PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 24100

Electricity & Optics

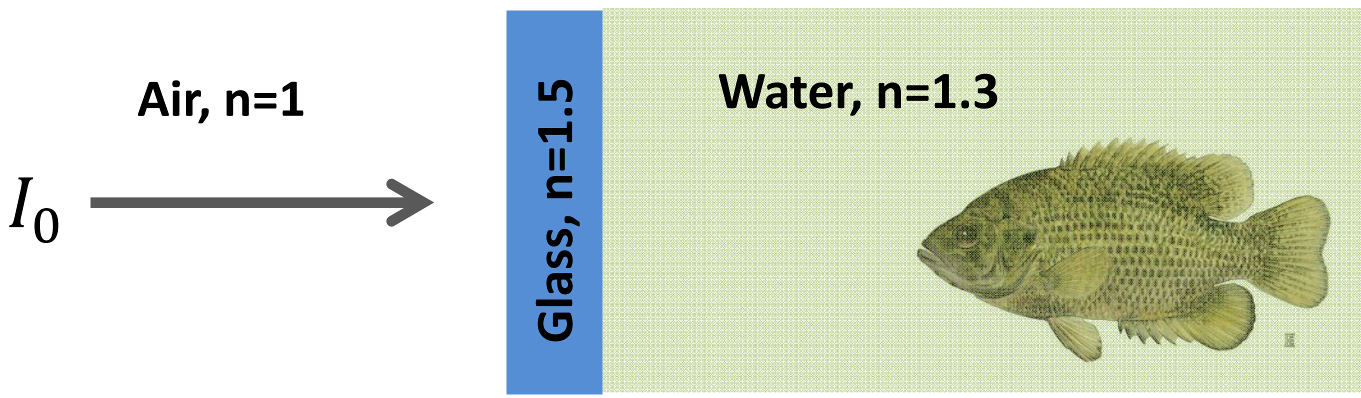
Lecture 24 – Chapter 32 sec. 1,2

Fall 2012 Semester

Matthew Jones

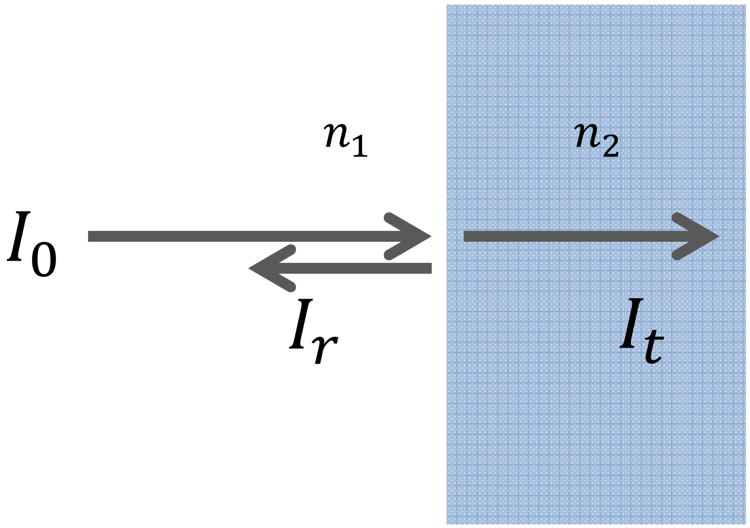
Question

- Compare how much light is reflected from a window, or from the side of a fish tank?



(a) More from the fish tank
(b) Less from the fish tank
(c) The same from both

Reflected Intensity

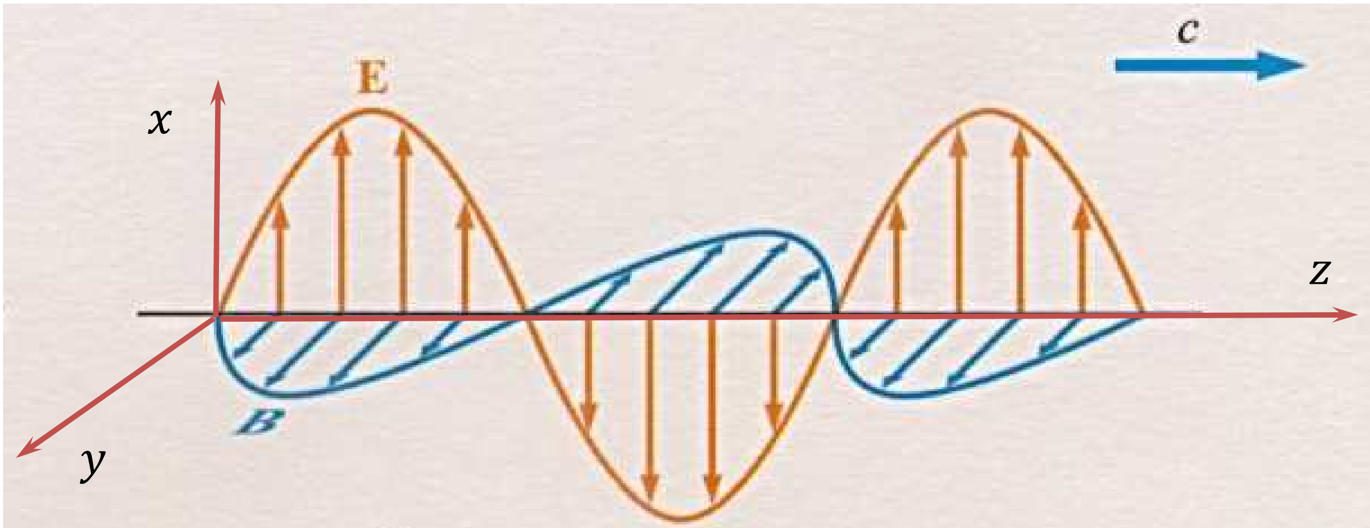


$$I_r = I_0 \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

- More light is reflected when the difference between indices of refraction is greater.
- Light reflected from the air-glass interface is the same for a fish tank and for a window.
- The window has an air-glass interface on the other side but the fish tank has an air-water interface:

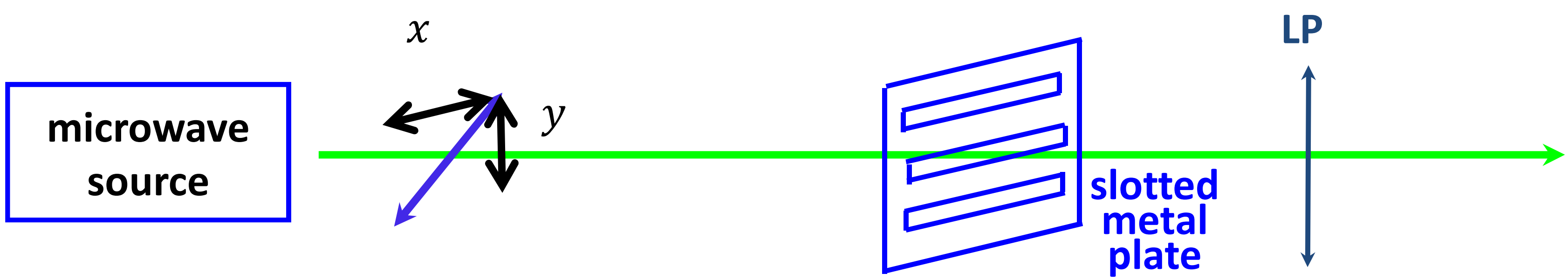
Less reflection (approximately 4.5% instead of 7.8%).

Polarized Light

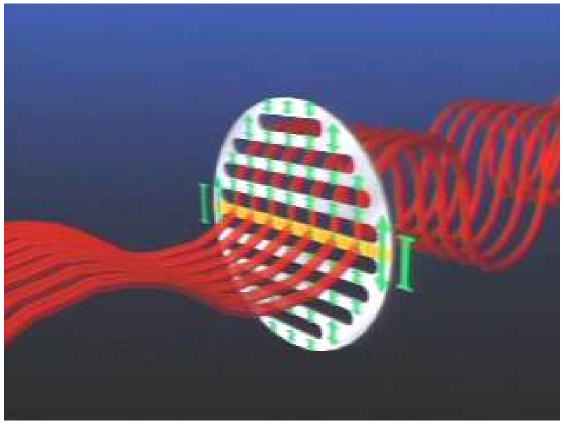


- When light propagates in the z-direction, the $\vec{E}$ field can be oriented in the x-y plane.
- Light is "unpolarized" when the direction of $\vec{E}$ is randomly oriented.
- If the orientation of the $\vec{E}$ field remains constant, we say that the light is "linearly polarized".
- The ability of some materials to absorb or scatter light can depend on the polarization.

Example with Microwaves

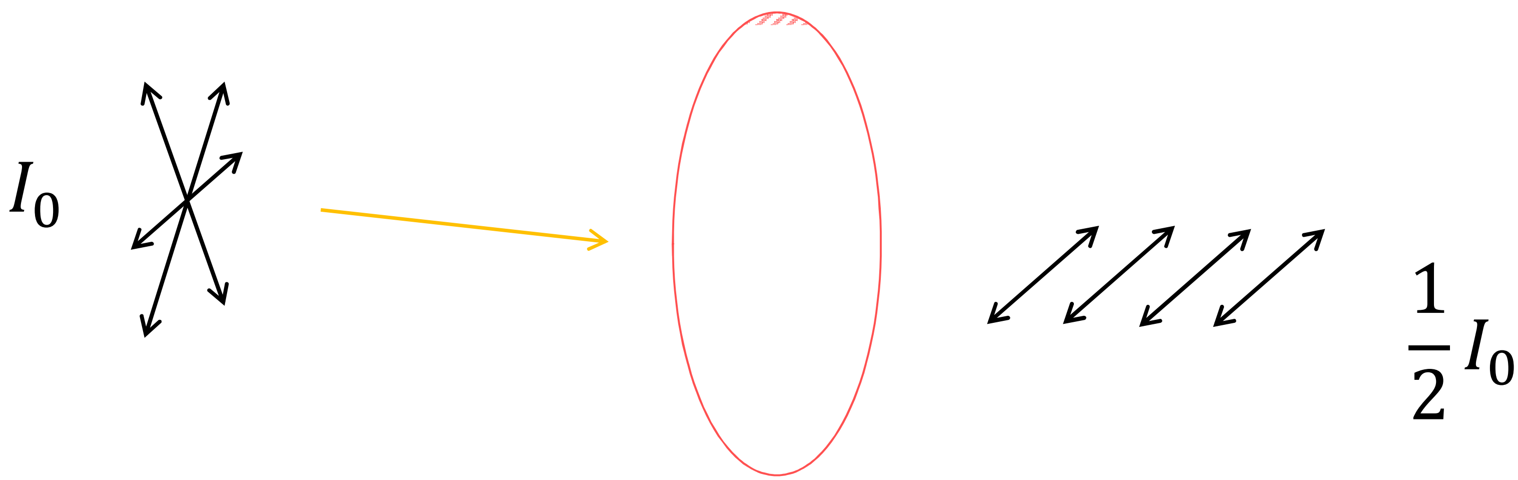


- The electric field in the x-direction induces currents in the metal plate and loses energy:
  - Horizontally polarized microwaves are absorbed
- No current can flow in the y-direction because of the slots
  - Vertically polarized microwaves are transmitted



Polarization by Absorption

- A polarizer absorbs the component with $\vec{E}$ oriented along a particular axis.
- The light that emerges is linearly polarized along the perpendicular axis.
- If the light is initially un-polarized, half the light is absorbed.

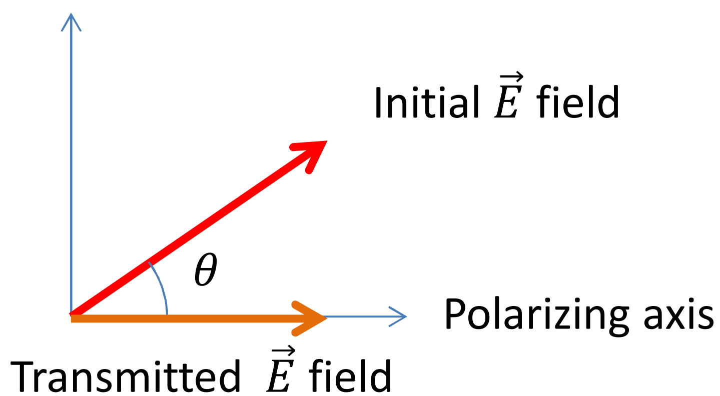


Two Polarizers

- Recall the relation between intensity and the electric field:

$$I = \frac{\langle E^2 \rangle}{Z_0}$$

- When linearly polarized light passes through another polarizer, only the component of light along its axis is transmitted:



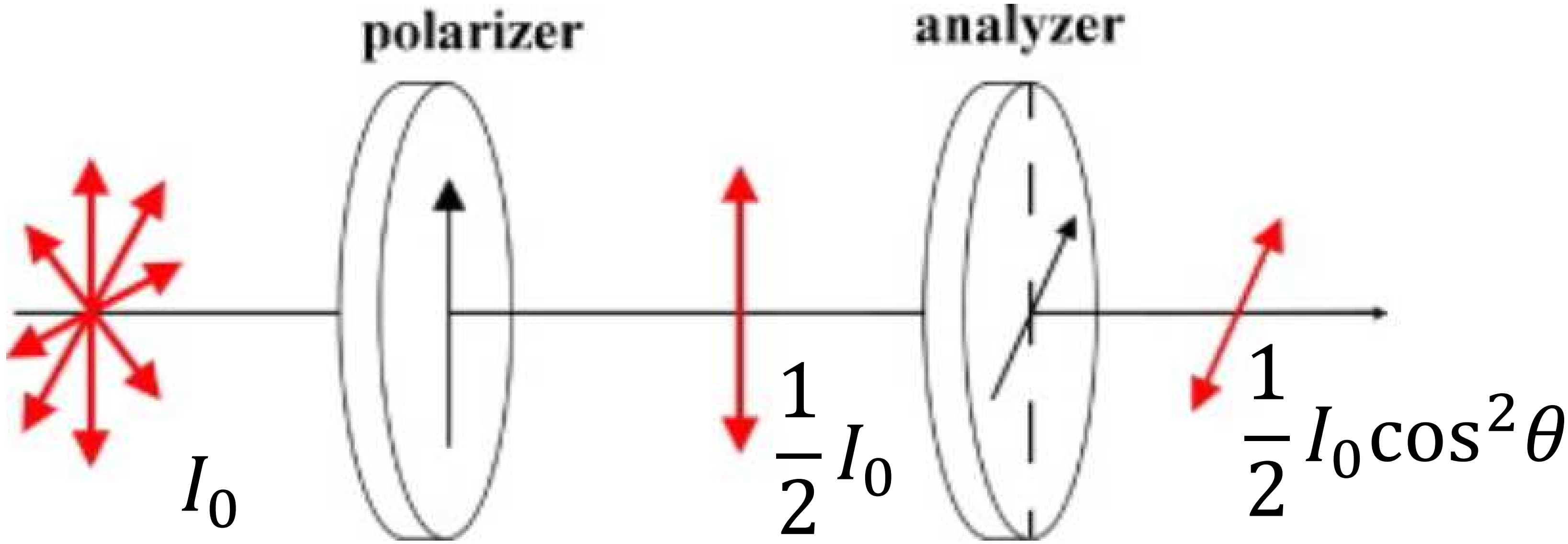
The transmitted $\vec{E}$ field has magnitude

$$\left|\vec{E}_{trans}\right| = \left|\vec{E}\right| \cos\theta$$

The transmitted intensity is

$$I_{trans} = I_0 \cos^2\theta$$

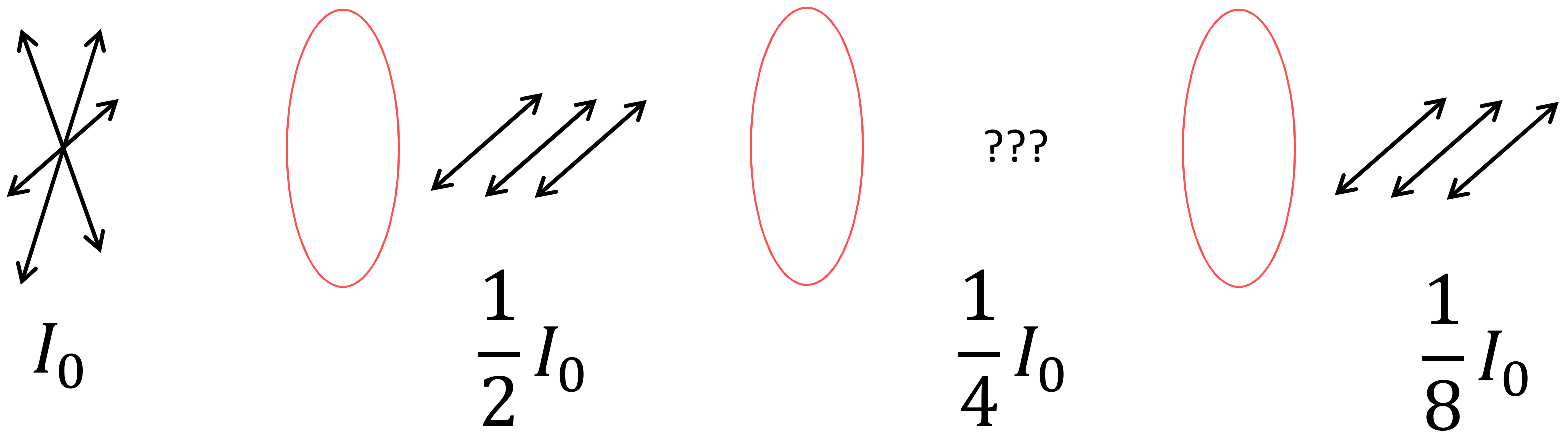
Malus’s Law



Malus’s Law: $I = I_0\cos^2\theta$

Question

- Un-polarized light passes through three polarizers

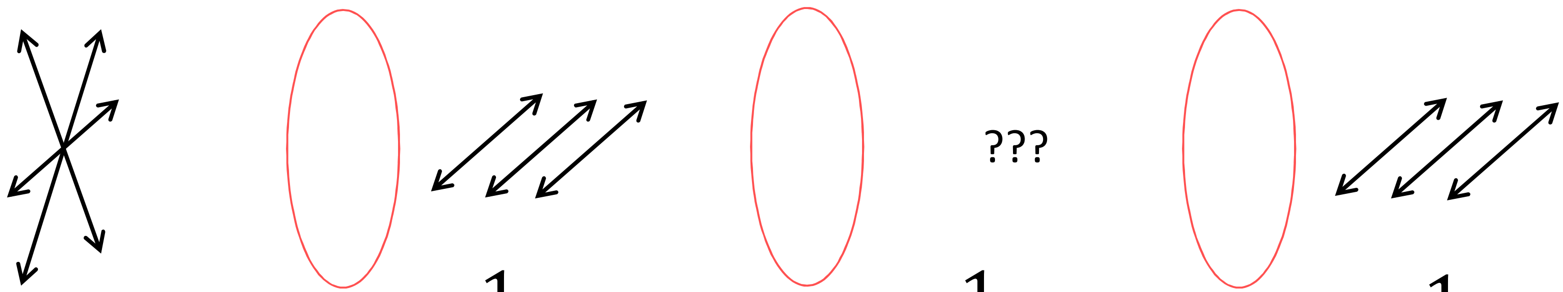


- The first and last polarizers have the same polarization axis.
- At what angle is the middle polarizer oriented?

(a) 0^0
(b) 90^0
(c) 45^0
(d) 135^0

Question

- Un-polarized light passes through three polarizers



- Intensity is reduced by $\cos^2\theta = \frac{1}{2}$
  - $\cos\theta = \pm 1/\sqrt{2}$
  - $\theta = 90°$ or $135°$

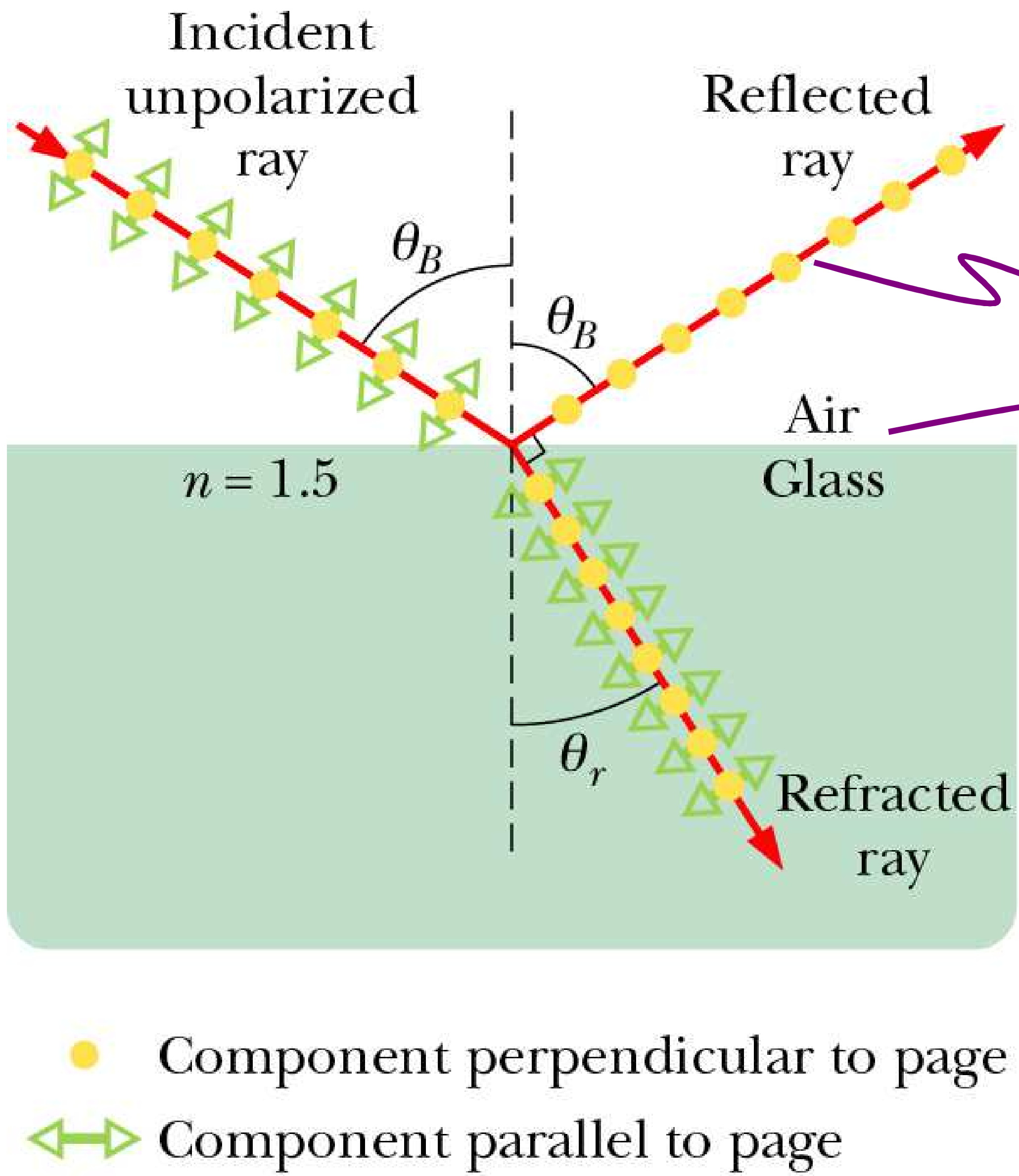
(a) 0^0

(b) 90^0

(c) 45^0

(d) 135^0

Polarization by Reflection



partially polarized

reflecting surface

If $\theta_i = \theta_B$, then reflected light will be fully polarized.

$\theta_r + \theta_B = 90^o$

$n_1 \sin \theta_B = n_2 \sin(90 - \theta_B)$

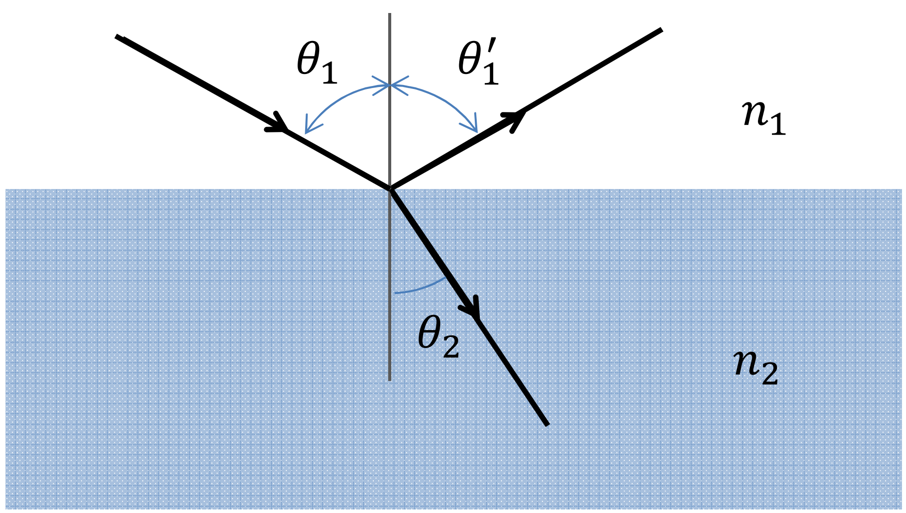
$n_1 \sin \theta_B = n_2 \cos \theta_B$

$$\boldsymbol{\theta_B = \arctan (n_2/n_1)}$$

(Brewster's angle)

Geometric Optics

- When the wavelength of light is much shorter than the sizes of objects it interacts with, we can ignore the wave-like nature and treat it as rays that propagate in straight lines.



Reflection:

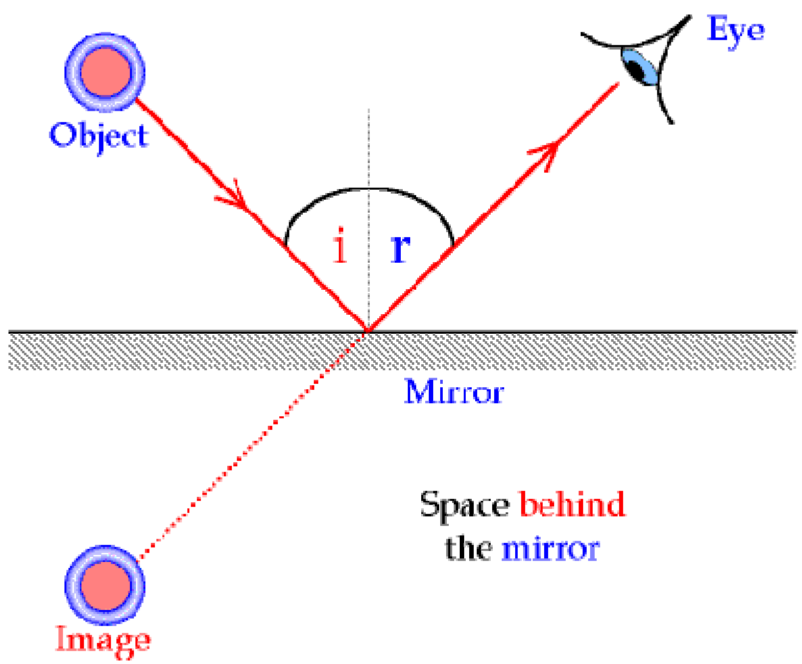
$$\theta_1' = \theta_1$$

Refraction:

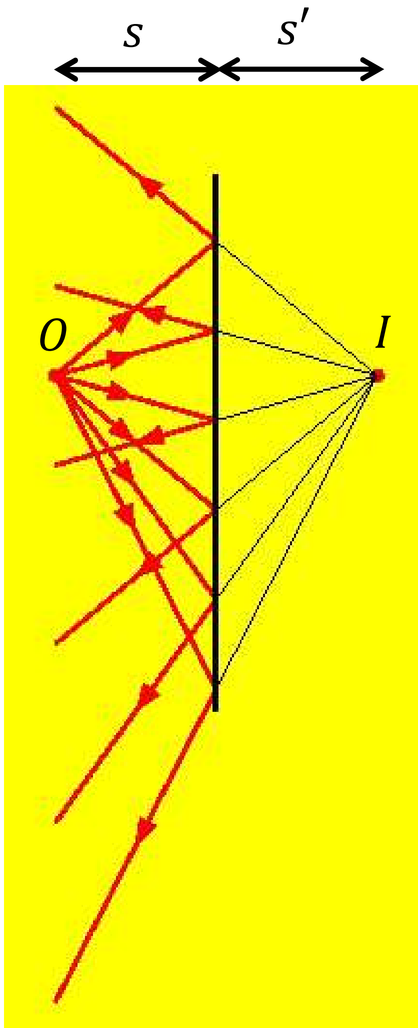
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Types of Images

- **Virtual image**: light *appears* to emanate from a point
- **Real image**: light actually does emanate from a point
- Example:



Images in a Plane Mirror



Notation:

O is the object, a point source of light.

s is the perpendicular distance from O to the mirror.

s' is the perpendicular distance from the mirror to the intersection point of the extensions.

I is the image point. It is virtual because the rays do not pass through I.

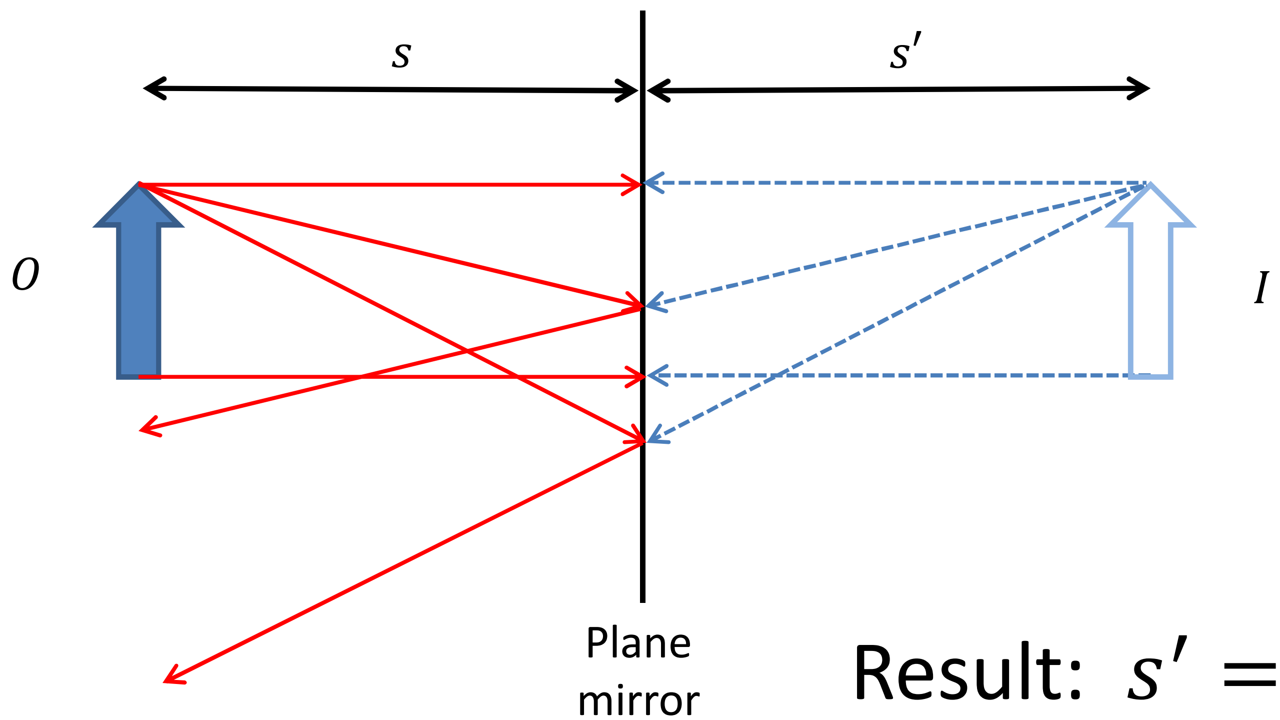
Convention:

object distance, s is positive

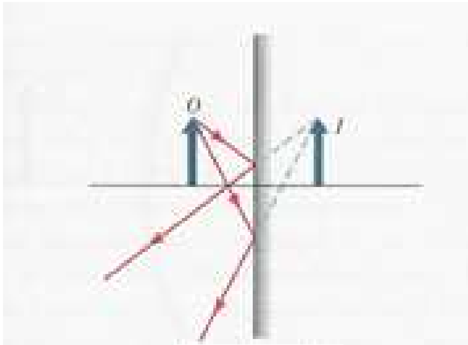
image distance, s' is negative

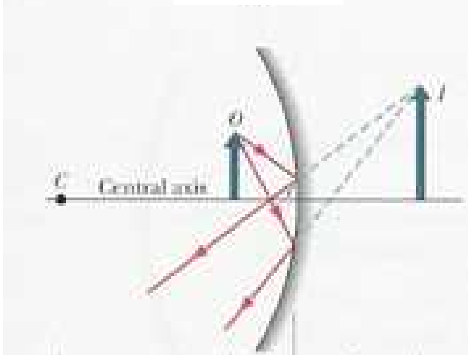
Extended Objects

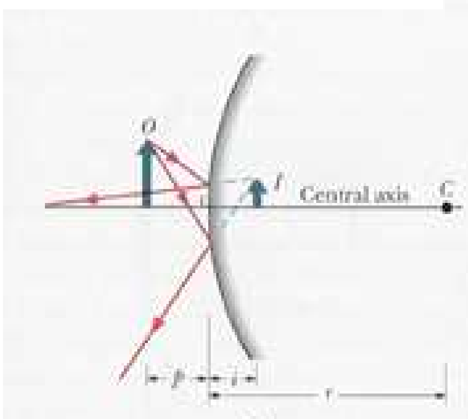
- We can deduce the form of the virtual image by extending rays from each point:



Result: $s' = -s$



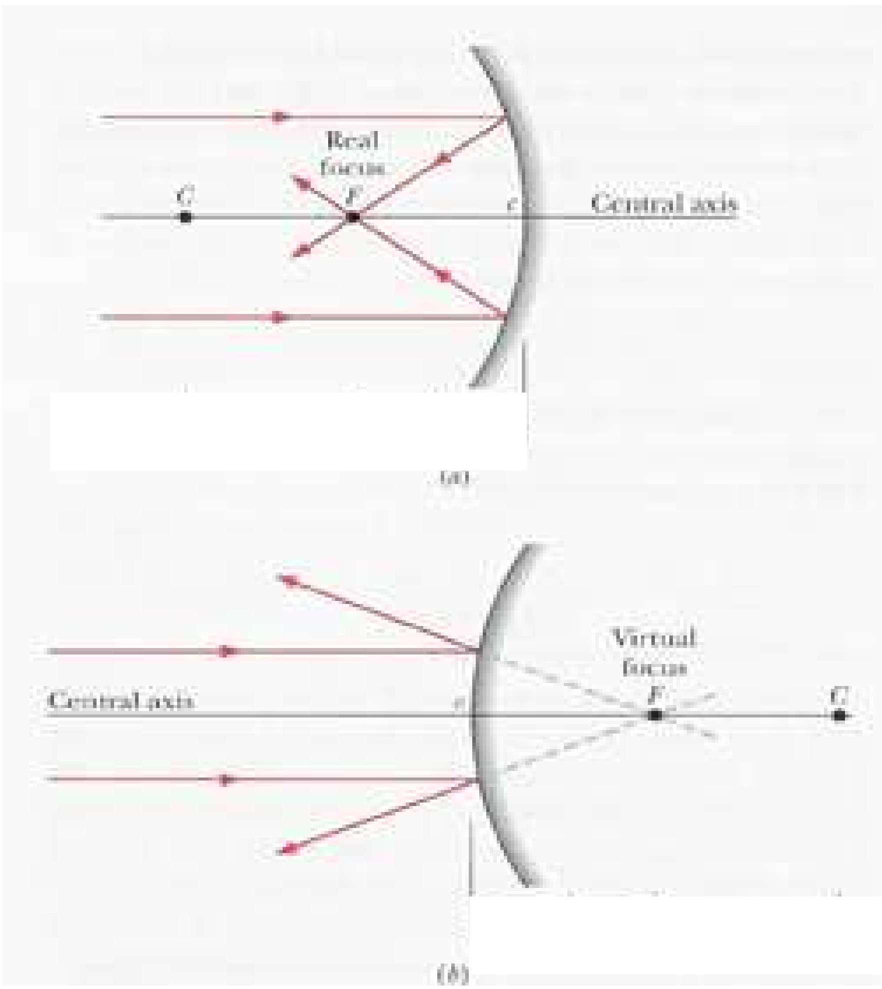




Spherical Mirrors

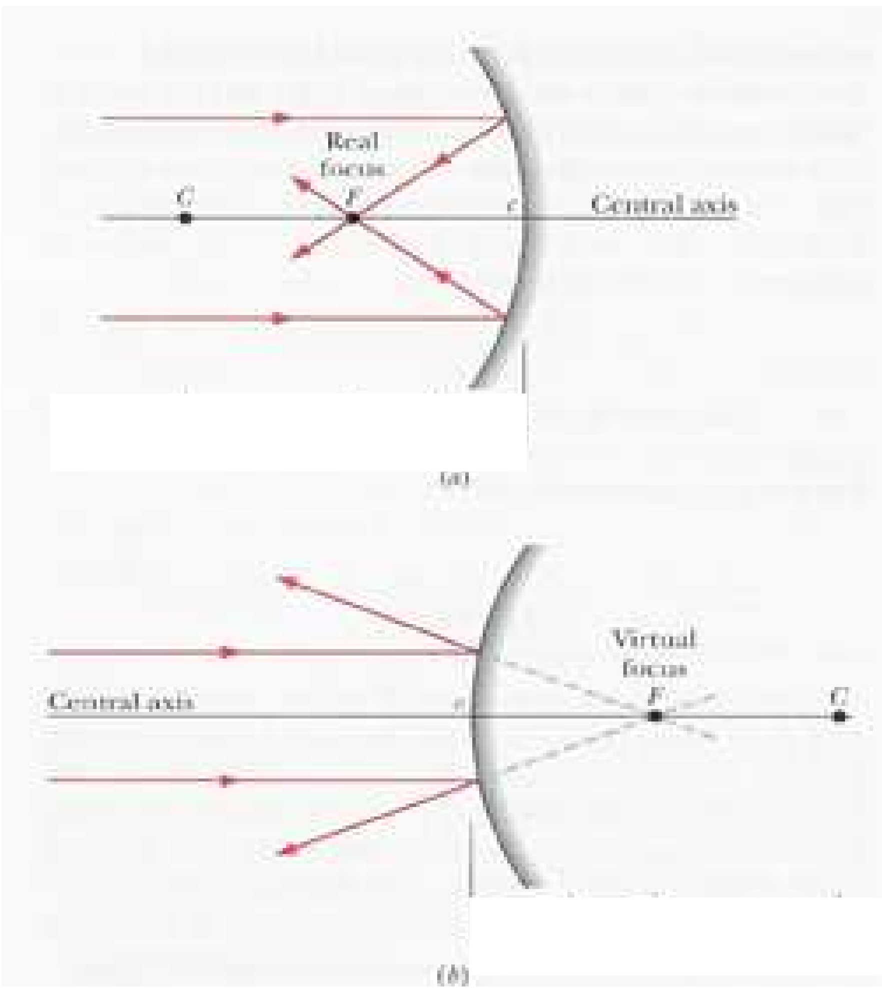
- Plane mirror:
  - Object height = Image height
- Concave mirror:
  - Center of curvature is in front of the mirror.
  - Object height < Image height
- Convex mirror:
  - Center of curvature is behind the mirror
  - Object height > Image height

Focal Points of Spherical Mirrors



- Concave:
  - Parallel rays are reflected through a common point, F
  - *Real image*
- Convex:
  - Extensions of parallel rays emerge from a common point, F
  - Virtual image

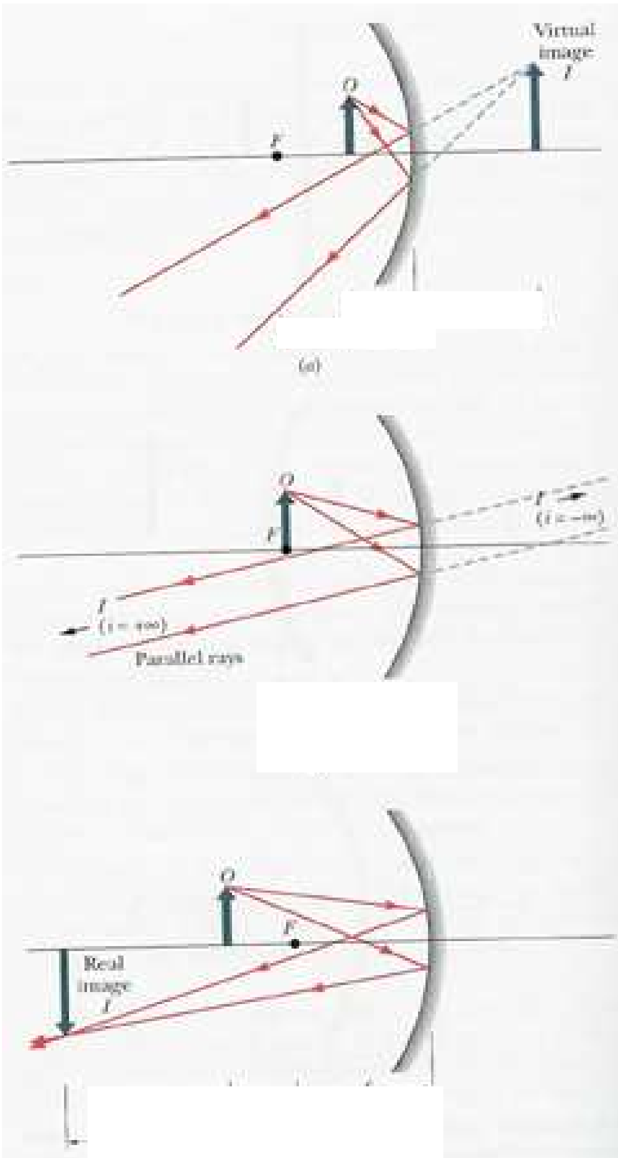
Focal Points of Spherical Mirrors



Sign convention:

- Concave:
  - Radius of curvature, $r > 0$
  - Focal length, $f > 0$
- Convex:
  - Radius of curvature, $r < 0$
  - Focal length, $f < 0$

Images from Concave Mirrors



- When $s < f$:
  - the image is larger
  - it appears behind the mirror
  - it has the same orientation
- When $s = f$:
  - the reflected rays are parallel
  - the image is ambiguous
- When $s > f$:
  - the image is larger
  - it appears in front of the mirror
  - it is inverted

Spherical Mirrors

- For spherical mirrors, the focal length is ½ the radius of curvature:

$$f = \frac{r}{2}$$

- Why the funky sign conventions?

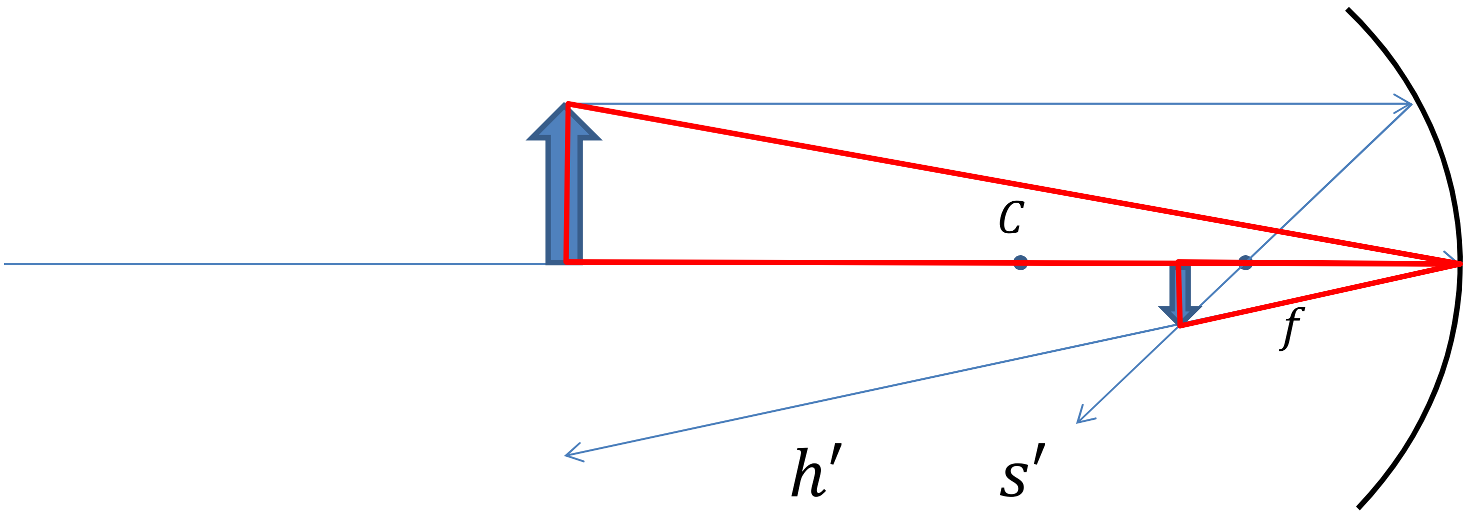
$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

- Magnification:

$$m = \frac{h'}{h}$$

Magnification

- Magnification is the size of the image, measured perpendicular to the central axis



$$m = \frac{h'}{h} = -\frac{s'}{s}$$

- For planar mirrors,

$$s' = -s$$
$$m = +1$$

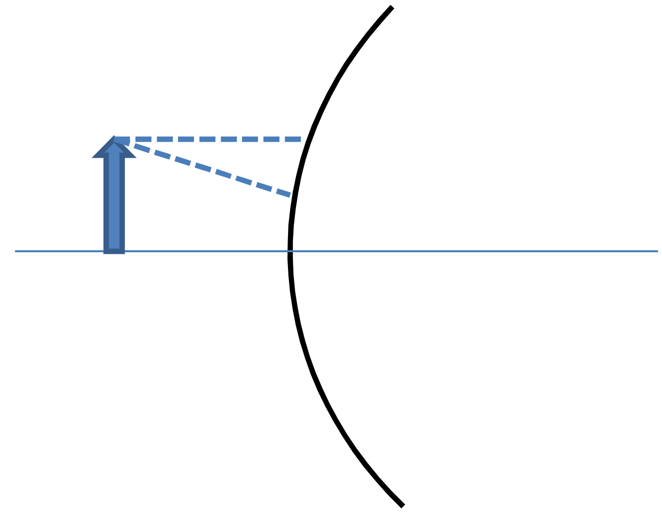
Drawing Images

From each point on an image we can draw four lines:

1. A ray that is parallel to the central axis is reflected through the focal point, f
2. A ray that passes through the focal point, f, is reflected parallel to the central axis
3. A ray that passes through the center of curvature, C is reflected back on itself
4. The reflection of a ray that hits the mirror at a point on the central axis is symmetric about the axis

Example 1

Where do the rays which are reflected from the convex mirror shown intersect?



1A

(a) to left of 

(b) to right of 

(c) they don't intersect

1B What is the nature of the image of the arrow?

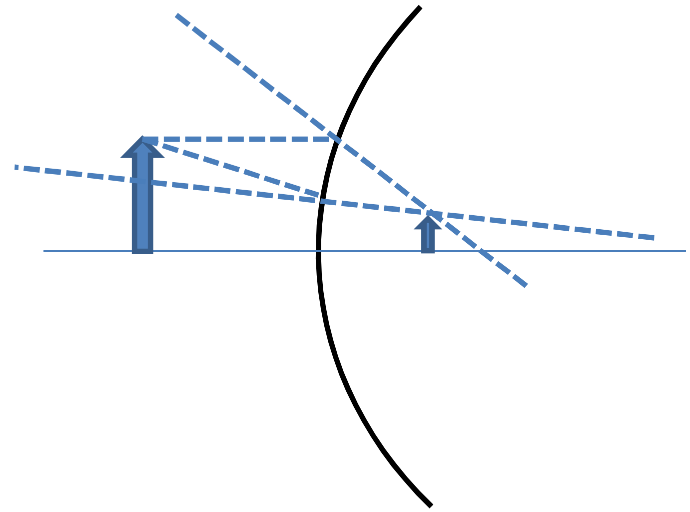
(a) Inverted and in front of the mirror

(b) Inverted and in back of the mirror

(c) Upright and in back of the mirror

Example 1

Where do the rays which are reflected from the convex mirror shown intersect?



1A

(a) to left of 

(b) to right of 

(c) they don’t intersect

1B What is the nature of the image of the arrow?

(a) Inverted and in front of the mirror

(b) Inverted and in back of the mirror

(c) Upright and in back of the mirror

Summary

Equations for mirrors :

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$$

$$M=-\frac{s'}{s}$$

when the following sign conventions are used:

Mirror Type	Object Location	Image Location	Image Type	Image Orientation	Sign of f r s' m
Plane	Anywhere	Opposite side of mirror from object	Virtual	Same orientation as object	
Concave	Inside F	Opposite side of mirror from object	Virtual	Same orientation as object	
Concave	Outside F	Same side as object	Real	Inverted	
Convex	Anywhere	Opposite side of mirror from object	Virtual	Same orientation as object	

Question

A fly at about eye level is 10 cm in front of a plane mirror; you are behind the fly, 30 cm from the mirror. What is the distance between your eyes and the apparent position of the fly's image in the mirror?

(A) 10 cm
(B) 20 cm
(C) 30 cm
(D) 40 cm
(E) 60 cm