General Physics (PHY 2130)

Lecture XIV

- Refraction of light
  - thin lenses
- Wave optics
  - Interference
  - Diffraction
- Tips for the Final Exam

WAYNE STATE UNIVERSITY

http://www.physics.wayne.edu/~apetrov/PHY2130/

Lightning Review

Last lecture:

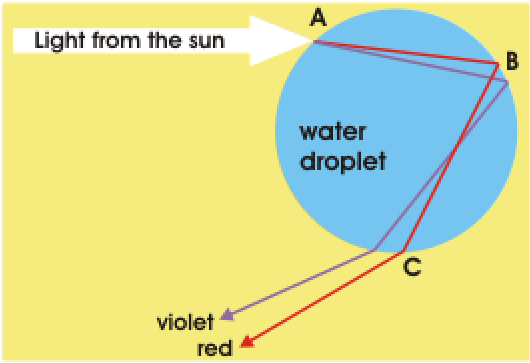
1. Mirrors
   - ✓ Plane mirrors
   - ✓ Spherical mirrors

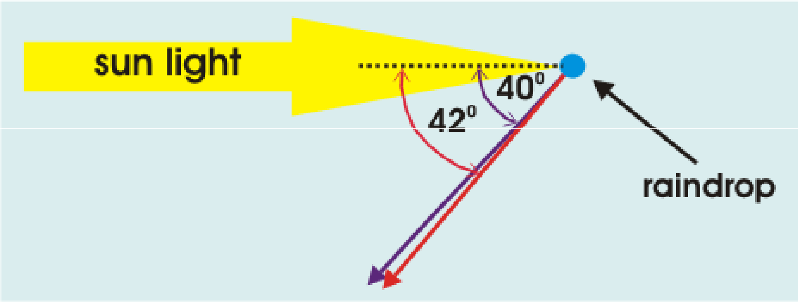
Note: homework solutions are posted on the web!

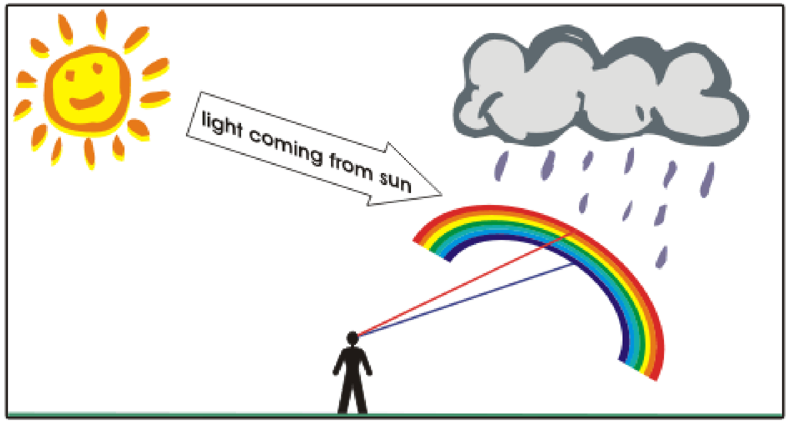
Prelude: Rainbow

Recall last lecture…

- In a rainbow, _raindrops_ in the air act like tiny _prisms_. Light enters the drop at A, is reflected at the back of the drop at B and leaves the drop at C. In the process the sunlight is broken into a spectrum just like it is in a triangular glass prism.
- The angle between the ray of sunlight coming in and the ray coming out of the drops is 42 degrees for red and 40 degrees for violet rays.
- This small angular difference between the returning rays causes us to see the bow.





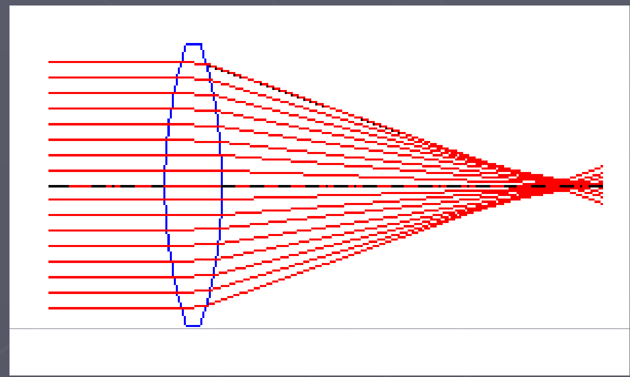


Review Problem: Explain why the top of the rainbow appears red, while the bottom appears violet and not other way around?

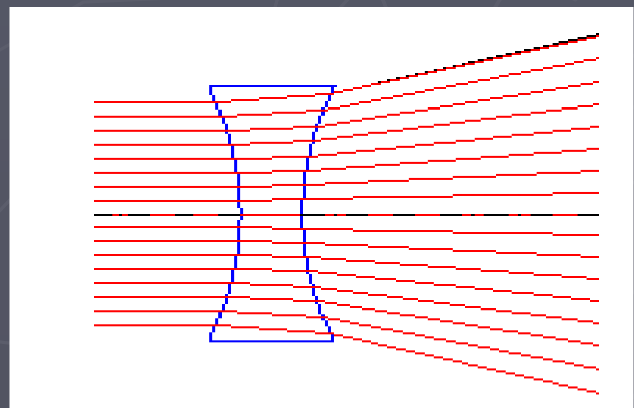
Reflection and Refraction of Light
Thin lenses

Introduction

- Thin lens consists of piece of glass or plastic ground so each of its two refracting surfaces is segment of sphere or plane.
- Examples:



Converging lens

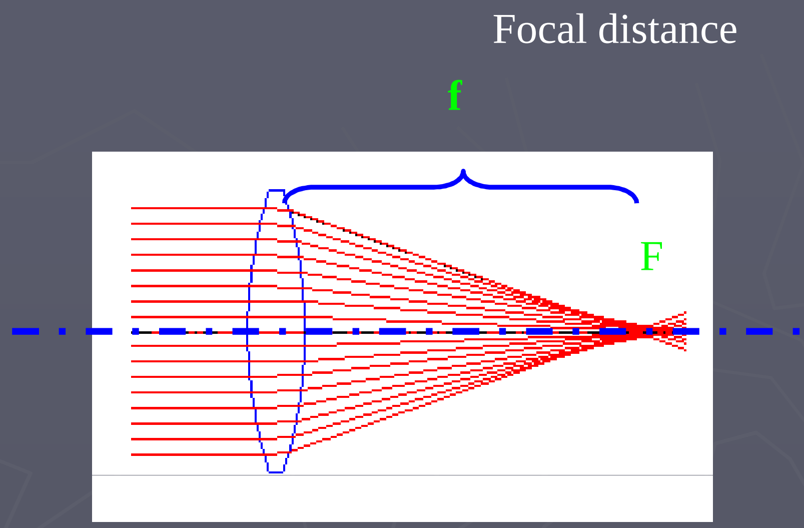


Diverging lens

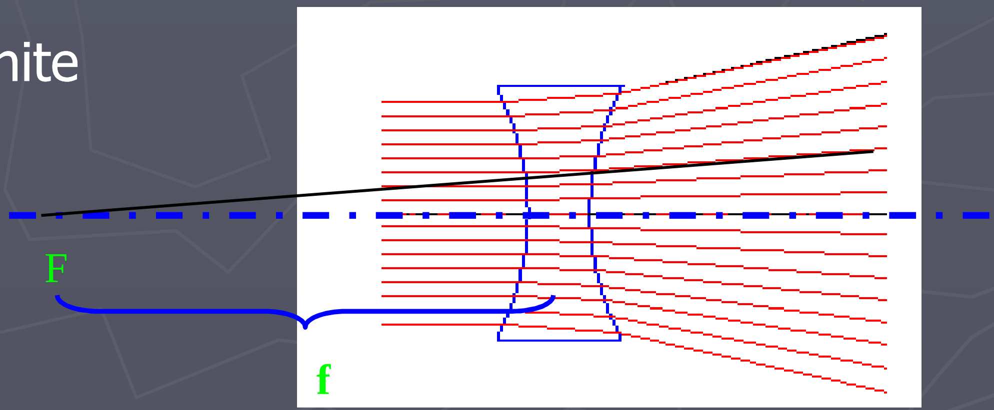
Definitions

- Just as for mirrors, define principal axis
  - line passing through the "center" of the lens

and focal length,
  - image distance that corresponds to an infinite object distance



Converging lens



Diverging lens

Lens equations

Similar to mirror equations

- Can use geometry to compute image magnification and image position.

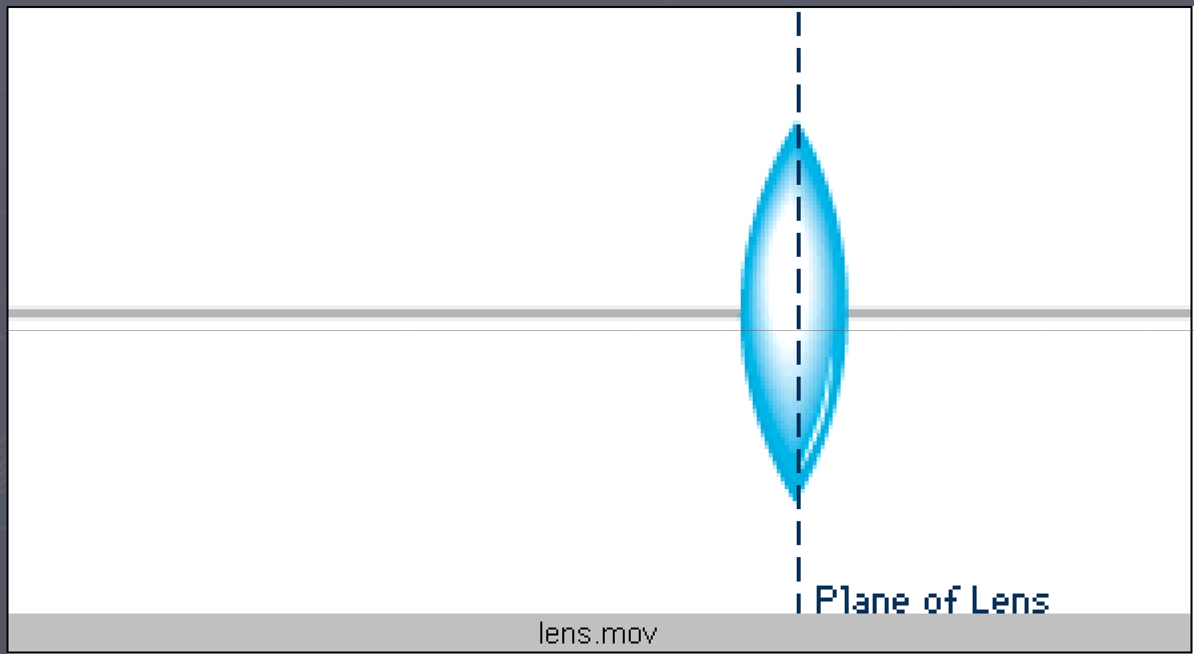
$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

$$M = \frac{h'}{h} = -\frac{q}{p}$$

p = object distance
q = image distance

- Note on sign conventions:
  - p is always positive
  - q is positive when image and object are on the different sides of the lens and negative otherwise.
  - f is positive for converging lens and negative for diverging lens.

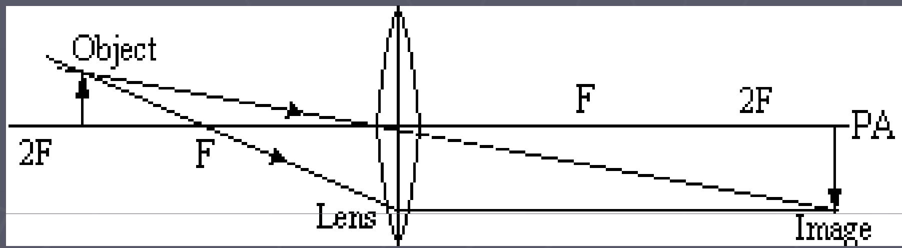
Let's watch a movie!



Construction of images: convergent lenses

- Use two (or more) rays to construct an image
- Same method (mirrors):
  - Light ray parallel to the principal axis will be refracted through the focal point
  - Light ray passing through the center of the lens will be refracted undeviated
  - Light ray passing through the focal point will be refracted parallel to the principal axis.

Example 1: p>f



Example 1: converging lens

An object is placed in front of a convergent lens at the distance of 40.0 cm. Find (a) distance between the image and the lens (b) lateral magnification if the focal distance of the lens is 20.0 cm.

Example 1:

Given:

lens parameters:
focal distance: f = 20.0 cm
p = 40.0 cm

Find:

q = ?
M = ?

(a) Use lens equation:

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f} \qquad (1)$$

Inserting the available data for f and p the unknown image distance can be determined as

$$\frac{1}{q}=\frac{1}{f}-\frac{1}{p}=\frac{1}{20cm}-\frac{1}{40cm}=+\frac{1}{40cm} \qquad (2)$$

$$q={}^{40cm}\!/_{1}=+40cm$$

✓

(b) Lateral magnification can be found from

$$M=-\frac{q}{p}=-\frac{(+40.0cm)}{40.0cm}=-1$$

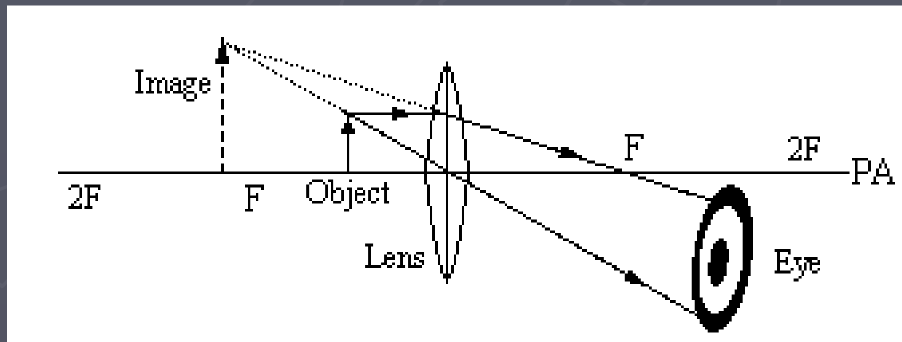
✓

The image is real and inverted!

Construction of images: convergent lenses

- Use two (or more) rays to construct an image
- Same method:
  - Light ray parallel to the principal axis will be refracted through the focal point
  - Light ray passing through the center of the lens will be refracted undeviated
  - Light ray passing through the focal point will be refracted parallel to the principal axis.

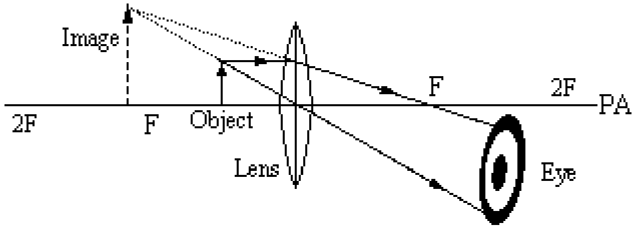
Example 2: p<f



Example 2: converging lens

An object is placed in front of a convergent lens at the distance of 10.0 cm. Find (a) distance between the image and the lens (b) lateral magnification if the focal distance of the lens is 20.0 cm.

Example 2:



(a) Use lens equation:

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f} \qquad (1)$$

Given:

lens parameters:
focal distance: f = 20.0 cm
p = 10.0 cm

Find:

q = ?
M = ?

Inserting the available data for f (>0) and p (>0) the unknown image distance can be determined as

$$\frac{1}{q}=\frac{1}{f}-\frac{1}{p}=\frac{1}{20cm}-\frac{1}{10cm}=-\frac{1}{20cm} \qquad (2)$$

$$q=-{}^{20cm}\!/_{1}=-20cm$$

✓

(b) Lateral magnification can be found from

$$M=-\frac{q}{p}=-\frac{(-20.0cm)}{10.0cm}=+2$$

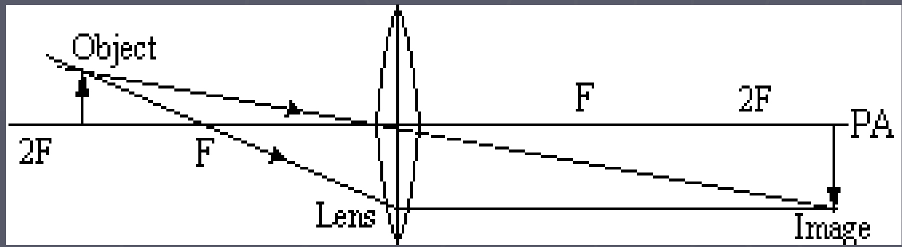
✓

The image is virtual and upright!

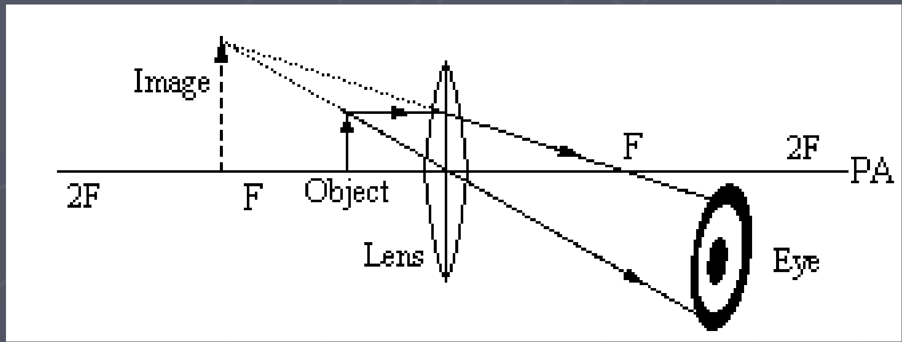
Construction of images: convergent lenses

- Use two (or more) rays to construct an image
- Same method:
  - Light ray parallel to the principal axis will be refracted through the focal point
  - Light ray passing through the center of the lens will be refracted undeviated
  - Light ray passing through the focal point will be refracted parallel to the principal axis.

Example 1: p>f



Example 2: p<f



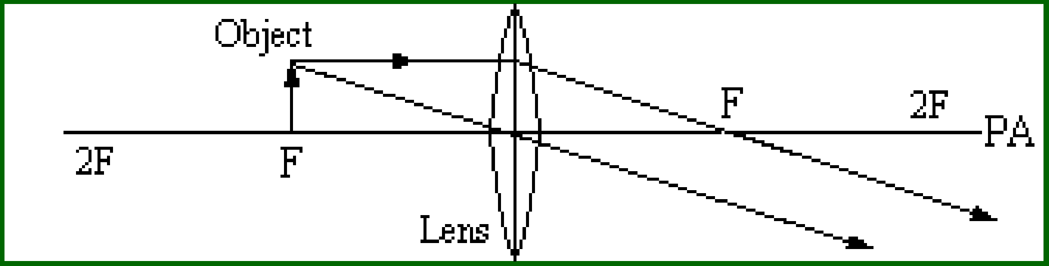
Thus, the question:

Question

What happens if the object is placed at the distance that is equal to the focal distance?

Question

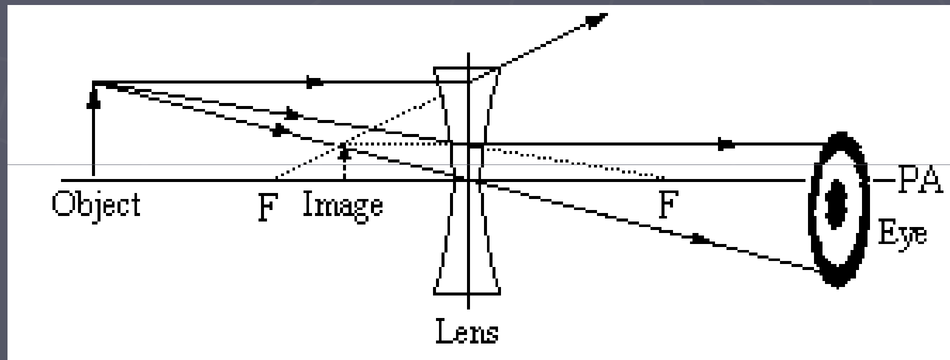
What happens if the object is placed at the distance that is equal to the focal distance?



The image will not be formed: light rays are parallel!

Construction of images: divergent lenses

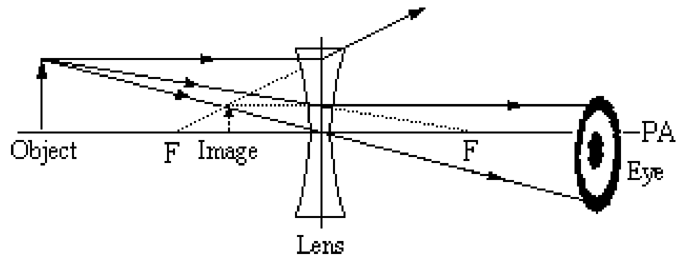
- Use two (or more) rays to construct an image
- Same method:
  - Light ray parallel to the principal axis will be refracted through the focal point
  - Light ray passing through the center of the lens will be refracted undeviated
  - Light ray passing through the focal point will be refracted parallel to the principal axis.



Example 3: diverging lens

An object is placed in front of a divergent lens at the distance of 40.0 cm. Find (a) distance between the image and the lens (b) lateral magnification if the focal distance of the lens is 20.0 cm.

Example 3:



Given:

lens parameters:
focal distance: f = 20.0 cm
p = 10.0 cm

Find:

q = ?
M = ?

(a) Use lens equation:

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f} \quad (1)$$

Inserting the available data for f (<0) and p (>0) the unknown image distance can be determined as

$$\frac{1}{q}=\frac{1}{f}-\frac{1}{p}=\frac{1}{-20cm}-\frac{1}{40cm}=-\frac{3}{40cm} \quad (2)$$

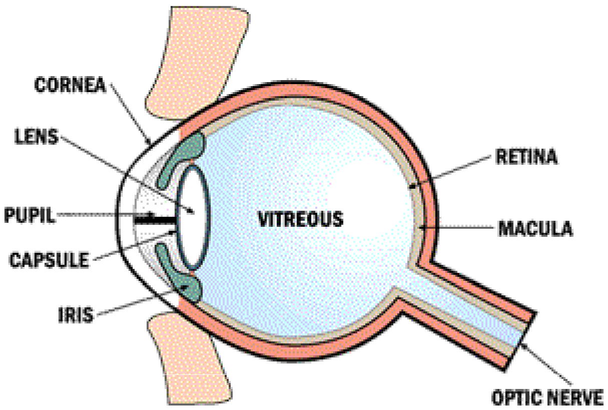
$$q=-{}^{40cm}\!/_{3}=-13.3cm$$

(b) Lateral magnification can be found from

$$M=-\frac{q}{p}=-\frac{(-13.3cm)}{40.0cm}=+0.33$$

The image is virtual and upright!

Human Eye



Pupil - the opening in the center of the iris.
Iris - the colored membrane between the lens and the cornea - its color determines the color of the eye. It separates the anterior and posterior chambers of the eyeball. It contracts and dilates to regulate the entry of light.
Lens - the normally transparent structure behind the pupil. Tiny muscles attached to it cause it to contract or relax, thereby focusing light rays to form an image on the retina.
Cornea - the clear outer covering of the eye.
Optic nerve - the nerve carrying impulses for sight from the retina to the brain.
Retina - The innermost layer of the eye. The light sensitive structure on which light rays come to focus.
Capsule - the transparent membrane that surrounds and encloses the lens.

HOW THE EYE WORKS

Light rays enter the eye through the cornea, which is the main focusing element of the eye. The cornea bends the light rays through the pupil. The light rays then pass through the lens, which adjusts their path in order to bring them to focus on the retina at the back of the eye. The retina contains nerve cells which convert the light rays into electrical impulses. The impulses are sent through the optic nerve to the brain, where they are interpreted as an image.

Wave optics

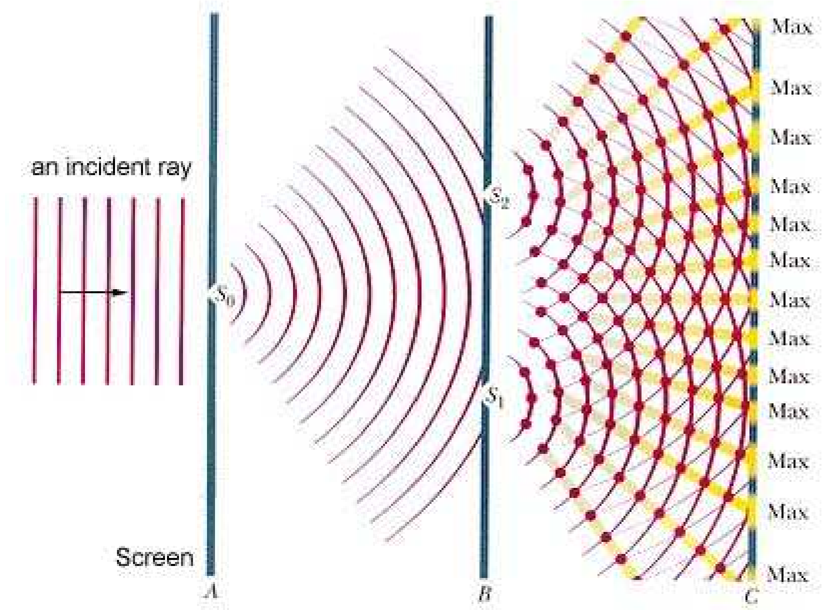
(interference, diffraction, polarization..)

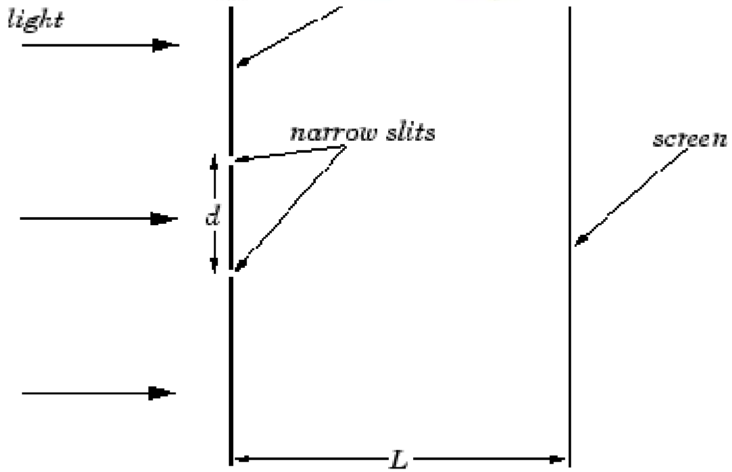
1. Interference

- Conditions for interference:
  - light sources must be coherent (must maintain a constant phase wrt each other)
  - sources must have identical wavelength
  - superposition principle must apply

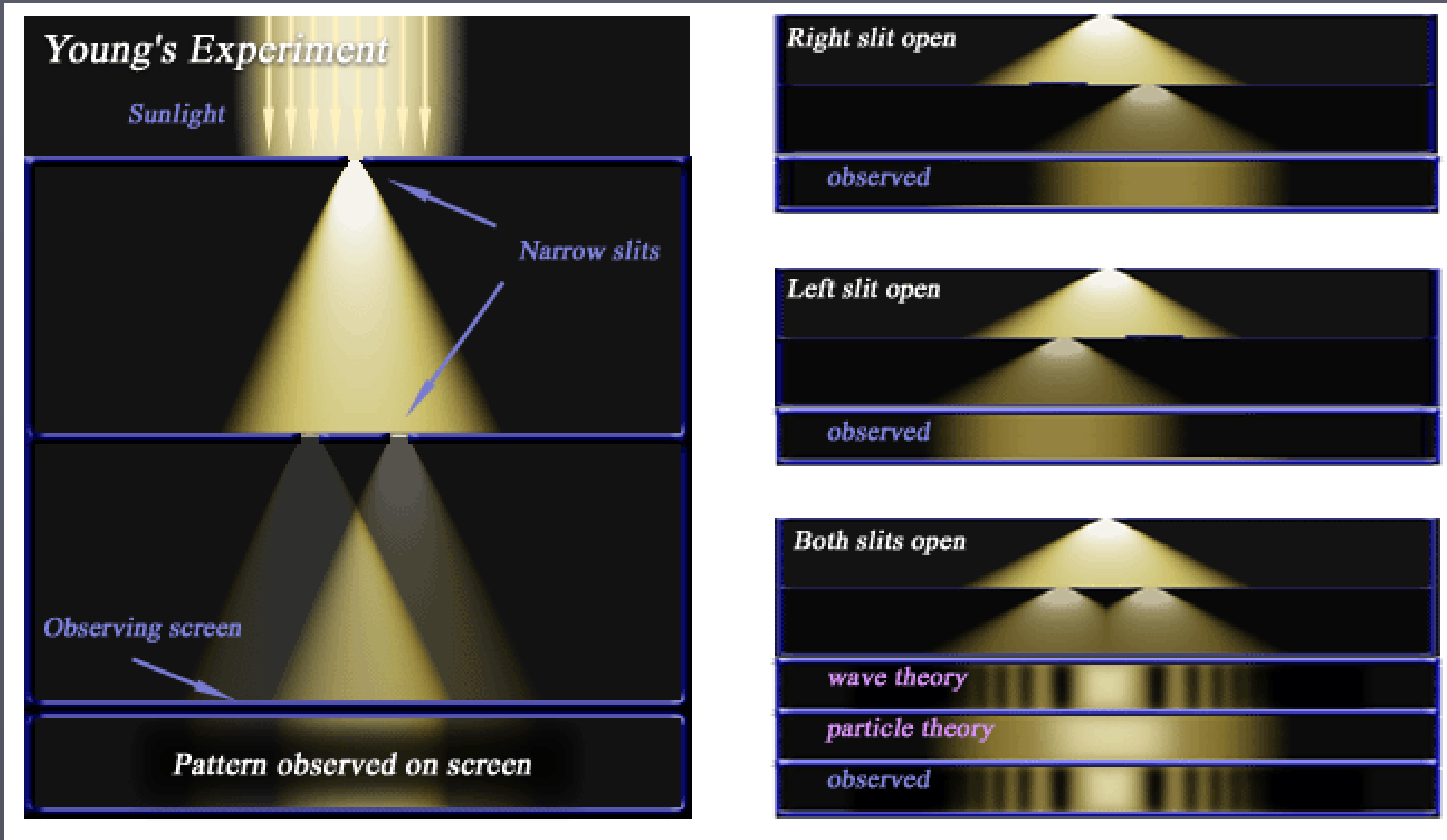
Young’s double-slit interference

- ► Setup: light shines at the plane with two slits
- ► Result: a series of parallel dark and bright bands called fringes





Young’s double-slit interference



Young's double-slit interference

- Path difference:

$$\delta = d \sin\theta$$

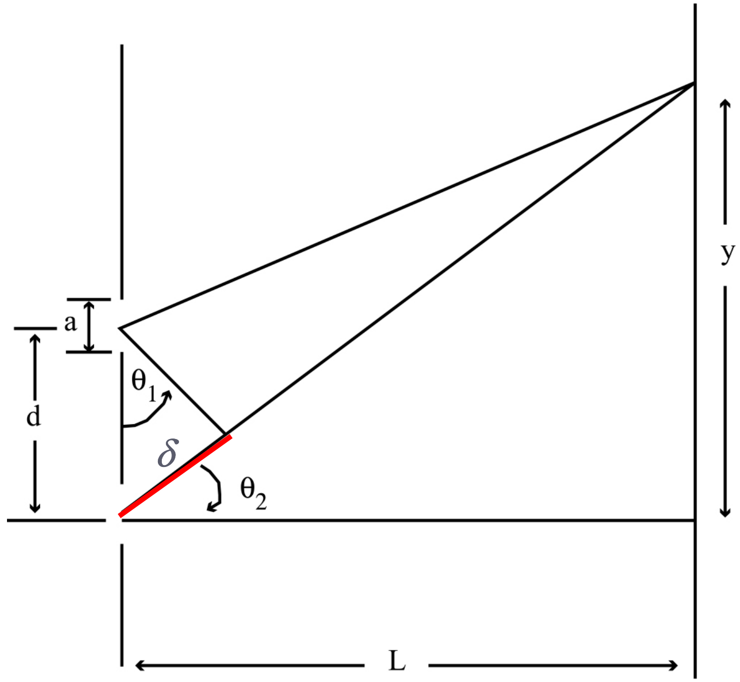
If: $\delta = m\lambda$: constructive interference

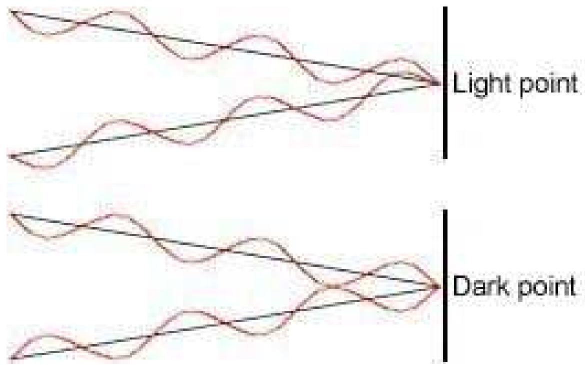
If: $\delta = (m+1/2)\lambda$: destructive int.

$$\sin\vartheta \approx \tan\vartheta = \frac{y}{L}, \text{ thus:}$$

$$y_{\text{bright}} = L\sin\vartheta = \frac{\lambda L}{d} m,\; m = 0, \pm 1, \pm 2, \ldots$$

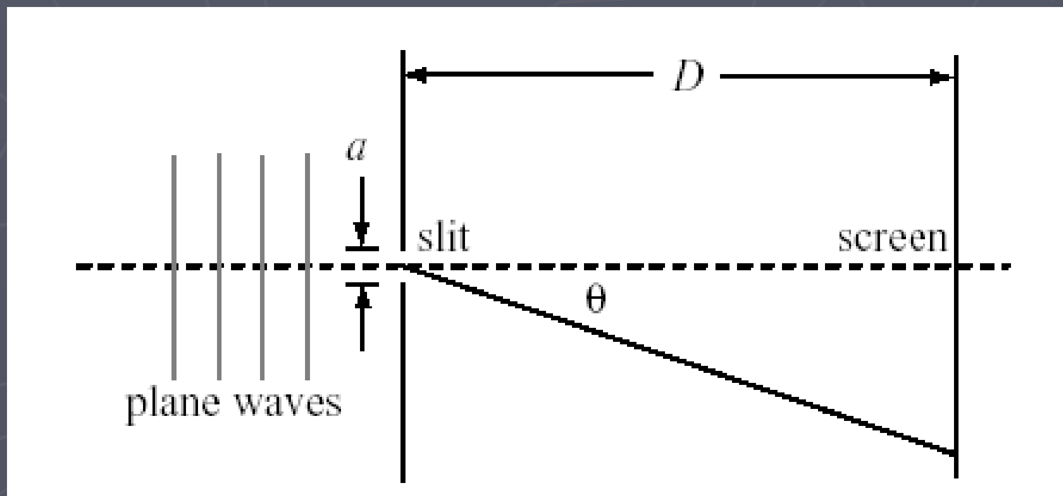
$$y_{\text{dark}} = L\sin\vartheta = \frac{\lambda L}{d}\left(m + \frac{1}{2}\right),\; m = 0, \pm 1, \pm 2, \ldots$$





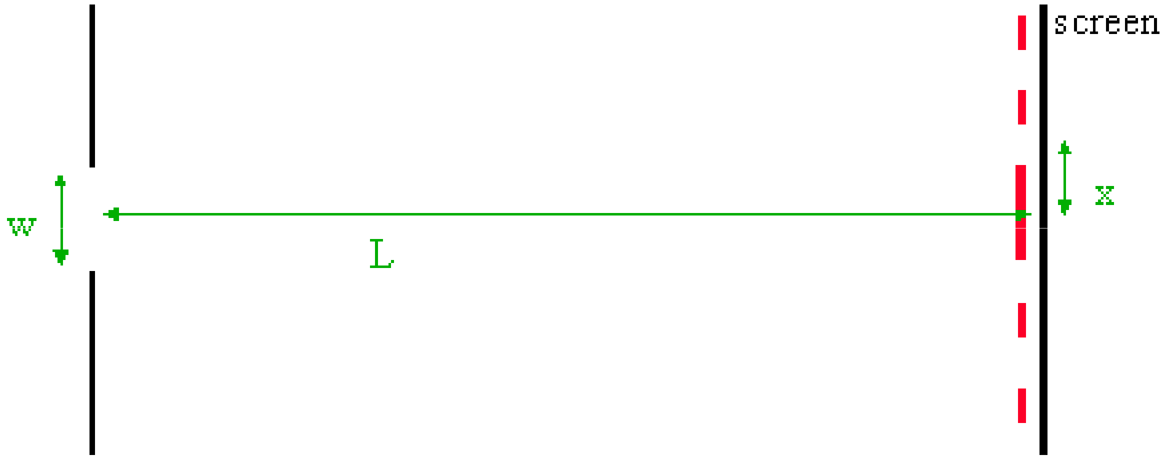
2. Diffraction

- Diffraction occurs when light deviates from a straight line path and enters a region that would otherwise be shadowed.
  - "bending of light around corner"
- Single-slit diffraction
  - Each portion of the slit acts as a source of waves: interference



Diffraction: single slit

How can we explain the pattern from light going through a single slit?



1. Divide: each source width *a/2n*
2. Find path difference *for destructive interference:*

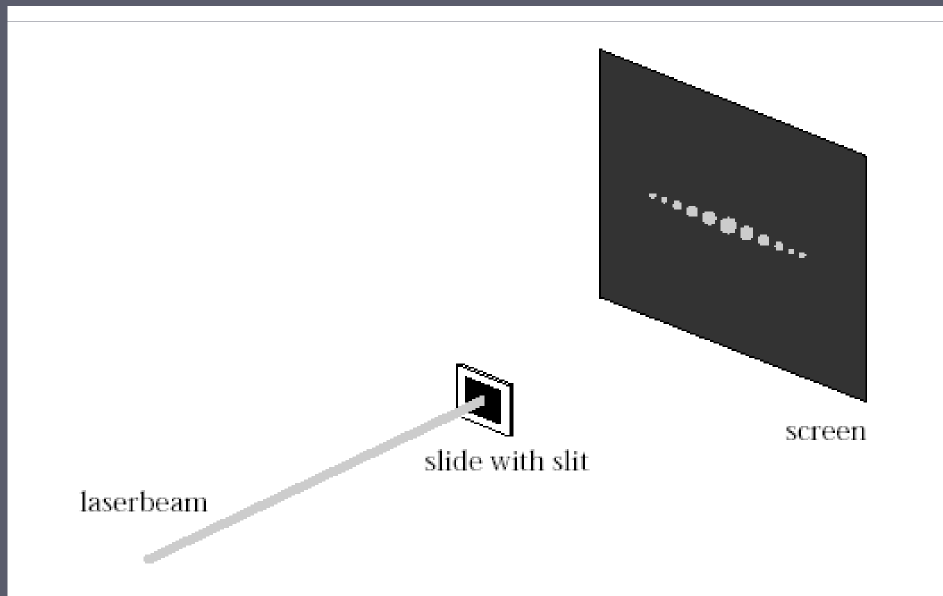
   $d = \lambda/2 = (a/2) \sin \theta$, so $\lambda = a \sin \theta$, *or*

$$\sin \vartheta = m\frac{\lambda}{2}, \; m = \pm 1, \pm 2, \ldots$$

THE FINAL Question

The pattern on the screen is due to a narrow slit that is

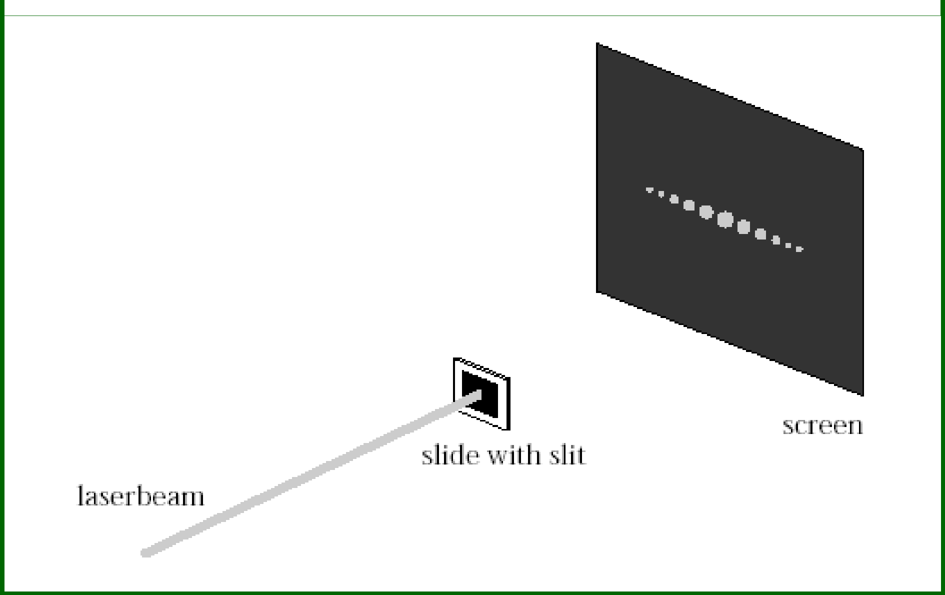
1. horizontal
2. vertical



THE FINAL Question

The pattern on the screen is due to a narrow slit that is

1. horizontal
2. vertical ✓



Note: diffraction is most pronounced for small apertures, and hence diffraction occurs in the direction of the smallest dimension of the slit.

Review before the Final Exam

Useful tips:

1. Do and understand all the homework problems.
2. Review and understand all the problems done in class.
3. Review and understand all the problems done in the textbook.
4. Talk to your professor if you have questions!!!

Final Exam Review

- Motion in one and two dimensions
  - motion with constant velocity and acceleration
- Newton laws and equilibrium
  - Mechanical equilibrium, motion
- Work and energy
  - Work, kinetic and potential energy. Reference levels. Elastic energy.
  - Conservation of energy. Power.
- Momentum and collisions
  - Impulse-momentum theorem. Conservation of momentum.
- Circular motion and gravity
  - Angular velocity and acceleration. Centripetal acceleration.
  - Newton's law of universal gravitation.
- Rotational dynamics

Final Exam Review

- Solids and fluids
  - density and pressure
  - buoyant force
  - Archimedes’ principle
  - Fluids in motion
- Heat
  - temperature
  - thermal expansion
  - ideal gas
  - specific heat
  - phase transitions
- Laws of Thermodynamics
  - Heat and internal energy
  - Work and heat
  - Heat Engines
    - The Carnot Engine
  - Entropy
- Vibrations and waves
  - Hooke’s law, spring-mass system
  - Elastic potential energy
  - Period and frequency
  - Wave motion

Final Exam Review

- Sound
  - Intensity, sound level
  - Doppler effect
  - Standing waves
- Light
  - Reflection and refraction
  - Snell's law
  - Mirrors and lenses