Physics 102: Lecture 17

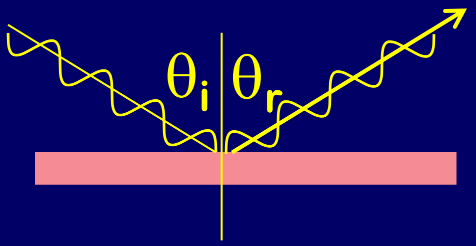
Reflection and Refraction of Light

Recall from last time….

Last Time

Reflection:

$$\boxed{\theta_i = \theta_r}$$



Flat Mirror:

image equidistant behind

Spherical Mirrors:

Concave or Convex

Today

Refraction:

$$\boxed{n_1 \sin(\theta_1) = n_2 \sin(\theta_2)}$$

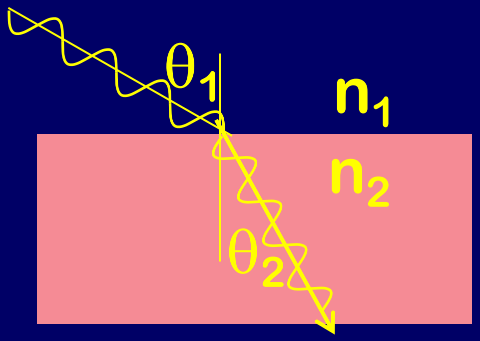


Image formation using spherical mirrors

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.

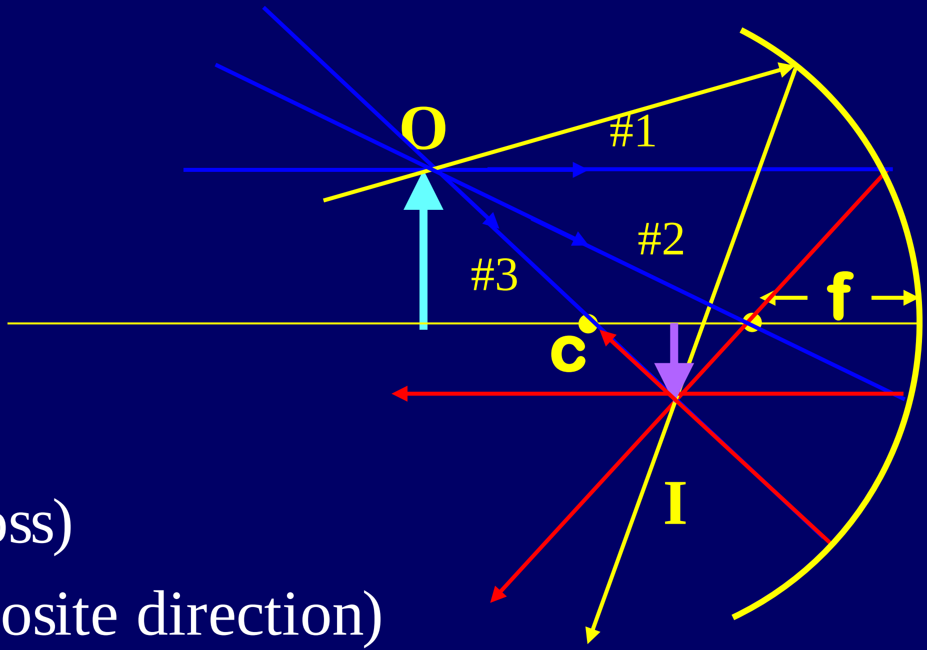


Image is (in this case):

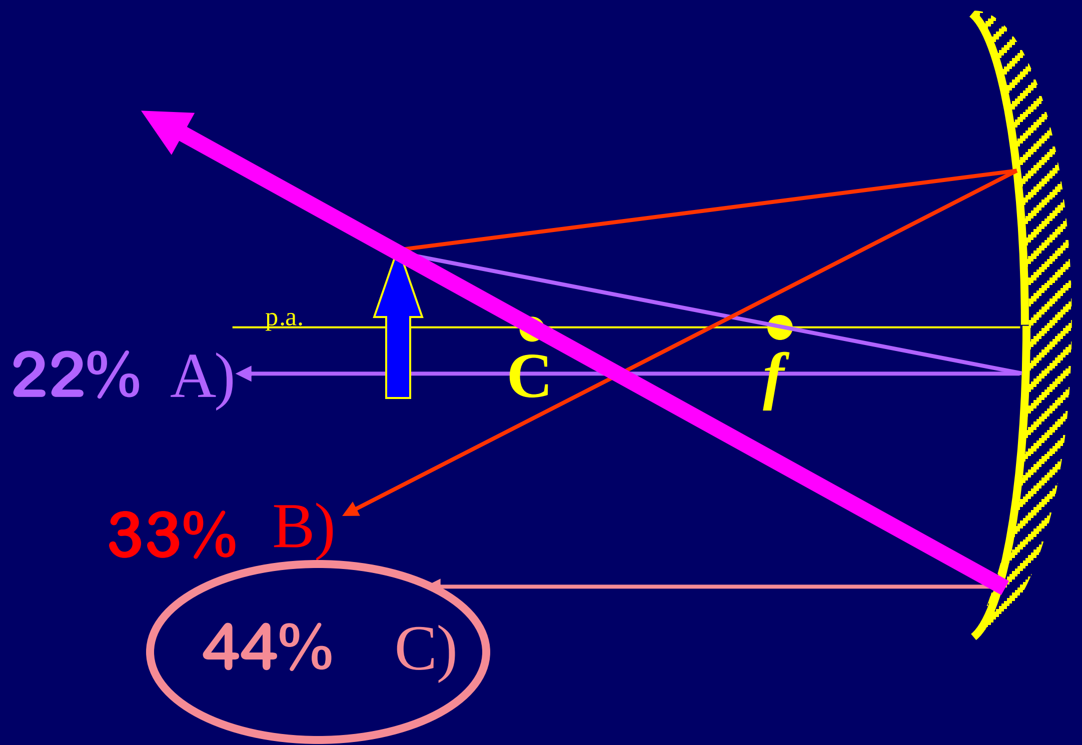
- Real (light rays actually cross)
- Inverted (Arrow points opposite direction)
- Reduced (smaller than object)

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

ACT: Checkpoint 1.1

Which ray is NOT correct?

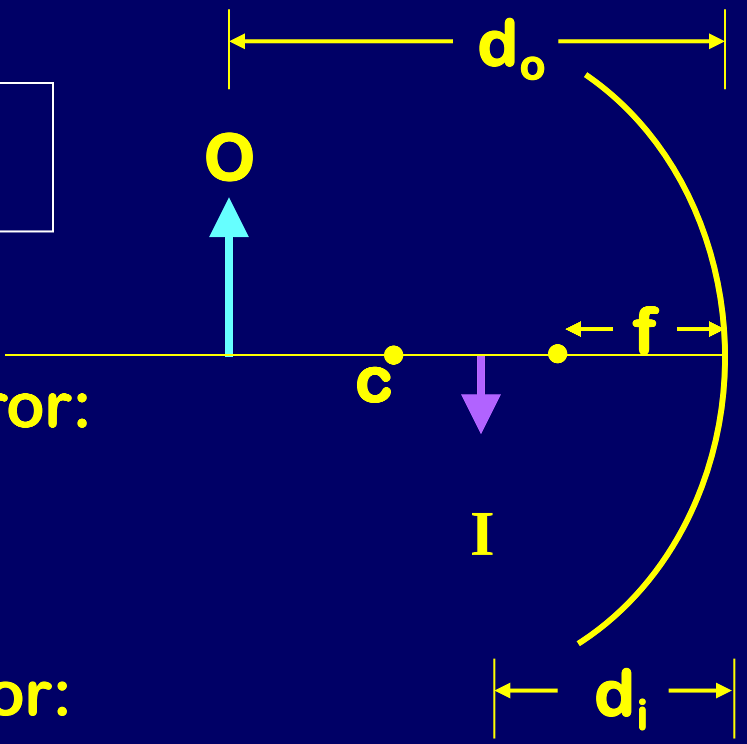
Ray through center should reflect back on self.



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:

23% 1) Always Real

26% 2) Always Virtual

51% 3) Sometimes Real, Sometimes Virtual

Concave mirror: $f > 0$

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

Mirror Equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_0}$$

d_i is positive if $d_0 > f$; negative is $d_0 < f$.

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

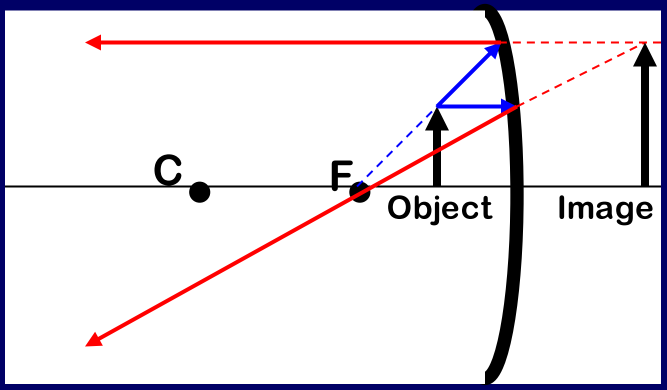
Mirror Equation:

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

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_0}$$

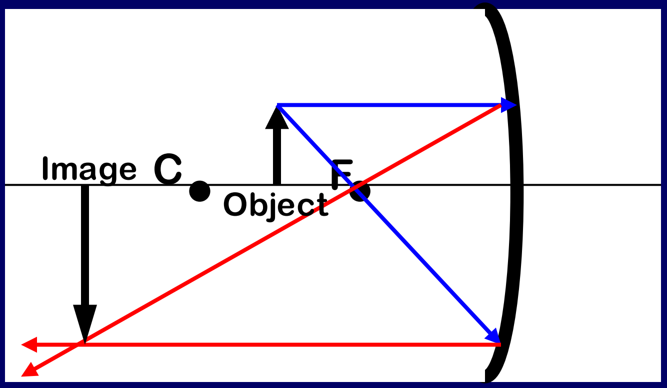
- Concave mirror: $f > 0$
- Object in front of mirror: $d_o > 0$
- Virtual image means behind mirror: $d_i < 0$
- When $d_o < f$ then $d_i < 0$ virtual image.

3 Cases for Concave Mirrors



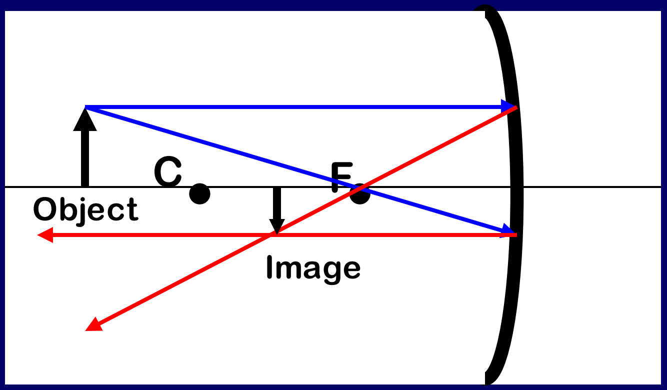
Inside F

Virtual



Between C&F

Real

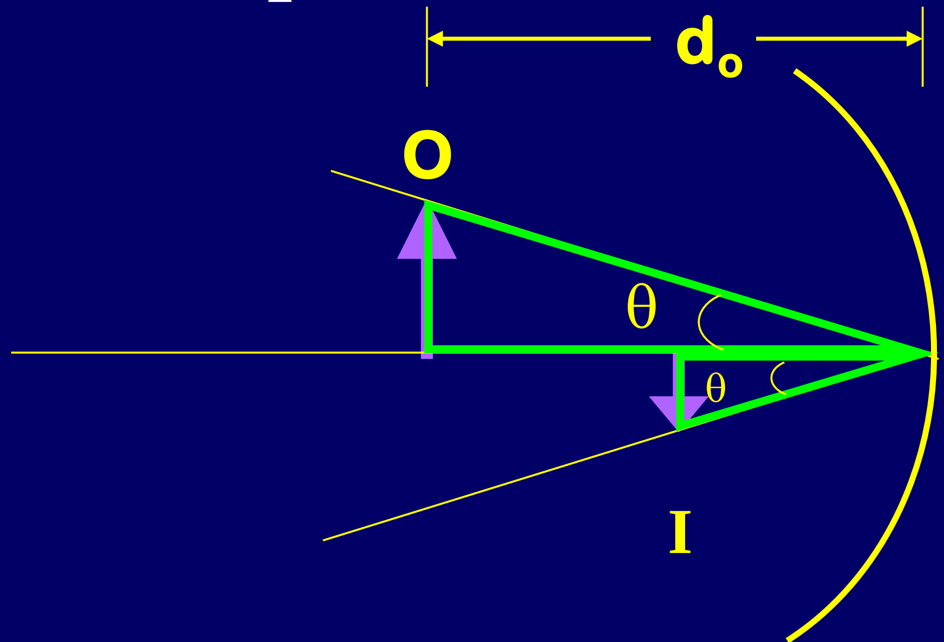


Past C

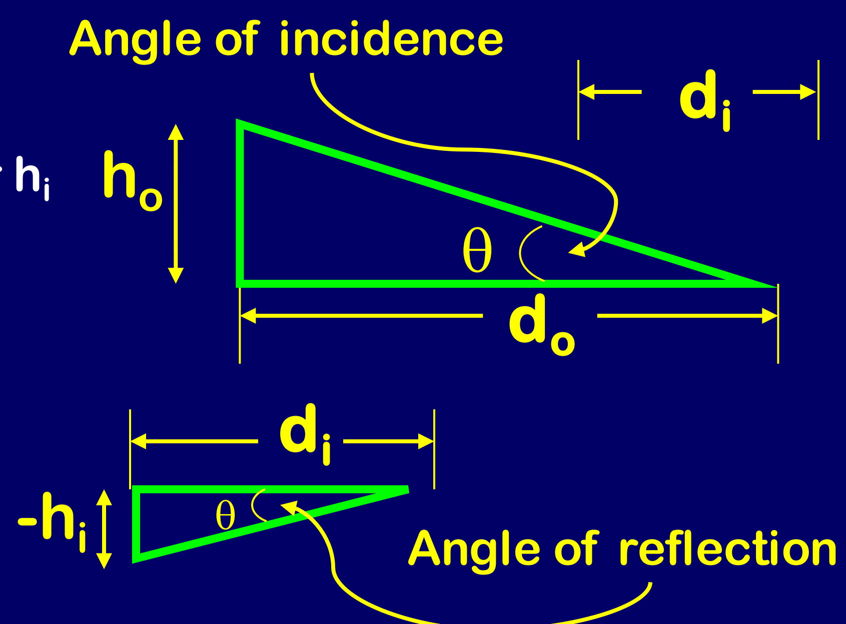
Real

Magnification Equation

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



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



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

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 cm (in front of mirror)

Real Image!

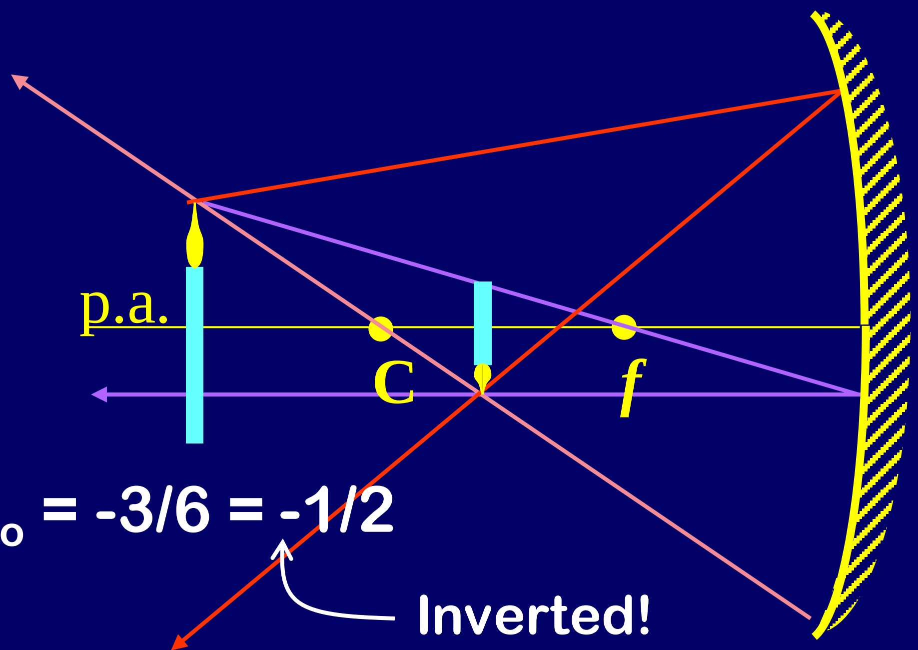
Checkpoint 1.2

Compared to the candle, the image will be:

30% • Larger

54% • Smaller

16% • Same Size



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

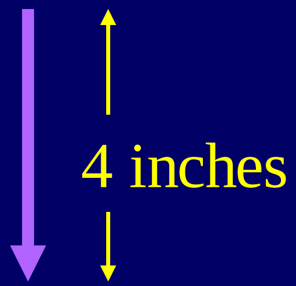
Inverted!

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?

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



A. 2 inches

B. 4 inches

C. 8 inches

Magnitude gives us size.

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

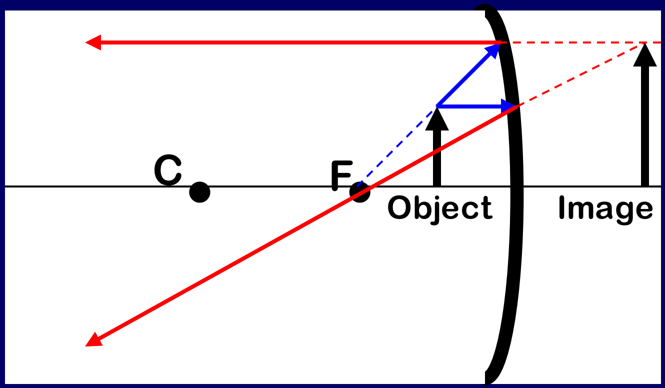
What direction will the image arrow point?

A. Up

B. Down

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

3 Cases for Concave Mirrors

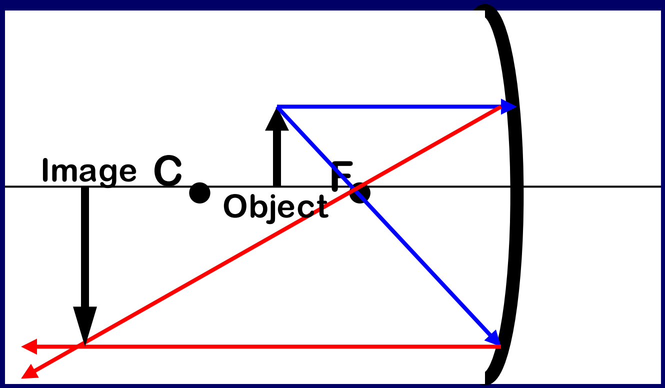


Inside F

Upright

Enlarged

Virtual

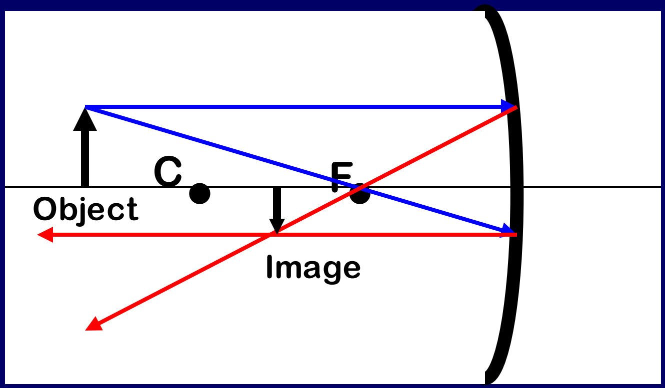


Between C&F

Inverted

Enlarged

Real



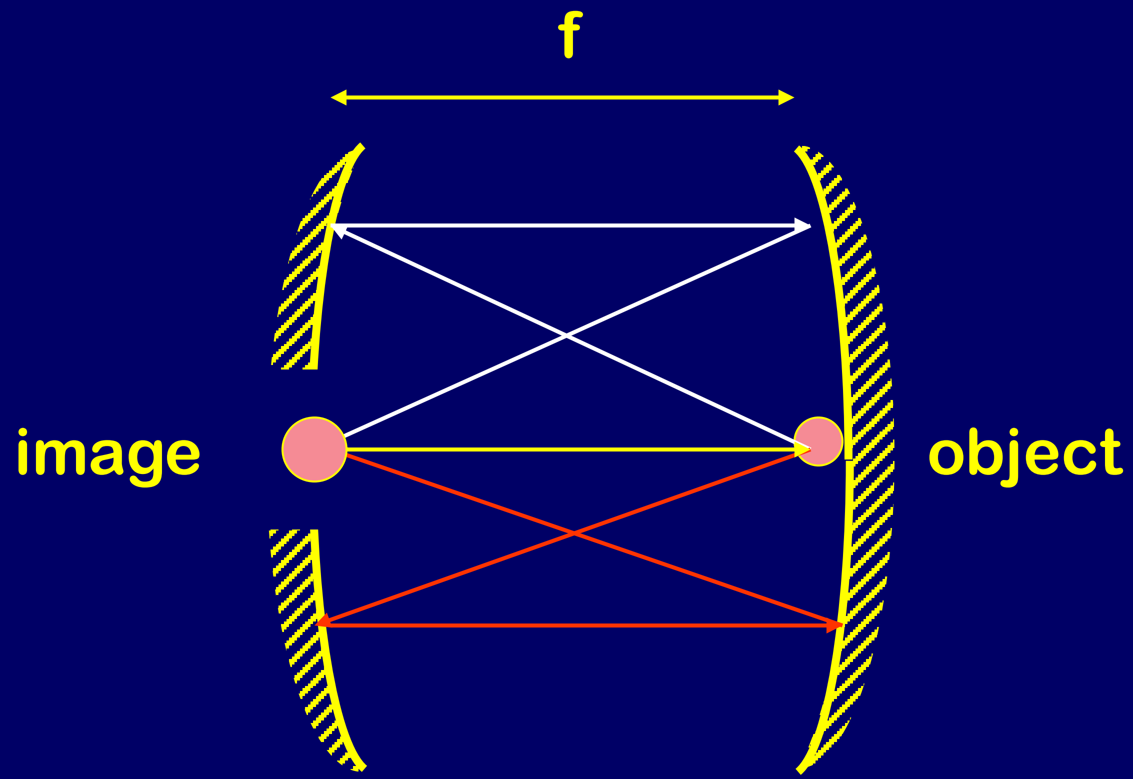
Past C

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.

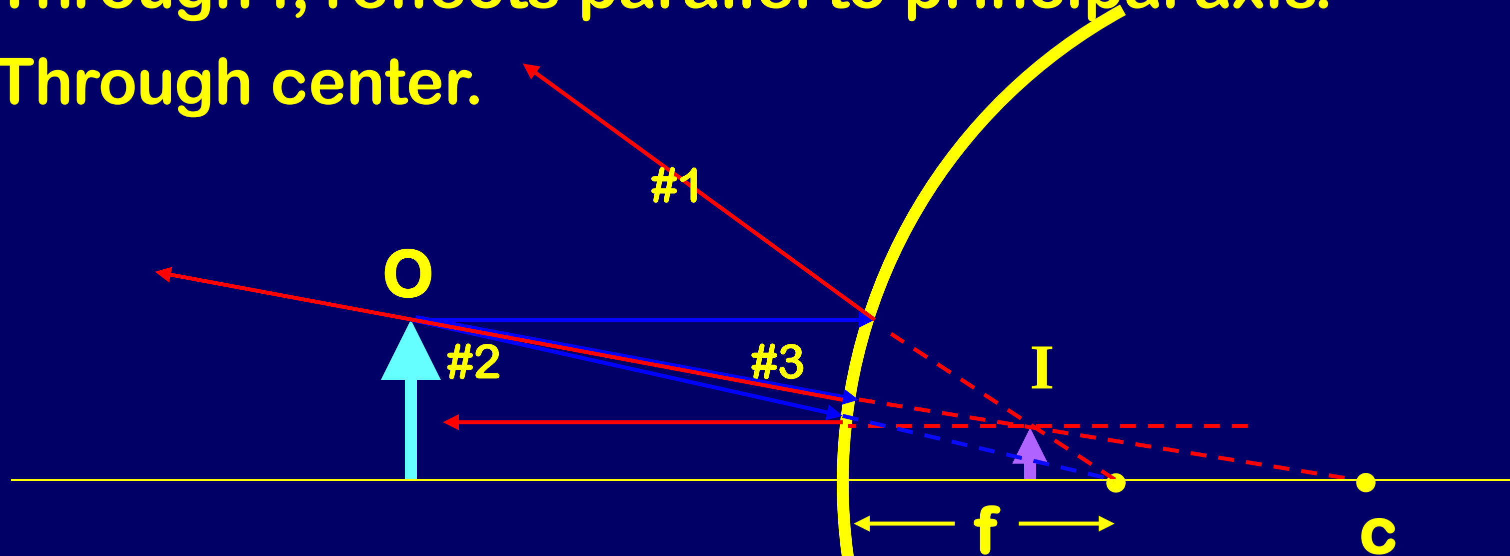


Image is:

Virtual (light rays don't really cross)

Upright (same direction as object)

Reduced (smaller than object)

(<u>always</u> 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.

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

$d_i = -\,2$ cm (behind mirror)

Virtual Image!

Determine the magnification of the candle.

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

m = + 1/3

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

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

$h_i = +\,3$ cm

Image is Upright!

Checkpoint 1.4

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

Mirror Equation:

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

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

- **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 $|d_i|<|f|$**

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_0}$$

d_i is negative!

f is negative

d_o is positive

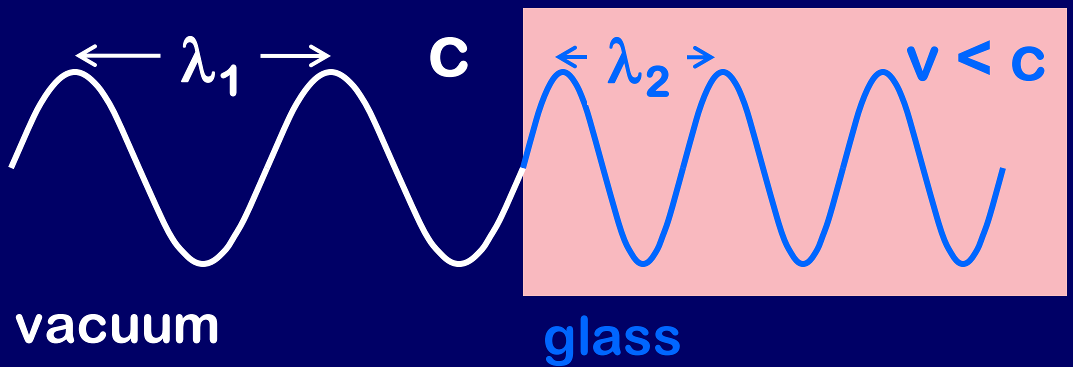
Mirror Summary

- 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
- $|f| = R/2$
- $$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$
- $$\mathbf{m} \equiv \frac{\mathbf{h_i}}{\mathbf{h_o}} = -\frac{\mathbf{d_i}}{\mathbf{d_o}}$$

Index of Refraction

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

In a medium (air, water, glass...) light is <u>slower</u>



Frequency is the <u>same</u>, wavelength <u>decreases</u>

$$v = \lambda f$$

"Index of refraction"

Speed of light in medium → $\boxed{v = c/n}$

Speed of light in vacuum

n is a property of the medium:

$n_{vacuum} = 1$

$n_{air} = 1.0003$

$n_{water} = 1.33$

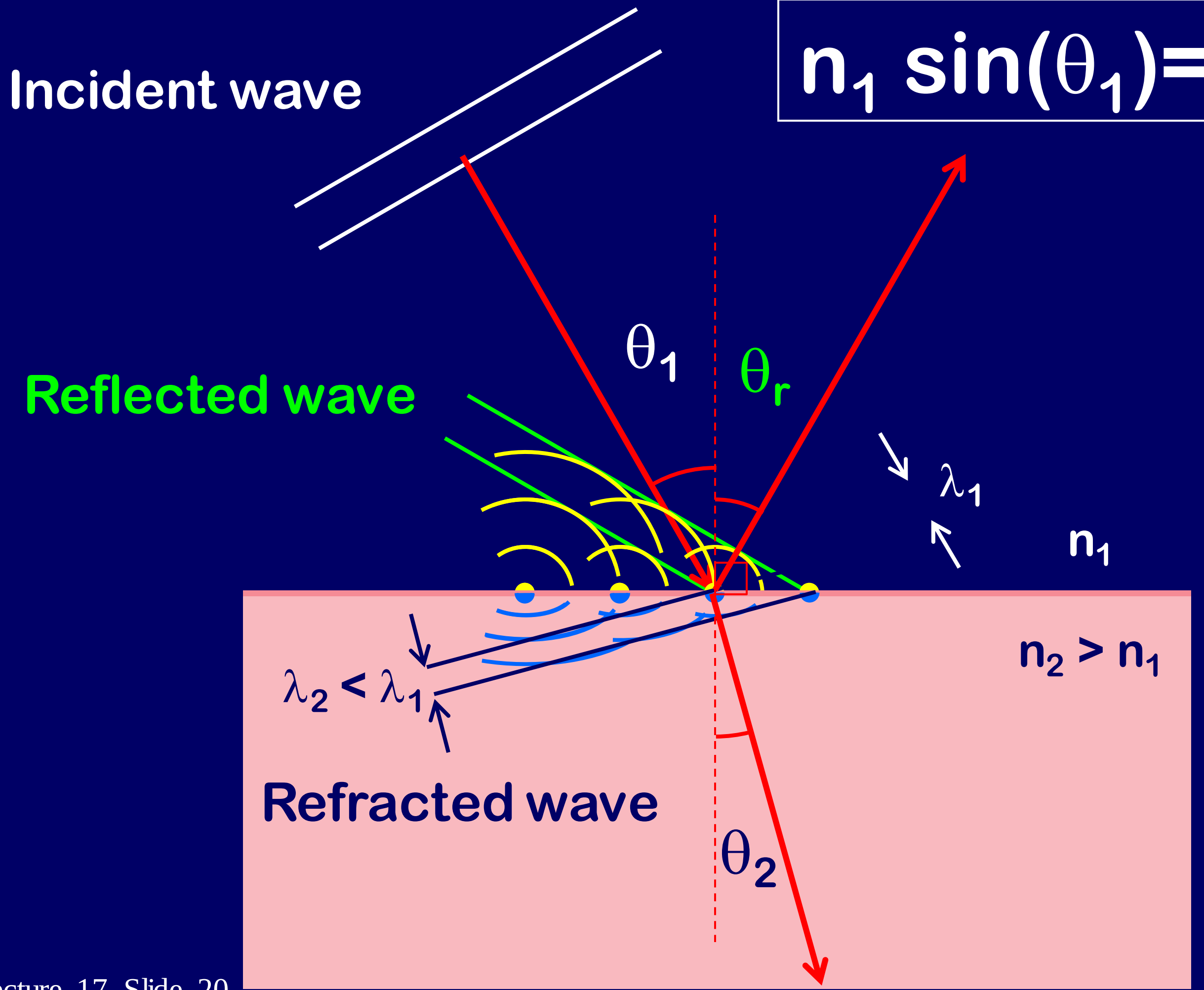
$n_{glass} = 1.50$

$\boxed{n \geq 1}$

Snell's law of Refraction

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

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



Example

Snell's Law Practice

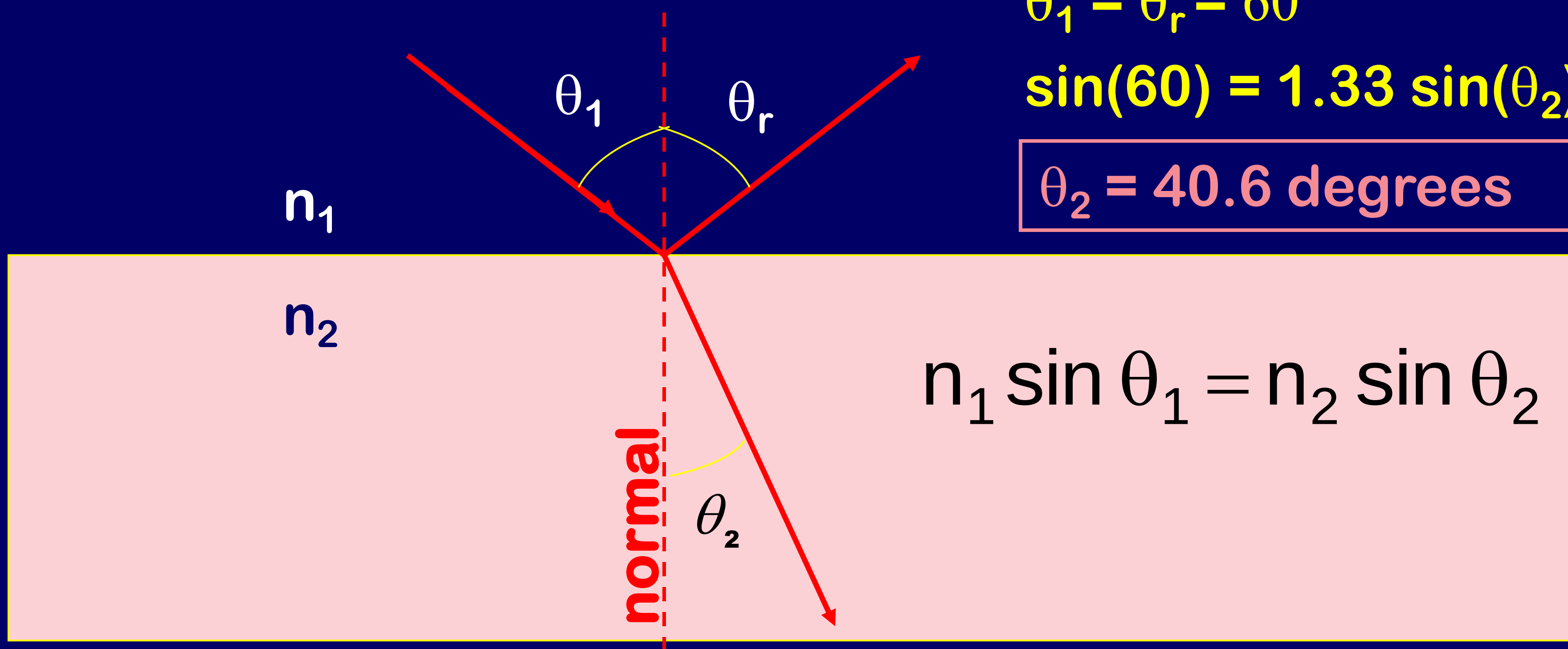
Usually, there is both reflection and refraction!

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?

$\theta_1 = \theta_r = 60$

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

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



Have a Fantastic Spring Break!