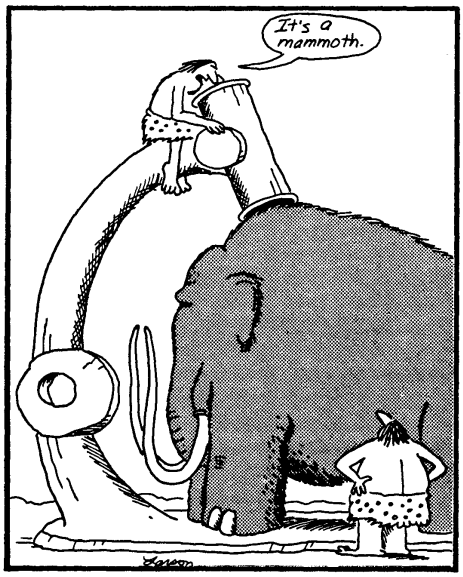
April 24, 2017 Physics 132 Prof. E. F. Redish

- **<u>Theme Music:</u>**
  Justin Timberlake
  Mirrors

- **<u>Cartoon:</u>**
  Gary Larson
  The Far Side



Early microscope

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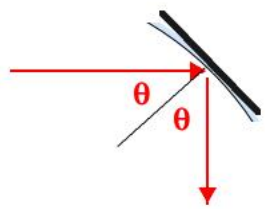
Outline

- Images produced by a curved mirror
- Image equations for a curved mirror
- Light in dense media: Snell's law
- Snell's law in Newton's model
- Thin lenses

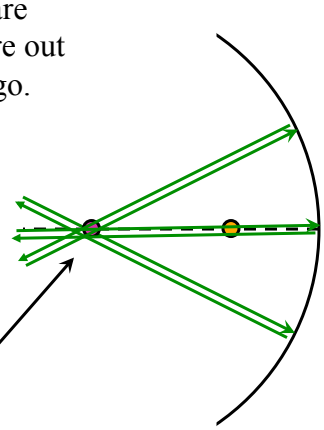
4/24/17 Physics 132 **2**

What happens when a ray hits a curved mirror?



A Spherical Mirror: Central Rays

A few rays are easy to figure out where they go.

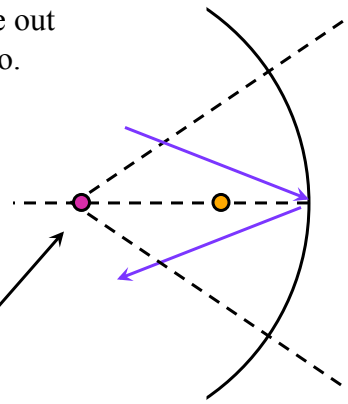


All rays satisfy the "angle of incidence = angle of reflection" measured to the normal to the surface

All rays through the center strike the mirror perpendicular to the surface and bounce back along their incoming path.

A Spherical Mirror: Central Ray

A few rays are easy to figure out where they go.



All rays satisfy the "angle of incidence = angle of reflection" measured to the normal to the surface

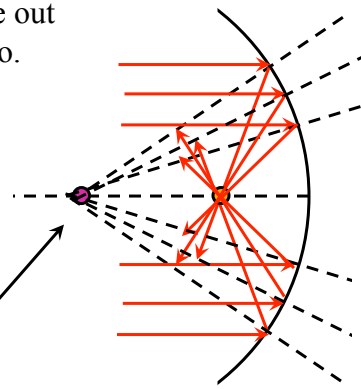
The ray hitting the central line of the diagram is particularly simple.

center of sphere

4/24/17 Physics 132 **5**

A Spherical Mirror: Parallel Rays

A few rays are easy to figure out where they go.



All rays satisfy the "angle of incidence = angle of reflection" measured to the normal to the surface

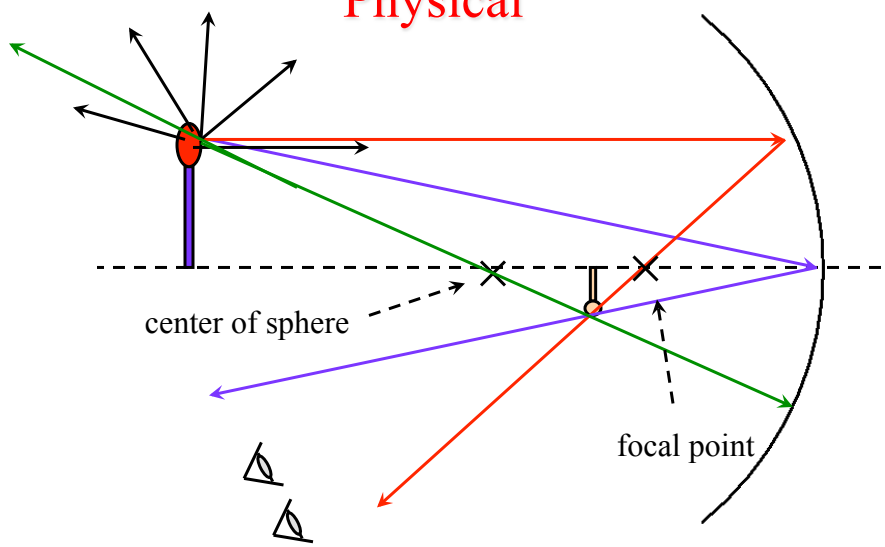
All rays parallel to and near an axis of the sphere reflect through a single point on the axis (the focal point)

center of sphere

4/24/17 Physics 132 **6**

Images in a Spherical Mirror: 1

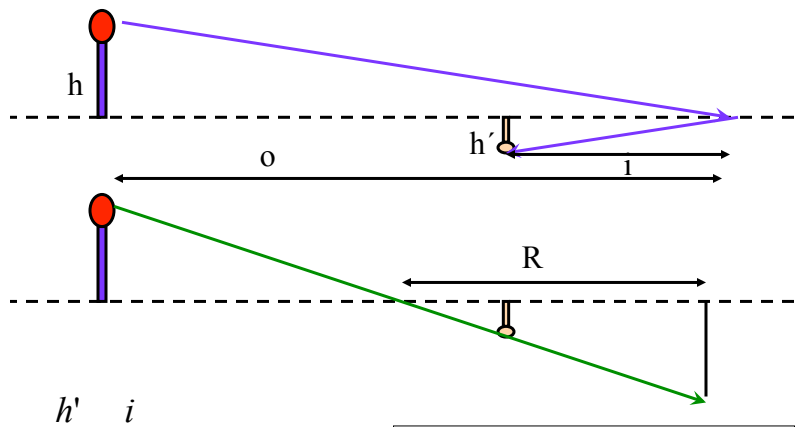
Physical



Kinds of Images: Real

- In the case of the previous slide, the rays seen by the eye do in fact converge at a point.
- When the rays seen by the eye do meet, the image is called *real*.
- If a screen is put at the real image, the rays will scatter in all directions and an image can be seen on the screen, just as if it were a real object.

Mathematical



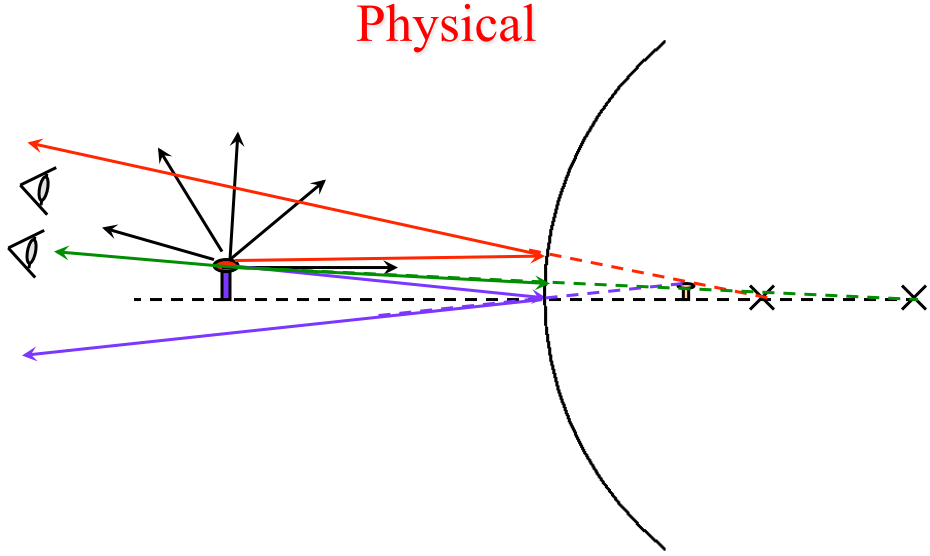
$$\frac{h'}{h} = \frac{i}{o}$$

$$\frac{h'}{h} = \frac{R-i}{o-R}$$

$$\Longrightarrow \quad \boxed{\frac{1}{f} = \frac{1}{i} + \frac{1}{o} \qquad f = R/2}$$

4/24/17 Physics 132 **10**

Images in a Spherical Mirror: 2
Physical

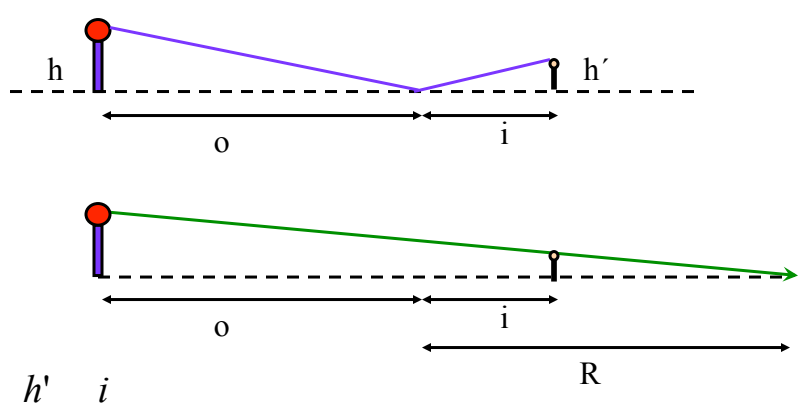


4/24/17 Physics 132 **11**

Kinds of Images: Virtual

- In the case of the previous slide, the rays seen by the eye do not converge at a point.
- When the rays seen by the eye extrapolate to a point but don't actually meet, the image is called *virtual*.
- In our case, the convergence point is behind the mirror.
- If we look at the virtual image from behind the mirror, what will we see?

Mathematical



$$\frac{h'}{h} = \frac{i}{o}$$

$$\frac{h'}{h} = \frac{R-i}{R+o}$$

$$\Longrightarrow \quad \boxed{\frac{1}{f} = \frac{1}{i} - \frac{1}{o} \qquad f = R/2}$$

Unifying Equation for Mirrors

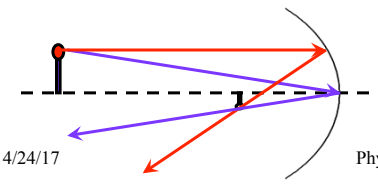
- If we treat our mirror quantities as "signed" and let the signs carry directional information, we can unify all the situations in a single set of equations.

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o} \qquad \frac{h'}{h} = \frac{i}{o} \qquad f = R/2$$

$h > 0$	$h' < 0$	$i > 0$, $o > 0$	$i < 0$, $o < 0$
$h < 0$	$h' > 0$		

$f < 0$

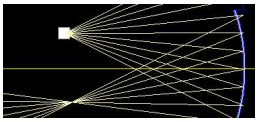
$f > 0$

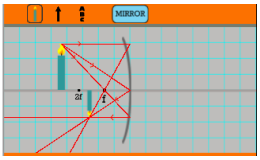


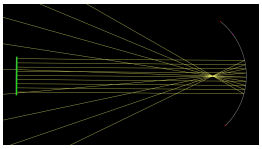
"standard" arrangement

Simulations

- Overview (lots of rays)
  - http://webphysics.davidson.edu/physlet_resources/dav_optics/Examples/optics_bench.html
- Optics bench (3 rays)
  - http://www.physicsclassroom.com/Physics-Interactives/Refraction-and-Lenses/Optics-Bench/Optics-Bench-Refraction-Interactive
- Ray optics sim
  - https://ricktu288.github.io/ray-optics/simulator/





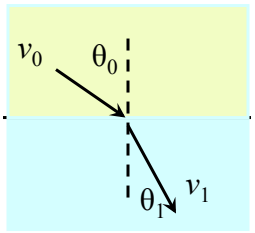


Changing media in Newton's model

- Newton has light as little fast moving particles.
- What happens when they move from air into a denser medium?
- Newton suggested the light particles moved faster in a denser medium (like sound).

Snell's Law in Newton's Model

- Assume that there is a lower (negative compared to vacuum) PE for light particles in a denser medium. Then light would go faster since $(KE + PE)_{\text{in vac}} = (KE + PE)_{\text{in medium.}}$
- Assume no friction as it passes through the boundary.
- Since it goes faster but the parallel component of the speed stays the same (N2!) the perpendicular component must be bigger, tipping the direction toward the normal.



$$v_0 \sin\theta_0 = v_1 \sin\theta_1$$

Compare to speed in vacuum = c

$$\frac{v_0}{c}\sin\theta_0 = \frac{v_1}{c}\sin\theta_1$$

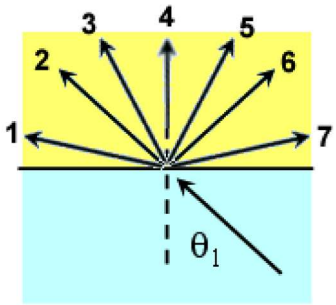
$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

A ray of light is moving from one medium (blue) into another (yellow). Which of the outgoing rays is the most plausible if

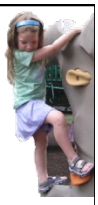
- both media have the same n?

- $n_{\text{blue}} > n_{\text{yellow}}$?

- $n_{\text{blue}} < n_{\text{yellow}}$?



4/24/17 Physics 132 **20**



Foothold Ideas 1:
The Physics

- Certain objects (the sun, bulbs,…) give off light.
- Light can travel through a vacuum.
- In a vacuum light travels in straight lines (rays).
- Each point on a rough object scatters light, spraying it off in all directions.
- A polished surface reflects rays back again according to the rule: *The angle of incidence equals the angle of reflection*.
- When entering a transparent medium, a light ray changes its direction according to the rule $n_1 \sin\theta_1 = n_2 \sin\theta_2$
- "n" is a property of the medium and n_{vac}=1.

4/24/17 Physics 132 **21**

Foothold Ideas 2:
The Psycho-physiology

- We only see something when light coming from it enters our eyes.
- Our eyes identify a point as being on an object by many mechanisms:
  - By tracing rays back to see where they converge.
  - By how they change when we move.
  - By our experience with objects and the world.

Kinds of Images

- Real
  - When the rays seen by the eye do meet, the image is called real.
  - If a screen is put at the real image, rays scatter in all directions and an image can be seen on the screen, just as if it were a real object.
- Virtual
  - When the rays seen by the eye extrapolate to a point but don't actually meet, the image is called virtual.