

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:

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

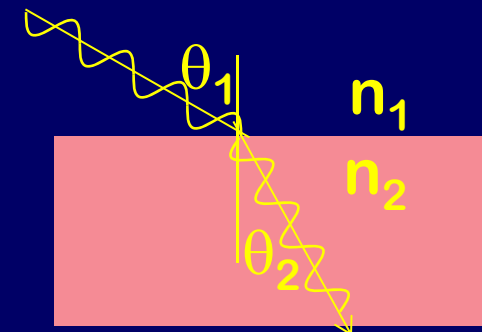
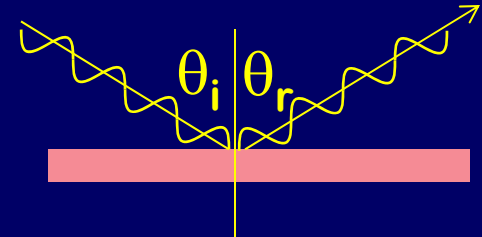


Image formation using spherical mirrors

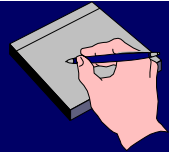


**Why are objects
“closer than they
appear”?**

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.

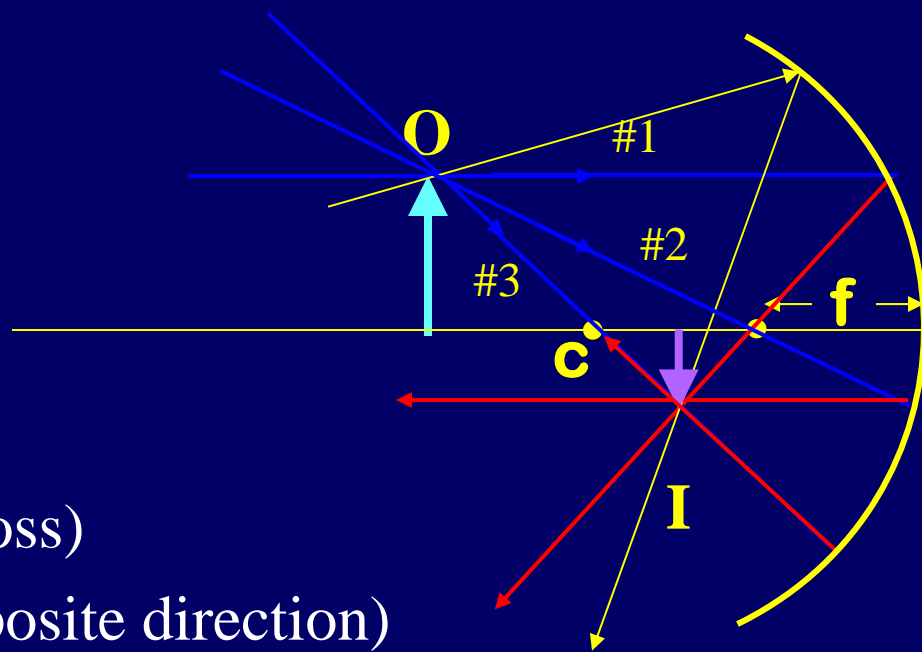


Image is (in this case):

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

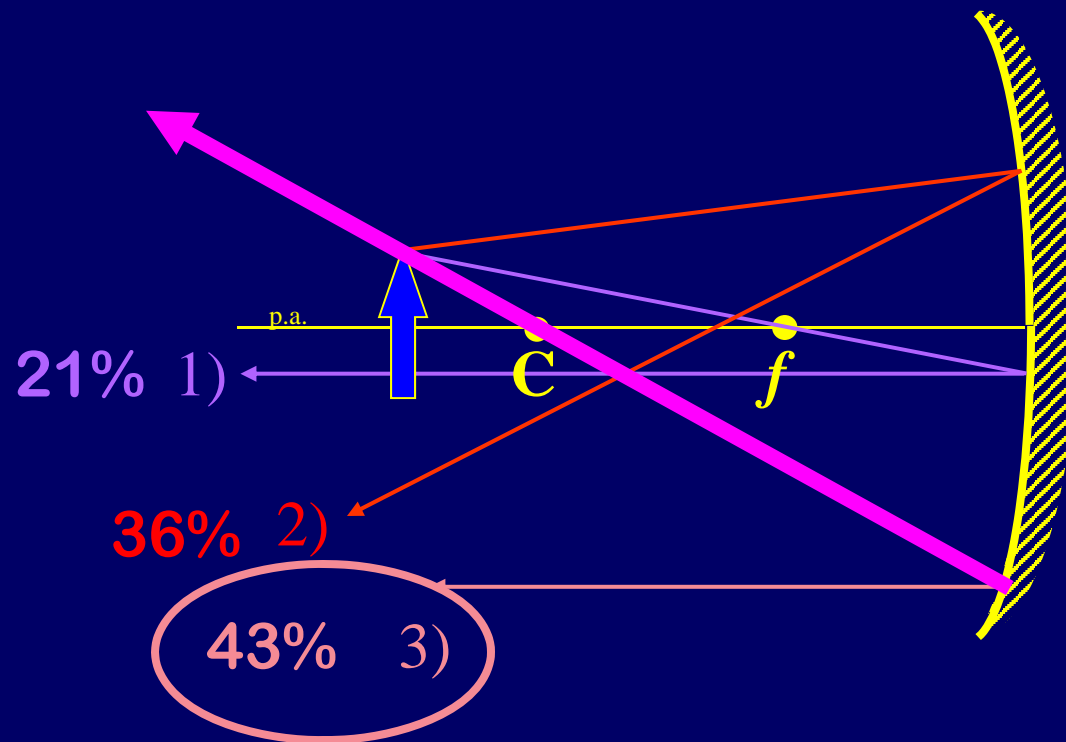
****Every other ray from object tip which hits mirror will reflect through image tip**



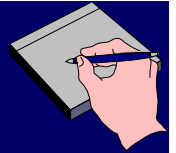
ACT: Checkpoint 1.1

Which ray is NOT correct?

Ray through center should reflect back on self.

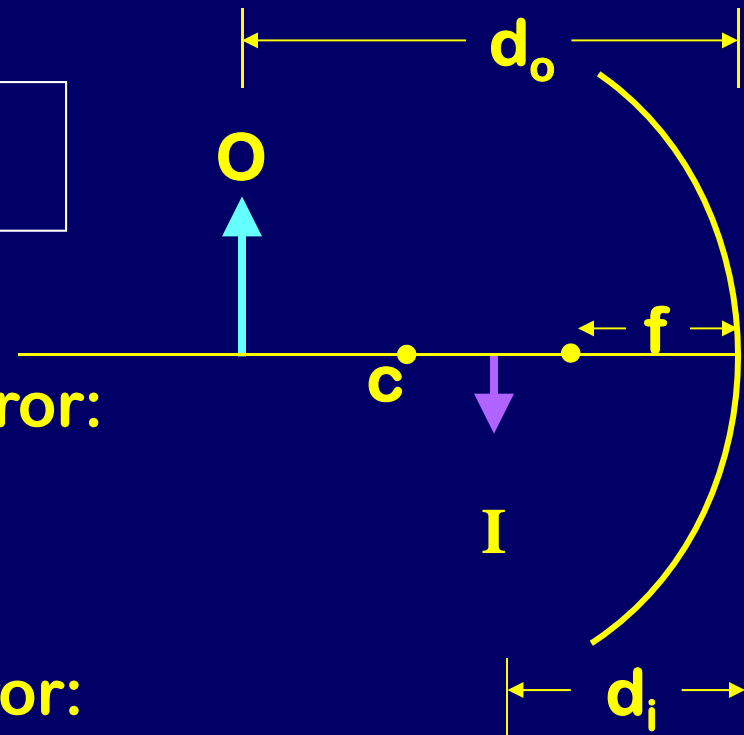


Mirror Equation



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

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 **$-R/2$**

Checkpoint 1.3

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

28% 1) Always Real

30% 2) Always Virtual

42% 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

Mirror Equation:

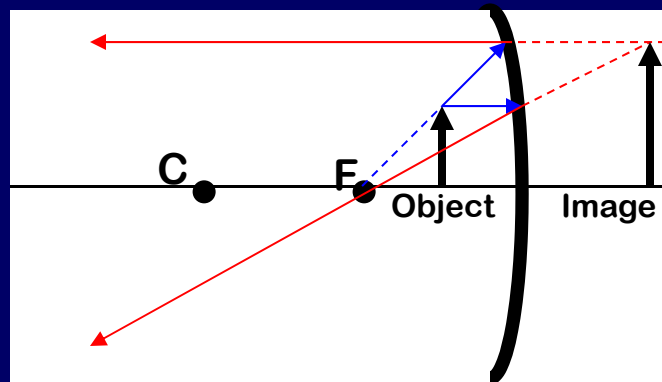
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

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

- 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.

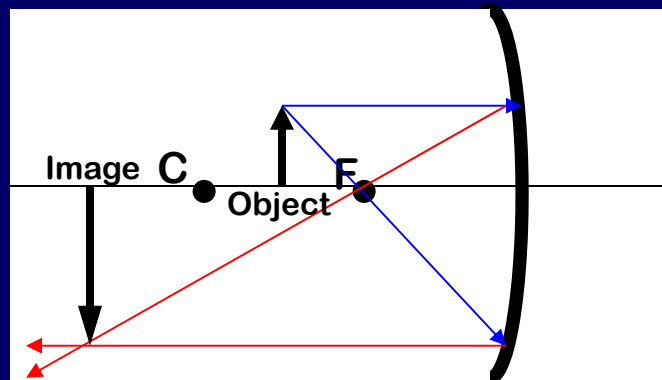
3 Cases for Concave Mirrors

Virtual



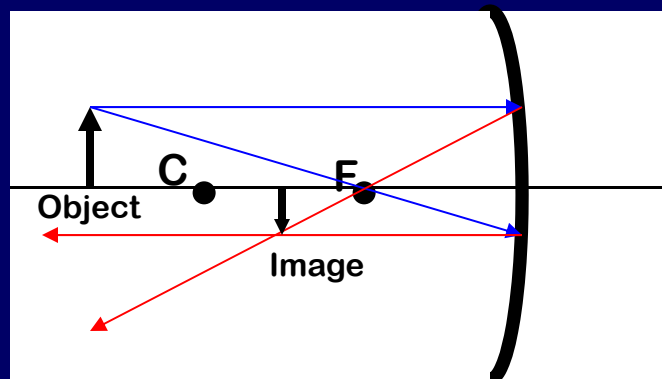
Inside F

Real



Between C&F

Real

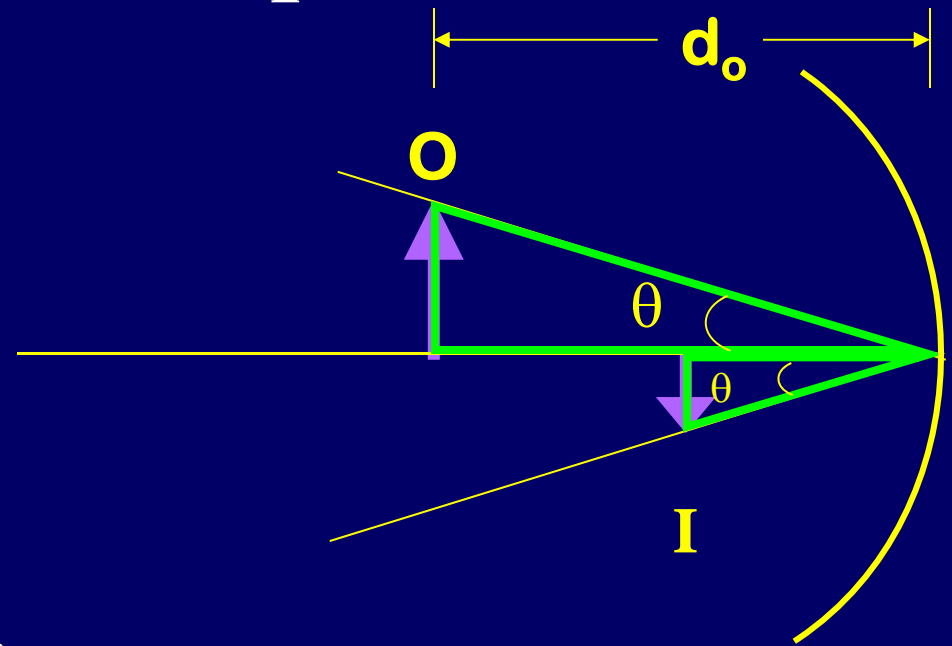


Past C

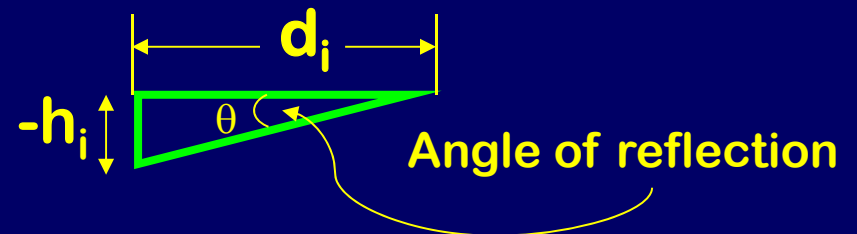
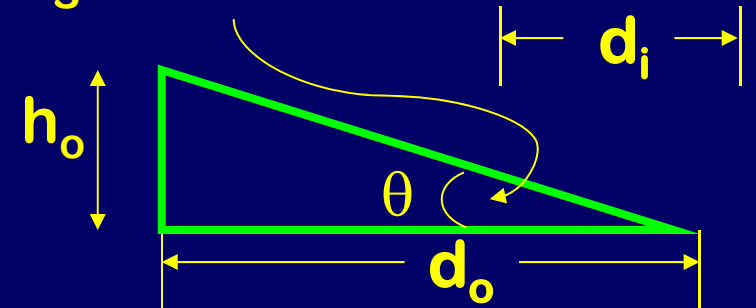
Magnification Equation

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

- **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 $f=2$ 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 1.2

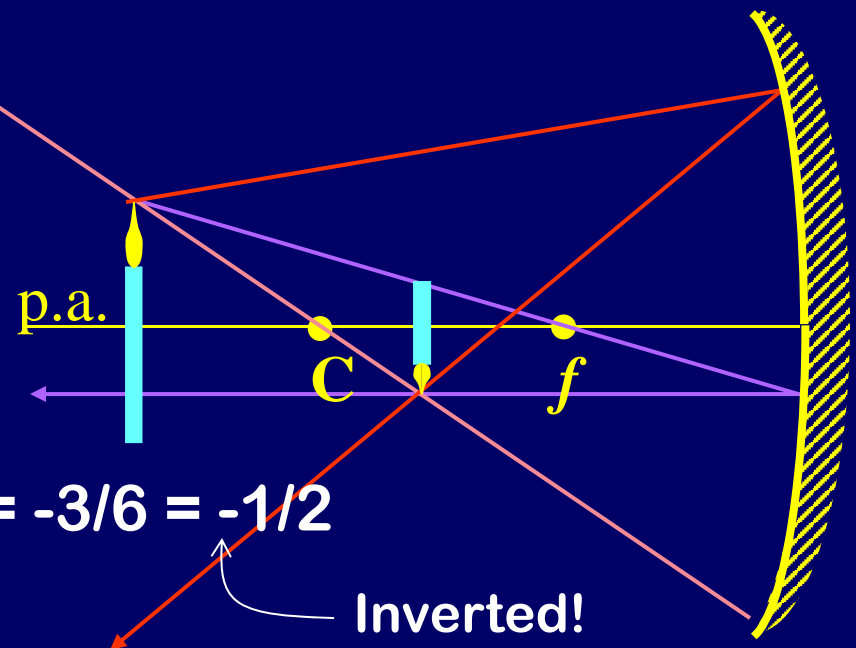
Compared to the candle, the image will be:

33% • Larger

54% • Smaller

13% • Same Size

$$m = -d_i / d_o = -3/6 = -1/2$$





ACT: Magnification

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

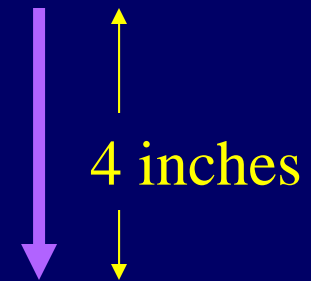
What is the size of the image?

A. 2 inches

B. 4 inches

C. 8 inches

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



Magnitude gives us size.

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

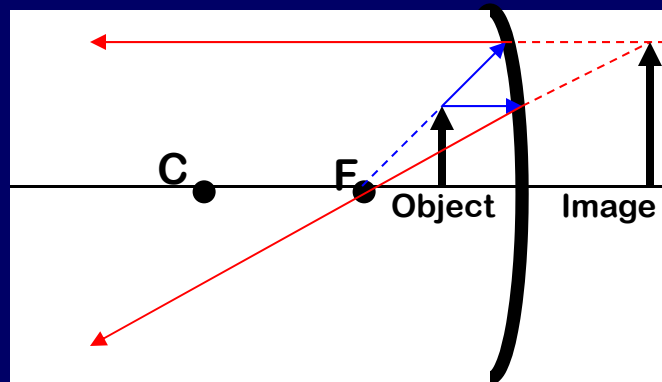
What direction will the image arrow point?

A. Up

B. Down

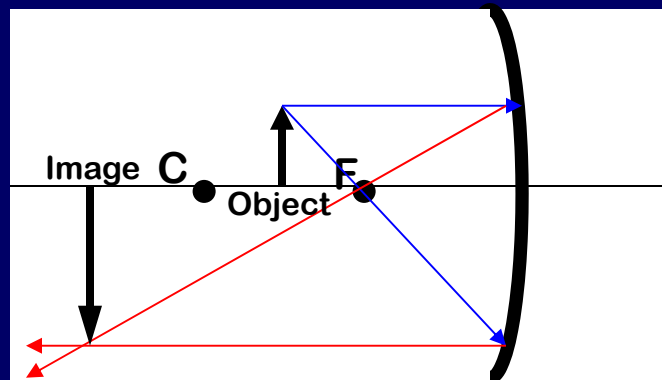
(-) sign tells us it's inverted from object

3 Cases for Concave Mirrors



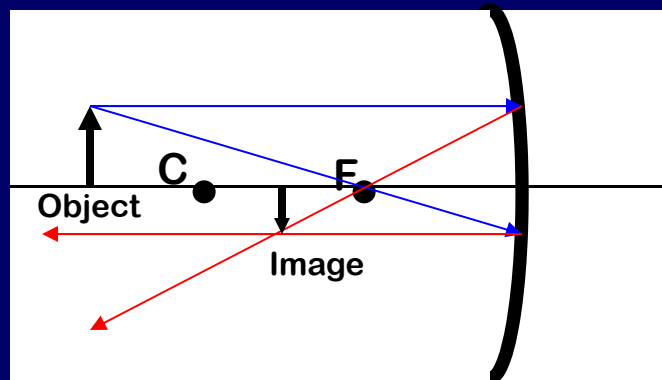
Inside F

Upright
Enlarged
Virtual



Between C&F

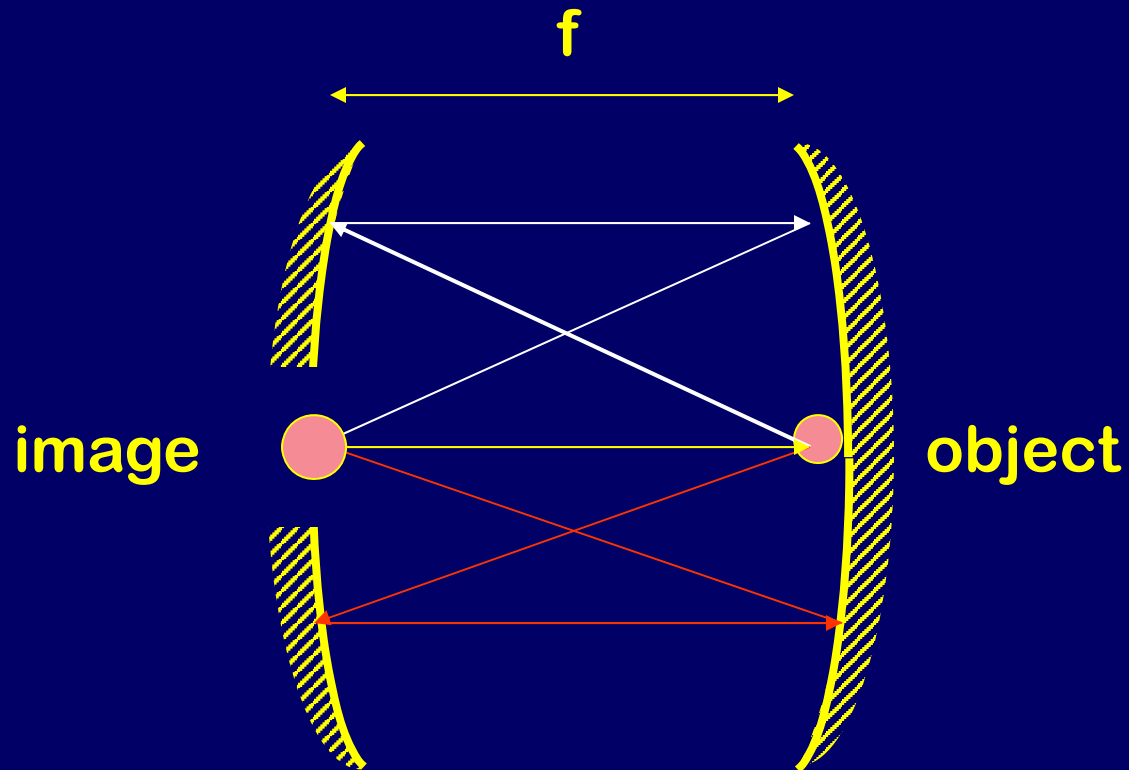
Inverted
Enlarged
Real



Past C

Inverted
Reduced
Real

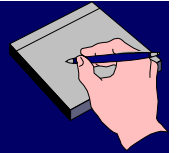
Demo: optical illusion



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.

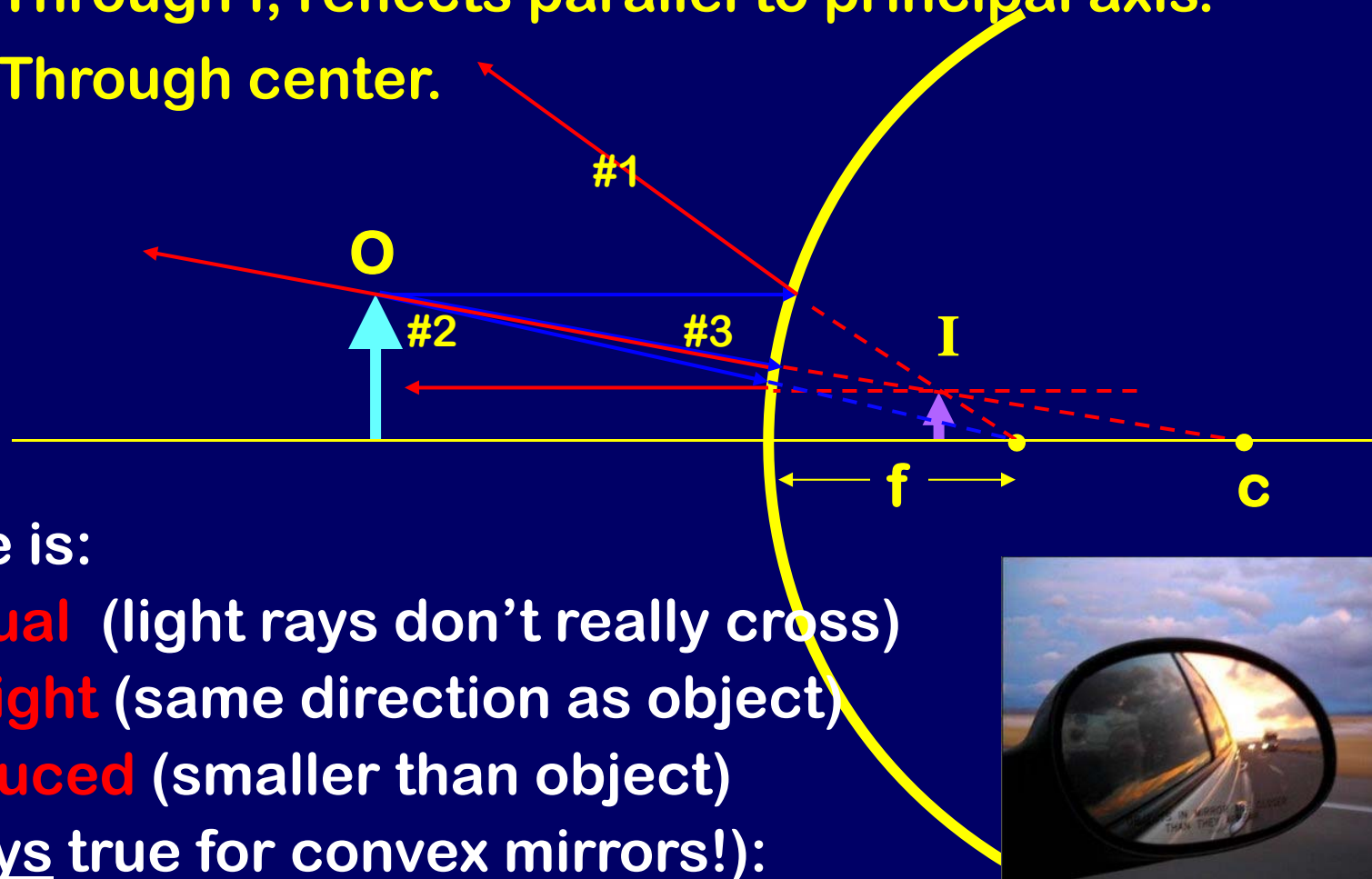


Image is:

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 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 $|d_i| < |f|$**

The diagram shows the mirror equation $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$ with three terms circled in purple. Arrows point from text labels to each term:
 - A purple arrow points from "d_i is negative!" to the circled $\frac{1}{d_i}$ term.
 - A purple arrow points from "f is negative" to the circled $\frac{1}{f}$ term.
 - A purple arrow points from "d_o is positive" to the circled $\frac{1}{d_o}$ term.

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

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

- $|f| = R/2$

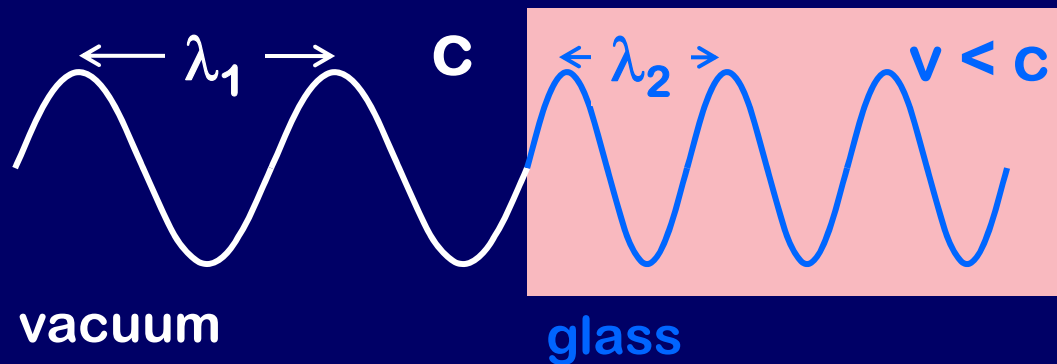
- $$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

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

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 \rightarrow

$$v = c/n$$

\uparrow
Speed of light in vacuum

n is a property
of the medium:

$$n_{\text{vacuum}} = 1$$

$$n_{\text{air}} = 1.0003$$

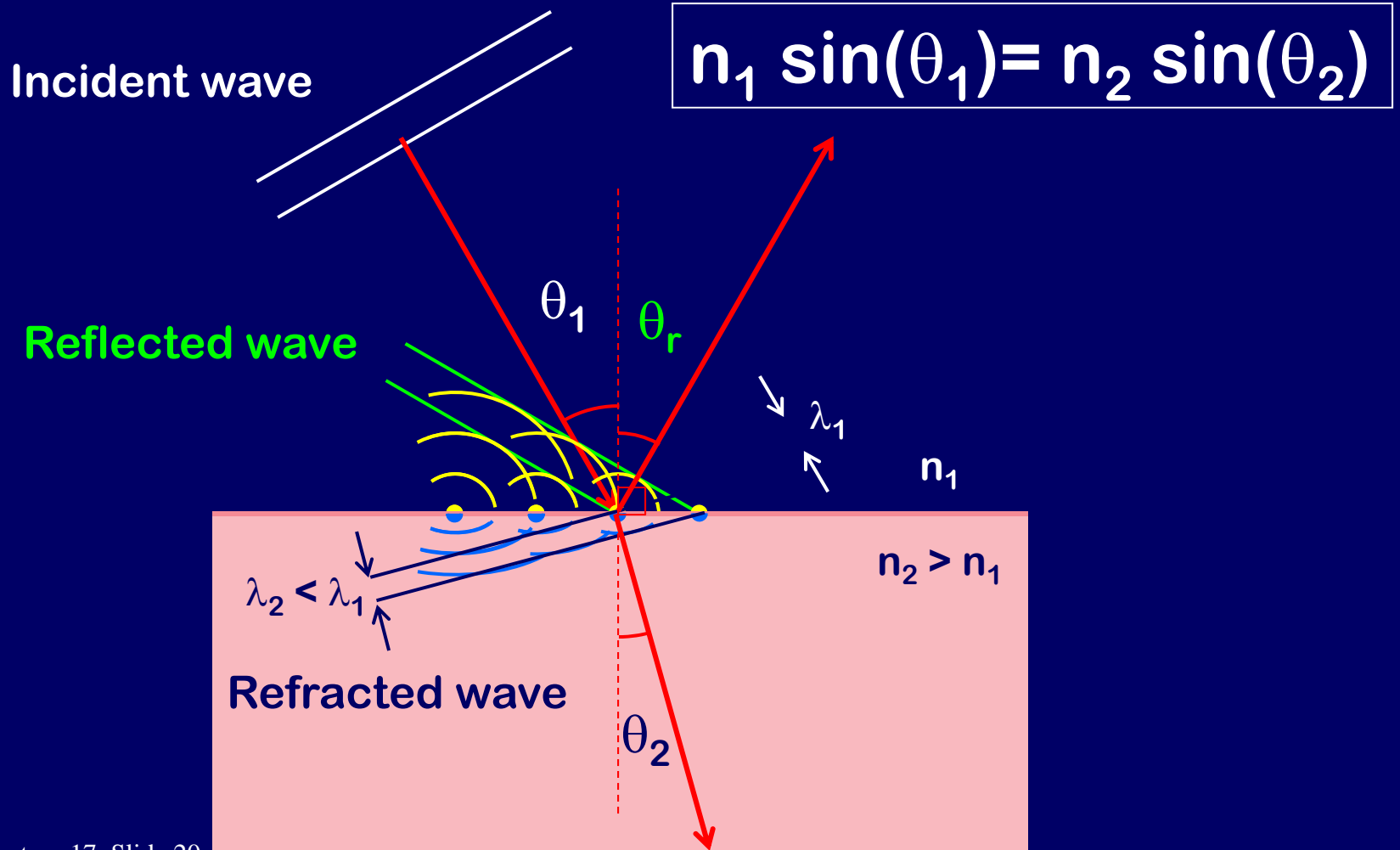
$$n_{\text{water}} = 1.33$$

$$n_{\text{glass}} = 1.50$$

$$n \geq 1$$

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



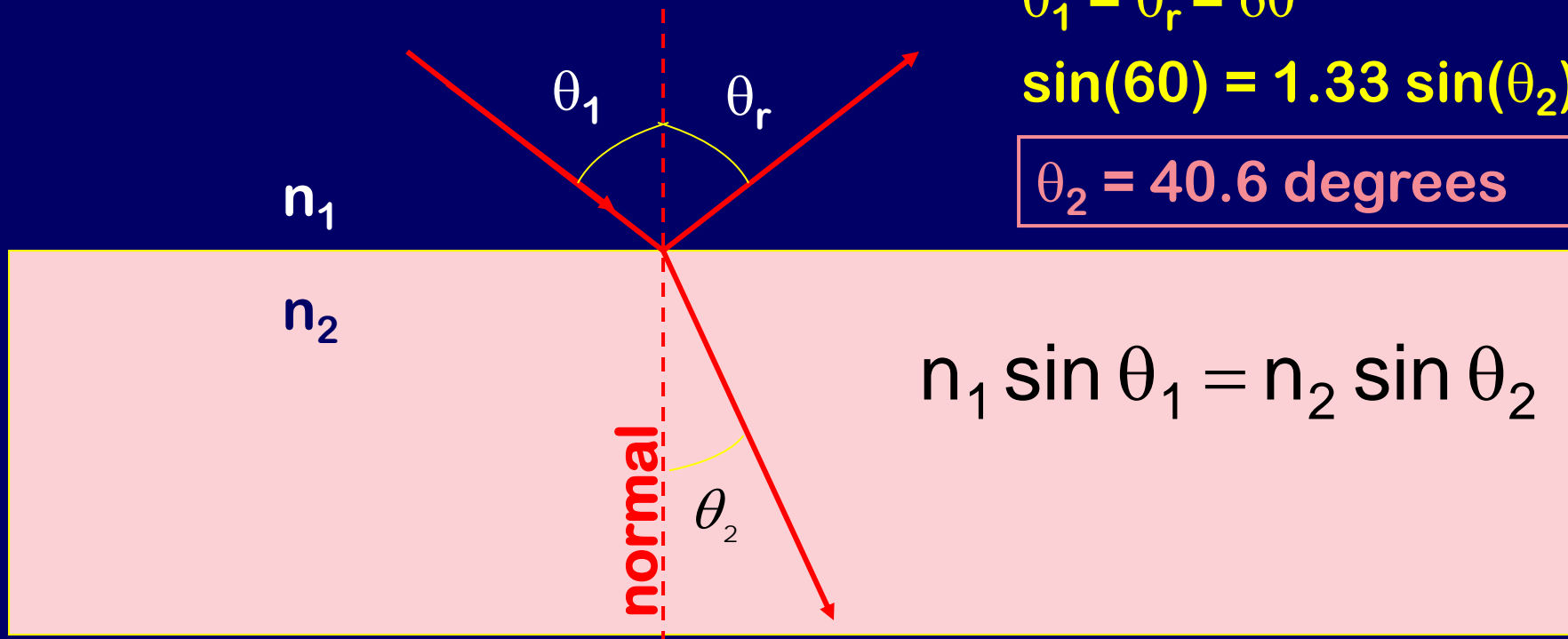
Usually, there is both **reflection** and **refraction**!

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 ?

$$\theta_1 = \theta_r = 60$$

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

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



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

Happy studying!