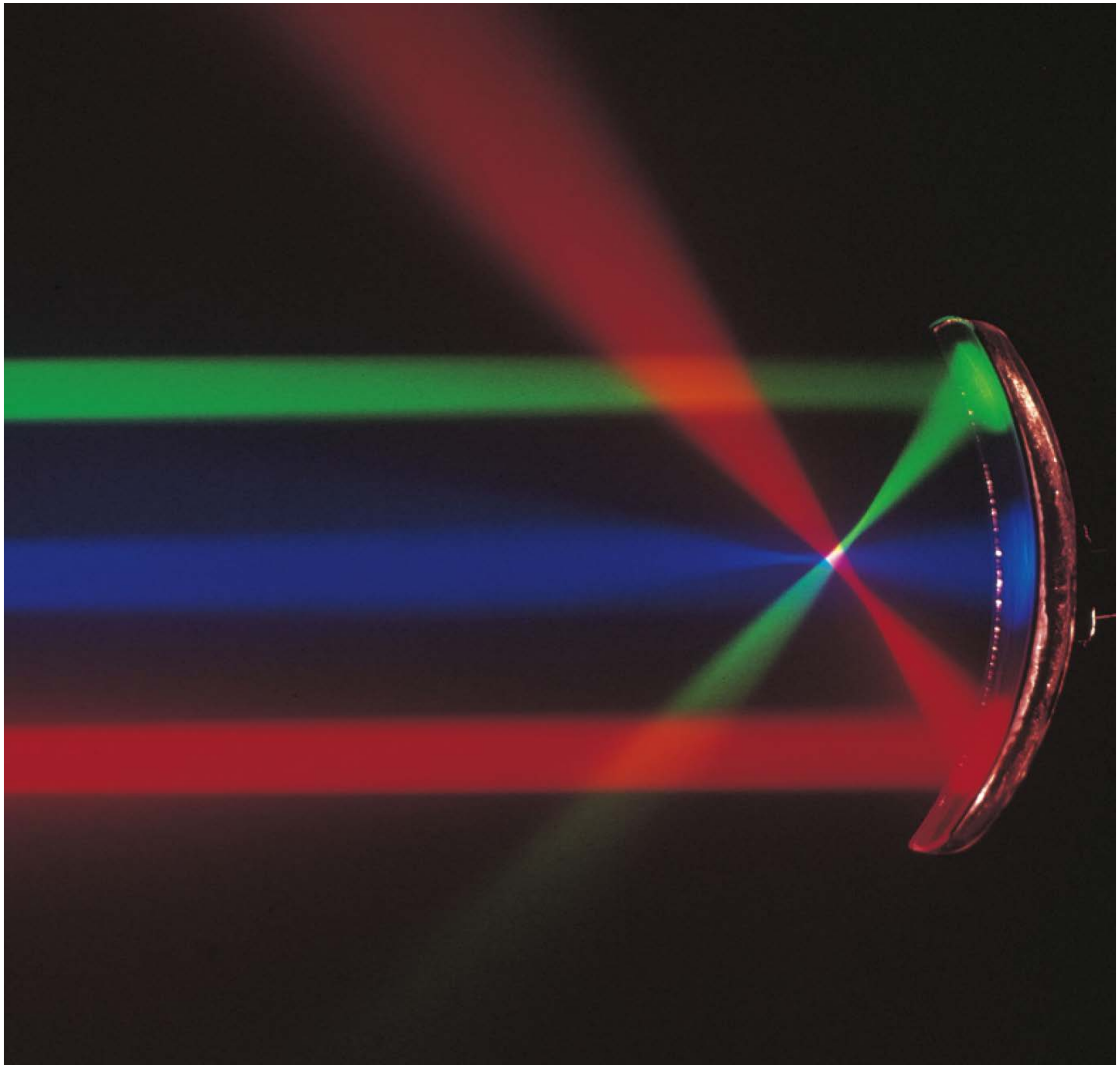
Reflection of parallel light rays:



Detail



$f = \frac{1}{2} R$



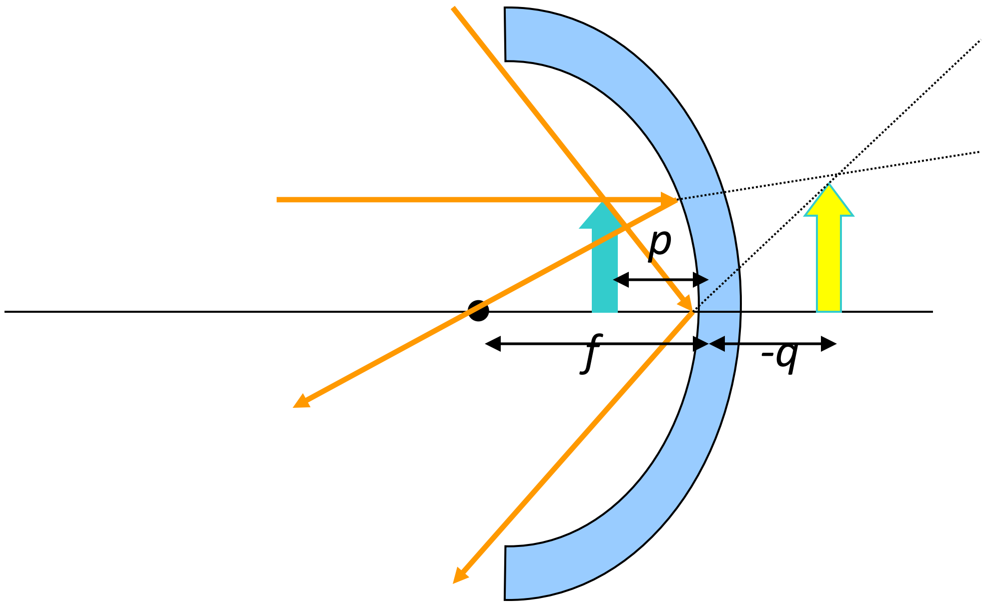
Why does this satellite-dish look like a concave mirror?

A. Because it is.
B. It doesn't – not shiny enough.

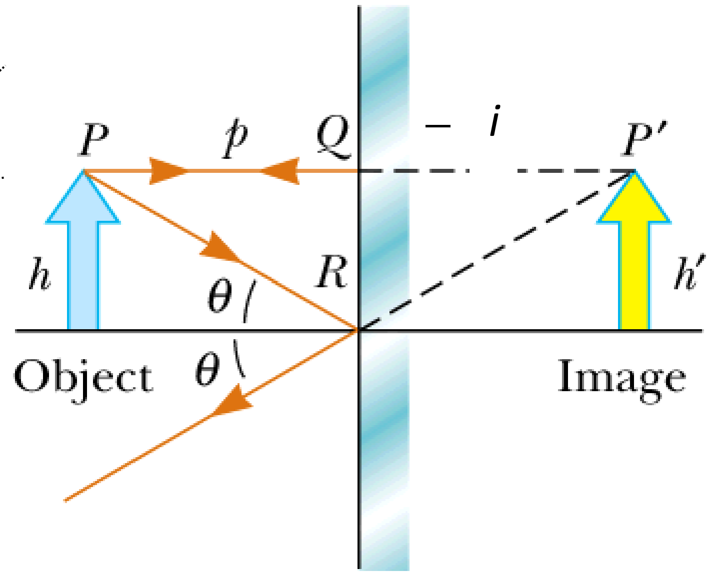
Where is the receive placed relative to the radius of curvature R?

A. Placed at R.
B. Placed at R/2.

Image formed in concave mirror:



Plane mirror:



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

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

Example: f = 4 cm

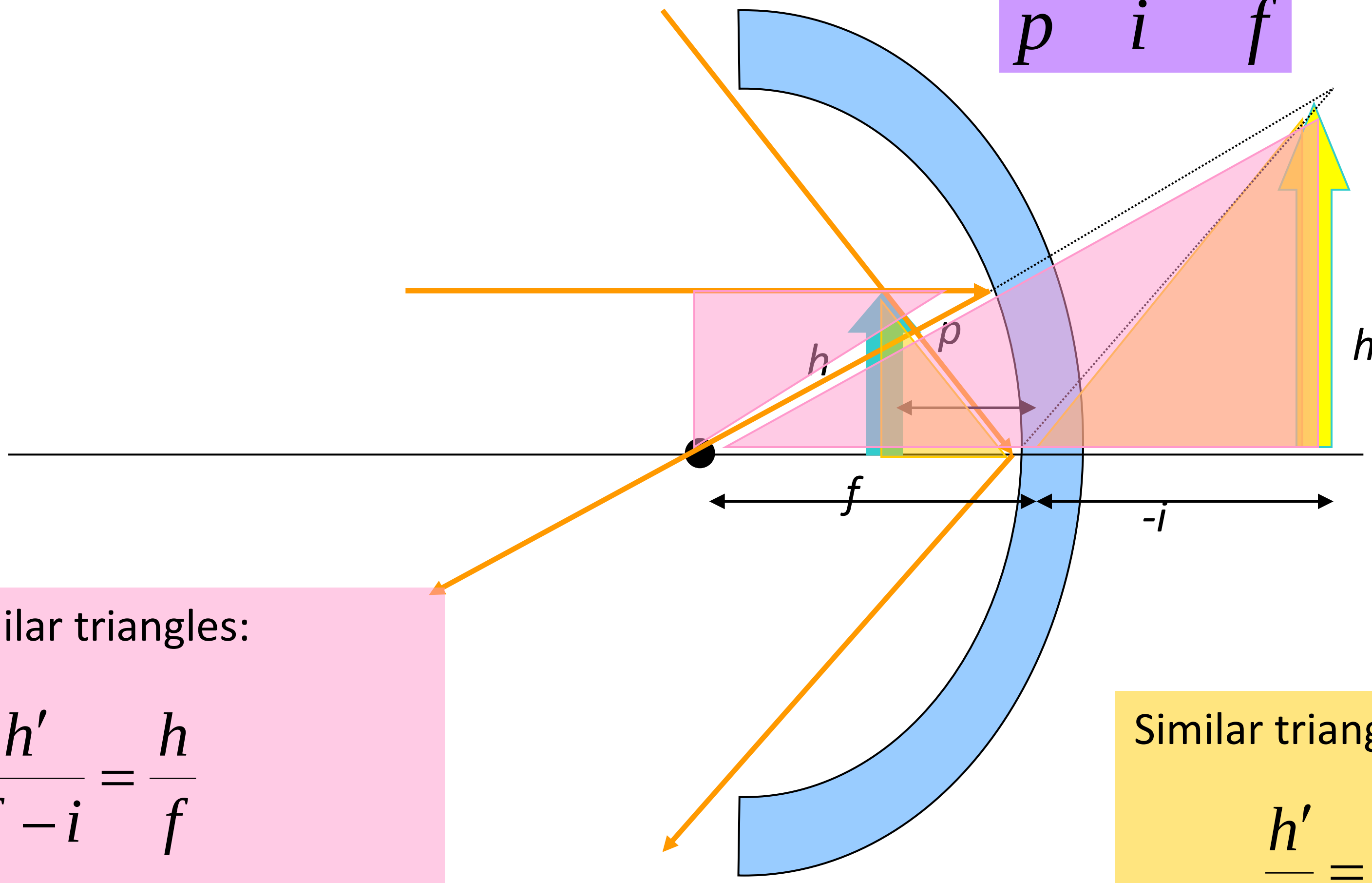
p = 1 cm

i = -1.33 cm

$$M=\frac{-i}{p}=\frac{1.33}{1}=1.33$$

“Proof” of mirror equation:

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



Similar triangles:

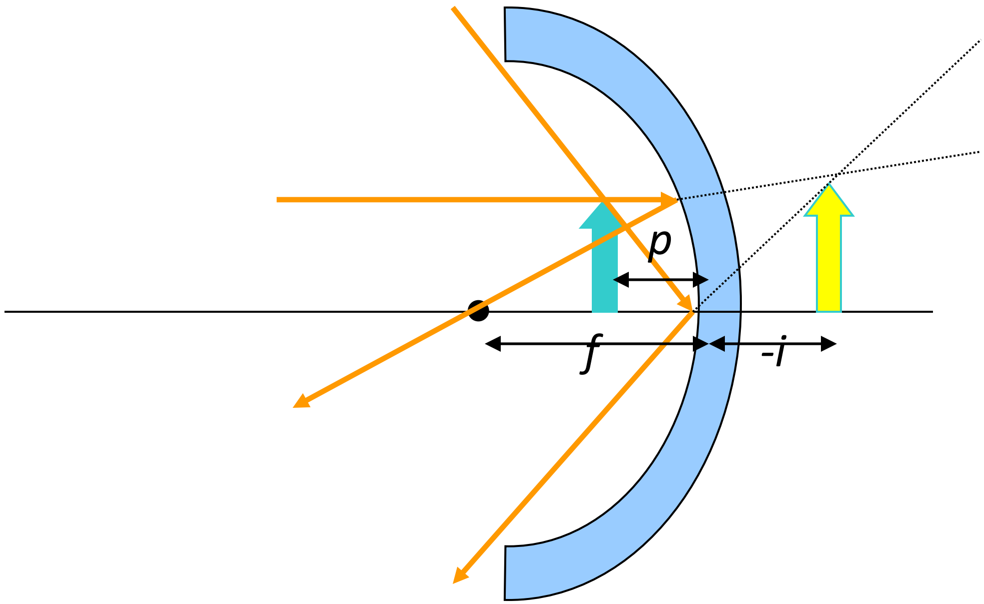
$$\frac{h'}{f-i}=\frac{h}{f}$$

$$\Rightarrow \frac{h'}{h}=\frac{f-i}{f}=\frac{-i}{p}$$

Similar triangles:

$$\frac{h'}{h}=\frac{-i}{p}$$

Image formed by concave mirror:



General result for virtual image formed by concave mirror

$p < f$

image is upright and increased in size

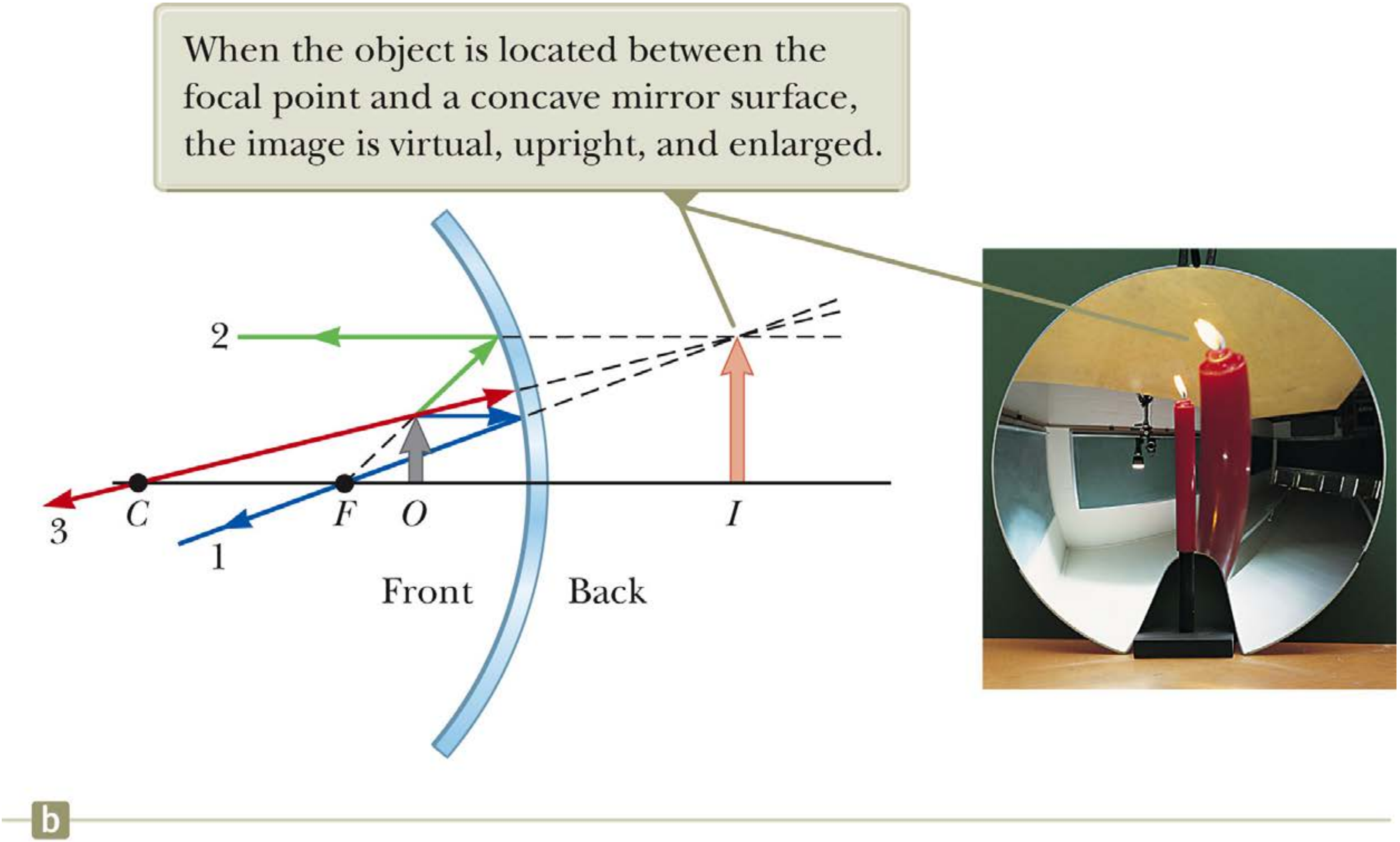
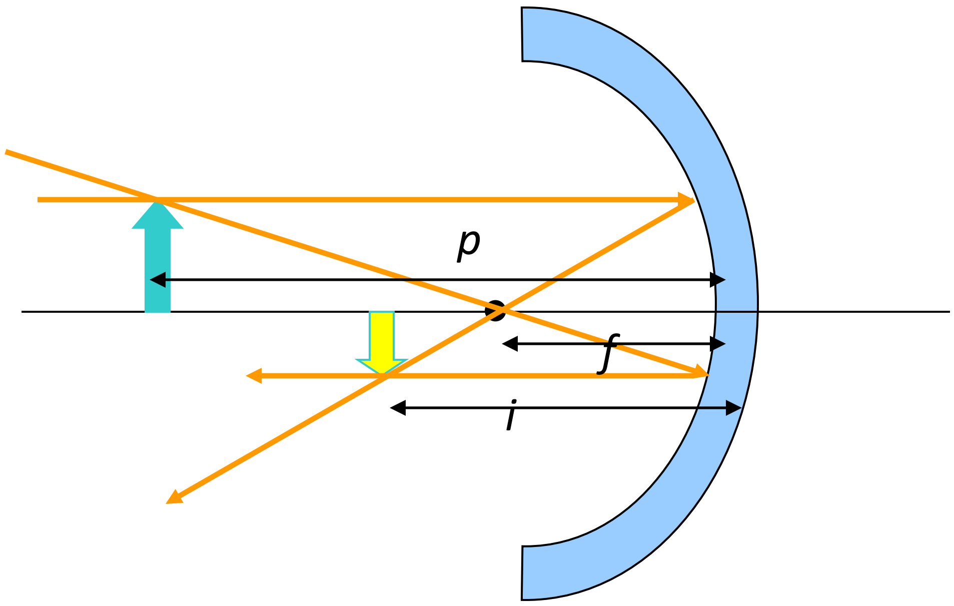

When the object is located between the focal point and a concave mirror surface, the image is virtual, upright, and enlarged.
2
3
C
F
O
I
1
Front
Back
b

Image formed by concave mirror:



Example: *f* = 4 cm

p = 10 cm

i = 6.67 cm

$$M = \frac{-i}{p} = \frac{-6.67}{10} = -0.667$$

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

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

When the object is located so that the center of curvature lies between the object and a concave mirror surface, the image is real, inverted, and reduced in size.

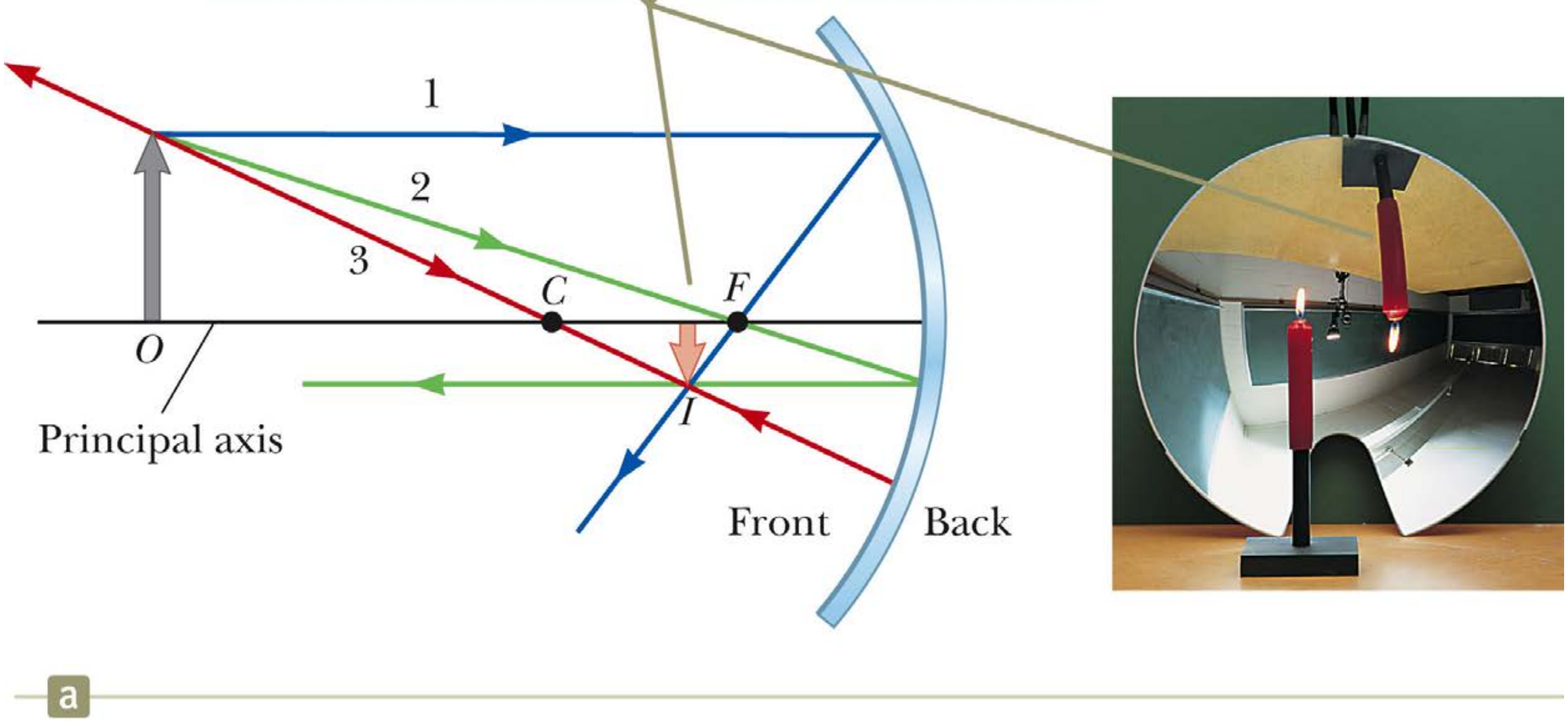
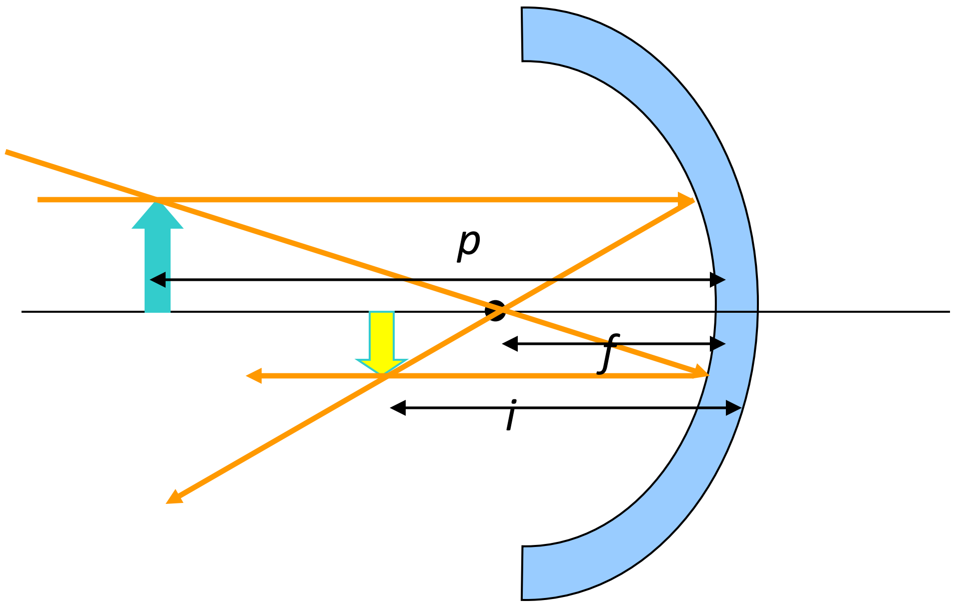


Image formed by concave mirror:



General result for real image formed by concave mirror

$p > f$

image is upside down

Is image always reduced in size?

(A) yes (B) no

Convex mirror

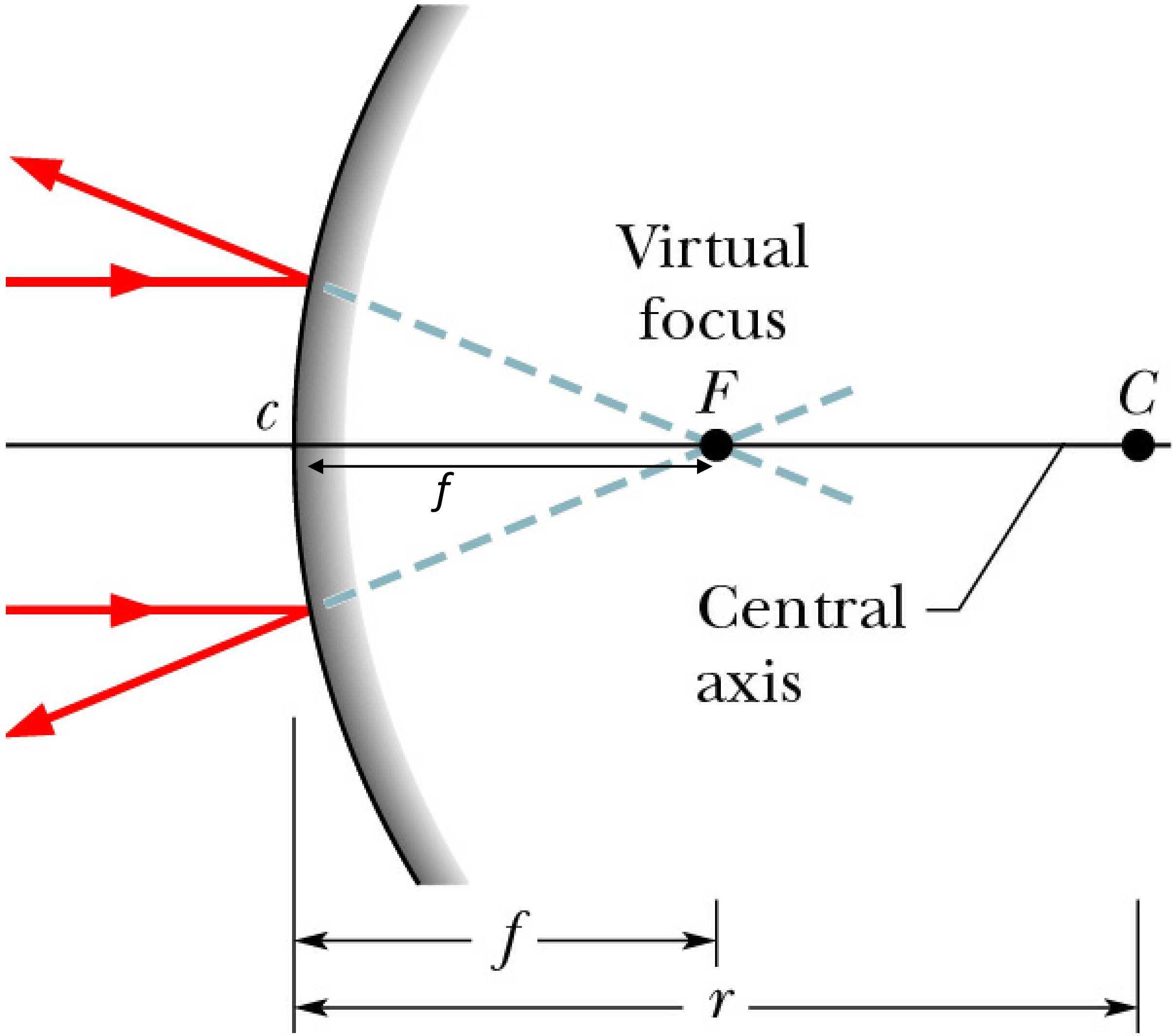
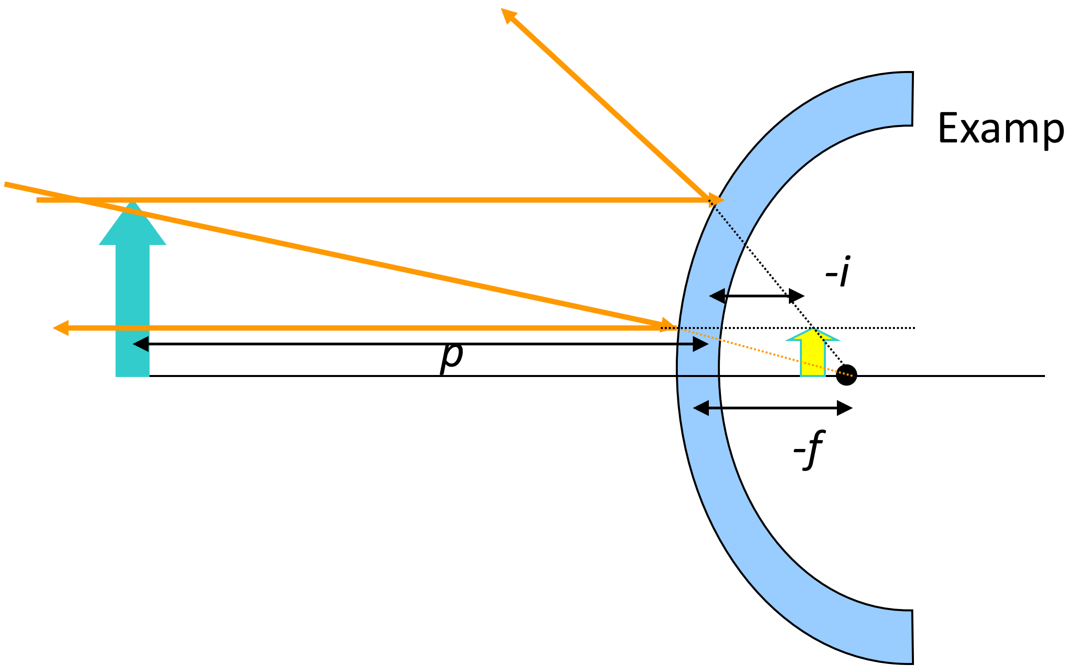


Image formed by convex mirror:



Example: f = -4 cm

p = 16 cm

i = -3.2 cm

$$M = \frac{-i}{p} = \frac{3.2}{16} = 0.2$$

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

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

General result for virtual image formed by convex mirror:

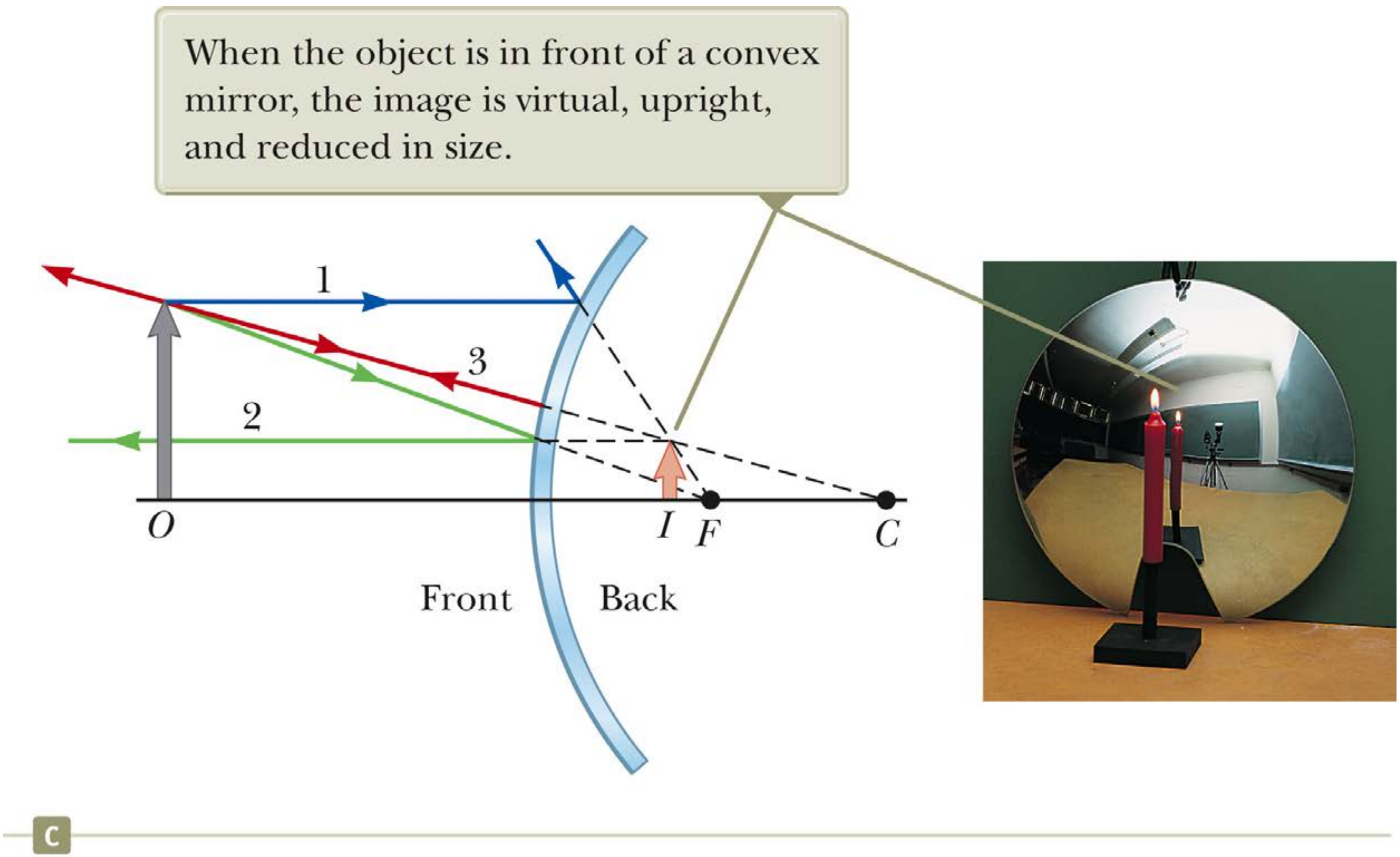
image is upright and decreased in size

Can the image formed by a convex mirror ever be *increased* in size ($|M|>1$)?

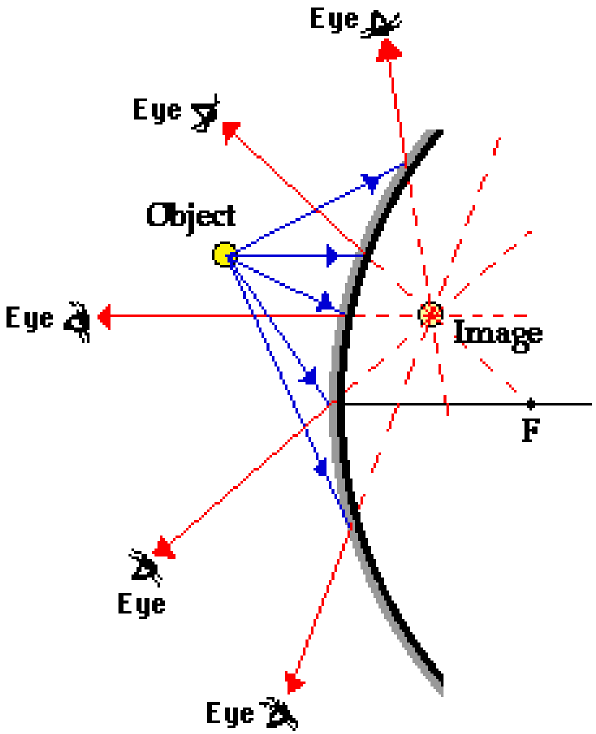
(A) yes (B) no

Is it possible to form a real image with a convex mirror?

(A) yes (B) no


When the object is in front of a convex mirror, the image is virtual, upright, and reduced in size.
1
3
2
O
I
F
C
Front
Back
C

Convex mirror used for surveillance:



http://www.physicsclassroom.com/class/refln/u13l4a.cfm

Suppose that you were behind the steering wheel and saw this image in your rear-view mirror. Which of these is likely to be true?

A. The truck is closer to you than it appears.
B. The truck is further from you than it appears.
C. Don’t change lanes just in case.