Phys 102 – Lecture 12

Currents & magnetic fields

Today we will...

- Learn how magnetic fields are created by currents
- Use specific examples
    - Long straight wire
    - Current loop
    - Solenoid
- Apply these concepts
    - Electromagnets & MRI

Currents generate B fields

A long straight wire carrying current *I* generates a *B* field

Magnitude

$$B_{wire} = \frac{\mu_0 I}{2\pi r}$$

Current

Distance from wire

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$$

"Permeability of free space"
(similar to ε_0 for electricity)

DEMO

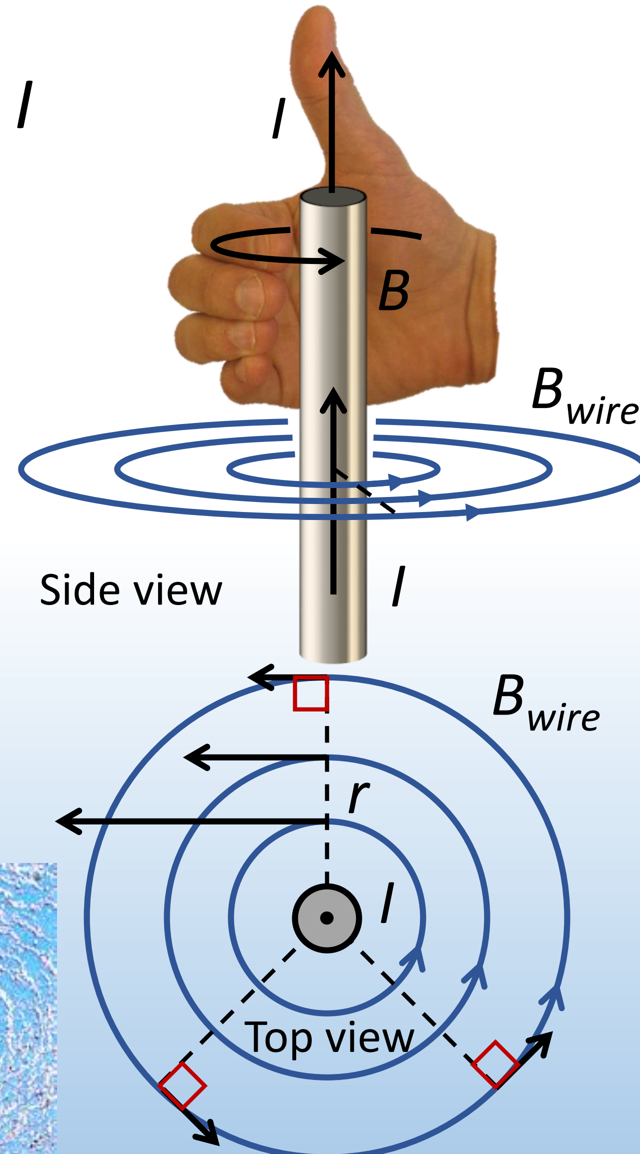
Direction

Right-hand rule for wire:

Thumb along *I*

Curl fingers along $\vec{B}$

B is ⊥ to *r*

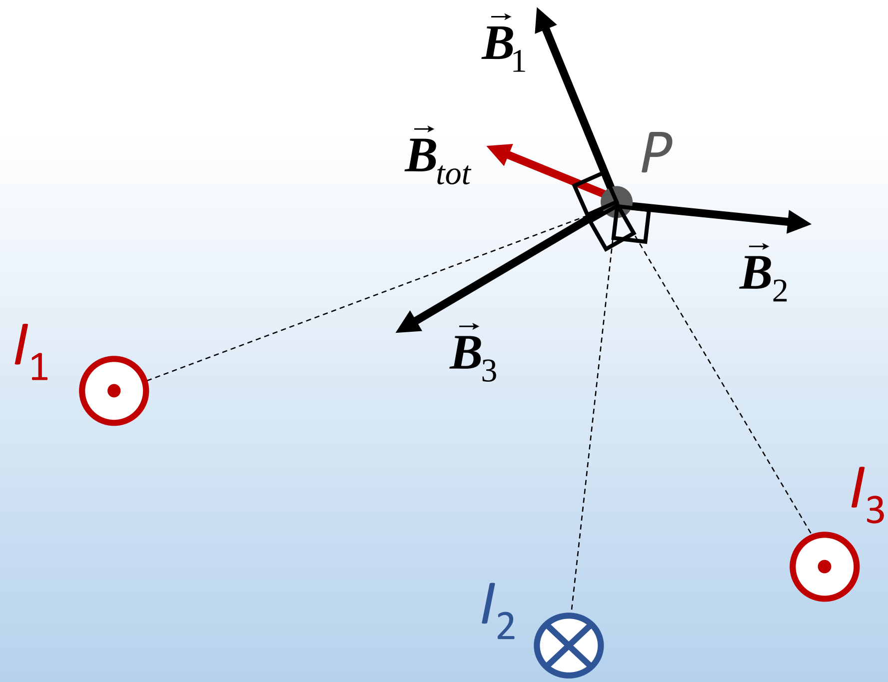


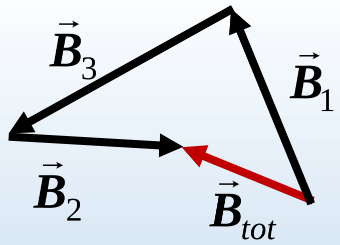
Superposition principle

Total *B* field due to several charges = sum of individual *B* fields

$$\vec{B}_{tot} = \sum \vec{B}$$

Ex: what is the *B* field at point *P* due to I_1, I_2, and I_3?





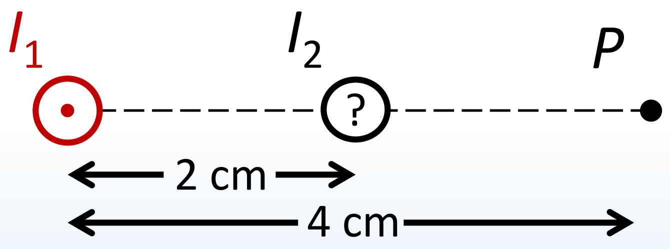
Order does not matter!

Same approach as for *E* fields

$$\vec{B}_{tot} = \vec{B}_1 + \vec{B}_2 + \vec{B}_3$$

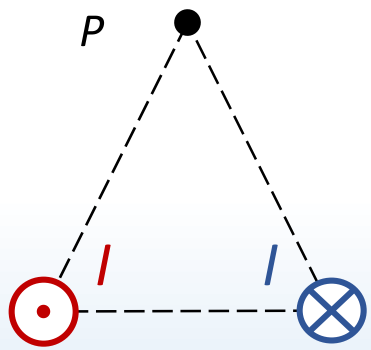
Calculation: 2 wires

A long straight wires 1 carries current I_1 = 0.1 A out of the page. What must be the *direction* and *magnitude* of the current I_2 in wire 2 such that there is no net *B* field at point *P*?



ACT: CheckPoint 1.1

Two long wires carry the same current *I* in opposite directions

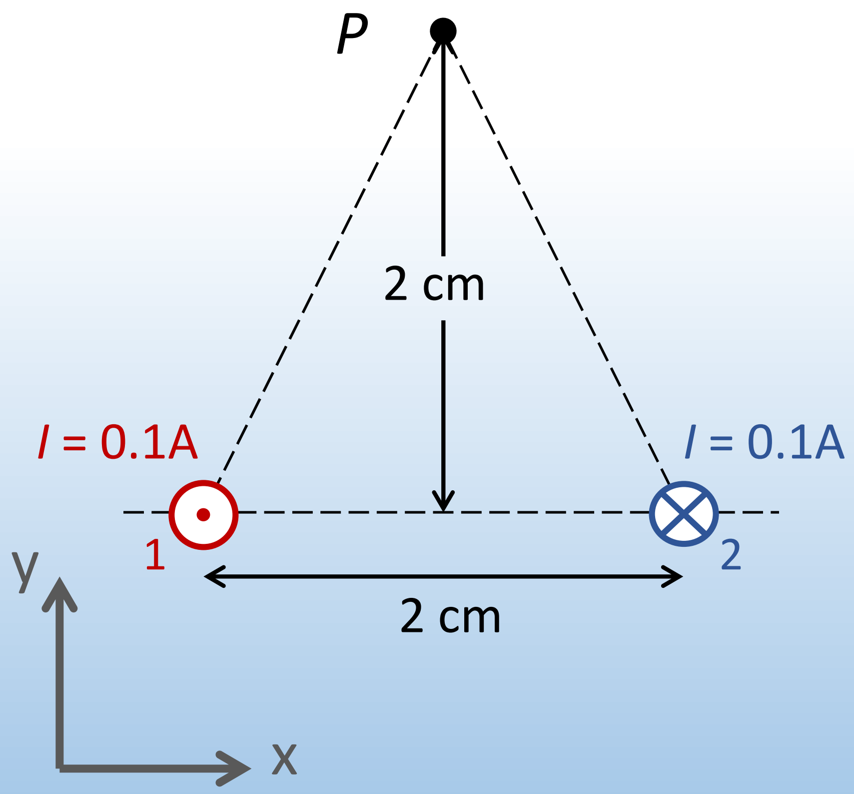


What is the direction of the total *B* field above and midway between the two wires at point *P*?

A. Left B. Right C. Up D. Down E. Zero

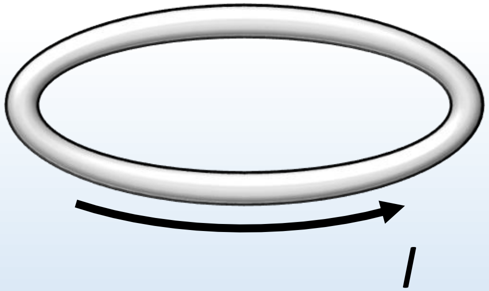
Calculation: B field from 2 wires

Calculate the magnitude of the total *B* field from the 2 wires at *P*



ACT: Current loop

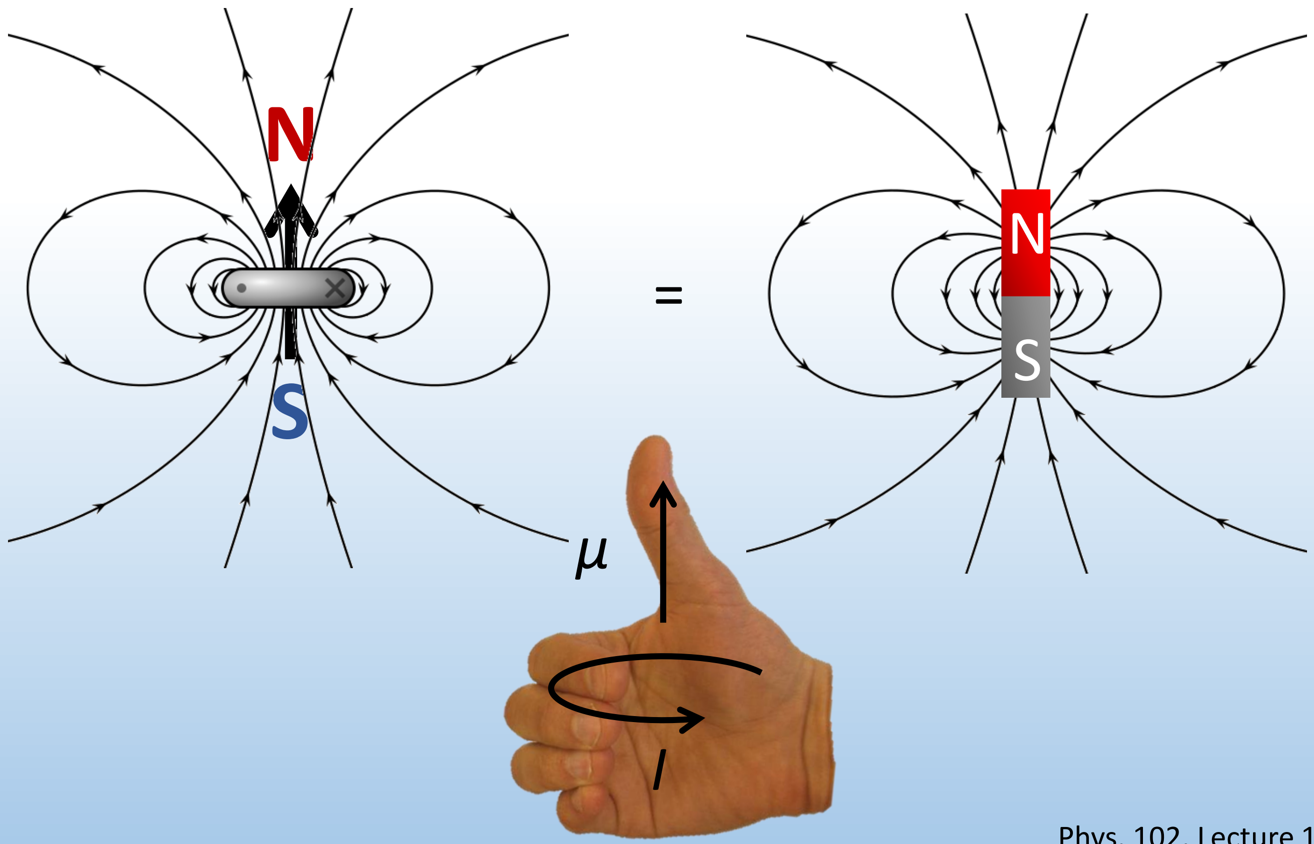
A loop of wire carries current as shown. In what direction is the *B* field at the center of the loop?



A. Left B. Right C. Up D. Down E. Zero

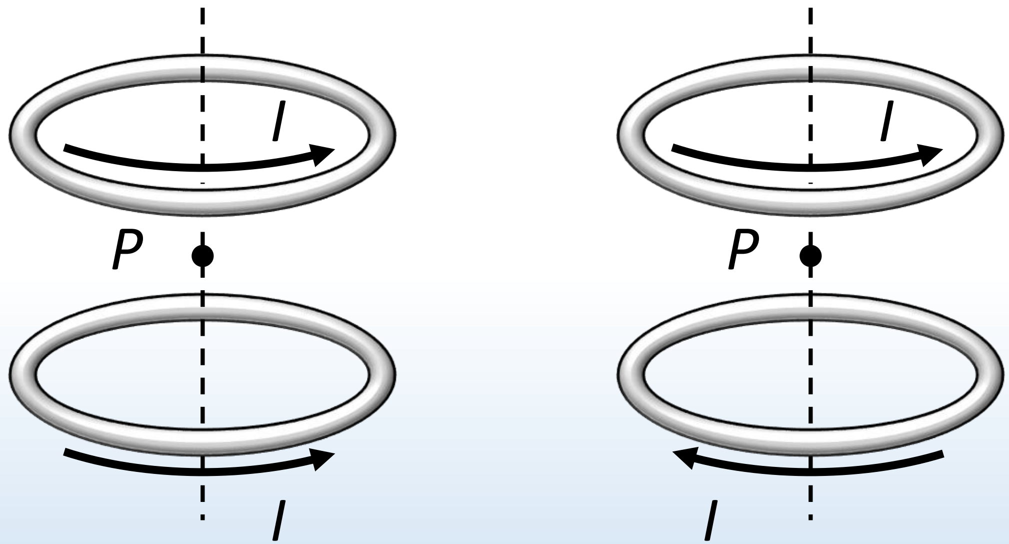
Current loops & magnetic dipoles

Recall Lect. 11: A current loop behaves like a magnetic dipole
Generates the same *B* field



ACT: Many current loops

Which configuration of two loops generates a larger *B* field at point *P* midway between the loops?



A. Left B. Right C. Same

Solenoid

A solenoid is a long coil consisting of *N* turns of wire

Magnitude

$$B_{sol} = \mu_0 n I$$

B field inside solenoid

Current

Number of turns of wire per length (in m) *N*/*L*

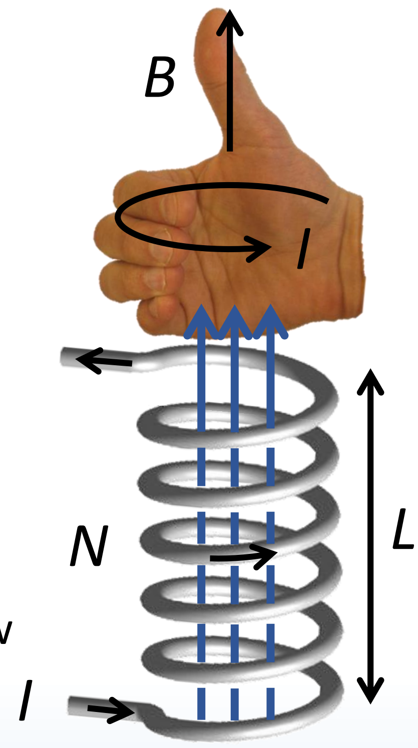
Note there no dependence on *r*.
B field inside solenoid is ***uniform***

Direction

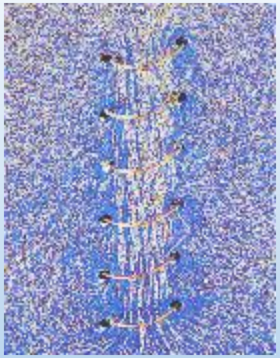
Right-hand rule for loop(s):

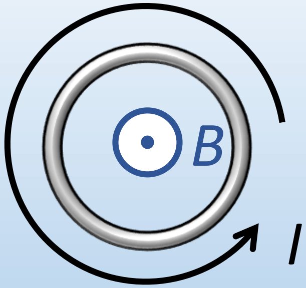
Curl fingers along *I*

Thumb along $\vec{B}$



Side view



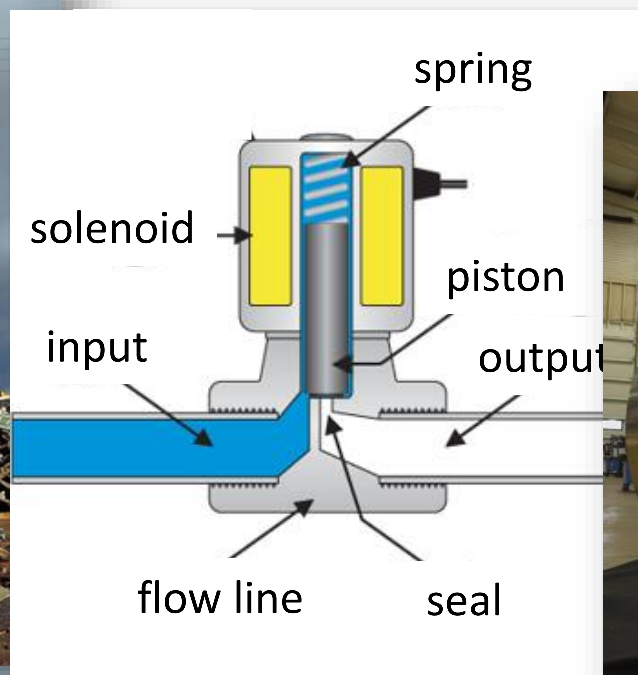


Top view

Electromagnets

Solenoids are a way to make *powerful* magnets that can be turned on and off!

Junkyard magnet

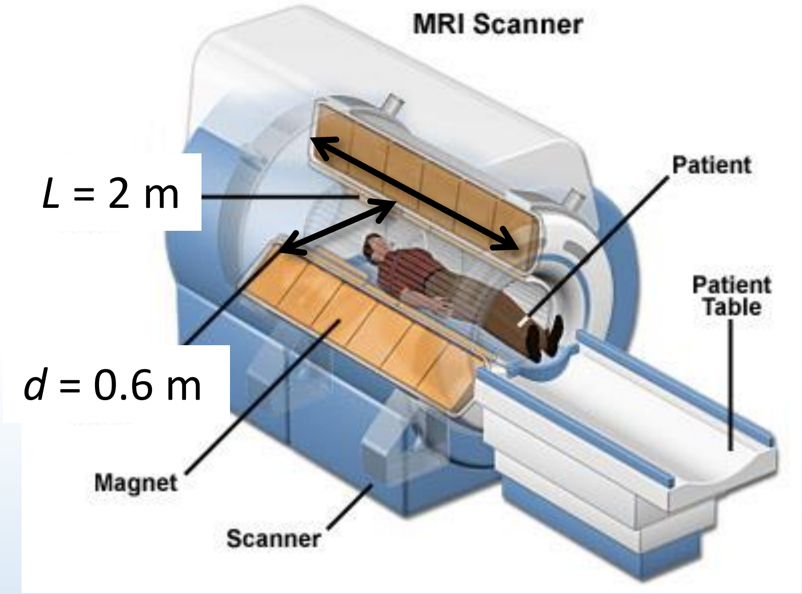


Solenoid valve

MRI magnet

Calculation: MRI magnet

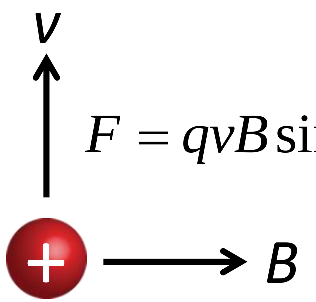
How many turns of wire are needed to generate a 1.5 T MRI magnet?



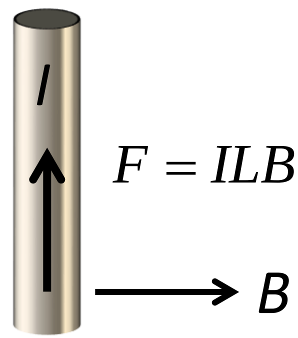
How much wire does that correspond to?

Magnetic field recap

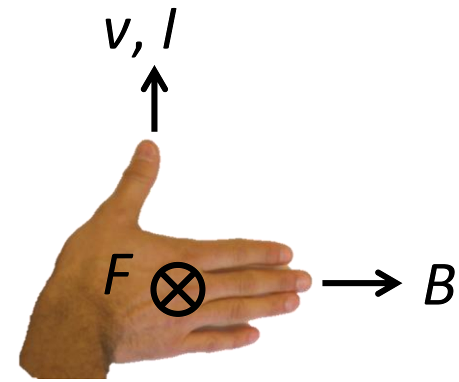
B fields exert forces on moving charges



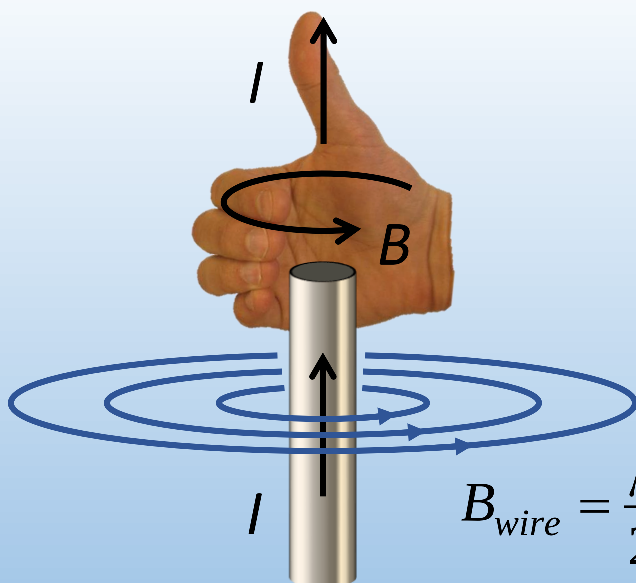
$$F = qvB\sin\theta$$



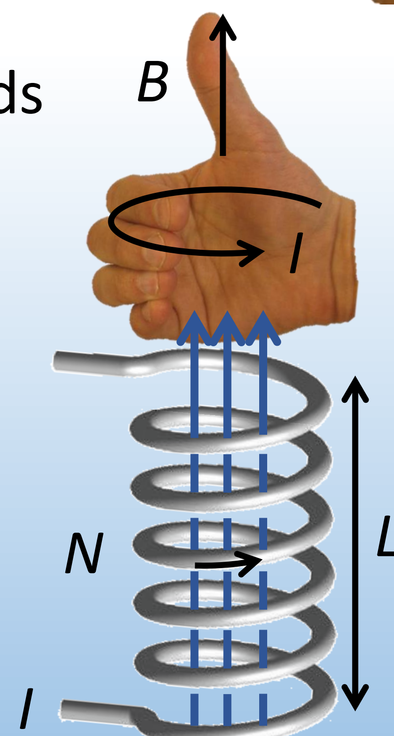
$$F = ILB\sin\theta$$



Moving charges generate *B* fields



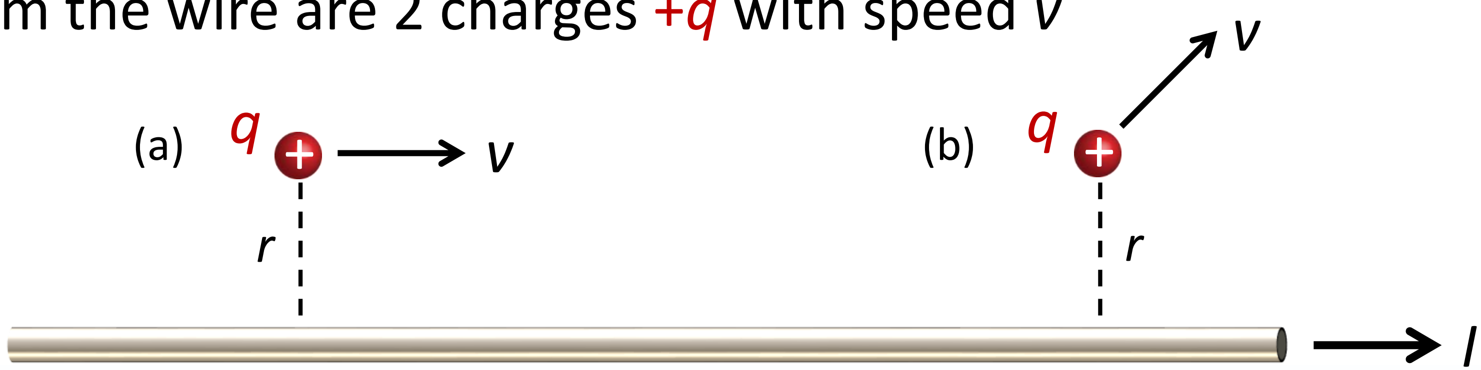
$$B_{wire} = \frac{\mu_0 I}{2\pi r}$$



$$B_{sol} = \mu_0 n I$$

ACT: CheckPoint 3.1

A long straight wire is carrying current *I* to the right. A distance *r* from the wire are 2 charges +*q* with speed *v*

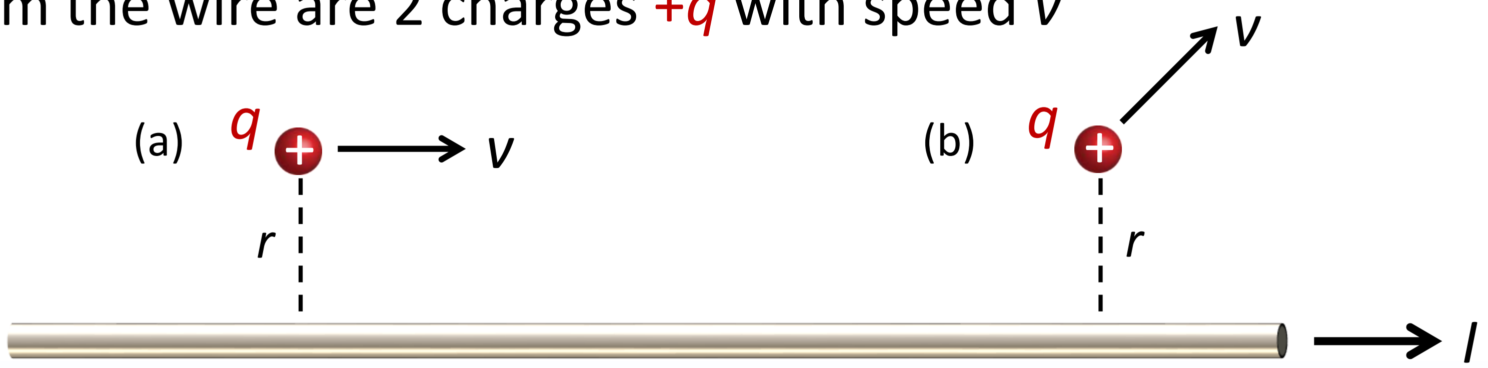


Compare the *magnitude* of magnetic force on *q* for (a) vs. (b)

A. (a) has the larger force
B. (b) has the larger force
C. force is the same for (a) and (b)

CheckPoint 3.1

A long straight wire is carrying current *I* to the right. A distance *r* from the wire are 2 charges +*q* with speed *v*



Compare the ***direction*** of magnetic force on *q* for (a) vs. (b)

ACT: Force between wires

Current-carrying wires generate *B* fields, *B* fields exert force on current-carrying wires. So, wires must exert forces on each other!

The two wires 1 & 2 carry current in the same direction. In which direction does the force on wire 2 point?

A. Toward wire 1
B. Away from wire 1
C. The force is zero

Force between wires

Wires generate *B* fields, *B* fields exert force on wires. Therefore, wires exert forces on each other

Direction

Magnitude

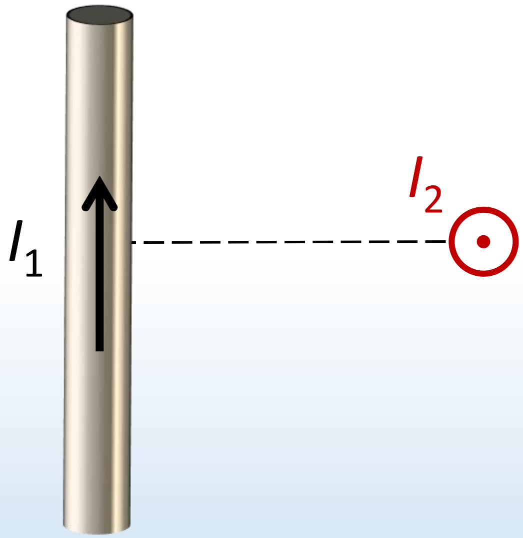
$$B_1 = \frac{\mu_0 I_1}{2\pi r} \qquad F_{21} = I_2 L B_1 \sin\theta$$

$$B_2 = \frac{\mu_0 I_2}{2\pi r} \qquad F_{12} = I_1 L B_2 \sin\theta$$

DEMO

ACT: Force between wires

The two wires 1 & 2 carry current in perpendicular directions.
In which direction does the force on wire 2 point?



A. Toward wire 1
B. Away from wire 1
C. The force is zero

Summary of today's lecture

- *B* fields are generated by currents
  - Long straight wire
  - Current loop
  - Solenoid

  } Don't confuse different RHRs!
- Current carrying wires exert forces on each other
  - Likes attract, opposites repel