Your questions/comments

ANNOUNCEMENT: Interested in *James Scholar Credit*? Submit HCLA form by Oct. 17. Proposals on Phys. 102 related topics are due by email Oct. 20.

“All of the different right hand rules are confusing me.”

“I really had a hard time understand the first and last checkpoint questions and I am struggling keeping all of these right hand rules straight. Any tricks to remember them and when to apply them??”

“How do you find the direction of the B field vectors like they did in the Superposition of B fields video and the first question of this checkpoint? I could not figure that out. The right hand rule for this part of the material is unclear”

“Definitely Checkpoint 3 was more difficult of all the questions in this checkpoint. Please go over this concept in lecture if possible! Thanks!”

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

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

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

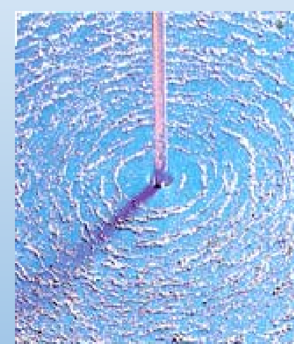
Direction

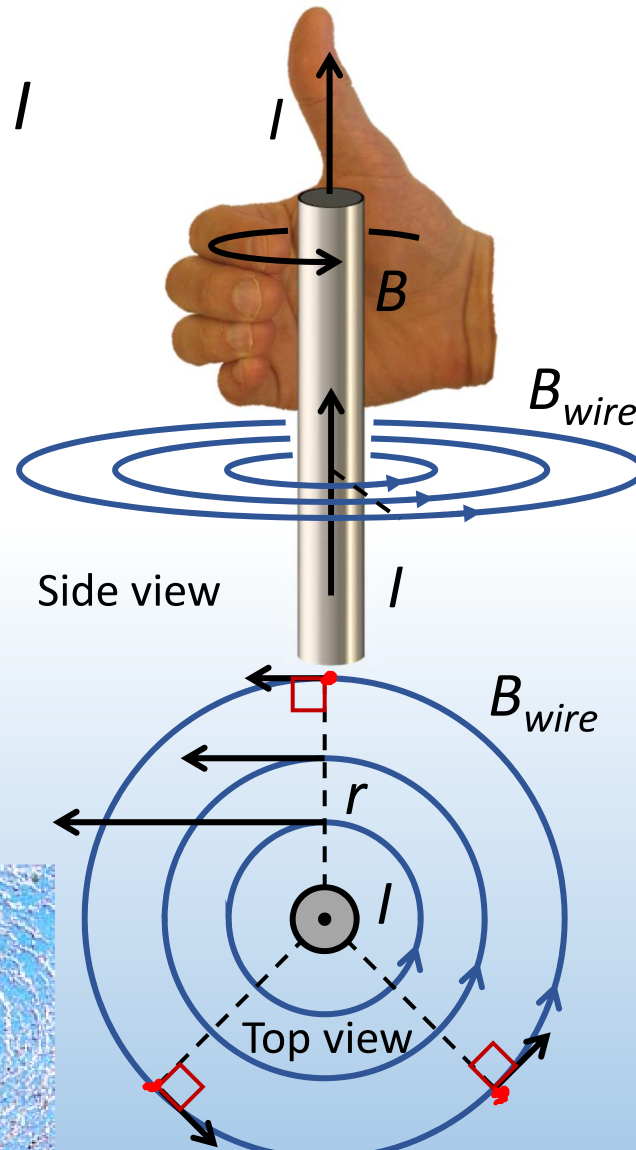
Right-hand rule for wire:

Thumb along *I*

Curl fingers along $\vec{B}$

B is $\perp$ to *r*



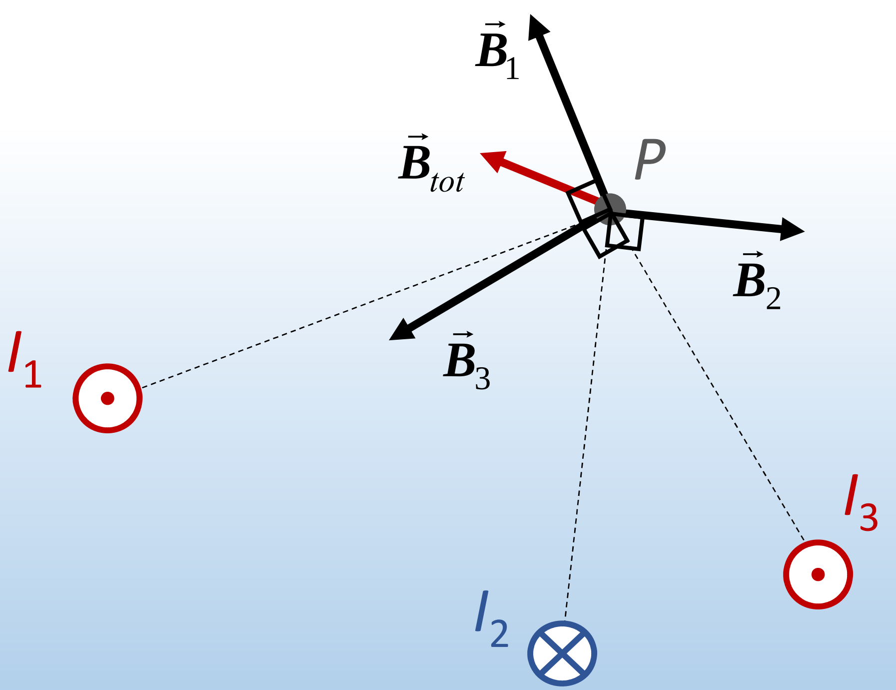


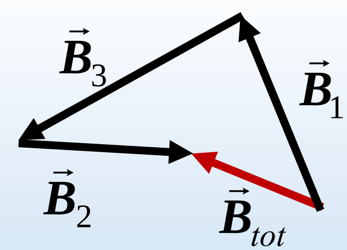
Superposition principle

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?





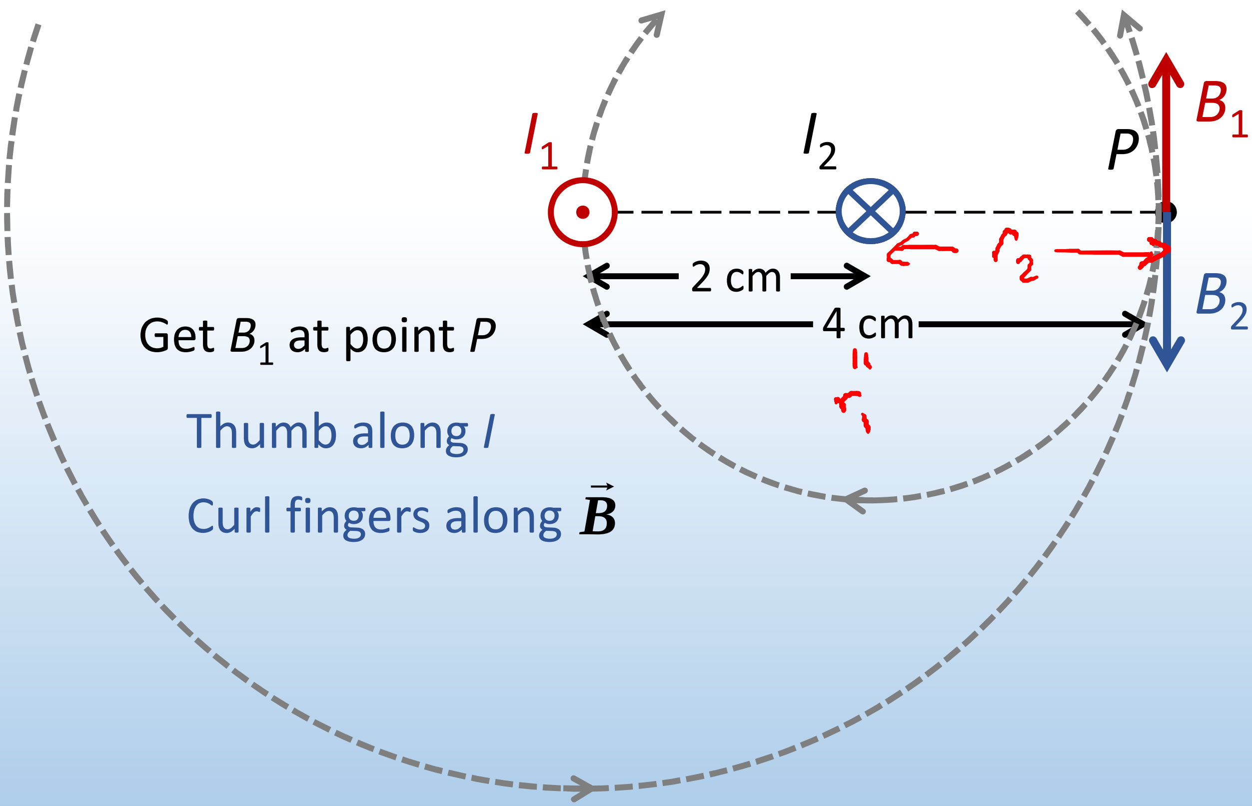
Order does not matter!

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?



Get B_1 at point P

Thumb along I

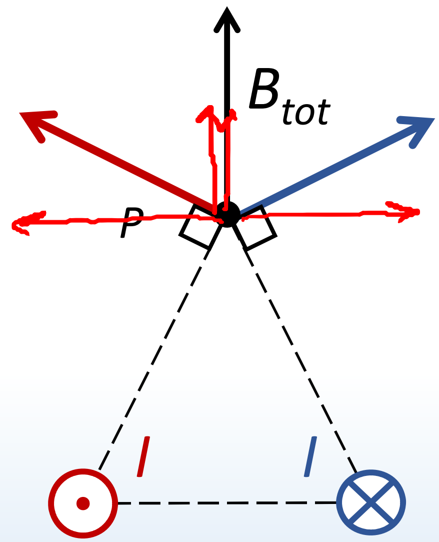
Curl fingers along $\vec{B}$

$$B_1 = \frac{\mu_0 I_1}{2\pi r_1} \qquad B_2 = \frac{\mu_0 I_2}{2\pi r_2}$$

$$\frac{I_2}{r_2} = \frac{I_1}{r_1} \qquad I_2 = \frac{I_1 r_2}{r_1} = 0.1\frac{0.02}{0.04} = 0.05A$$

ACT: CheckPoint 1.1

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

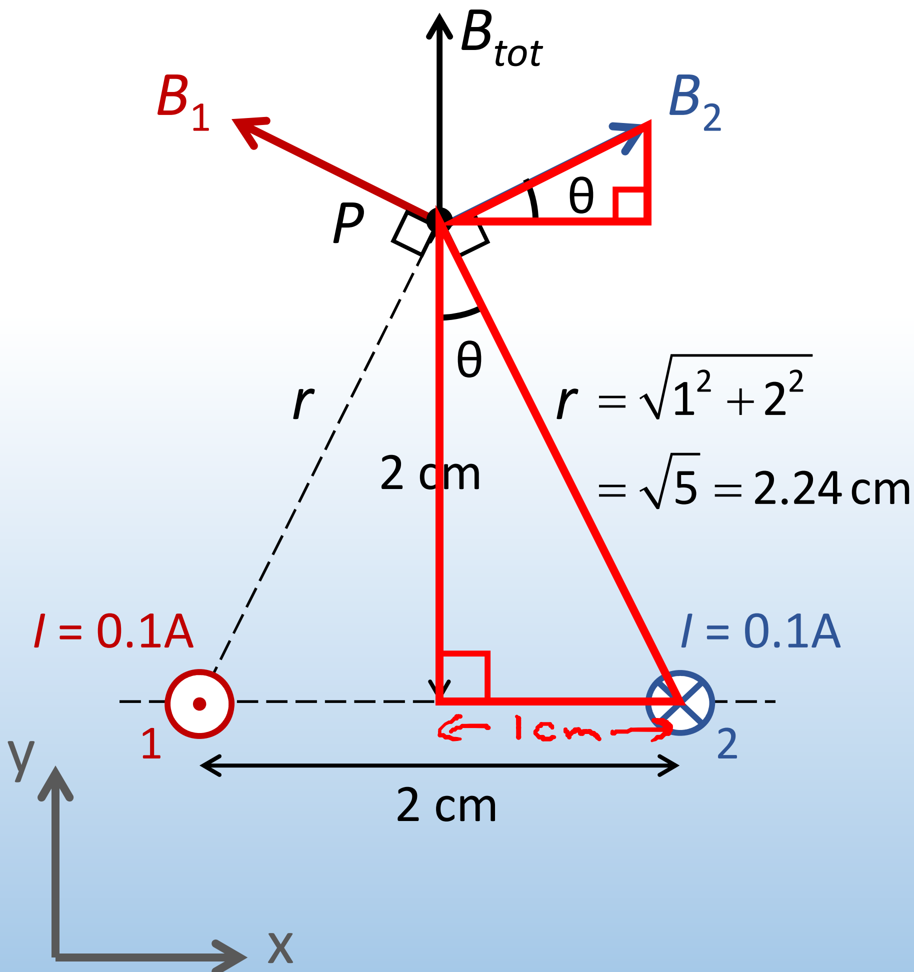


What is the direction of the total *B* field above and midway between the two wires at point *P*?

A. Left	B. Right	C. Up	D. Down	E. Zero
5%	13%	35%	9%	38%

Calculation: B field from 2 wires

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



B field magnitudes are the same at *P*:

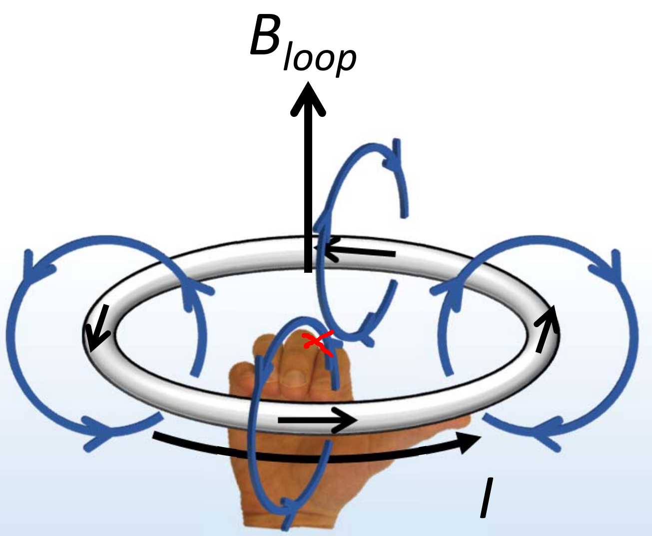
$$B_1 = B_2 = \frac{\mu_0 I}{2\pi r}$$

x components cancel,
y components are equal:

$$B_{tot} = B_{1,y} + B_{2,y}$$
$$= 2B_2 \sin\theta = 2B_2 \frac{1}{2.24}$$
$$= 2\frac{\mu_0 I}{2\pi r}\frac{1}{2.24}$$
$$= \frac{4\pi\times10^{-7}\cdot 0.1}{\pi\cdot 0.0224}\frac{1}{2.24} = 0.8\mu T$$

ACT: Current loop

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



Approach: treat each segment of loop as a “straight” wire

Use RHR for wire

For each segment, *B* field at center of loop points up, so total *B* field is up

A. Left

B. Right

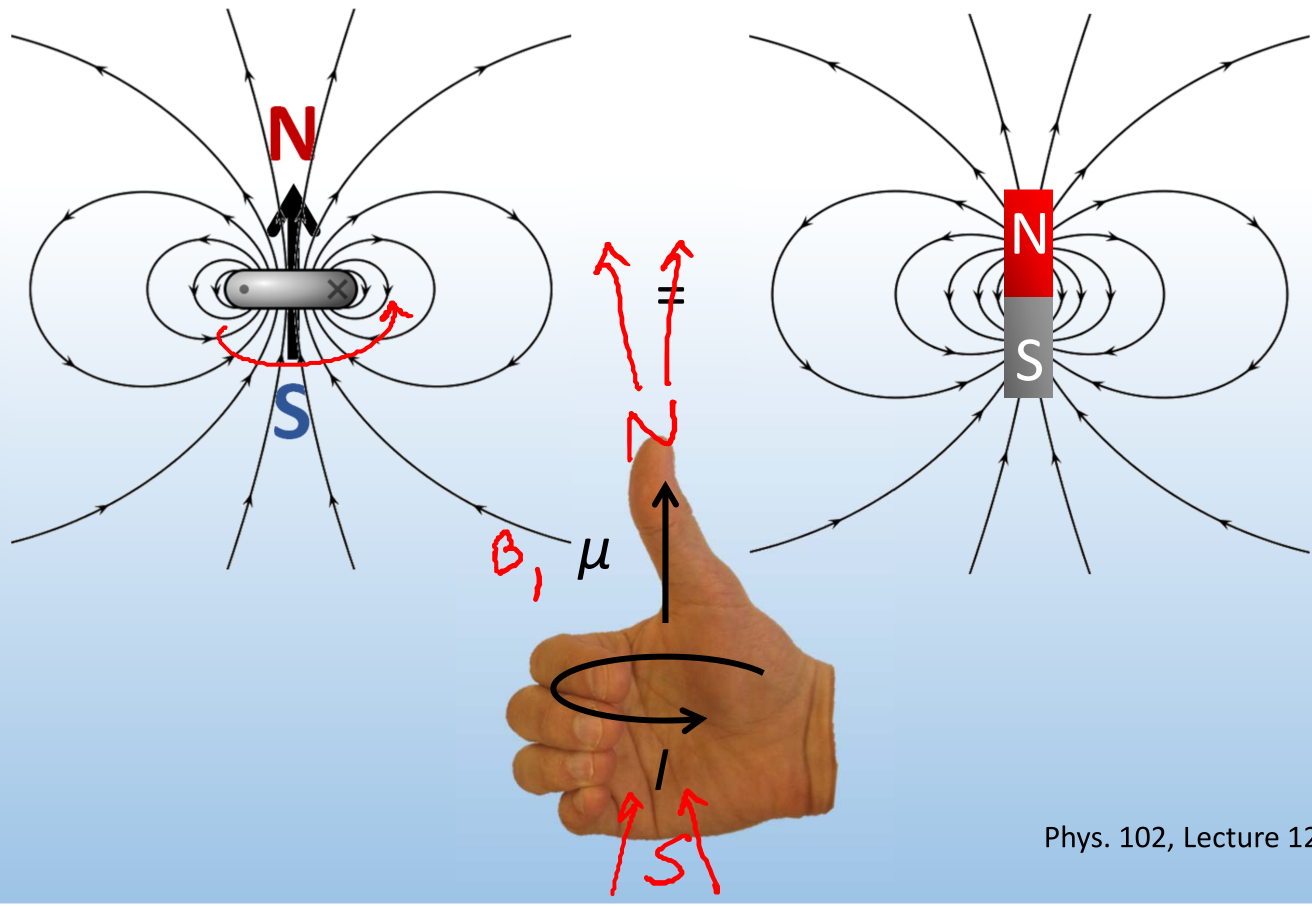
C. Up

D. Down

E. Zero

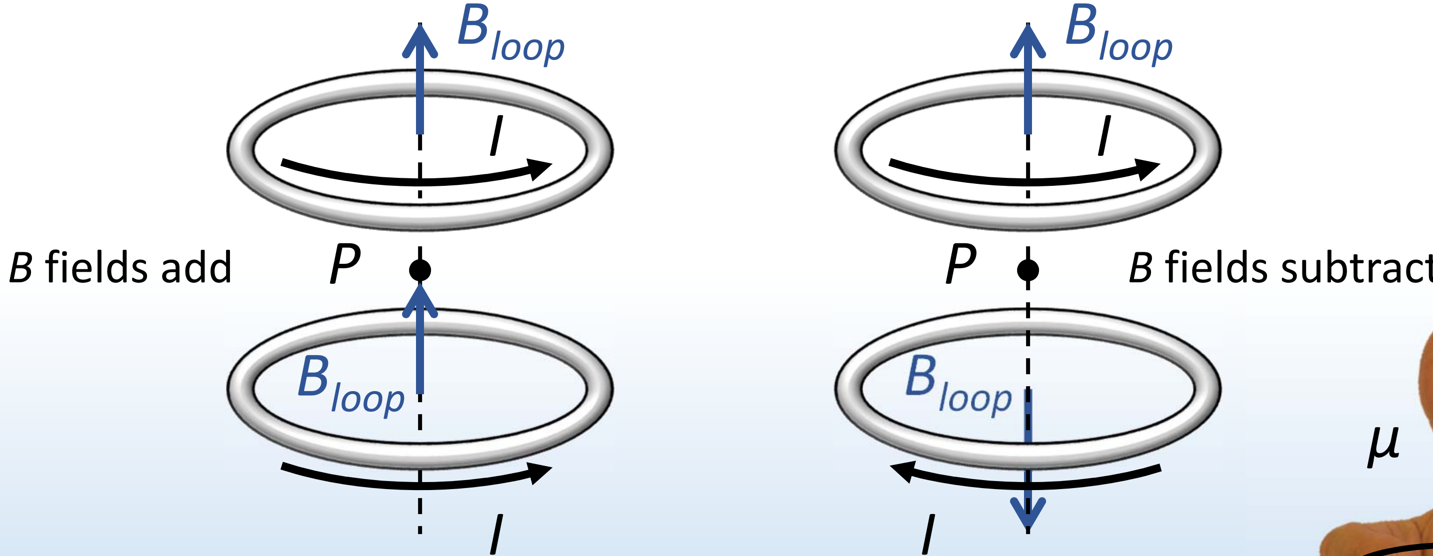
Current loops & magnetic dipoles

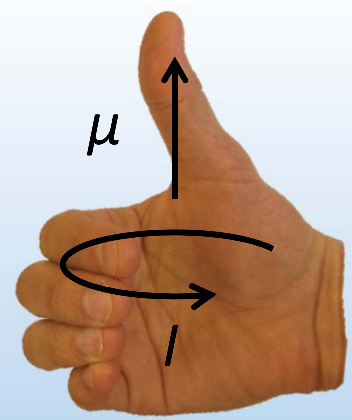
Recall Lect. 11: A current loop behaves like a magnetic dipole
Generates the same *B* field



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

By stacking many loops carrying current in same direction, we can generate large *B* fields

Solenoid

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

$\frac{Tm}{A}$

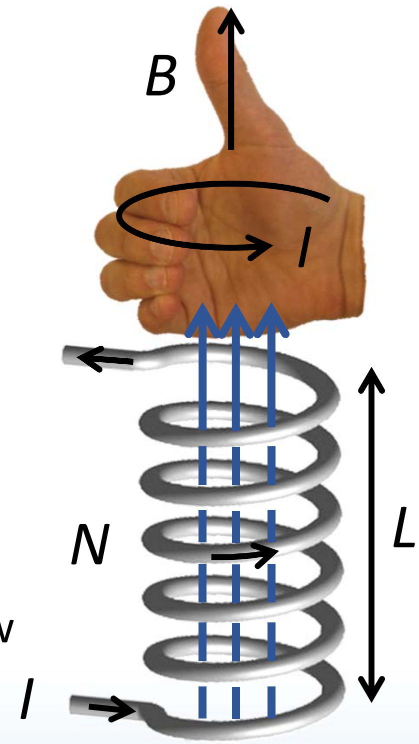
Magnitude

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

B field inside solenoid

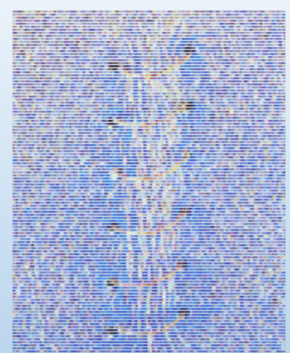
Current

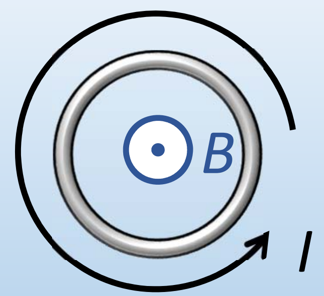
Number of turns of wire per length (in m) *N*/*L*



Side view

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





Top view

Direction

Right-hand rule for loop(s):

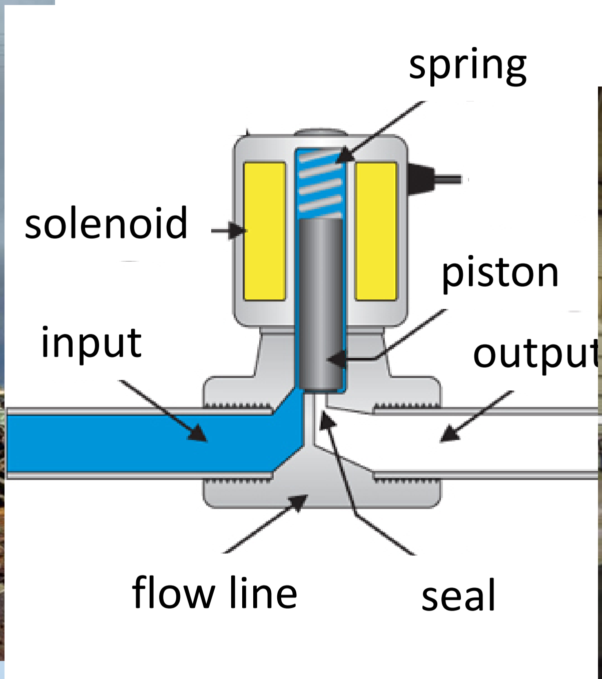
Curl fingers along *I*
Thumb along $\vec{B}$

CheckPoint 2
83%

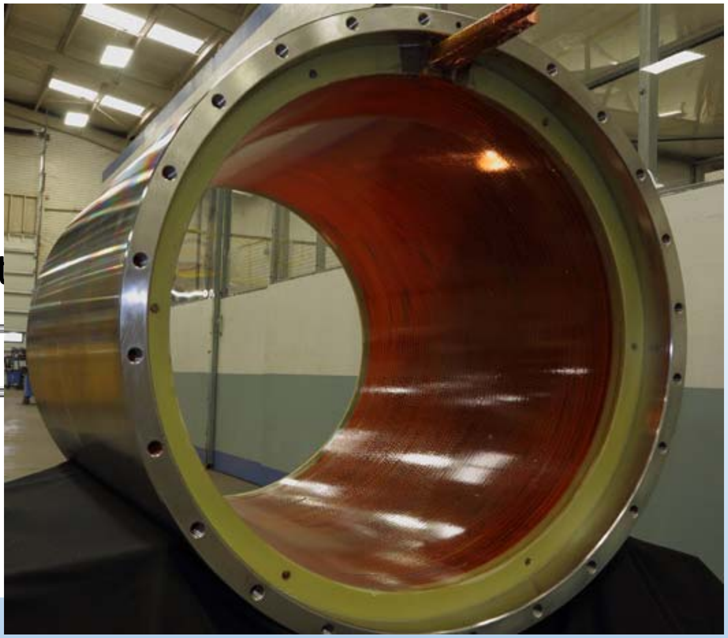
Electromagnets

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

Junkyard magnet



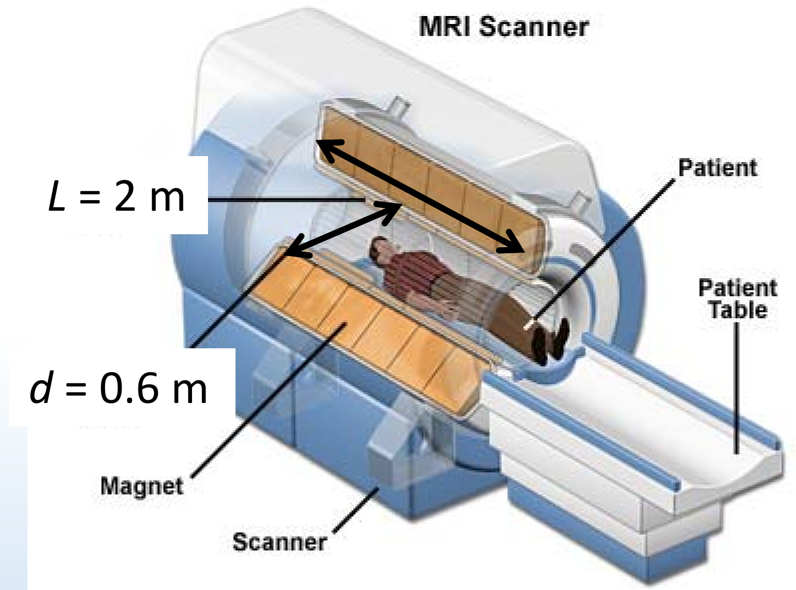
Solenoid valve



MRI magnet

Calculation: MRI magnet

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



$I = 1000\,A$

$$B_{sol} = \mu_0 \frac{N}{L} I \qquad N = \frac{B_{sol} L}{\mu_0 I} = \frac{1.5 \cdot 2}{4\pi \times 10^{-7} \cdot 1000} \approx 2400$$

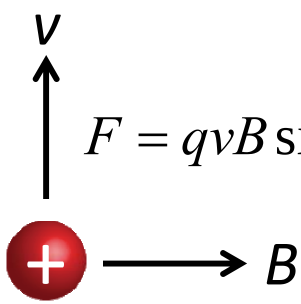
How much wire does that correspond to?

$$\ell = N\pi d \approx 2400 \cdot \pi \cdot 0.6 = 4.5\,\mathrm{km}$$

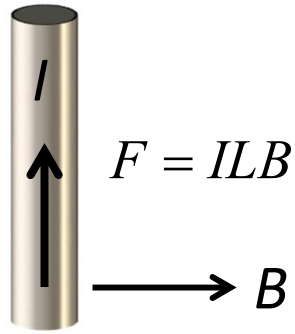
Magnetic field recap

B fields exert forces on moving charges

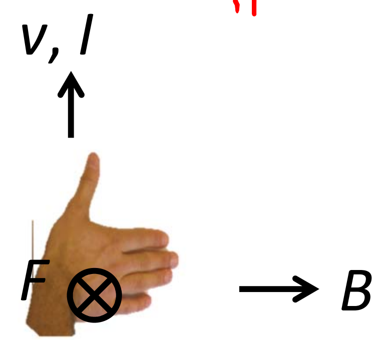
Type I



$$F = qvB\sin\theta$$

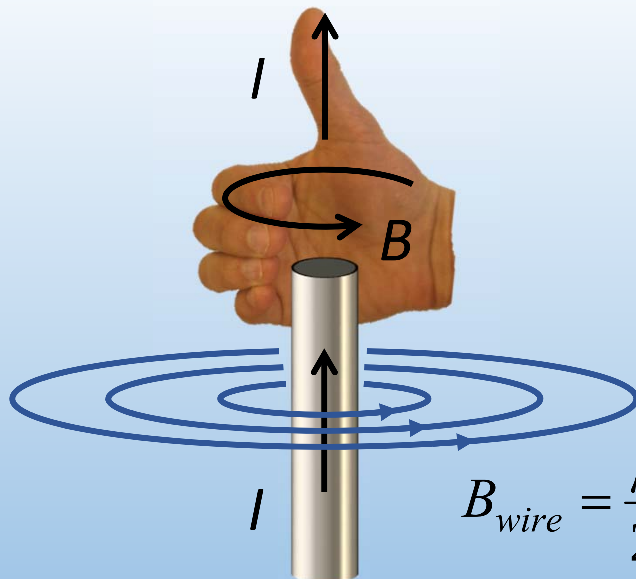


$$F = ILB\sin\theta$$

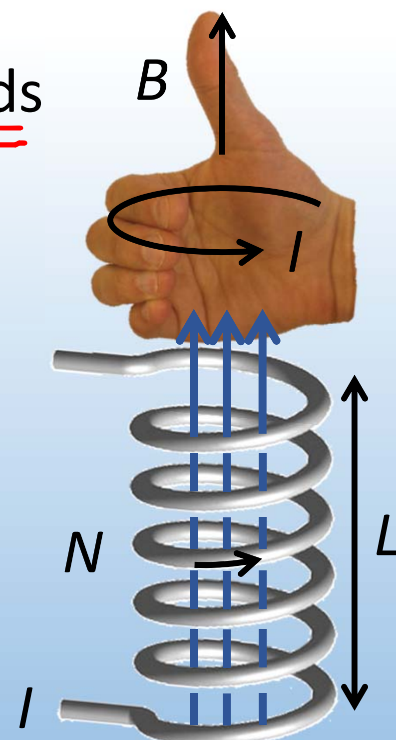


Moving charges generate *B* fields

Type II



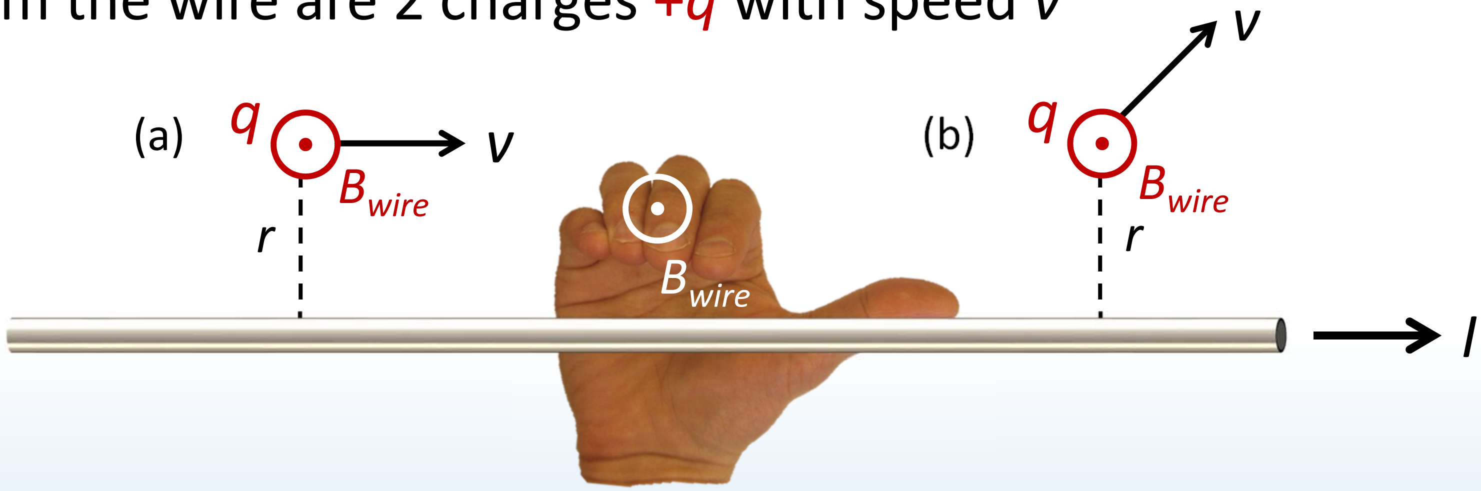
$$B_{wire} = \frac{\mu_0 I}{2\pi r}$$



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

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)

32% A. (a) has the larger force

35% B. (b) has the larger force

33% C. force is the same for (a) and (b)

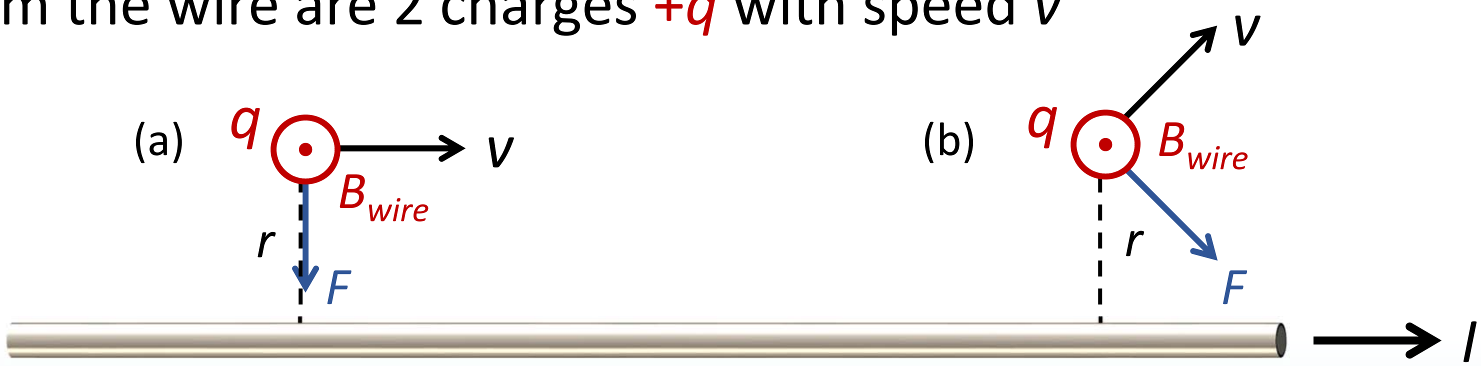
$F = qvB_{wire}\sin\theta$ Same *q*, *v*

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

Same θ = 90°

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)

Thumb along *v*

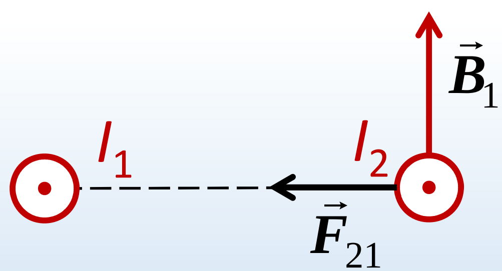
Fingers along $\vec{B}_{wire}$

$\vec{F}$ on +*q* is *out of palm*

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

1. Get *B* field from wire 1 at wire 2

   Thumb along I_1

   Curl fingers along $\vec{B}_1$

2. Get *F* from B_1 on wire 2

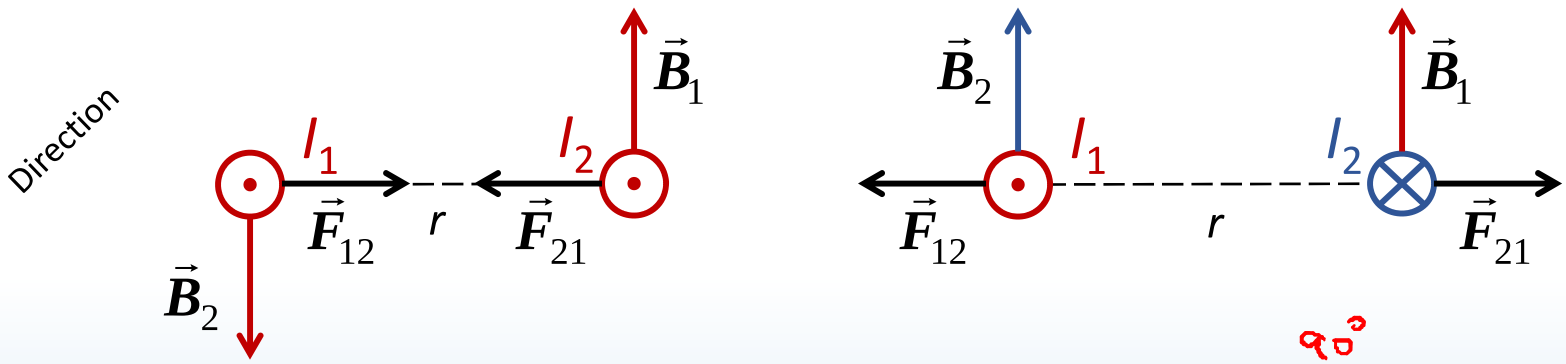
   Thumb along I_2

   Fingers along $\vec{B}_1$

   $\vec{F}$ on I_2 is *out of palm*

Force between wires

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



RHR for B field from wires

Thumb along I

Curl fingers along $\vec{B}$

Magnitude

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

90°

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

Likes attract, opposites repel!

RHR for F on wire

Thumb along I

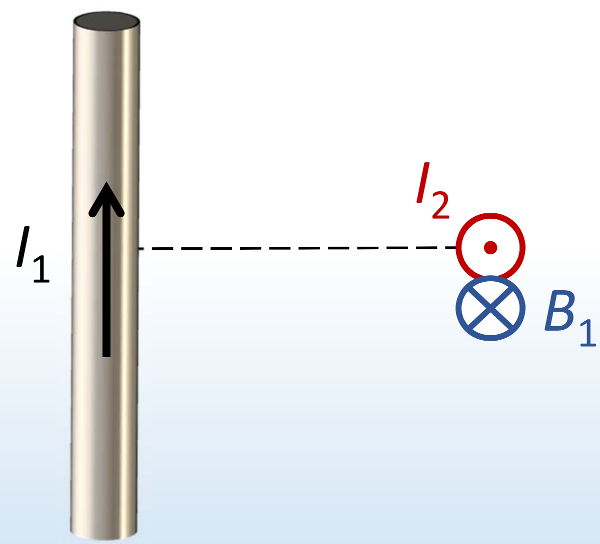
Fingers along $\vec{B}$

$\vec{F}$ on I is *out of palm*

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?



Get B field from wire 1 at wire 2

Thumb along I_1

Curl fingers along $\vec{B}_1$

A. Toward wire 1

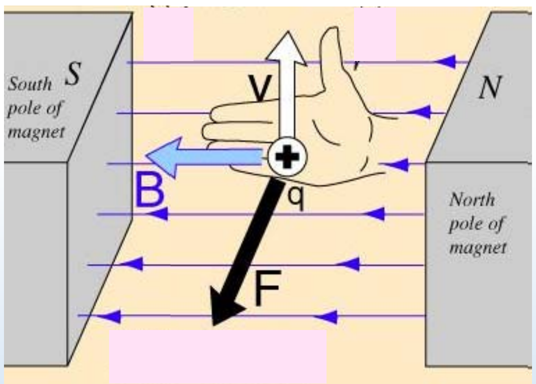
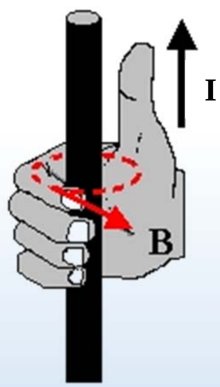
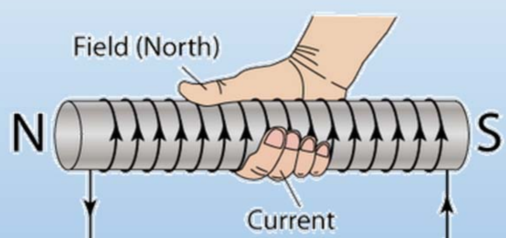
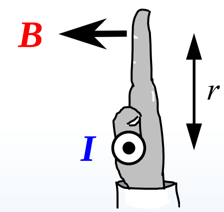
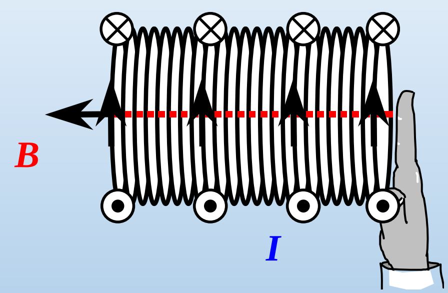
B. Away from wire 1

C. The force is zero

B_1 is parallel to wire 2

$F_{21} = I_2 L B_1 \sin\theta \quad \theta = 180°$

Summary of right hand rules

Force on moving *q*	*B* field from current *I* — Standard	*B* field from current *I* — Alternate
	Straight wire  Solenoid 	Straight wire  Solenoid 

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