Review of Unit 10-12:

- *Electric field can exert electric force on a charged object*.
- Similarly, *magnetic field can exert magnetic force* on a magnetic object (e.g. a permanent magnet) or on a moving charged particle.

<u>Review of Unit 10-12:</u>

- **Two ways to create magnetic field**:

  1. *Permanent magnet*. The magnetic field created by a permanent magnet looks similar to the electric field created by an electric dipole.

  2. *Moving electric charges* like electric current in a wire.

Review of Unit 10-12:

- **Three ways to calculate magnetic field due to current**:

1. Biot-Savart Law (analogous to Coulomb's Law for electric field):

$$dB = \frac{\mu_0 I dl}{4\pi r^2} \qquad \text{OR} \qquad \vec{B} = \frac{\mu_0}{4\pi}\int \frac{I d\vec{l} \times \vec{r}}{r^3}$$

$\mu_0 = 4\pi \times 10^{-7} N / A^2$ Permeability of free space

Unit for magnetic field: Tesla = $T = N/A\ m$

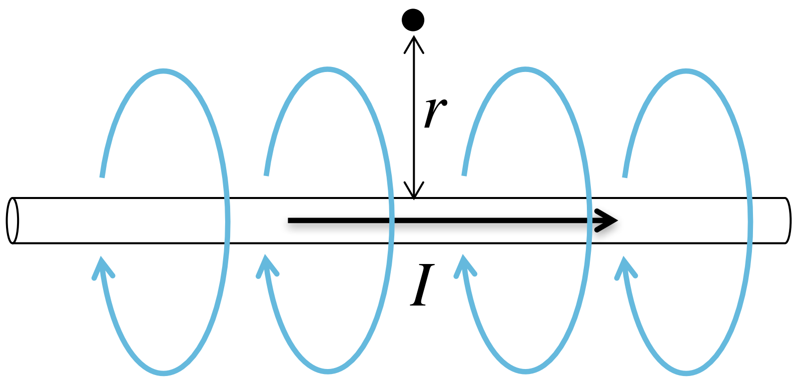
1. Ampere's Law (analogous to Gauss's Law for electric field):

$$B \cdot pathlength = \mu_0 I_{encl}$$

2. *Principle of superposition*

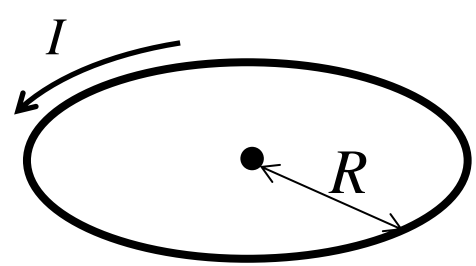
Review of Unit 10-12:

- Magnetic field due to an infinitely long, straight current-carrying wire:



Magnitude: $B = \dfrac{\mu_0 I}{2\pi r}$ Direction: the right-hand rule

- Magnetic field at the center of a circular current-carrying loop:



Magnitude: $B = \dfrac{\mu_0 I}{2R}$ Direction: the right-hand rule

A circular loop of wire carries a current counterclockwise.

What is the direction of the magnetic field at the center of the loop?

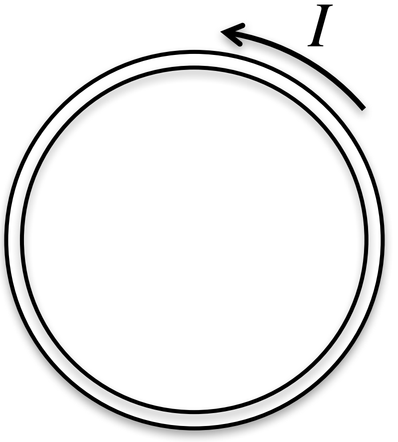
A. To the left

B. To the right

C. Into the screen

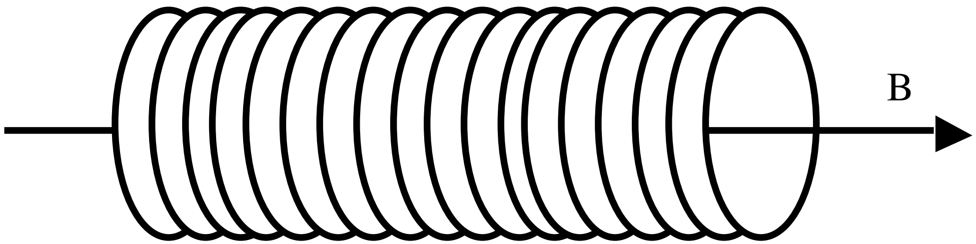
✓ D. Out of the screen

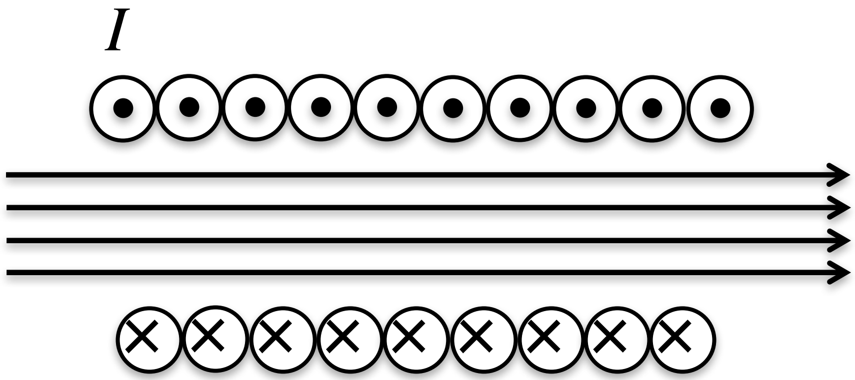
E. None of the above



Review of Unit 10-12:

- Magnetic field due to a solenoid:





Magnitude: $B = 0$ outside

$B = \mu_0 n I$ inside

n = number of turns per unit length

Direction: the right-hand rule

In which of the following case(s), can you use Ampere's law to find the magnetic field?

- I. An infinitely long, straight current-carrying wire
- II. At the center of a circular current loop
- III. A solenoid
- IV. A coaxial cable
- V. A charged particle moving at a constant velocity

A. I only

B. III and IV

✓ C. I, III, and IV

D. I, II, III, and IV

E. All of the above

Figure below is an end-on view of two long, straight parallel wires each carrying current I in the same direction.

What is the direction of the net magnetic field at point P?

A. Upward

B. Downward

C. Into the screen

D. Out of the screen

✓ E. None of the above

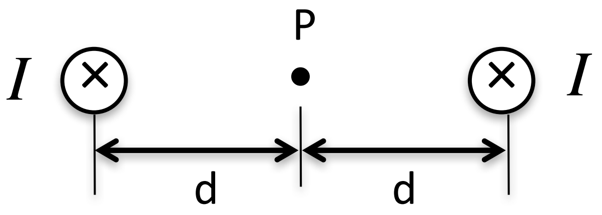


Figure below is an end-on view of two long, straight parallel wires each carrying current I but in opposite directions.

What is the direction of the net magnetic field at point P?

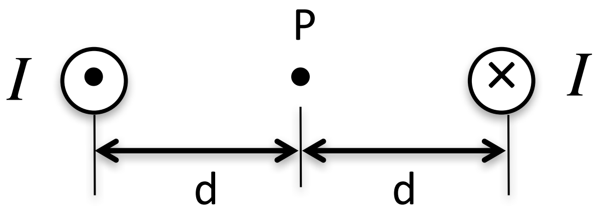
✓ A. Upward

B. Downward

C. Into the screen

D. Out of the screen

E. None of the above



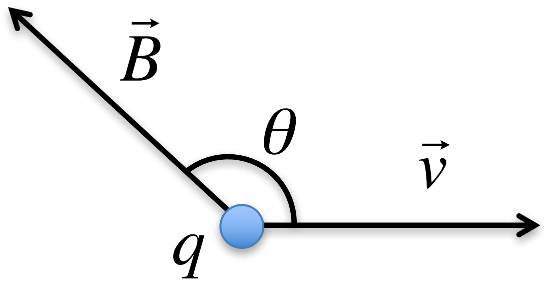
Review of Unit 10-12:

- **Four key characteristics of magnetic force on a charged particle**:

   1. Magnitude proportional to the charge of the moving particle
   2. Magnitude proportional to the strength of the magnetic field
   3. Magnitude proportional to the speed of the particle
   4. Direction perpendicular to the magnetic field and particle’s velocity

Review of Unit 10-12:

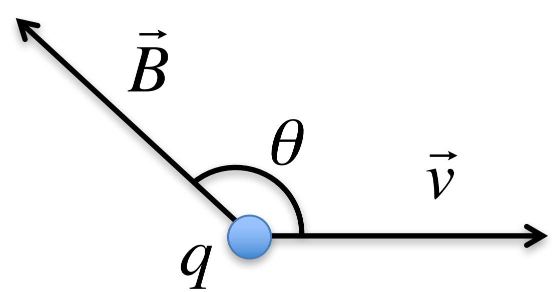
- **Magnitude of the magnetic force on a charged particle**:



$$F = |q| v B \sin\theta$$

Review of Unit 10-12:

- **Direction of magnetic force**: the Right-hand Rule
  1. Draw $\vec{v}$ and $\vec{B}$ with their tails together
  2. Imagine turning $\vec{v}$ toward $\vec{B}$
  3. Curl the fingers of your right hand in the same direction
  4. If q > 0, your thumb points in the direction of force
     If q < 0, your thumb points in the opposite direction



Force out of the page if q is positive

Review of Unit 10-12:

- **Alternatively:**

$$\vec{F} = q\vec{v} \times \vec{B}$$

If a negatively charged particle travels in a uniform magnetic field as shown below, what is the direction of the magnetic force?

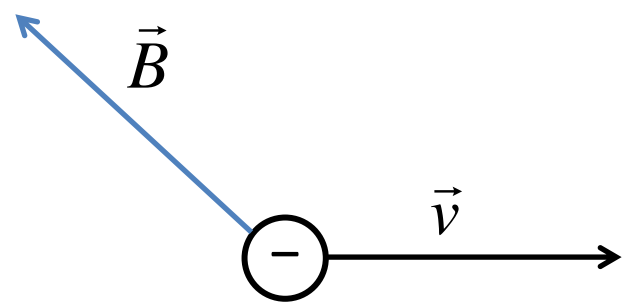
A. upward

B. downward

C. out of the screen (•)

✓ D. into of the screen (×)

E. none of the above



If a positively charged particle travels in a uniform magnetic field as shown below, what is the direction of the magnetic force?

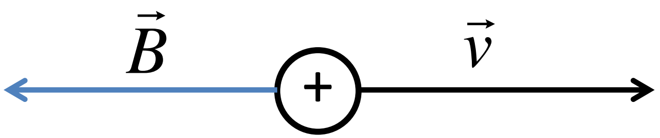
A. upward

B. downward

C. out of the screen (•)

D. into of the screen (×)

✓ E. none of the above



A long straight wire carries current in the positive *y*-direction.

A positive point charge moves in the positive *x*-direction.

The magnetic force that the wire exerts on the point charge is in

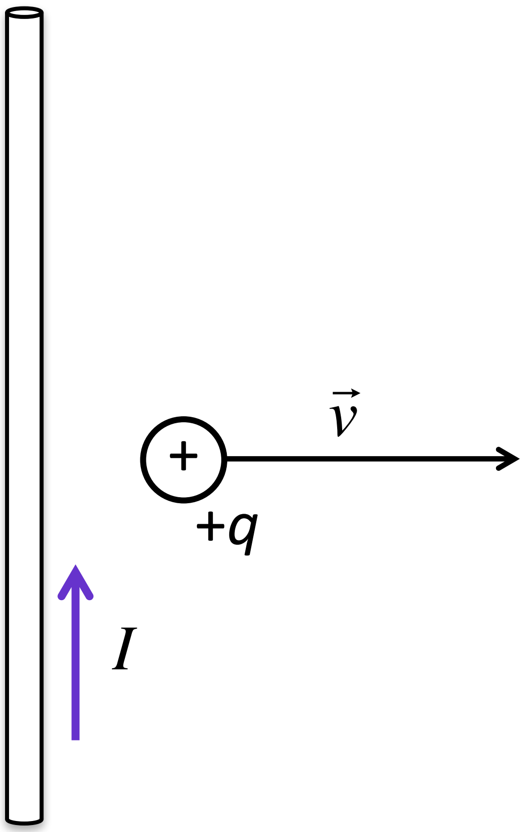
A. the positive *x*-direction.

B. the negative *x*-direction.

✓ C. the positive *y*-direction.

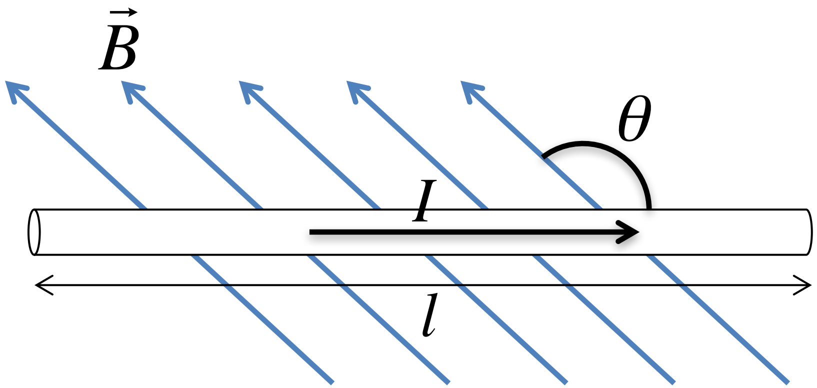
D. the negative *y*-direction.

E. none of the above



Review of Unit 10-12:

- **Magnetic force on a straight, current-carrying wire segment**:

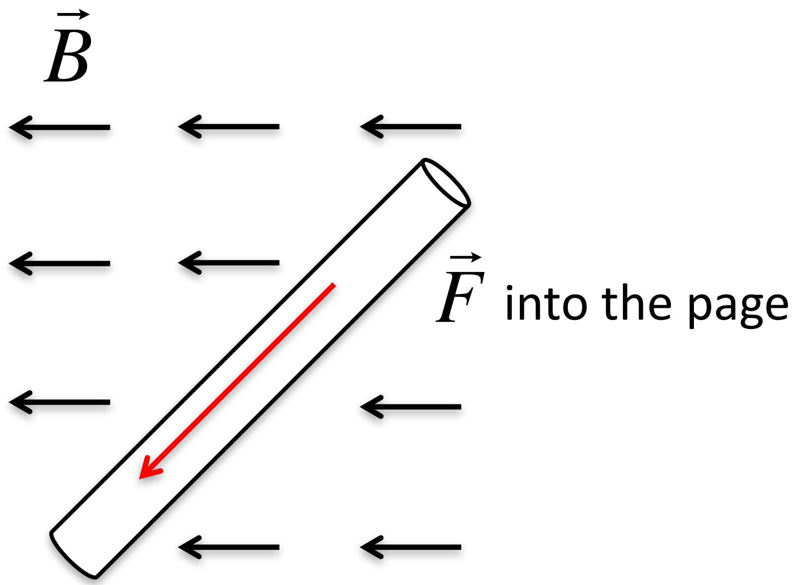


Magnitude: $F = IlB\sin\theta$

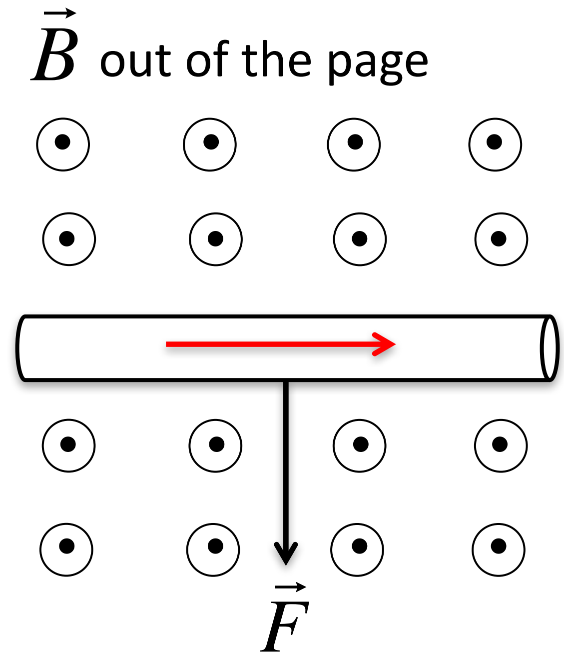
Direction: the right-hand rule

For each of the following, determine the direction of the current.

a)



b)



Review of Unit 10-12:

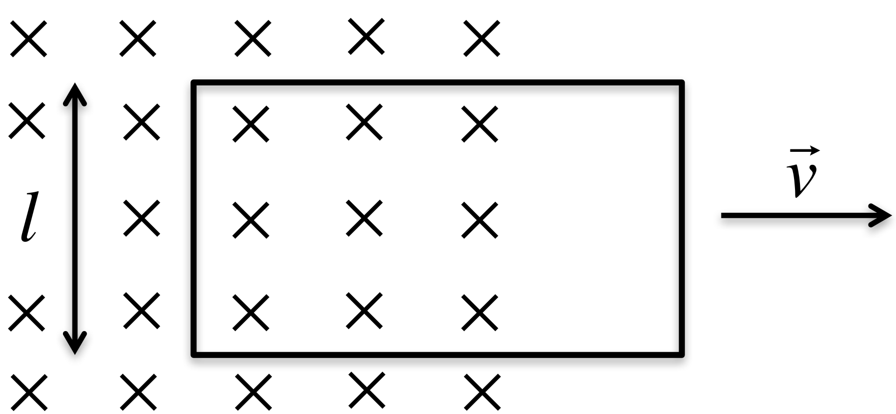
- **Magnetic induction**: generation of voltage difference due to a time-varying magnetic flux

- **Mathematically**:

$$\Delta V_{loop} = -\frac{d\Phi_B}{dt} \quad \text{Faraday's law of induction}$$

where $\Phi_B = \int \vec{B} \cdot d\vec{a}$ (magnetic flux)

- **Example:**



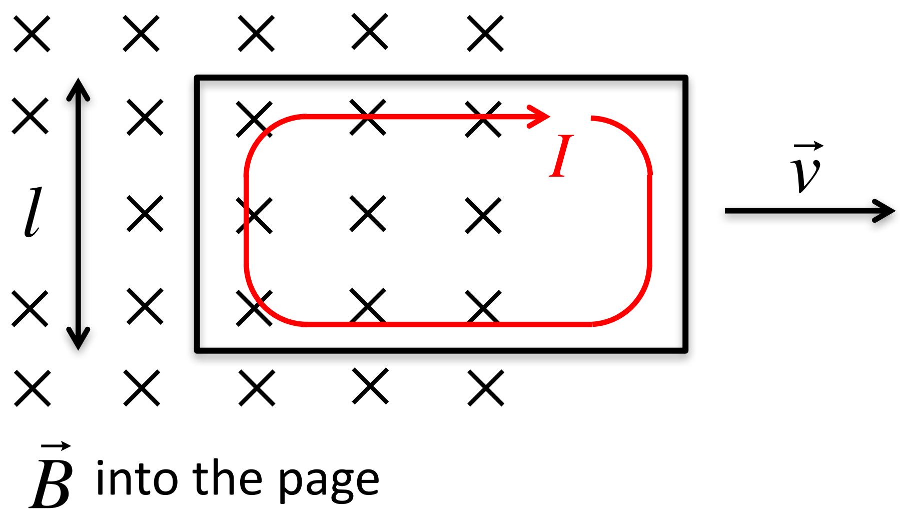
$\vec{B}$ into the page

$$\Delta V_{loop} = Bvl$$

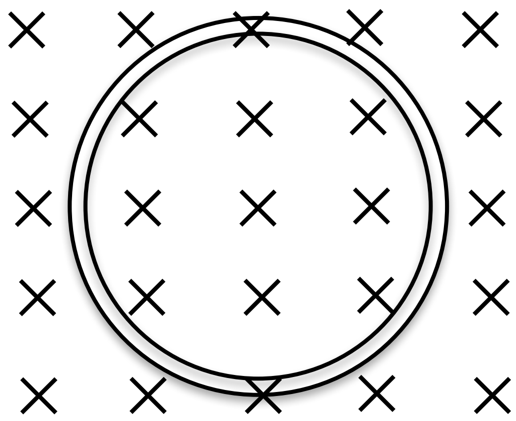
Review of Unit 10-12:

- **Lenz's Law**: induced current flows in a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induced the current.

- **Example:**



A circular loop of wire is in a region of spatially uniform magnetic field. The magnetic field is directed into the plane of the figure. If the magnetic field magnitude is *increasing*,



A. the induced current is clockwise.

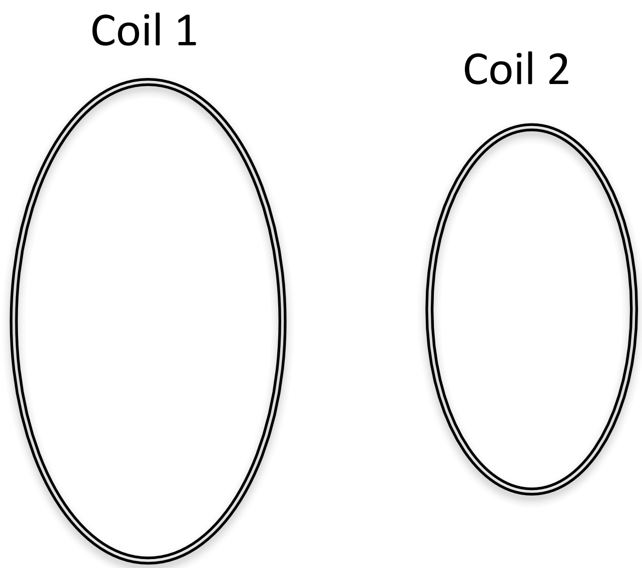
✓ B. the induced current is counterclockwise.

C. the induced current is zero.

D. The answer depends on the strength of the field.

Review of Unit 10-12:

- **Mutual inductance**: induction of voltage in one coil due to a change in current in a nearby loop.



$$\Delta V_2 = -M\frac{dI_1}{dt}$$

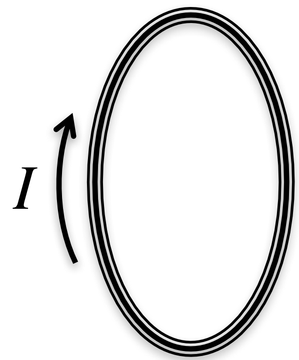
$$\Delta V_1 = -M\frac{dI_2}{dt}$$

(Unit of M: Henry = H = V s/A)

- Mutual inductance M relates the voltage induced in one loop to the change in current in another loop.

Review of Unit 10-12:

- **Self inductance (inductance)**: induction of emf in a coil due to a change in current in the same coil.



$$\Delta V_{loop} = -L\frac{dI}{dt}$$

(Unit of L: Henry = H = V s/A)

- Inductance L relates the voltage induced in one loop to a change in its current.
- **Inductors oppose changes in current.**

Review of Unit 10-12:

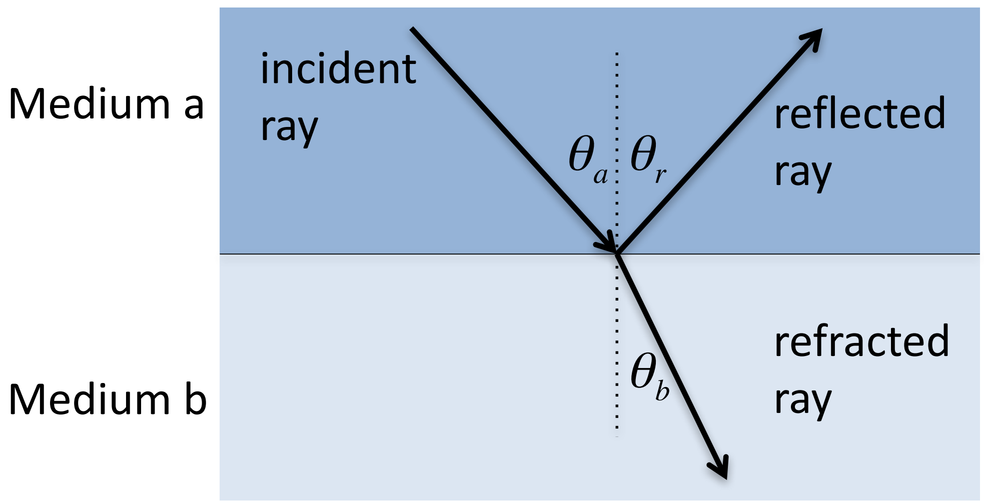
- Faraday's law tells us that a time-varying magnetic field induces electric field.
- Maxwell deduced that a time-varying electric field induces a magnetic field.

- Time-varying electric field and magnetic field can sustain each other to form electromagnetic waves.
- Electromagnetic waves travel at speed given by

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3.00 \times 10^8 m/s \Rightarrow \text{Light = Electromagnetic wave}$$

Review of Unit 10-12:

- **Two transparent media with flat interface**



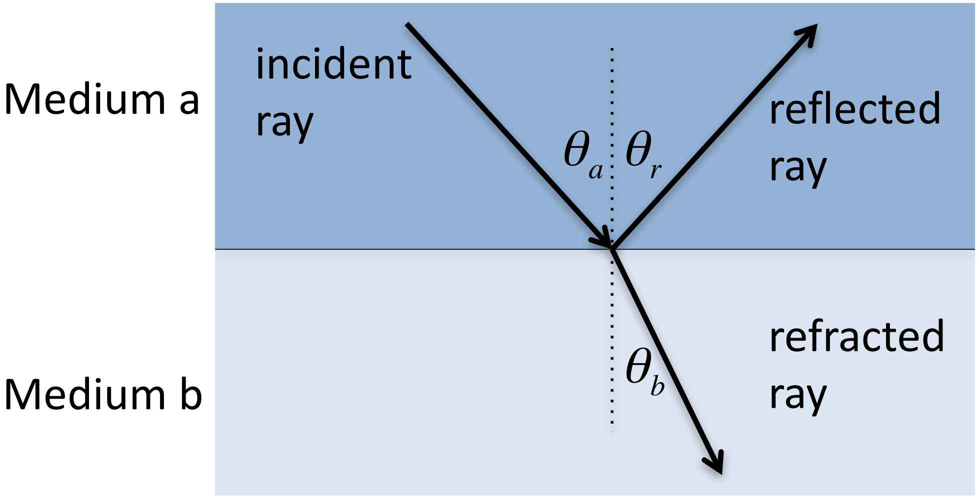
θ_a = angle of incidence

θ_r = angle of reflection

θ_b = angle of refraction

Review of Unit 10-12:

- **Law of reflection:** $\theta_r = \theta_a$



Two mirrors are perpendicular to each other.

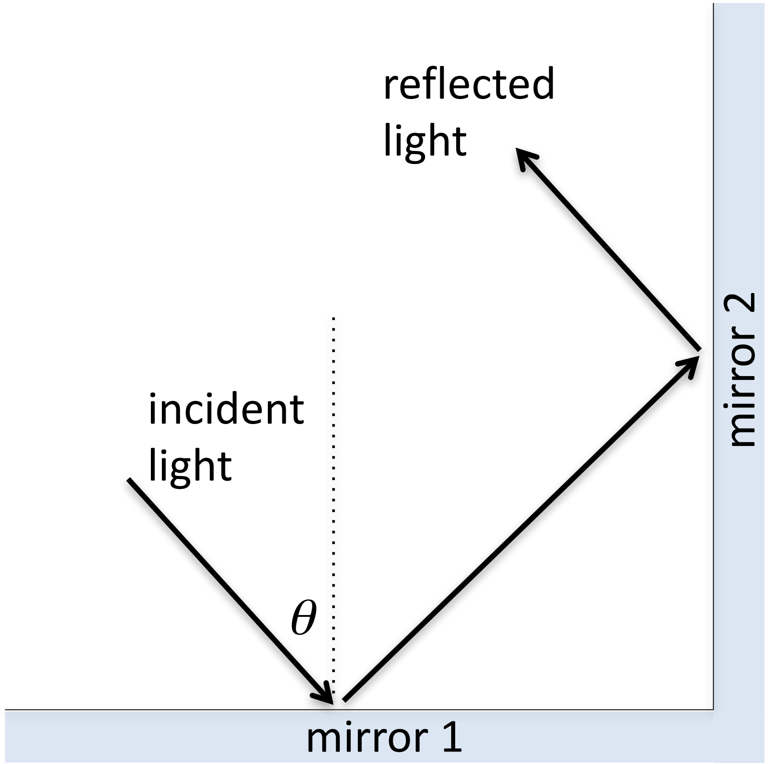
The final direction of the light relative to its original direction is

✓ A. always opposite

B. opposite only if $\theta_a = 30°$

C. opposite only if $\theta_a = 45°$

D. never opposite

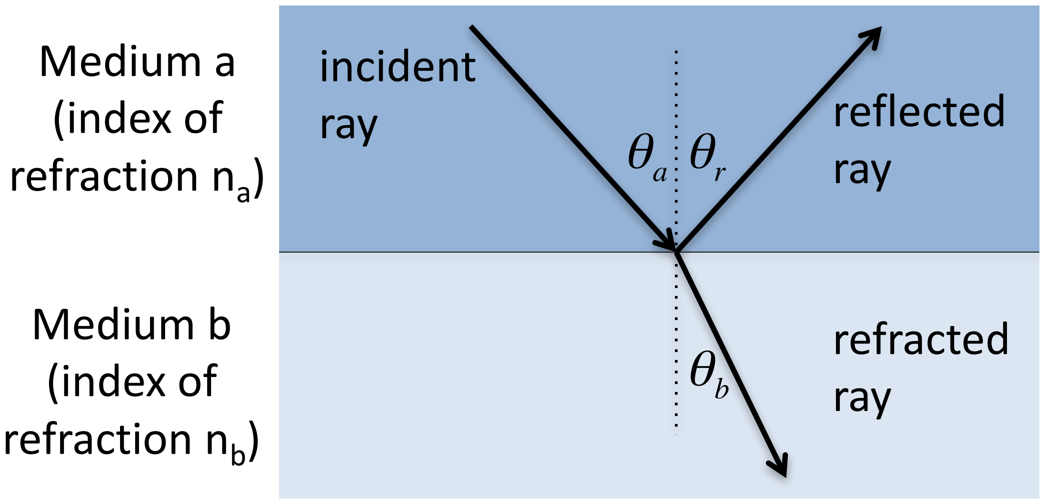


Retroreflectors

http://en.wikipedia.org/wiki/Retroreflector

Review of Unit 10-12:

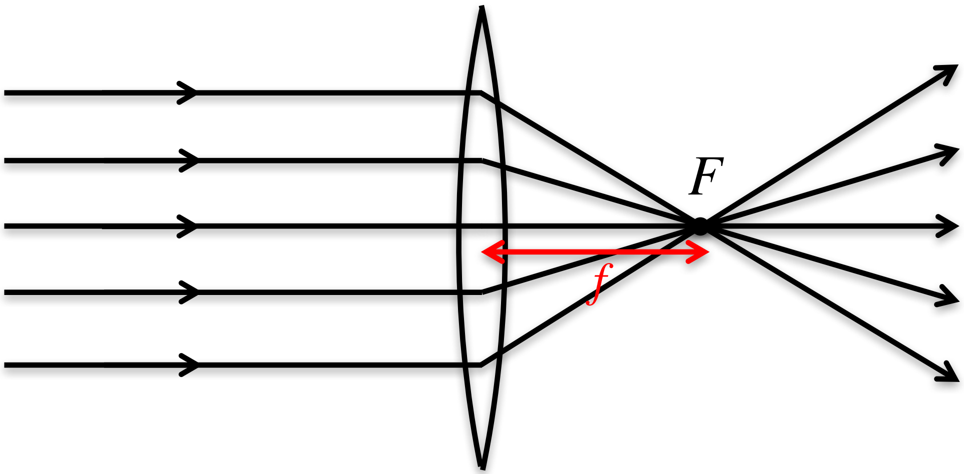
- **Law of refraction (Snell's Law):** $n_a \sin\theta_a = n_b \sin\theta_b$



- If $n_a < n_b$, the ray is bent toward the normal.
- If $n_a > n_b$, the ray is bent away from the normal.
- Refraction is due to a change in the wavelength of light when it is traveling through different materials.

Review of Unit 10-12:

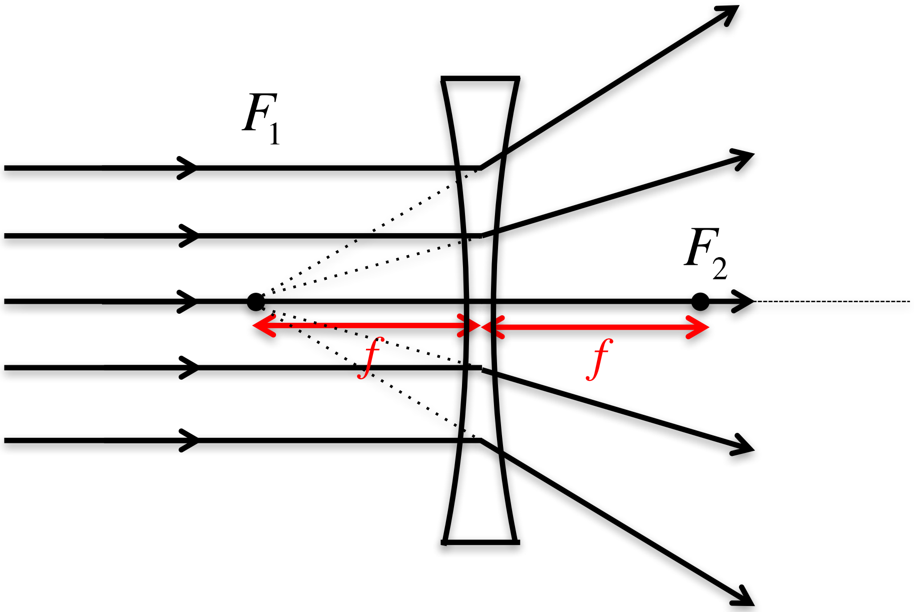
- **Converging/Convex Lens** ($f > 0$):



Incident parallel rays converge to focal point F after being refracted by the lens.

f = focal length
defined positive for
converging lens

- **Diverging/Concave Lens** ($f < 0$):

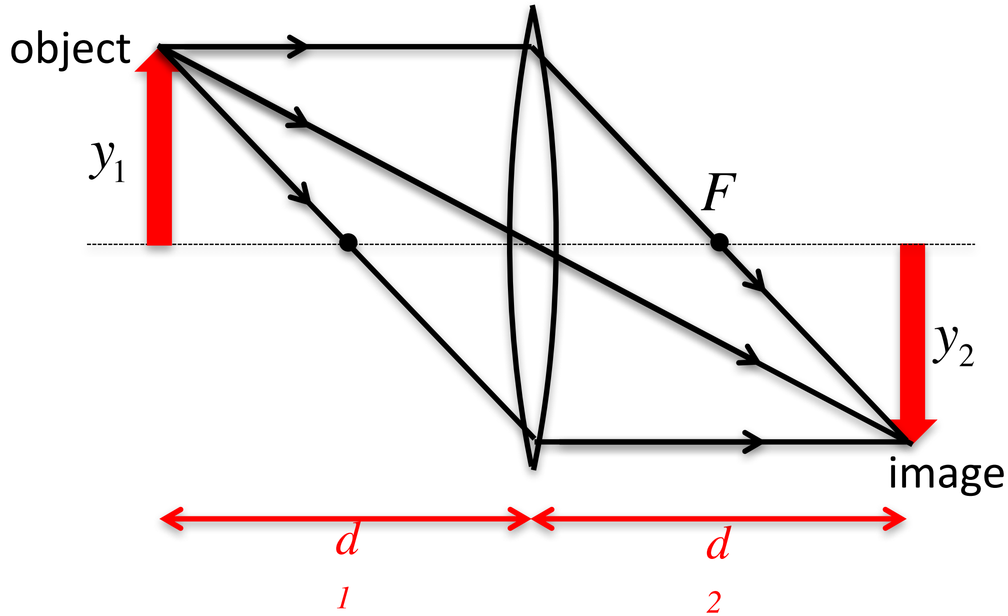


Incident parallel rays appear to diverge from F after being refracted by the lens.

f = focal length
defined negative for
diverging lens

Review of Unit 10-12:

- **Image formed by a convex mirror**:



- **Mathematically**:

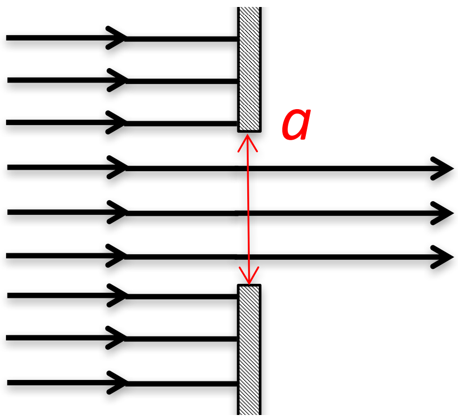
$$\frac{1}{f} = \frac{1}{d_1} + \frac{1}{d_2}$$ Thin lens equation

$$M = \frac{y_2}{y_1} = \frac{d_2}{d_1}$$ Magnification

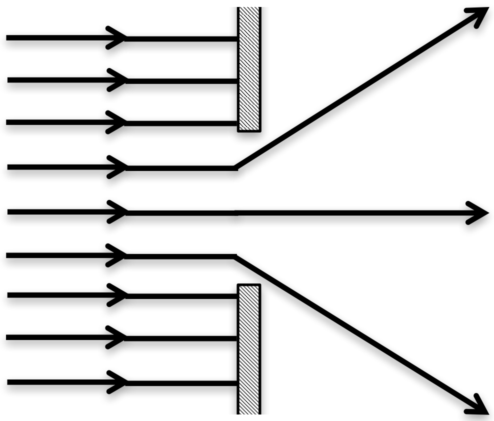
Review of Unit 10-12:

- **Ray optics is not sufficient to describe all optical (light) phenomena.**
- **For example,**

Ray optics predicts



But if $a \approx \lambda$



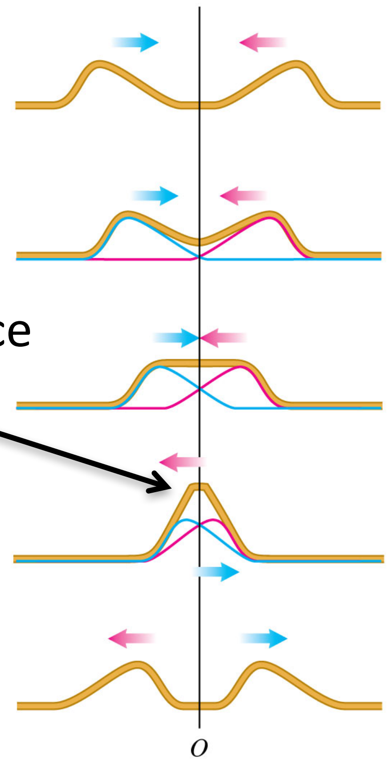
Cannot be explained by geometric optics

- Geometric optics cannot describe optical phenomena such as diffraction because it ignores the wave nature of light.

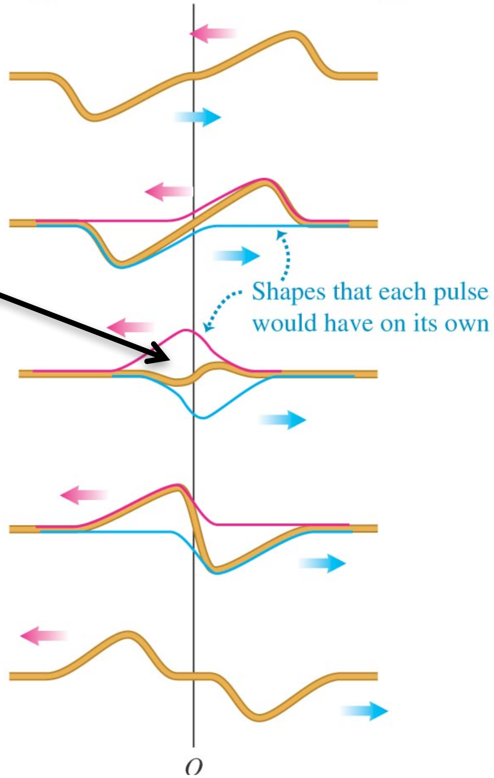
Review of Unit 10-12:

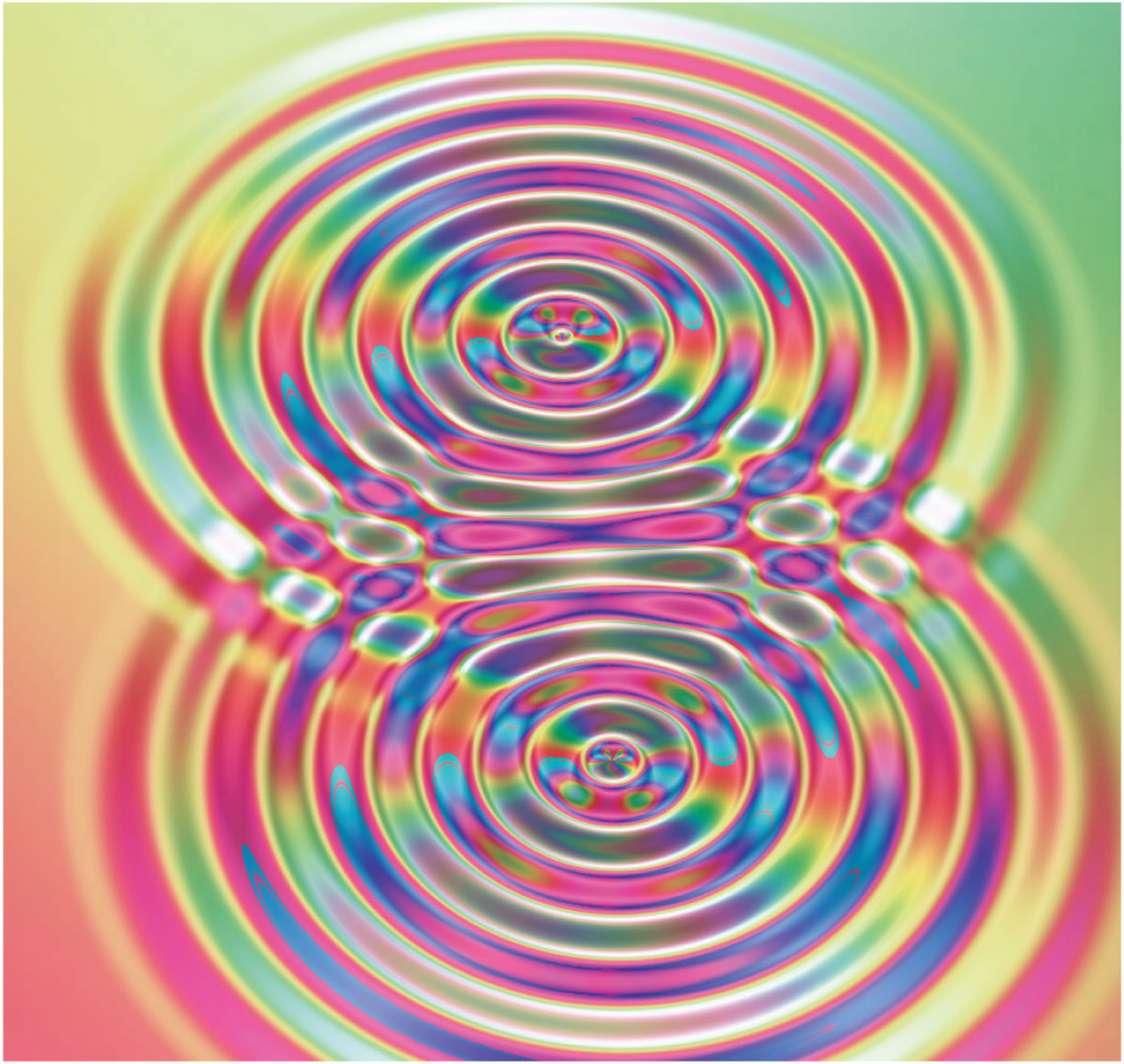
- Interference occurs when two (or more) waves overlap.

Constructive interference: two waves reinforce each other

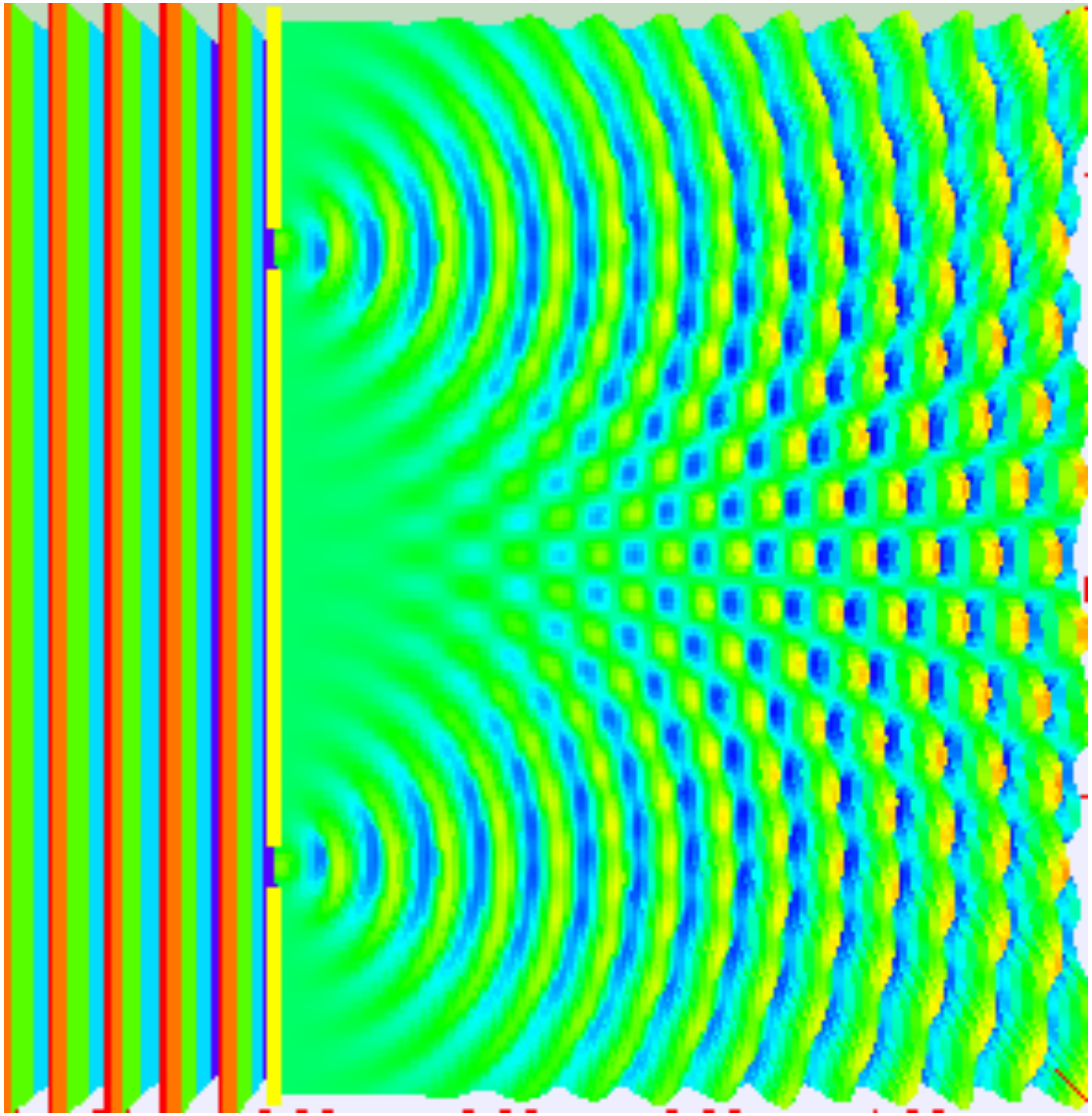


Destructive interference: two waves cancel or partially cancel each other





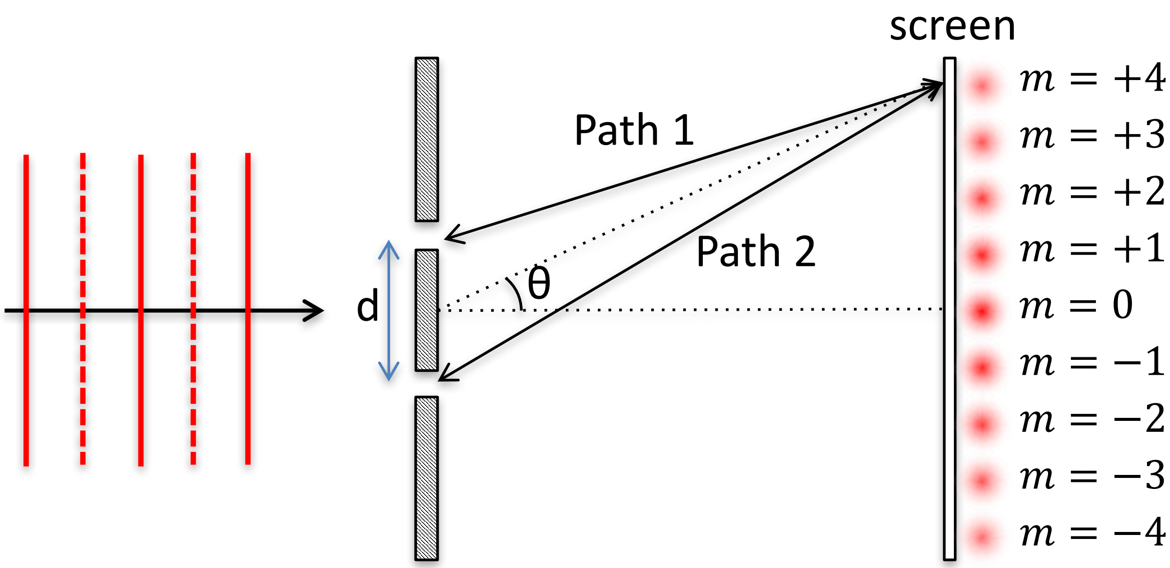
Double-Slit Diffraction



http://en.wikipedia.org/wiki/File:Doubleslit3Dspectrum.gif

Review of Unit 10-12:

- **Double-Slit Diffraction:**



Constructive interference: $d\sin\theta = m\lambda$

Destructive interference: $d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$

where $m = 0, \pm 1, \pm 2, \ldots$