Physics 102: Lecture 17

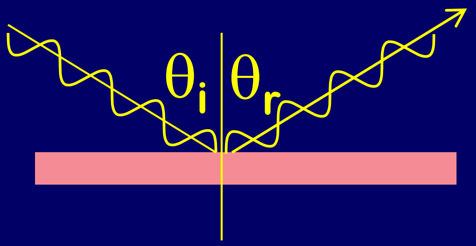
Reflection and Refraction of Light

Recall from last time….

Last Time

Reflection:

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



Flat Mirror:

image equidistant behind

Spherical Mirrors:

Concave or Convex

Today

Refraction:

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

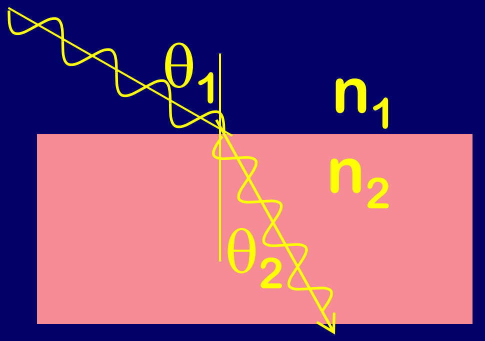


Image formation using spherical mirrors

Why are objects "closer than they appear"?

Key Ideas:

- **Principal rays**
- **Mirror equation & Magnificati**

Concave Mirror Principal Rays

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

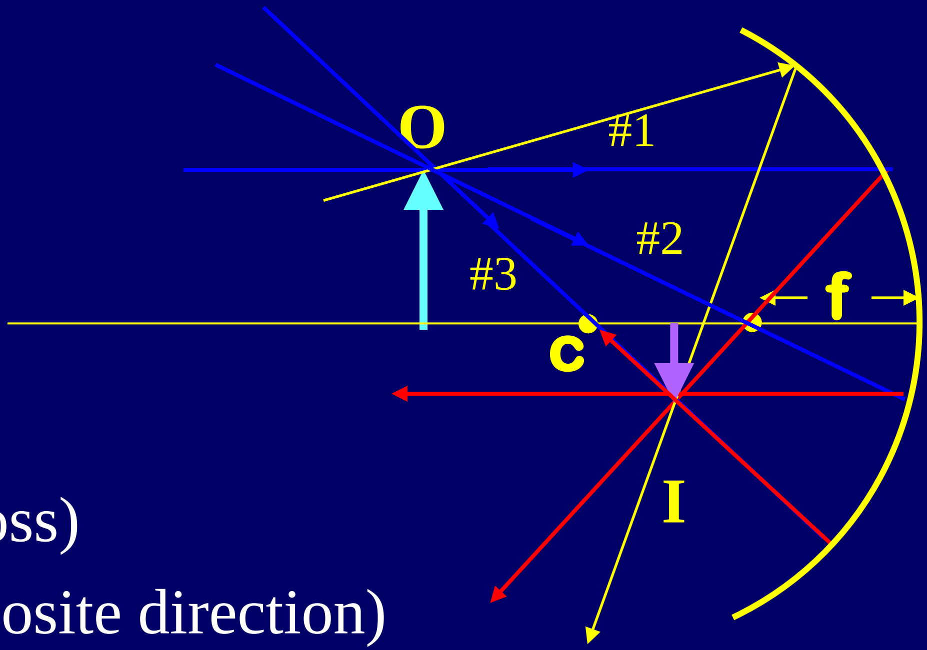


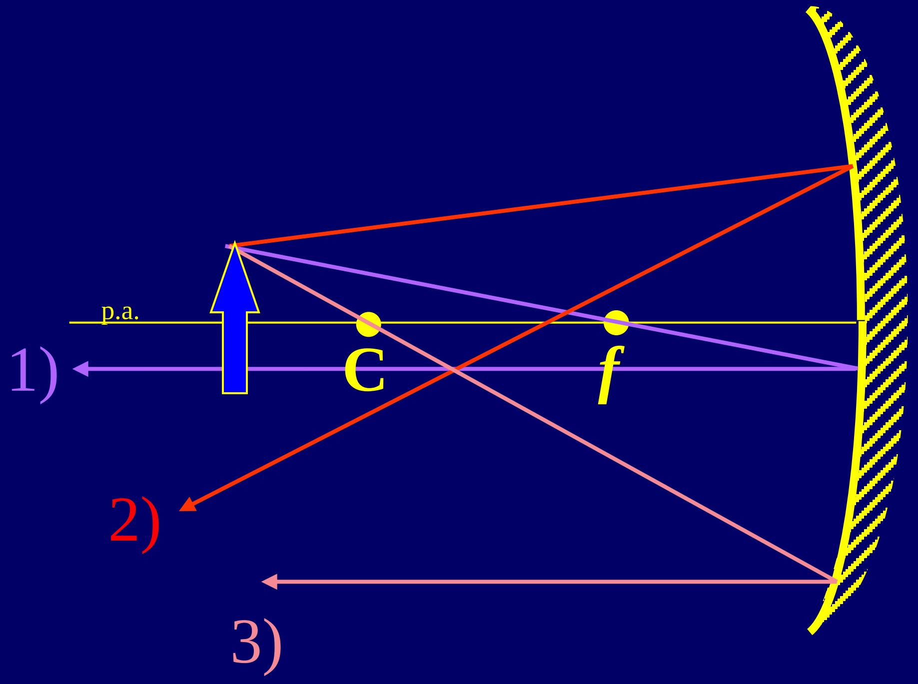
Image is (in this case):

- 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

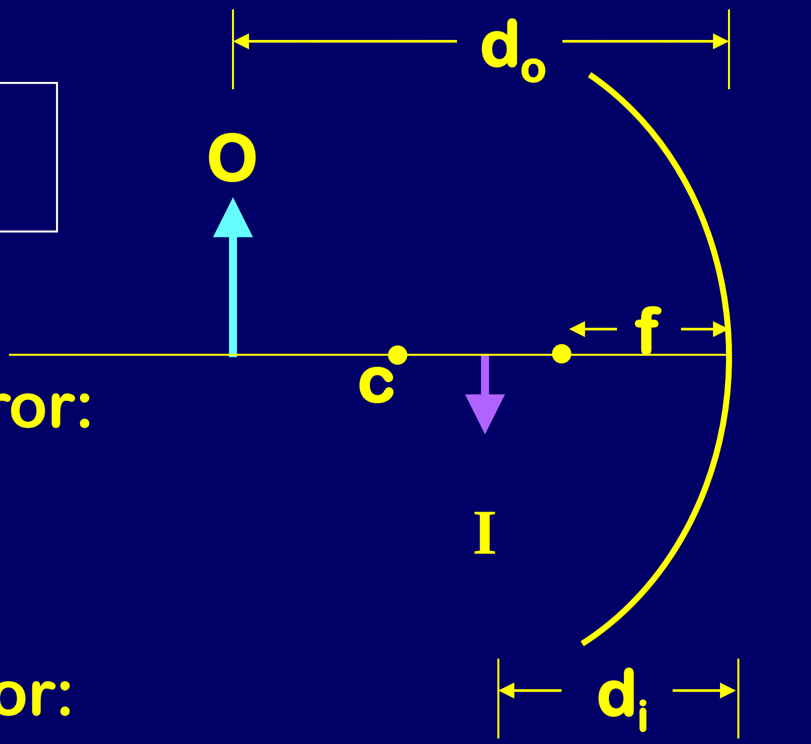
Which ray is NOT correct?



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 <u>in front</u> of mirror

  Negative: object <u>behind</u> mirror

- **d_i = distance image is from mirror:**
  - Positive: <u>real</u> image (in front of mirror)
  - Negative: <u>virtual</u> image (behind mirror)

- **f = focal length mirror:**
  - Positive: <u>concave</u> mirror +R/2
  - Negative: <u>convex</u> mirror –R/2

Checkpoint 1.3

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

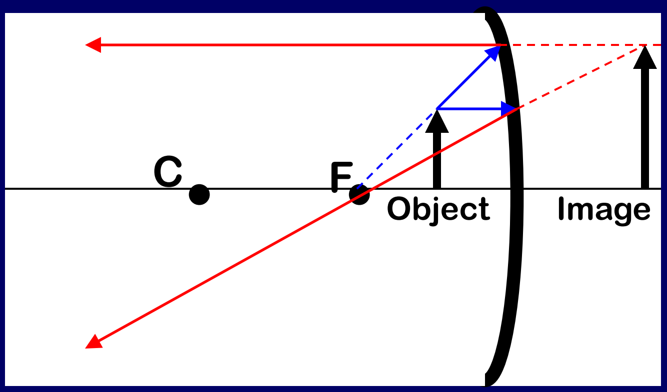
1) **Always Real**
2) **Always Virtual**
3) **Sometimes Real, Sometimes Virtual**

ACT: Concave Mirror

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

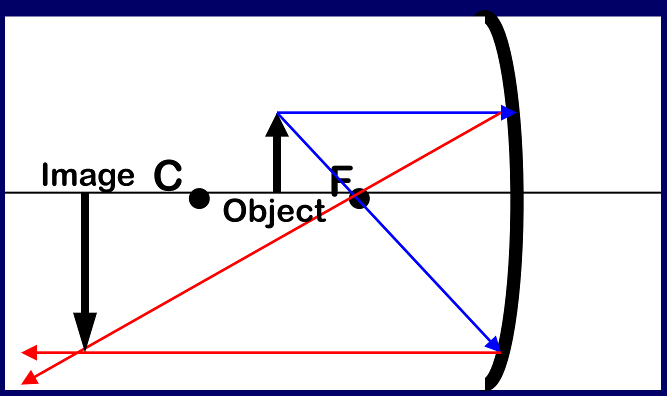
1) **Close to mirror**
2) **Far from mirror**
3) **Either close or far**
4) **Not Possible**

3 Cases for Concave Mirrors



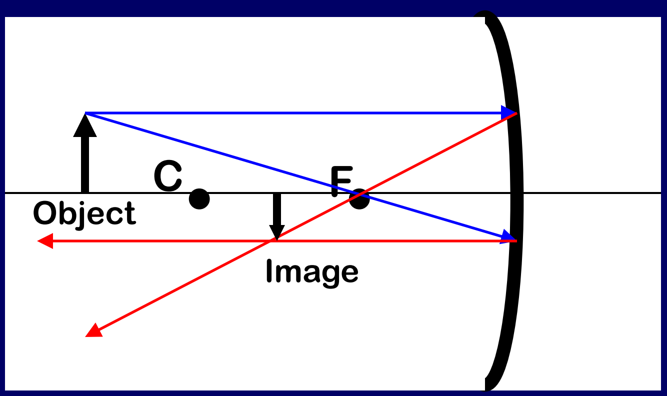
Virtual

Inside F



Real

Between C&F



Real

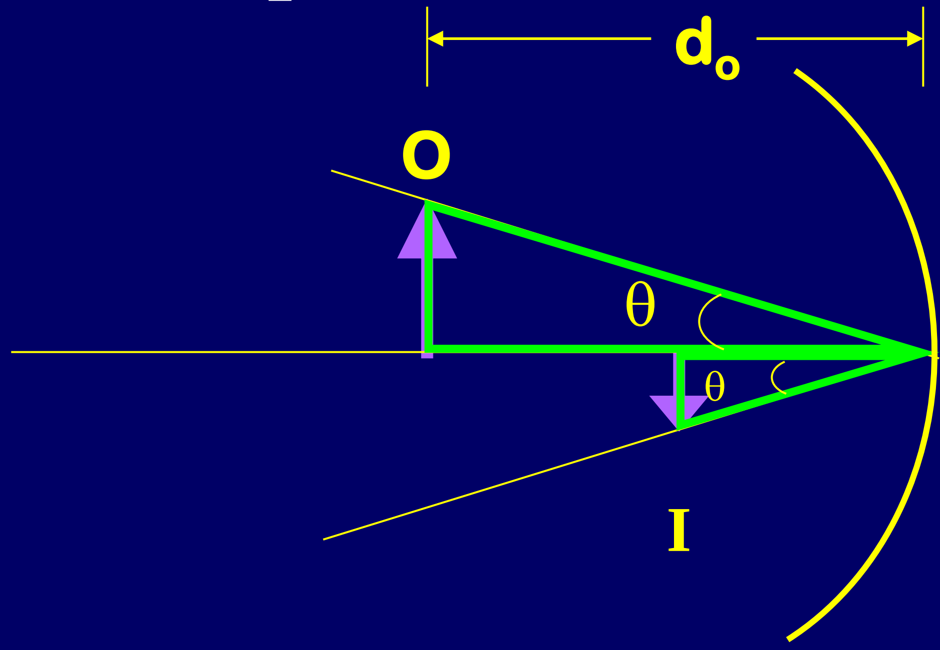
Past C

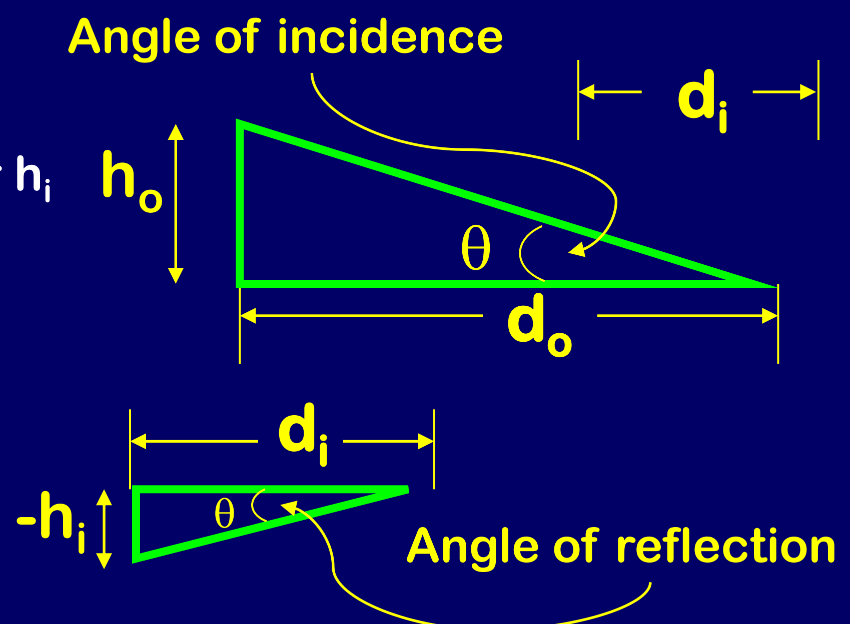
Magnification Equation

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

- **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

$$\tan(\theta) = \frac{h_o}{d_0} = -\frac{h_i}{d_i}$$





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.

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

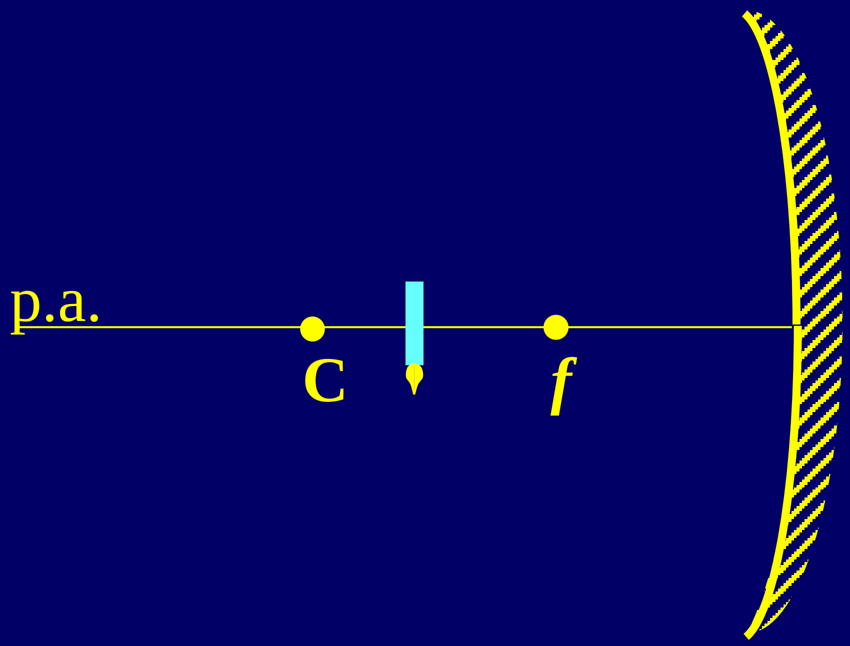
d_i = + 3 cm (in front of mirror)

Real Image!

Checkpoint 17.2

Compared to the candle, the image will be:

- Larger
- Smaller
- Same Size



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

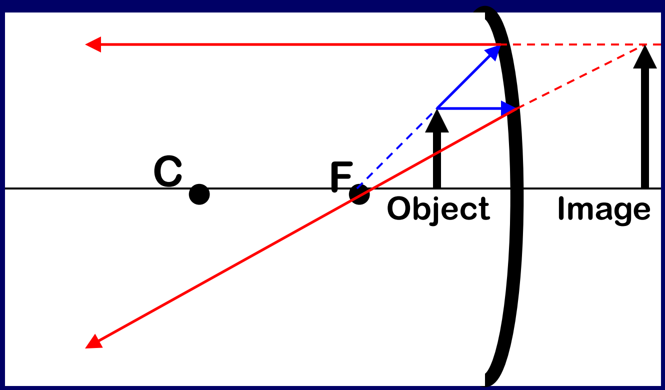
C. 8 inches

What direction will the image arrow point?

A. Up

B. Down

3 Cases for Concave Mirrors

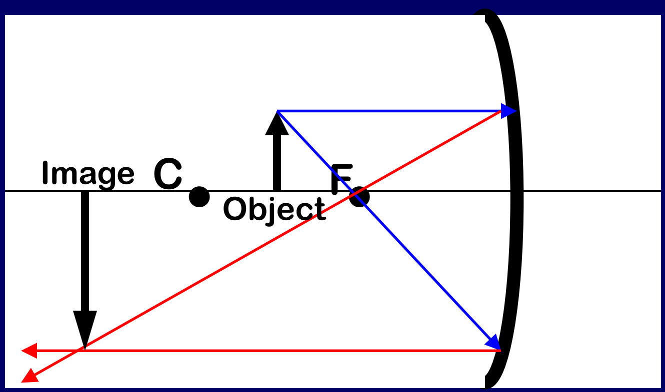


Inside F

Upright

Enlarged

Virtual

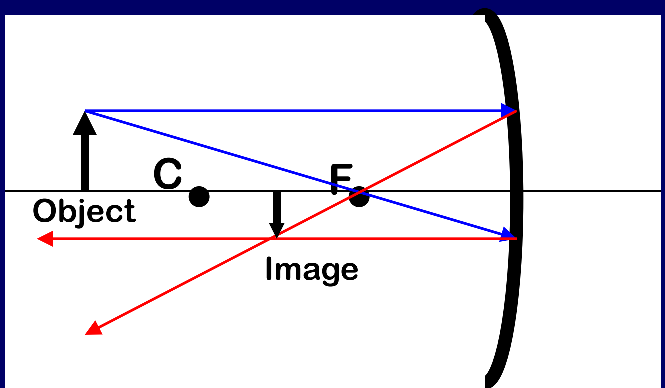


Between C&F

Inverted

Enlarged

Real



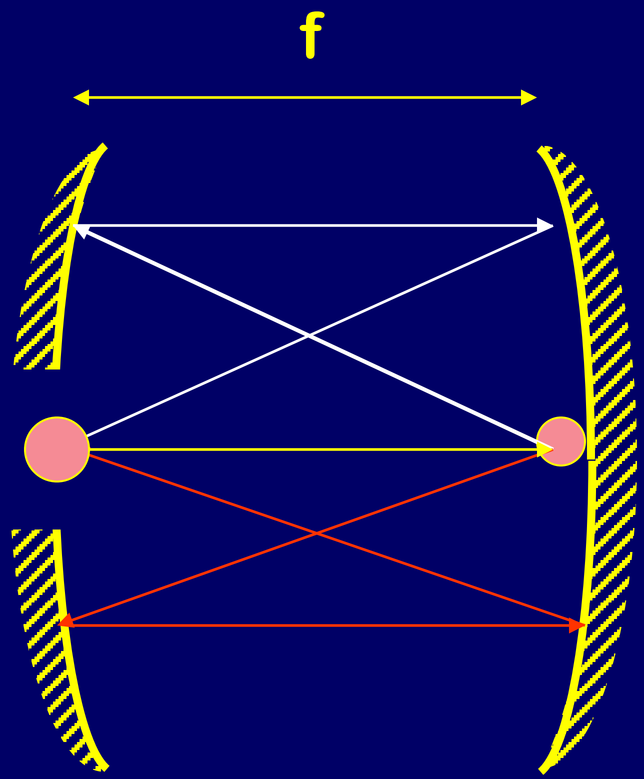
Past C

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.

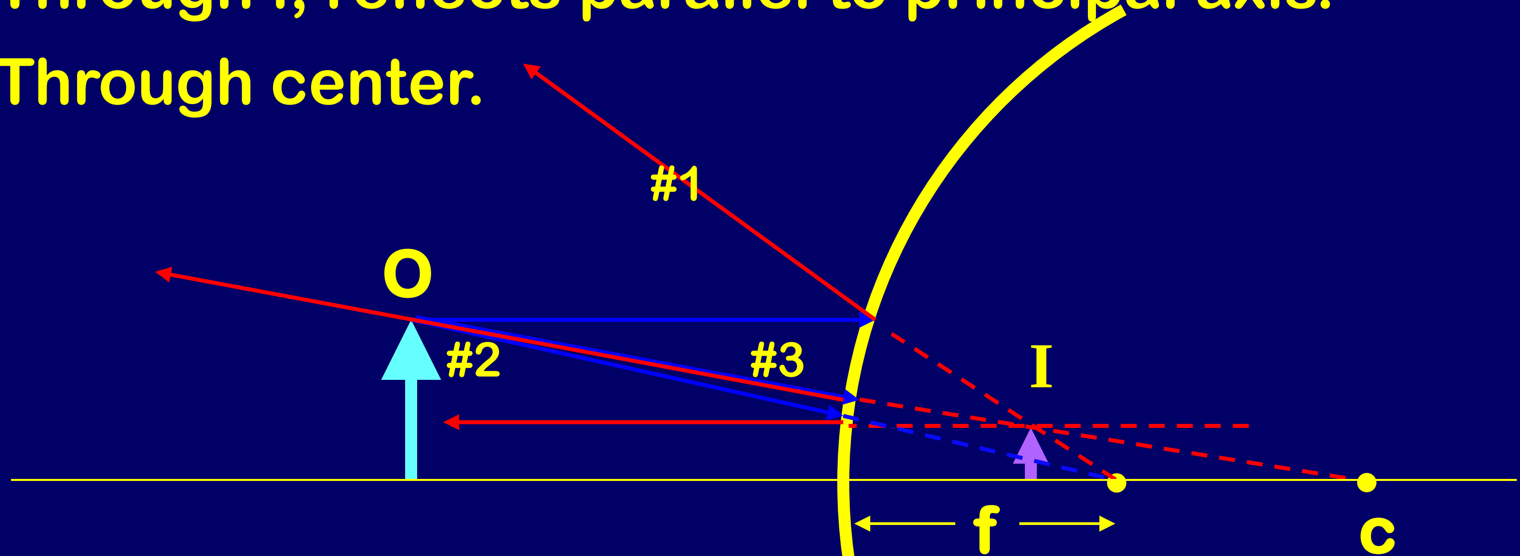


Image is:
- **Virtual** (light rays don't really cross)
- **Upright** (same direction as object)
- **Reduced** (smaller than object)

(<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.

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

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

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

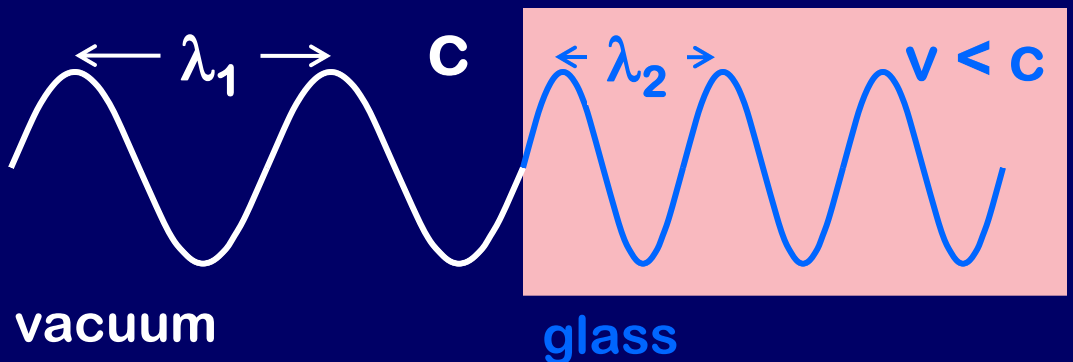
Mirror Summary

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

Index of Refraction

Recall speed of light c = 3×10^8 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:

$n_{vacuum} = 1$

$n_{air} = 1.0003$

$n_{water} = 1.33$

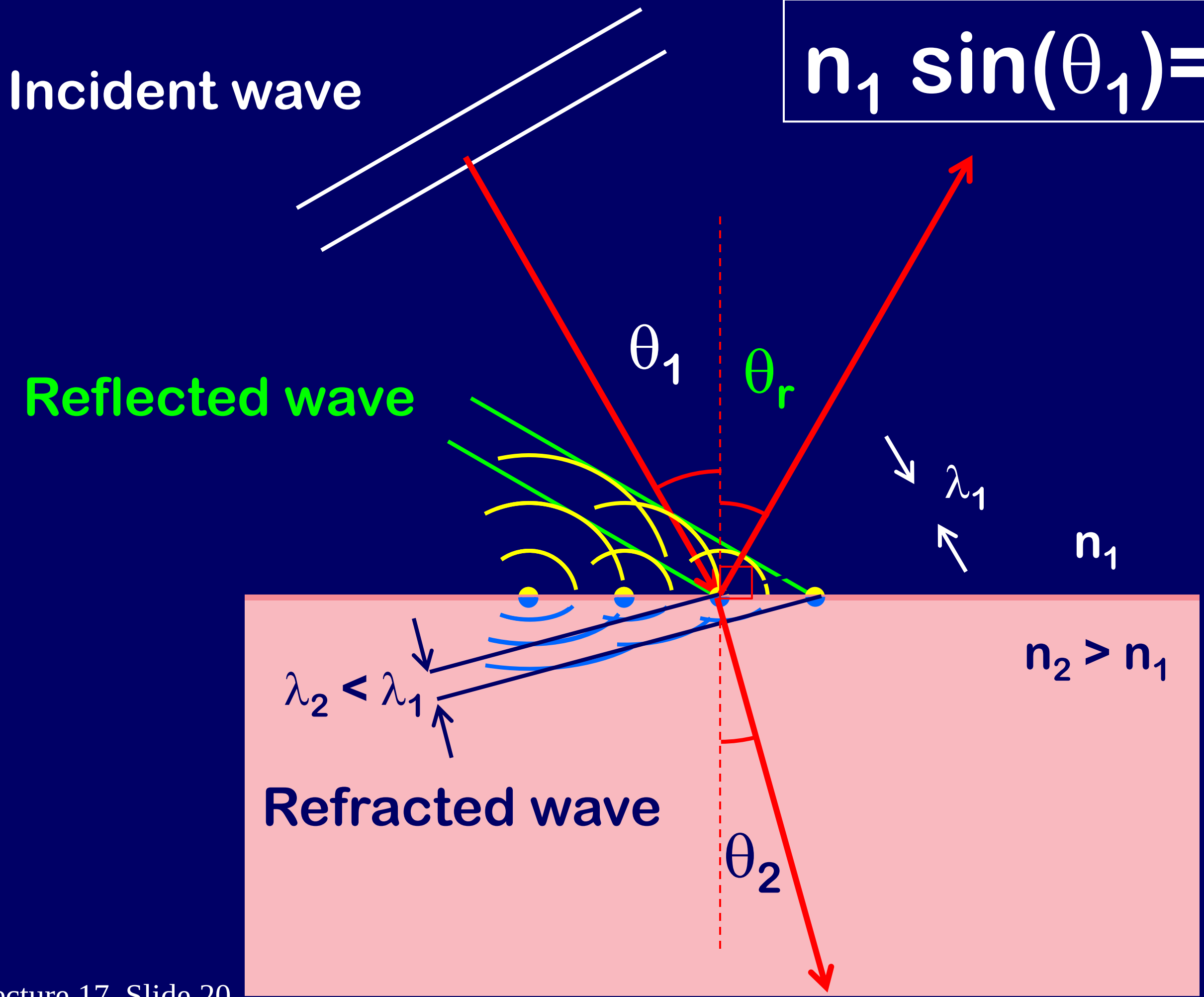
$n_{glass} = 1.50$

$\boxed{n \geq 1}$

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

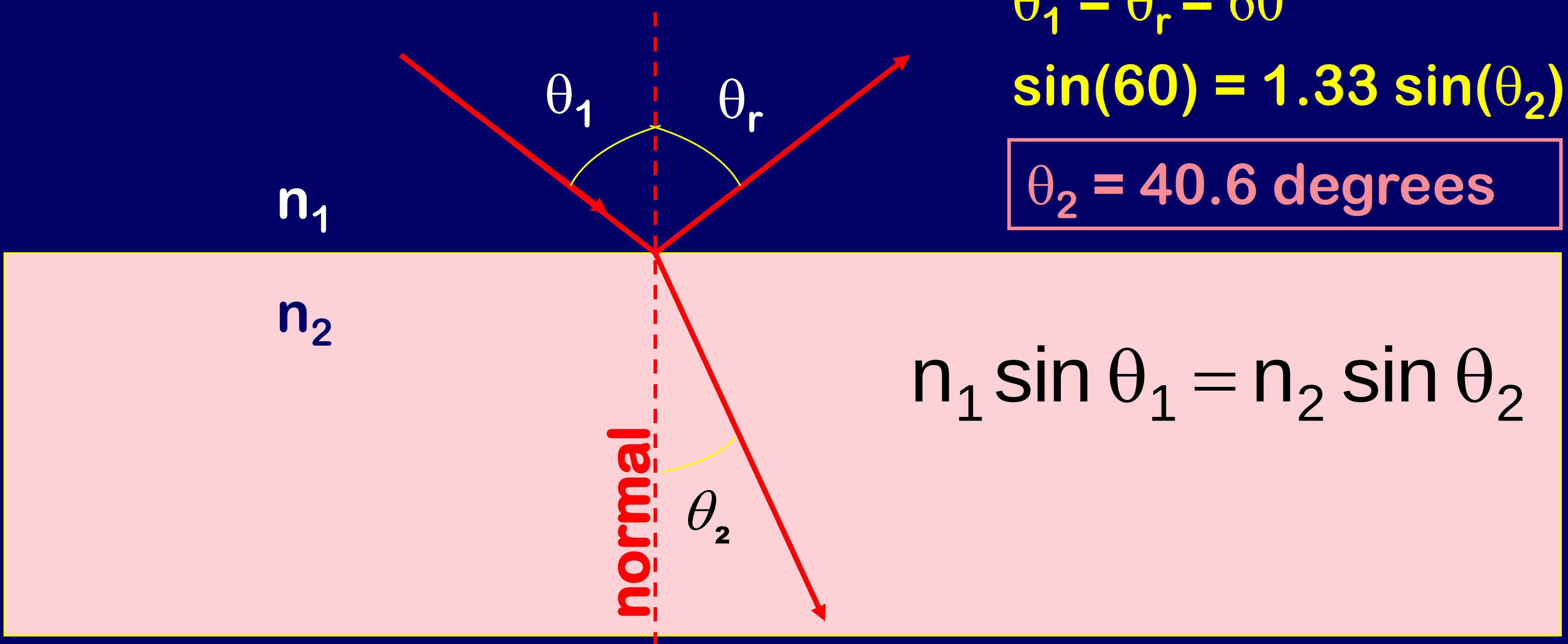
Usually, there is both reflection and refraction!

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 θ_r = 60. The other part of the beam is refracted. What is θ_2?

$\theta_1 = \theta_r = 60$

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

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



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