

Exam 2 results

- Raw mean = 71% Scaled mean = 75%
- Question 5 in exam 2
 - Found error in this question
 - Two answers are acceptable
- Concerned?
 - Different approach to studying, lectures, etc
 - Contact me: ychemla@illinois.edu
- Also, next homework assignments:
 - Homework 8 due Friday, Mar. 15
 - Homework 9 can now be opened

Physics 102: Lecture 17

Reflection and Refraction of Light



Recall from last time....

Last Time

Reflection:

$$\theta_i = \theta_r$$

Flat Mirror:

image equidistant behind

Spherical Mirrors:

Concave or Convex

Today

Refraction:

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

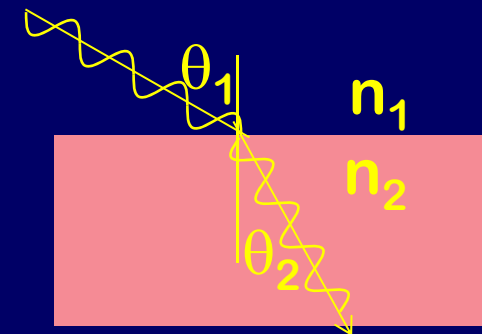
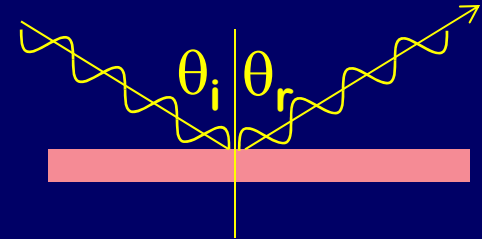


Image formation using spherical mirrors

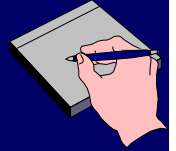


**Why are objects
“closer than they
appear”?**

Key Ideas:

- **Principal rays**
- **Mirror equation & Magnification**

Concave Mirror Principal Rays



- 1) Parallel to principal axis reflects through f .
- 2) Through f , reflects parallel to principal axis.
- 3) Through center.

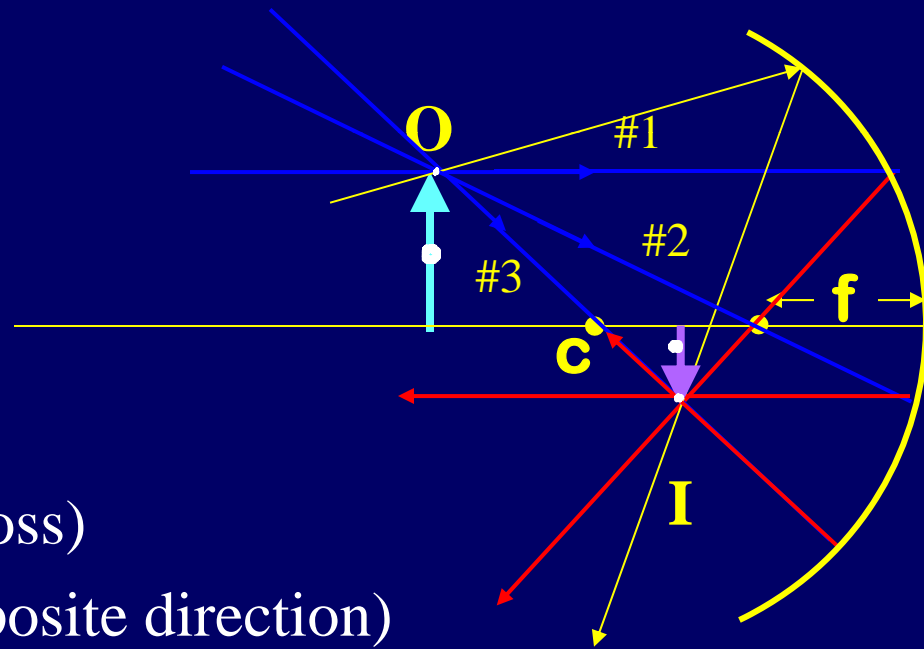


Image is (in this case):

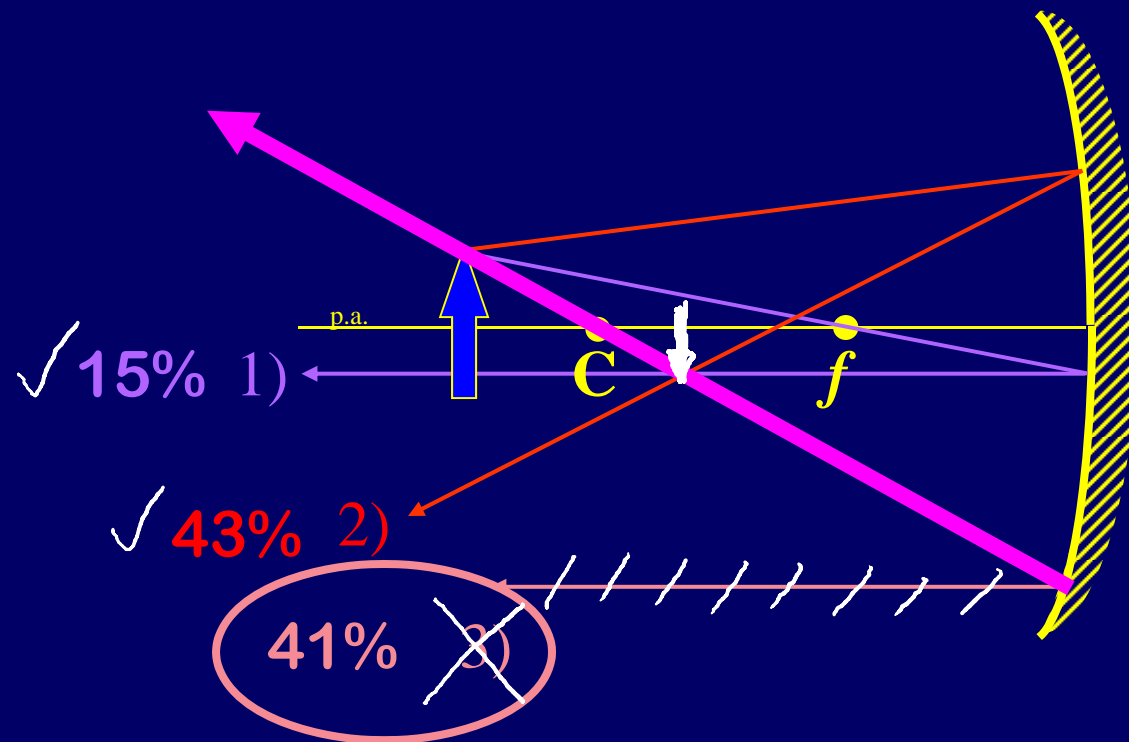
- Real (light rays actually cross)
- Inverted (Arrow points opposite direction)
- Reduced (smaller than object)

****Every other ray from object tip which hits mirror will reflect through image tip**

Checkpoint 1.1

Which ray is **NOT** correct?

Ray through center should reflect back on self.

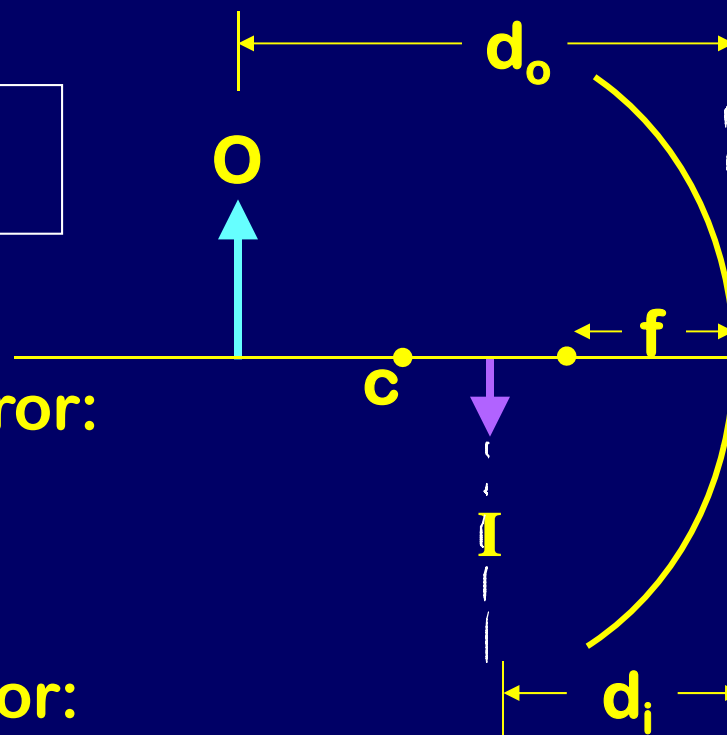


Mirror Equation



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

Works for concave, convex, or flat



- d_o = distance object is from mirror:

Positive: object in front of mirror

Negative: object behind mirror

- d_i = distance image is from mirror:

- Positive: real image (in front of mirror)

- Negative: virtual image (behind mirror)

- f = focal length mirror:

- Positive: concave mirror $+R/2$

- Negative: convex mirror $-R/2$

Flat $f = \infty$
 $\frac{1}{d_o} + \frac{1}{d_i} = 0$
 $d_i = -d_o$

Checkpoint 1.3

The image produced by a concave mirror of a real object is:

46% 1) Always Real

16% 2) Always Virtual

38% 3) Sometimes Real, Sometimes Virtual

Concave mirror: $f > 0$

Real Object means in front of mirror: $d_o > 0$

Mirror Equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

d_i is positive if $d_o > f$; negative if $d_o < f$.



ACT: Concave Mirror

Where in front of a concave mirror should you place an object so that the image is virtual?

- 1) Close to mirror
- 2) Far from mirror
- 3) Either close or far
- 4) Not Possible

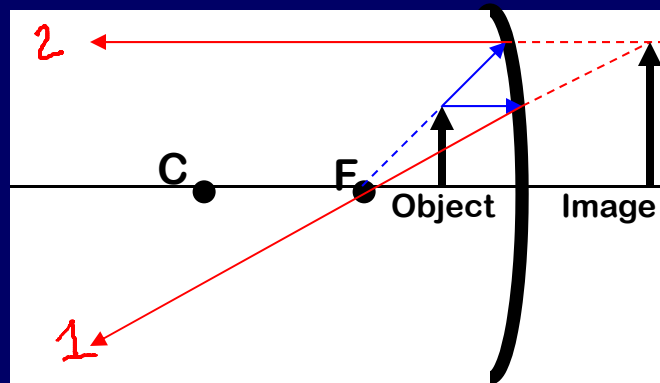
- Concave mirror: $f > 0$
- Object in front of mirror: $d_o > 0$
- Virtual image means behind mirror: $d_i < 0$
- When $d_o < f$ then $d_i < 0$ virtual image.

Mirror Equation:

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

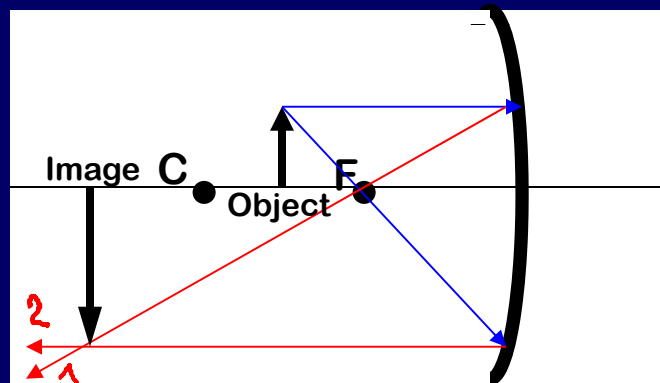
$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

3 Cases for Concave Mirrors



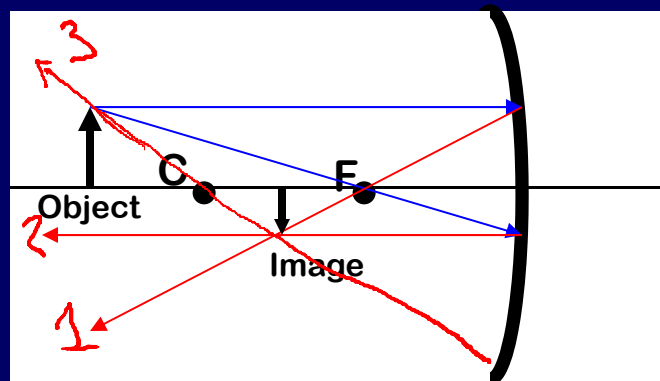
Virtual

Inside F



Real

Between C&F



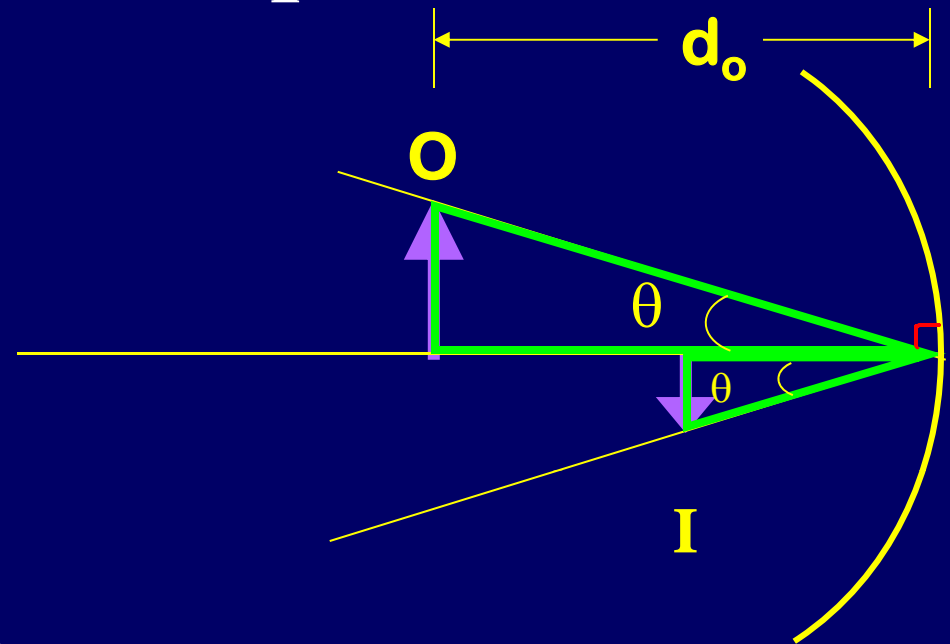
Real

Past C

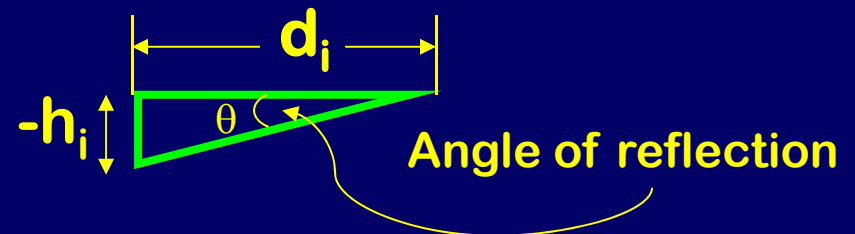
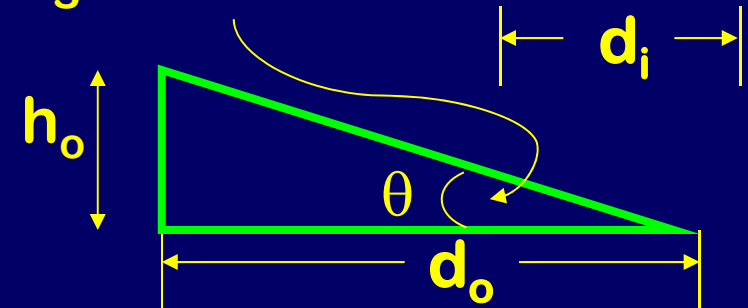
Magnification Equation

$$m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

- h_o = height of object:
 - Positive: always
- h_i = height of image:
 - Positive: image is upright
 - Negative: image is inverted
- m = magnification:
 - Positive / Negative: same as for h_i
 - < 1 : image is reduced
 - > 1 : image is enlarged



Angle of incidence



$$\tan(\theta) = \frac{h_o}{d_o} = \frac{-h_i}{d_i}$$

Example

Solving Equations

A candle is placed 6 cm in front of a concave mirror with focal length $f=2\text{ cm}$. Determine the image location.

$$\frac{1}{6\text{ cm}} + \frac{1}{d_i} = \frac{1}{2\text{ cm}}$$

$$d_i = +3\text{ cm (in front of mirror)}$$

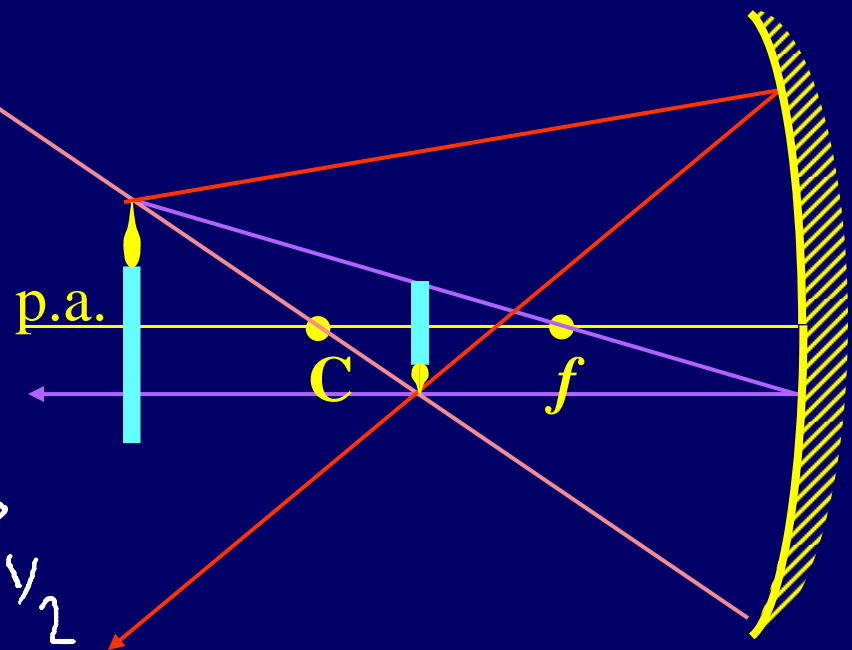
Real Image!

Checkpoint 17.2

Compared to the candle, the image will be:

- 25% • Larger
- 66% • Smaller
- 9% • Same Size

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \\ = -\frac{3}{6} = -\frac{1}{2}$$





ACT: Magnification

A 4 inch arrow pointing down is placed in front of a mirror that creates an image with a magnification of -2 .

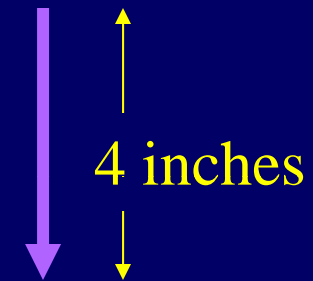
What is the size of the image?

A. 2 inches

B. 4 inches

C. 8 inches

$$m \equiv \frac{h_i}{h_o}$$



Magnitude gives us size.

$$h_i = mh_o = -2 \times 4$$

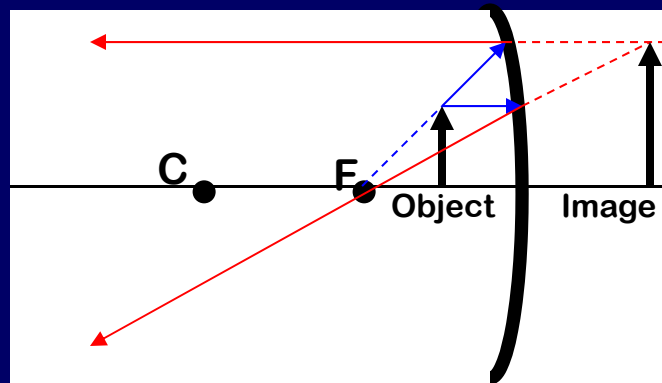
What direction will the image arrow point?

A. Up

B. Down

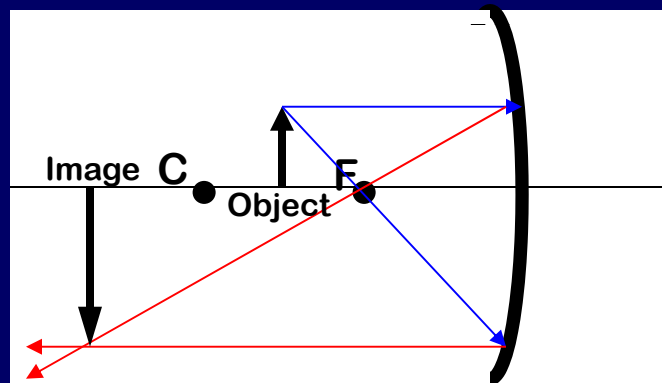
(-) sign tells us it's inverted from object

3 Cases for Concave Mirrors



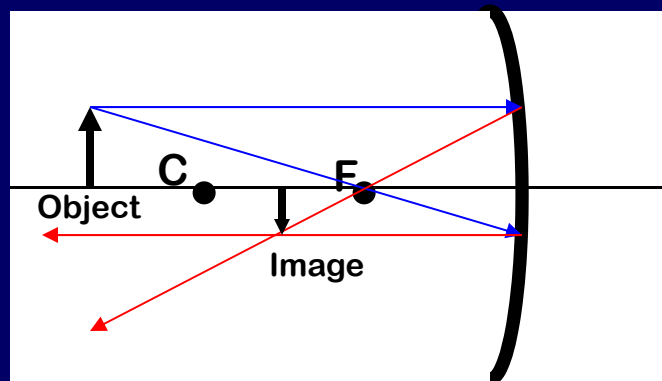
Inside F

Upright
Enlarged
Virtual



Between C&F

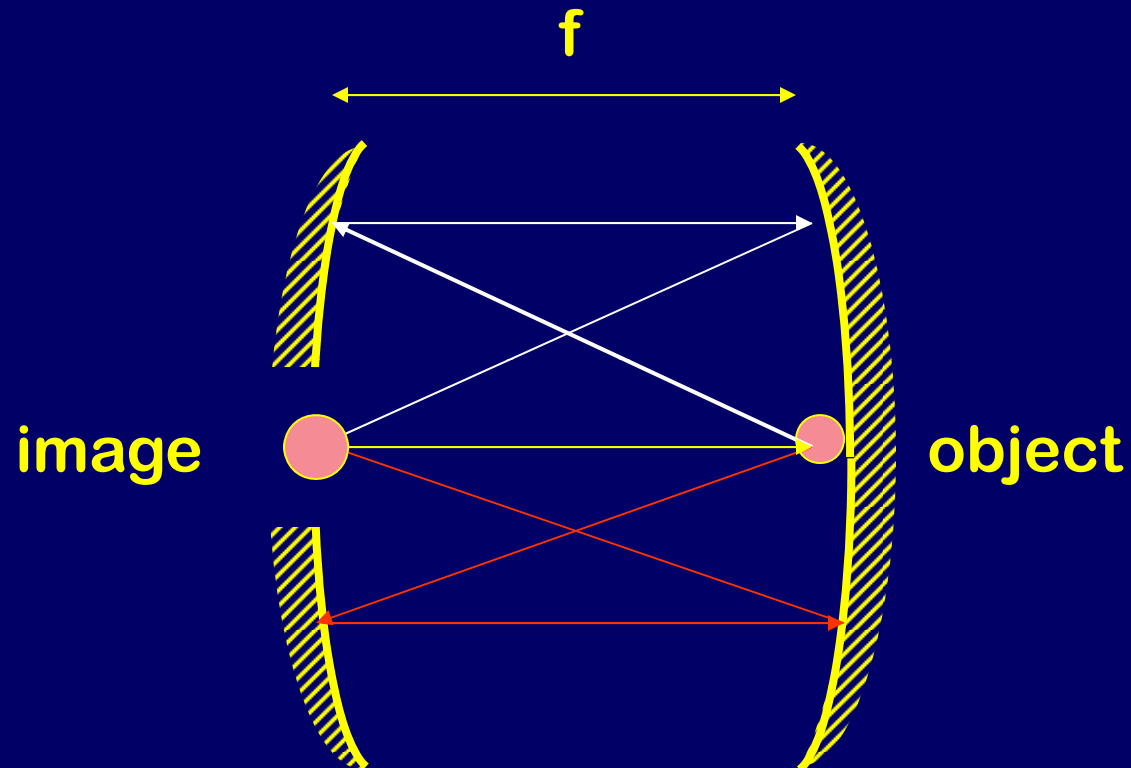
Inverted
Enlarged
Real



Past C

Inverted
Reduced
Real

Demo: optical illusion



Demo:

- two identical spherical mirrors
- each mirror is positioned at the focal point of the other

Convex Mirror Rays



- 1) Parallel to principal axis reflects through f .
- 2) Through f , reflects parallel to principal axis.
- 3) Through center.

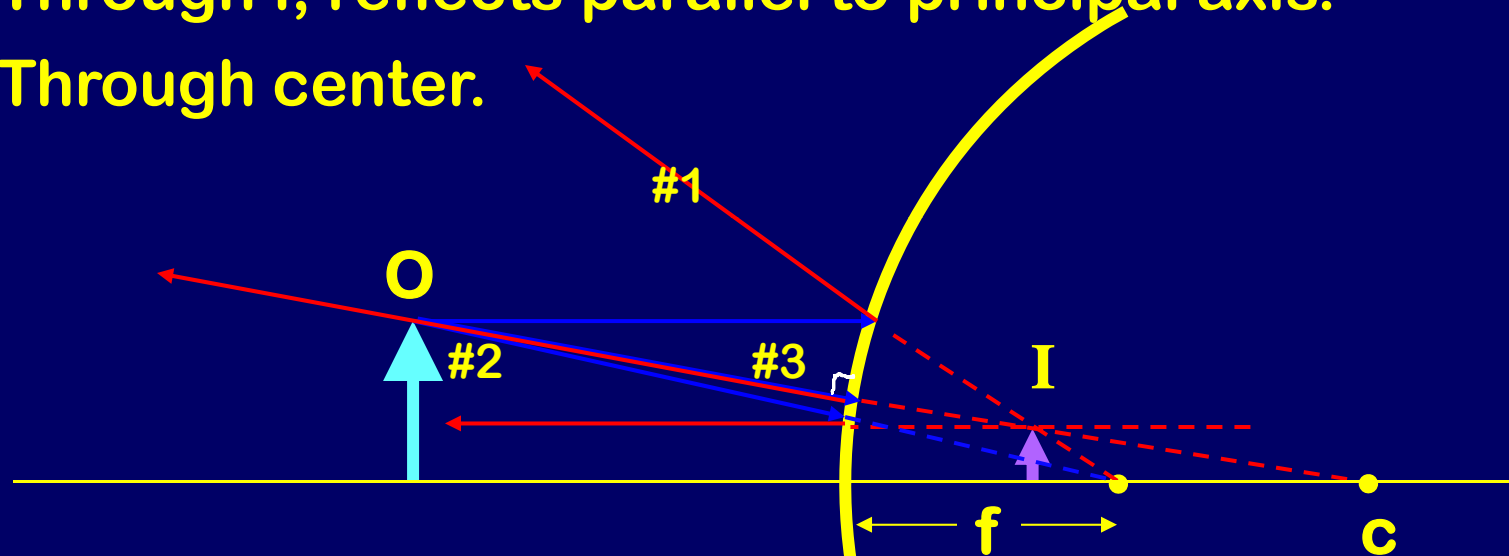


Image is:

Virtual (light rays don't really cross)

Upright (same direction as object)

Reduced (smaller than object)

(always true for convex mirrors!)



Example

Solving Equations

A candle is placed $d_o = 6$ cm in front of a convex mirror with focal length $f = -3$ cm. Determine the image location.

$$\frac{1}{6 \text{ cm}} + \frac{1}{d_i} = \frac{1}{-3 \text{ cm}}$$

$$d_i = -2 \text{ cm (behind mirror)}$$

Virtual Image!

Determine the magnification of the candle.

$$m \equiv -\frac{d_i}{d_o} = -\frac{-2 \text{ cm}}{6 \text{ cm}}$$

$$m = +1/3$$

If the candle is 9 cm tall, how tall does the image candle appear to be?

$$+1/3 = \frac{h_i}{9 \text{ cm}}$$

$$h_i = +3 \text{ cm}$$

Image is Upright!

Checkpoint 1.4

The image produced by a convex mirror of a real object is

- 1) always real
- 2) always virtual
- 3) sometimes real and sometimes virtual

Mirror Equation:

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

- Convex mirror: $f < 0$
- Object in front of mirror: $d_o > 0$
- $d_i < 0$ means virtual image!
- Image is always between F and mirror $|d_i| < |f|$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

d_i is negative!

f is negative

d_o is positive

Mirror Summary

- Angle of incidence = Angle of Reflection
- Principal Rays
 - Parallel to P.A.: Reflects through focus
 - Through focus: Reflects parallel to P.A.
 - Through center: Reflects back on self

- $|f| = R/2$

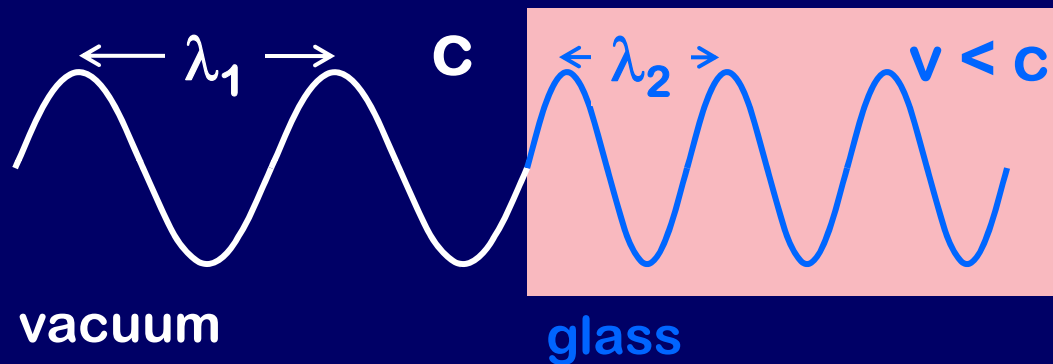
- $$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

- $$m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Index of Refraction

Recall speed of light $c = 3 \times 10^8$ m/s is in vacuum

In a medium (air, water, glass...) light is slower



Frequency is the same,
wavelength decreases

$$v = \lambda f$$

“Index of refraction”

Speed of light
in medium

$$v = c/n$$

Speed of light
in vacuum

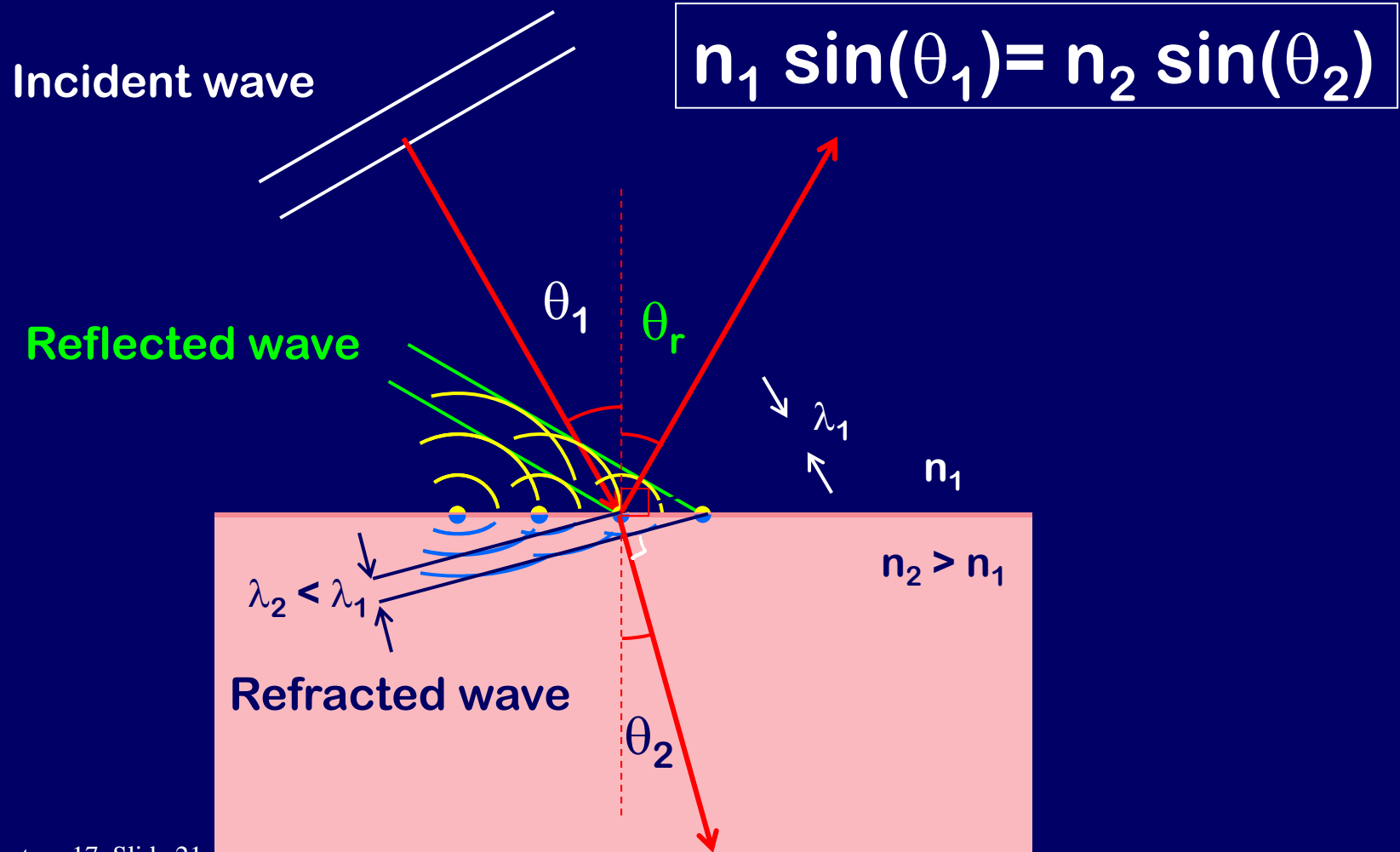
n is a property
of the medium:

$$\begin{aligned} n_{\text{vacuum}} &= 1 \\ n_{\text{air}} &= 1.0003 \\ n_{\text{water}} &= 1.33 \\ n_{\text{glass}} &= 1.50 \end{aligned}$$

$$n \geq 1$$

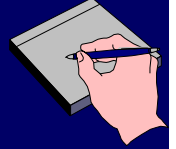
Snell's law of Refraction

When light travels from one medium to another, v (and λ) changes ($v = c/n$). So the light bends!



Example

Snell's Law Practice



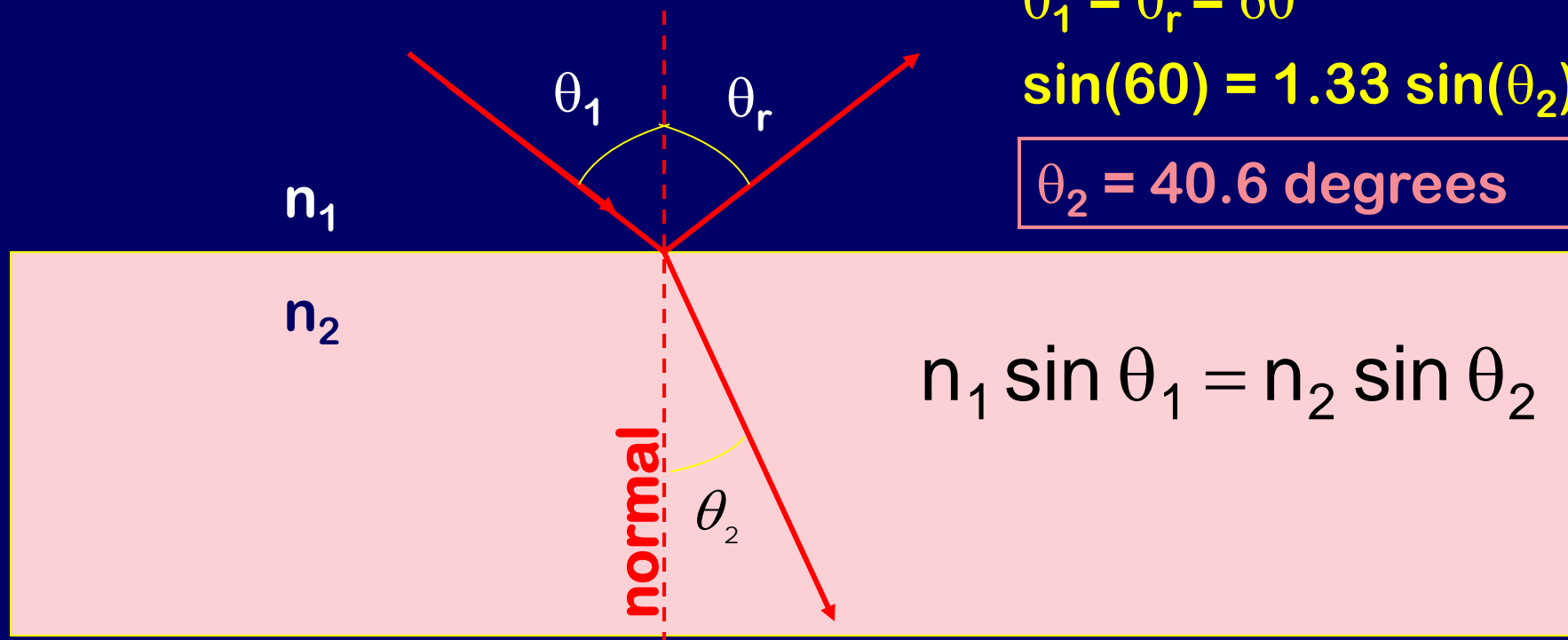
Usually, there is both **reflection** and **refraction**!

A ray of light traveling through the air ($n=1$) is incident on water ($n=1.33$). Part of the beam is reflected at an angle $\theta_r = 60$. The other part of the beam is refracted. What is θ_2 ?

$$\theta_1 = \theta_r = 60$$

$$\sin(60) = 1.33 \sin(\theta_2)$$

$$\theta_2 = 40.6 \text{ degrees}$$



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

Have a good break!