

# Your Comments

Please explain the right hand rule when there are two wires and you are trying to find the direction of the force. I am getting confused with all these right hand rules.

So do you have any age-old advice for Unofficial?

After Tuesdays lecture I felt like I understood the torque stuff, but as soon as I started going through these checkpoint questions I felt like I was in Memento and hadnt taken a single polaroid on Tuesday.

Can you explain mathematically, or at least qualitatively, the derivation/intuition of the Biot-Savart Law? I feel the pre-lecture presented it in a "trust us that this is true" fashion.

during the last couple lectures its been getting really noisy and hard to hear, especially for the last couple rows.

The reason there is such a discrepancy between checkpoint scores and i>clicker scores is that there is no incentive to do well on checkpoints, so most people simply click random answers and submit them. Not that I'm encouraging you to give points for accuracy on checkpoints.

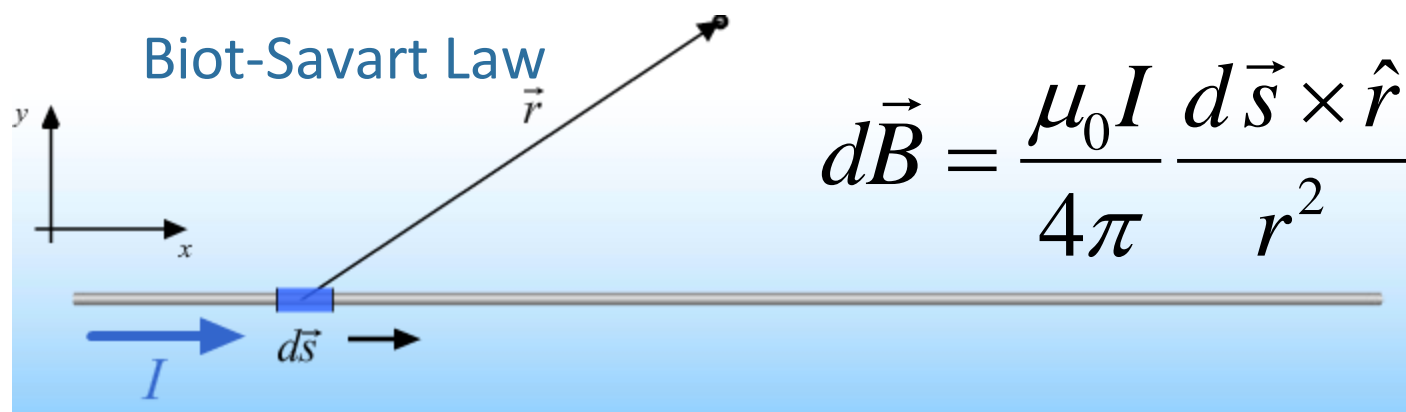
Is it okay to say that the B field produced by a loop will be parallel (or anti parallel) to mu vector of the loop cause mu and B want to be aligned? Also if E-fields and B-fields are related by Lorentz boosts, are mu naught and epsilon naught related?

My roommate and I are having a competition to see who can get on the board more, since I didn't just click through the prelecture like SOMEONE, I think I deserve a shoutout.

Are we going to have to constantly derive the Biot-Savart law for infinite wires with current (much like how we constantly used Gauss's Law to find the E-field for various spheres/cylinders), or is the  $(\mu_0 I)/(2\pi r)$  equation something we will use straight off the bat?

## Physics 212 Lecture 14

Today's Concept:



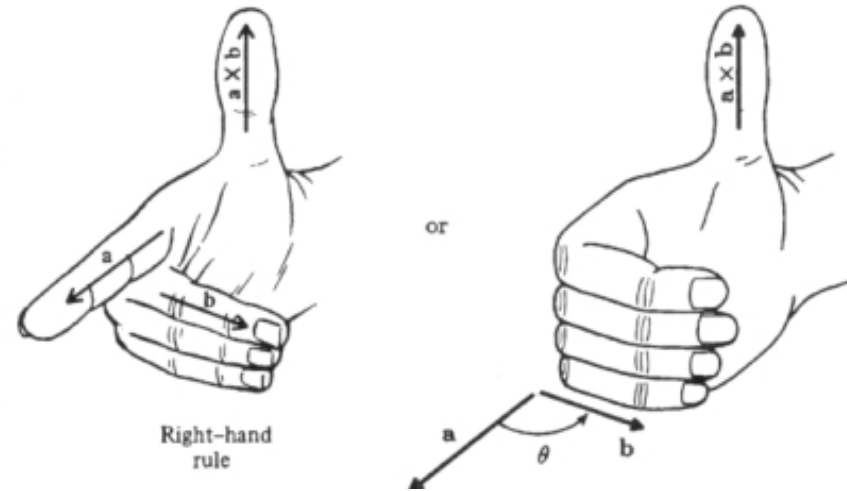
# Right Hand Rule Review

## 1. ANY CROSS PRODUCT

$$\vec{F} = q\vec{v} \times \vec{B} \quad \vec{F} = I\vec{L} \times \vec{B}$$

$$\vec{\tau} = \vec{r} \times \vec{F} \quad \vec{\tau} = \vec{\mu} \times \vec{B}$$

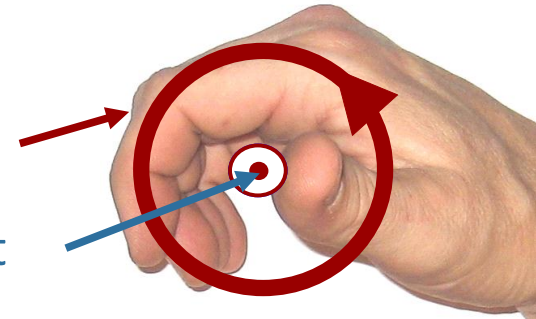
$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{d\vec{s} \times \hat{r}}{r^2}$$



## 2. Direction of Magnetic Moment

Fingers: Current in Loop

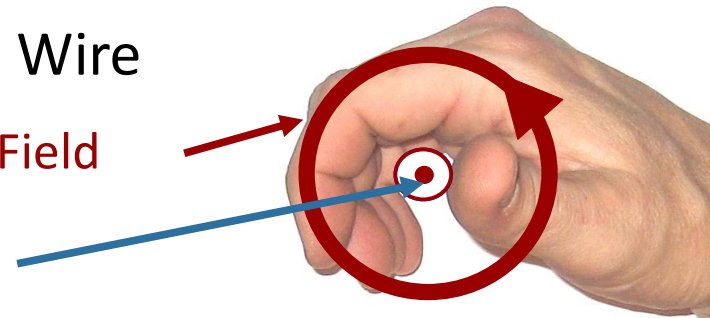
Thumb: Magnetic Moment



## 3. Direction of Magnetic Field from Wire

Fingers: Magnetic Field

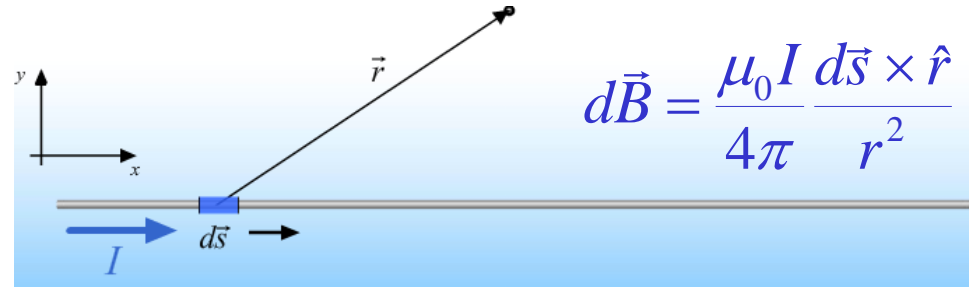
Thumb: Current



# Biot-Savart Law:

## What is it?

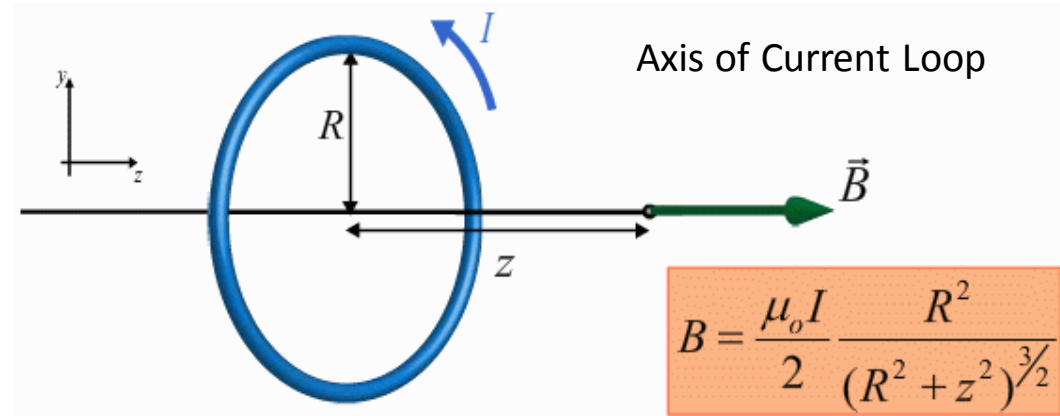
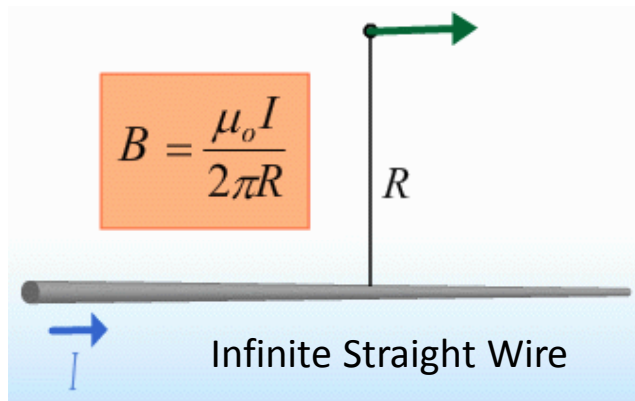
Fundamental law for determining the direction and magnitude of the magnetic field due to an element of current



We can use this law to calculate the magnetic field produced by ANY current distribution

**BUT**

Easy analytic calculations are possible only for a few distributions:



Plan for Today: Mainly use the results of these calculations!

**GOOD NEWS:** Remember Gauss' Law?  
Allowed us to calculate  $E$  for symmetrical charge distributions



**NEXT TIME:** Introduce Ampere's Law Allows us to calculate  $B$  for symmetrical current distributions

# *B* from Infinite Line of Current

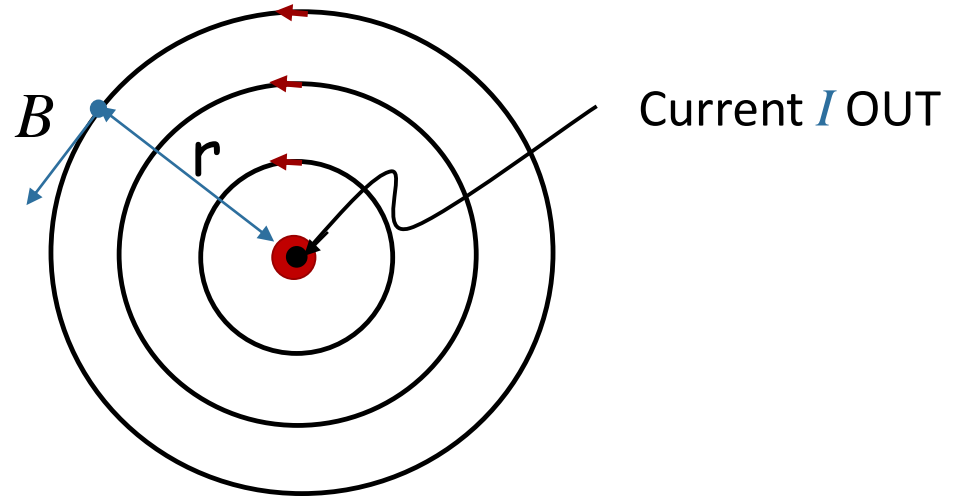
Integrating  $d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{d\vec{s} \times \hat{r}}{r^2}$  gives result

Magnitude:

$$B = \frac{\mu_0 I}{2\pi r}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$$

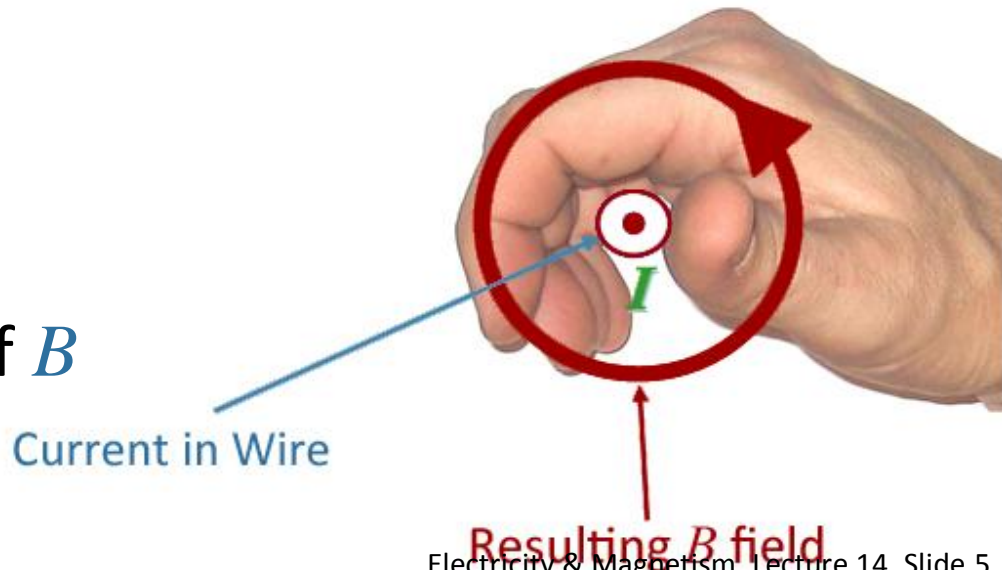
$r$  = distance from wire



Direction:

Thumb: on  $I$

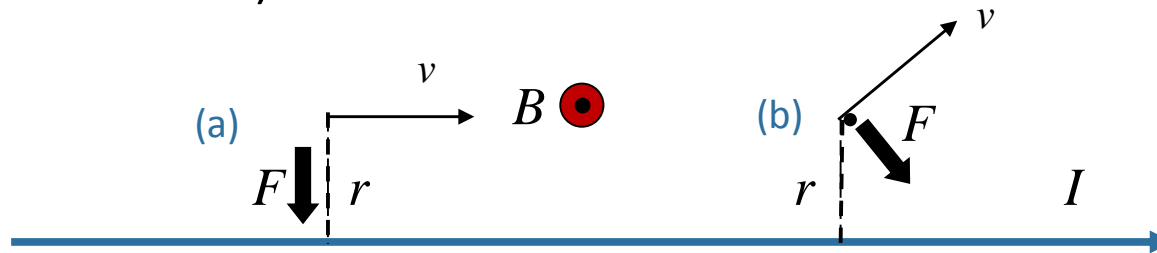
Fingers: curl in direction of  $B$



# Currents + Charges



A long straight wire is carrying current from left to right. Two identical charges are moving with equal speed. Compare the magnitude of the force on charge  $a$  moving directly to the right, to the magnitude of the force on charge  $b$  moving up and to the right at the instant shown (i.e. same distance from the wire).



A)  $|F_a| > |F_b|$

B)  $|F_a| = |F_b|$

C)  $|F_a| < |F_b|$

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

$$|\vec{F}| = qvB\sin\theta$$

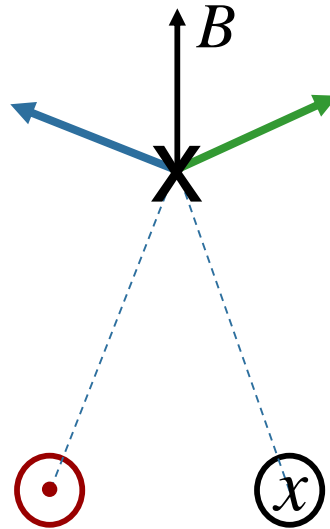
Same  $q$ ,  $|v|$ ,  $B$  and  $\theta (=90)$

Forces are in different directions

# Adding Magnetic Fields



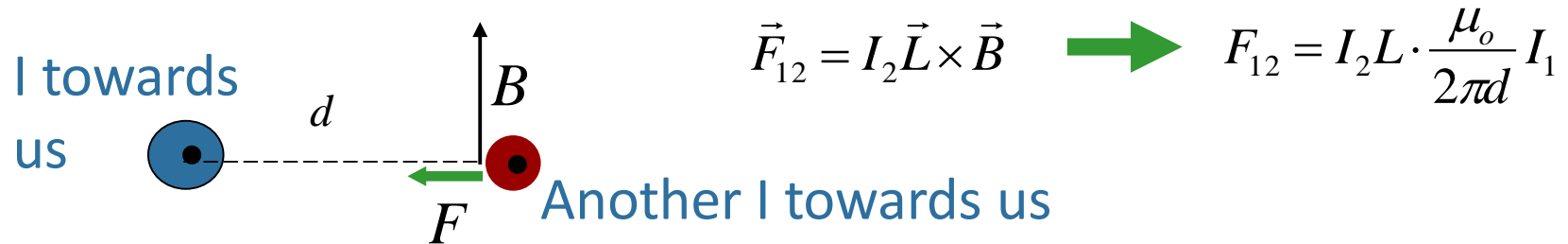
Two long wires carry opposite current



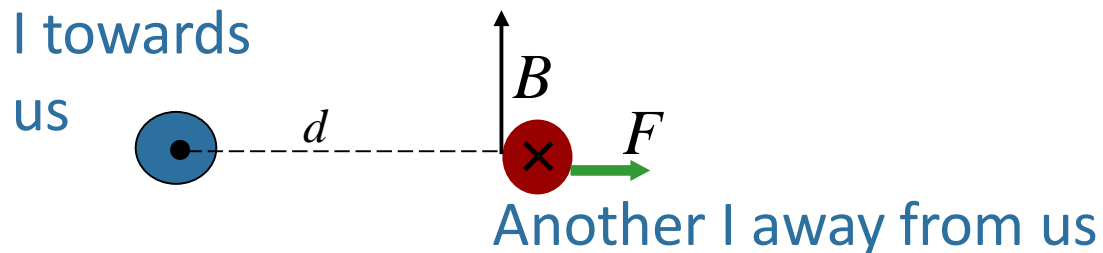
What is the direction of the magnetic field above, and midway between the two wires carrying current – at the point marked “X”?

- A) Left    B) Right    **C) Up**    D) Down    E) Zero

# Force Between Current-Carrying Wires

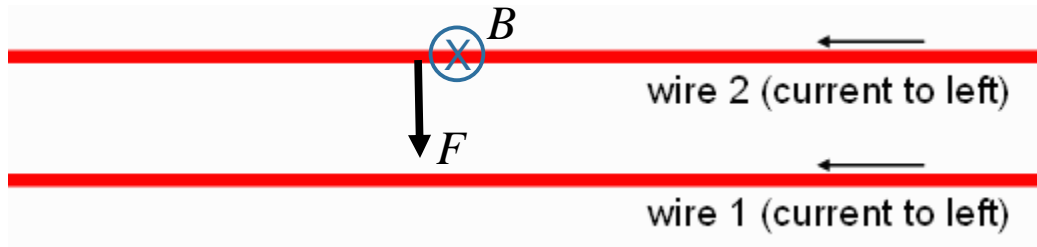


**Conclusion:** Currents in same direction attract!



**Conclusion:** Currents in opposite direction repel!

# Checkpoint 1



What is the direction of the force on wire 2 due to wire 1?

- A) Up B) Down C) Into Screen D) Out of screen E) Zero

**2 wires with same-direction currents are attracted**

What is the direction of the torque on wire 2 due to wire 1?

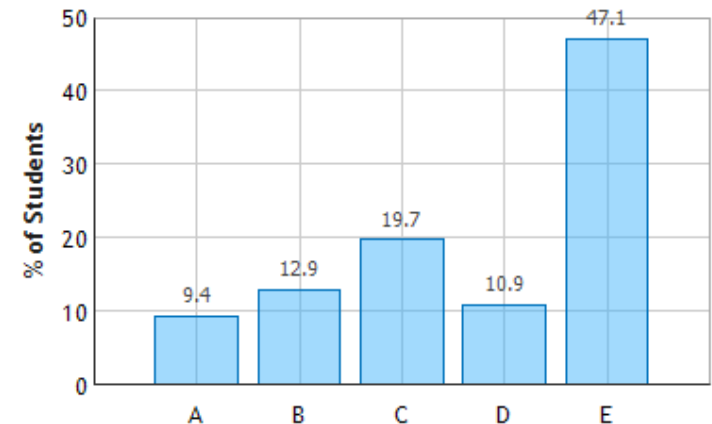
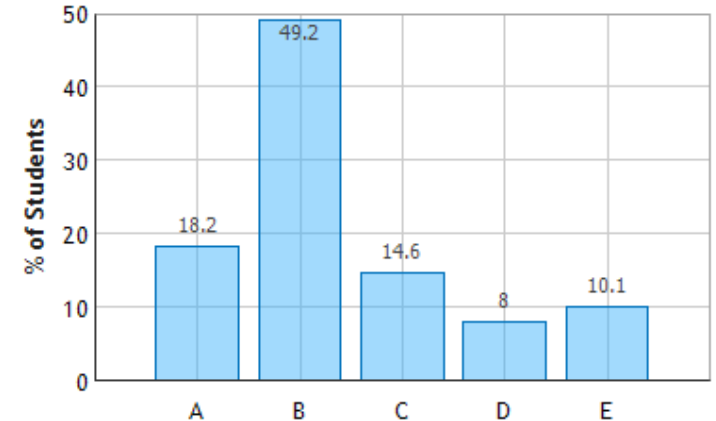
- A) Up B) Down C) Into Screen D) Out of screen E) Zero

Uniform force at every segment of wire

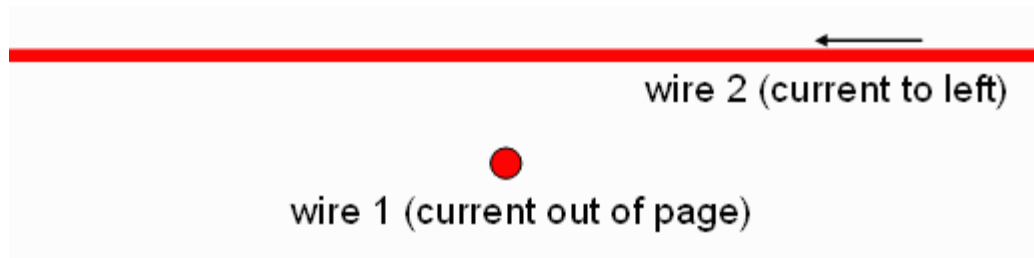


No torque about any axis

If two wires are carrying current, and we are asked to determine the direction of net torque on one wire (Checkpoint Question 1 Part 3), how do we determine the direction of the  $r$  vector?

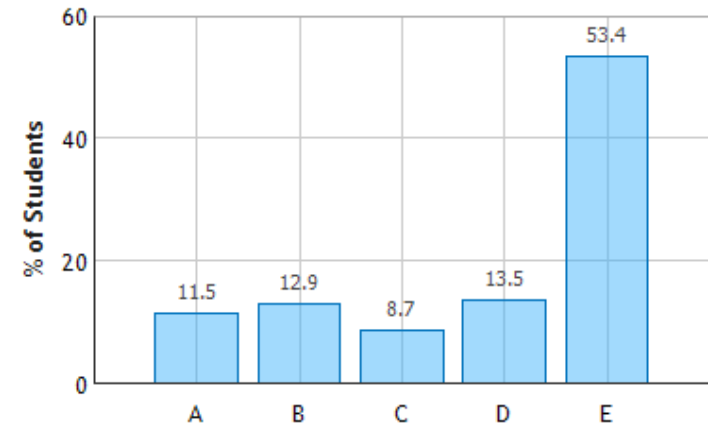


# Checkpoint 3



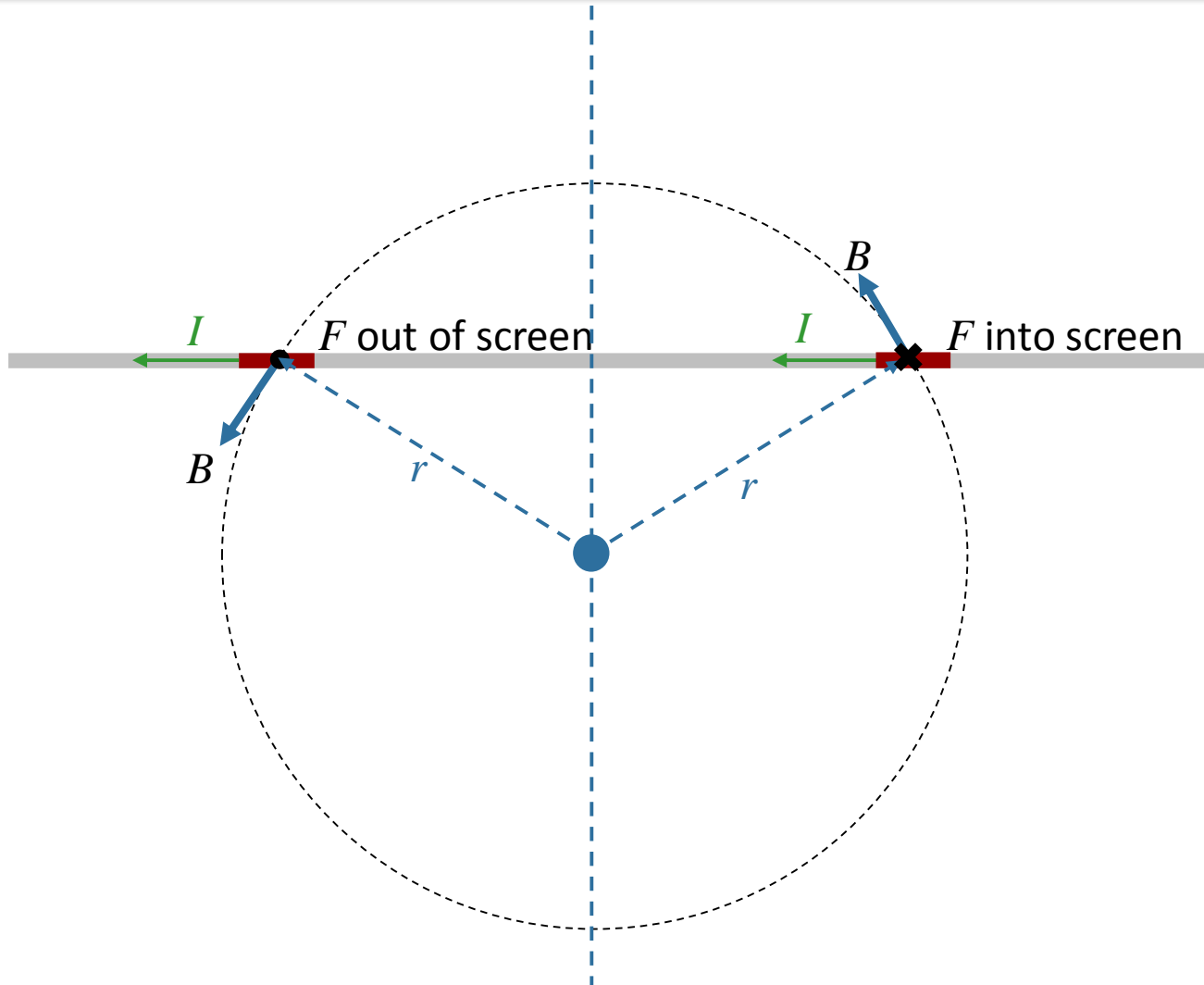
What is the direction of the force on **wire 2** due to **wire 1**?

- A) Up   B) Down   C) Into Screen   D) Out of screen   **E) Zero**



**WHY?**  
**DRAW PICTURE!**

# Consider Force on Symmetric Segments



Net Force is Zero!

# CheckPoint 3b



What is torque on wire 2, due to wire 1?

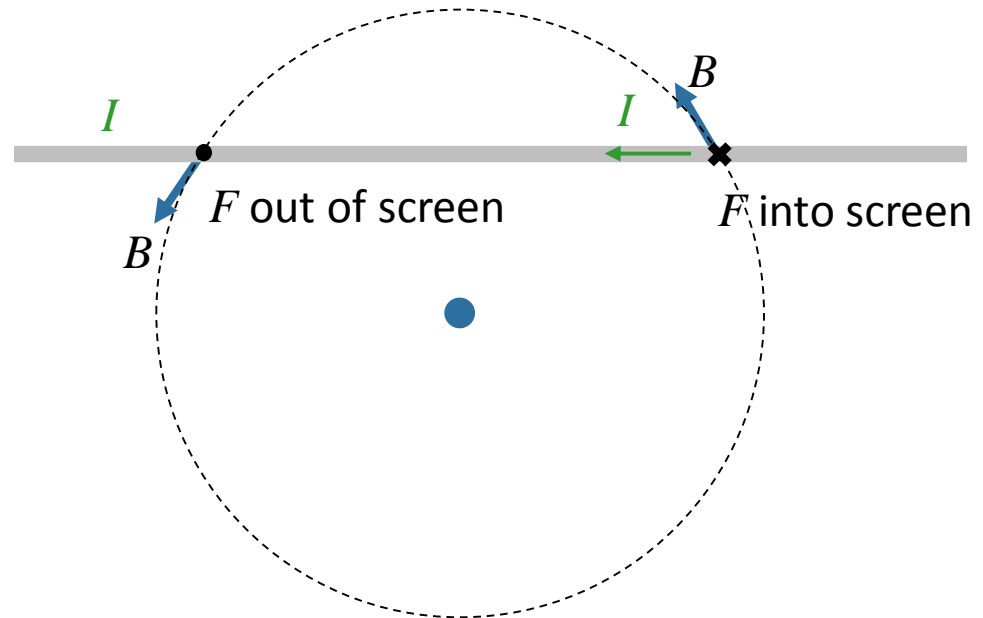
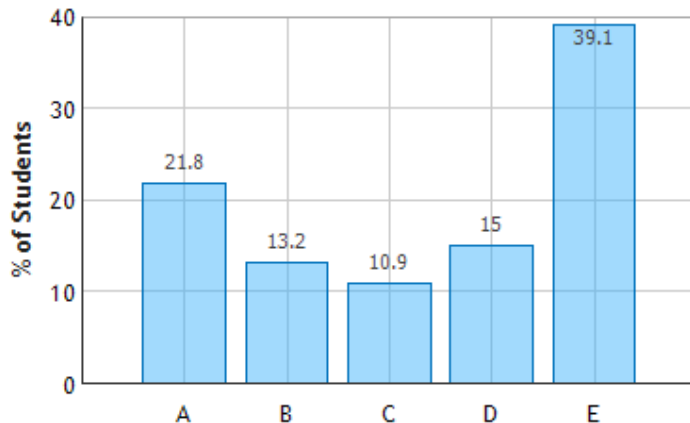


There is a net force on the right side pointing into the screen and a net force on the left side pointing out of the screen. Using the right hand rule, this means that the torque is pointing up.

**The wire will try to align with wire 1.**

- A) Up   B) Down   C) Into Screen   D) Out of screen   E) Zero

Forces and Torques on Current-Carrying Wires:  
Question 3 (N = 772)



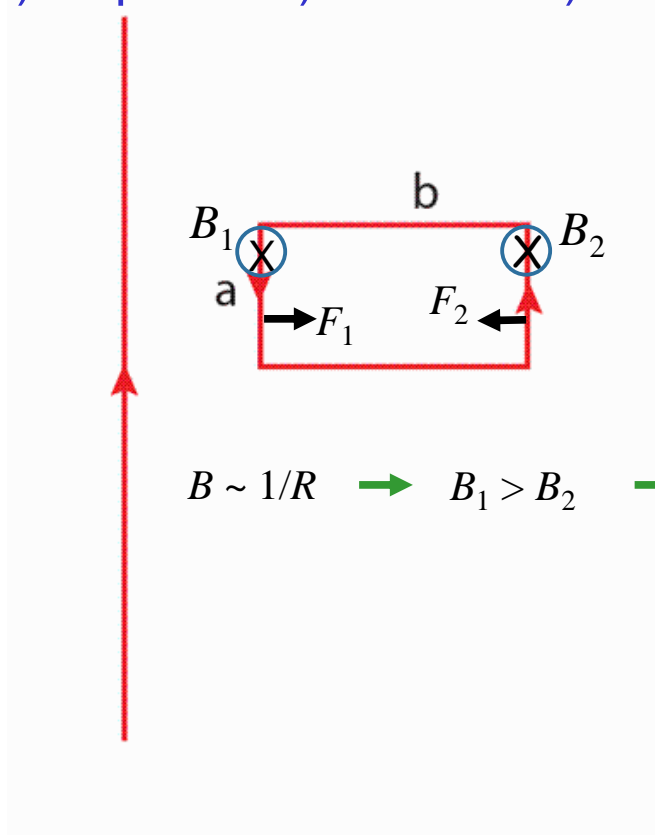
# Force on current loop near wire



A loop of wire with current flowing in a counterclockwise direction is located to the right of a long wire with current flowing up. As shown below.

What is the direction of the net force on the loop?

- A) Up    B) Down    C) Left    **D) Right**    E) Zero

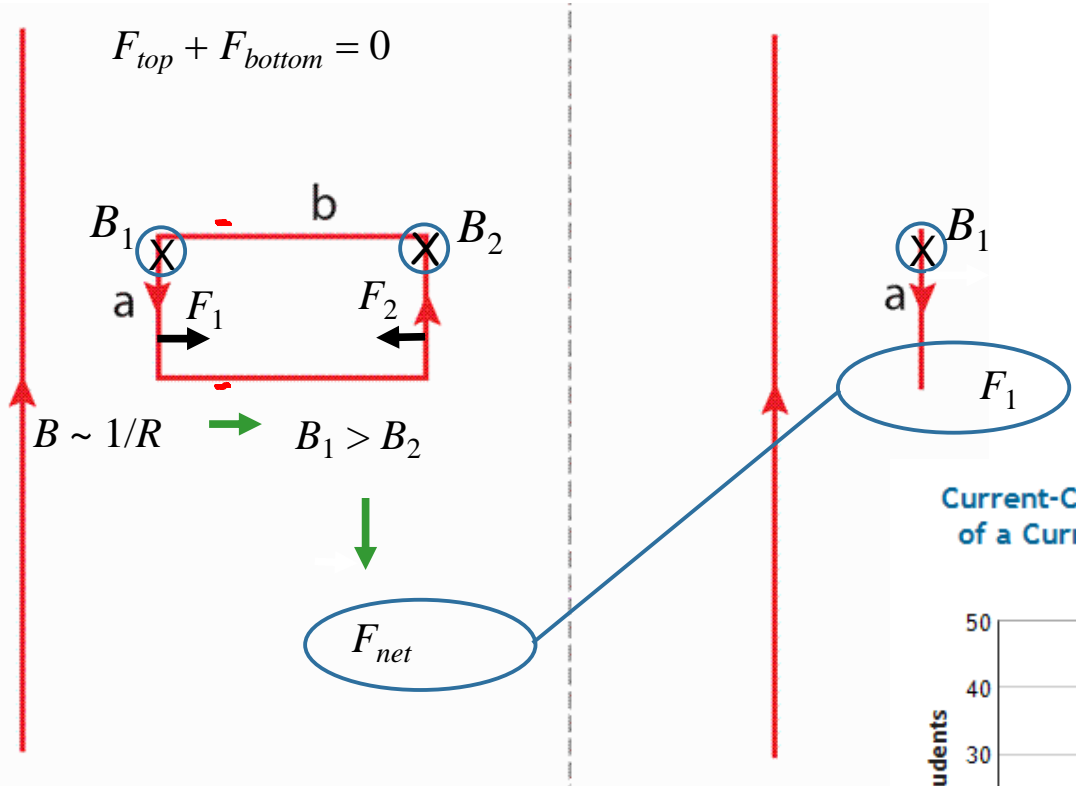


$$B \sim 1/R \quad \rightarrow \quad B_1 > B_2 \quad \rightarrow \quad F_1 > F_2$$

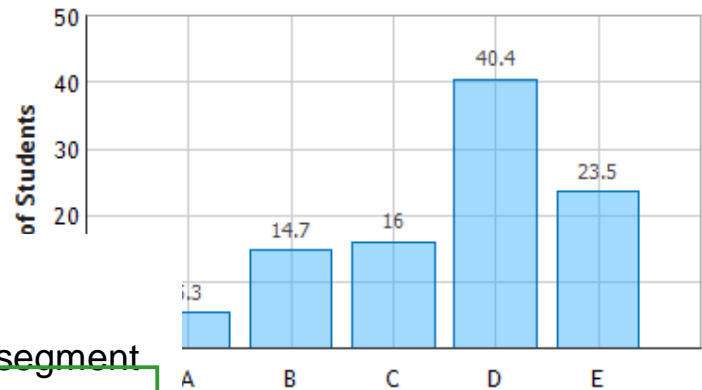
# Checkpoint 2



A current carrying loop of width  $a$  and length  $b$  is placed near a current carrying wire. How does the net force on the loop compare to the net force on a single wire segment of length  $a$  carrying the same amount of current placed at the same distance from the wire?

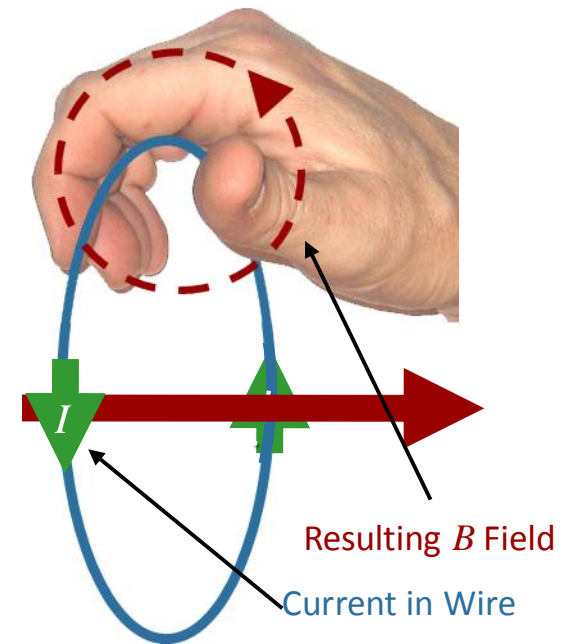
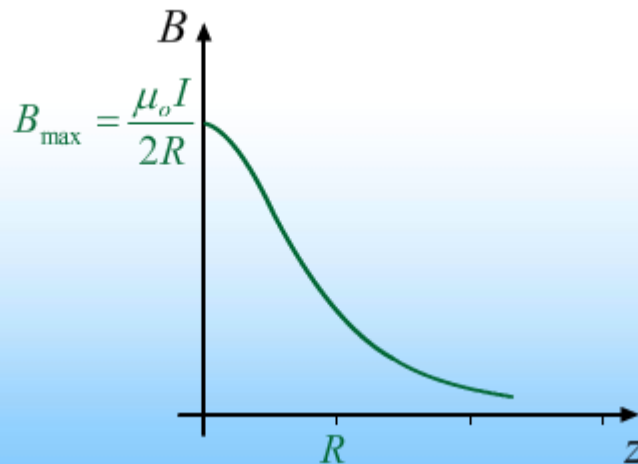
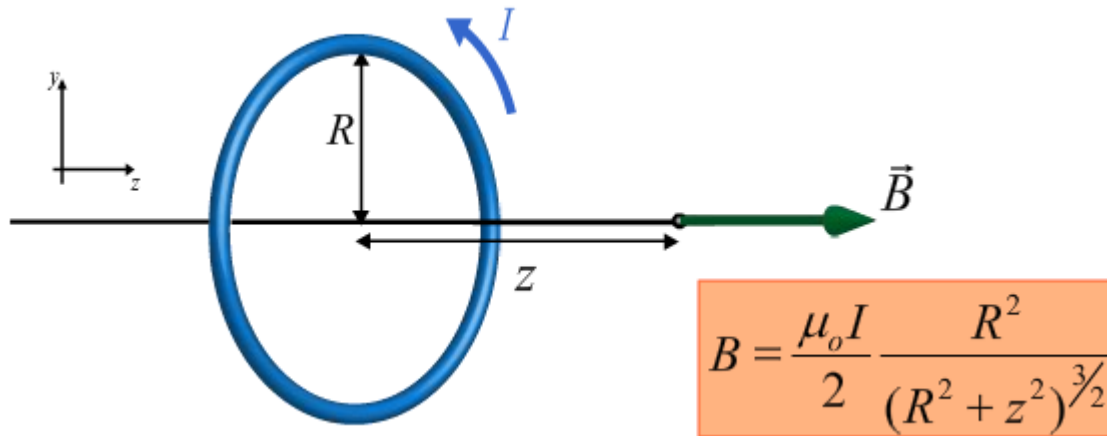


Current-Carrying Wires and Loops in the Field of a Current-Carrying Wire: Question 1 (N = 773)



- A. The forces are in opposite directions
- B. The net forces are the same
- C. The net force on the loop is greater than the net force on the wire segment
- D. The net force on the loop is smaller than the net force on the wire segment
- E. There is no net force on the loop

# B on axis from Current Loop



# Two Current Loops

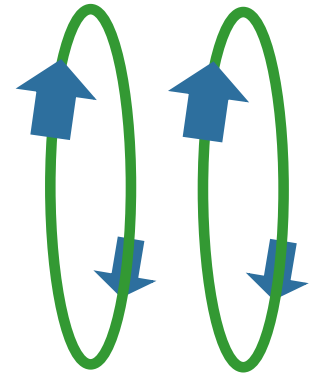


Two identical loops are hung next to each other. Current flows in the same direction in both.

The loops will:

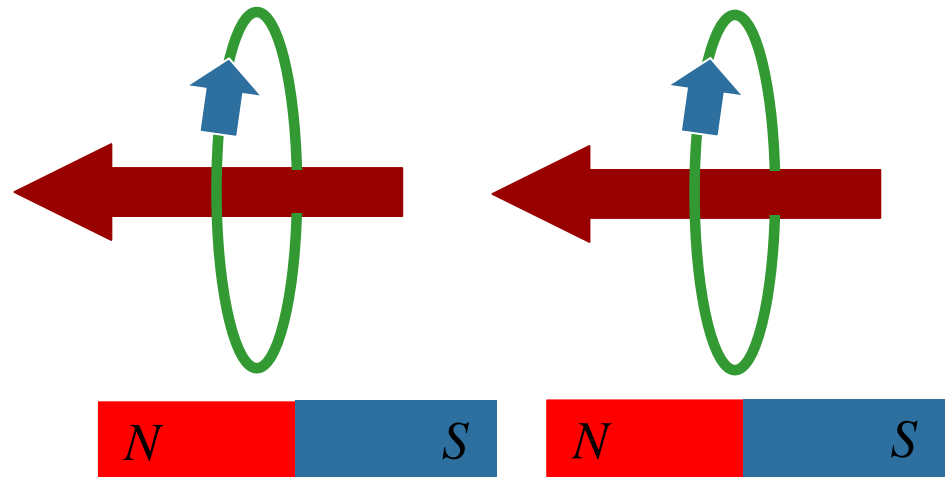
A) Attract each other

B) Repel each other



Two ways to see this:

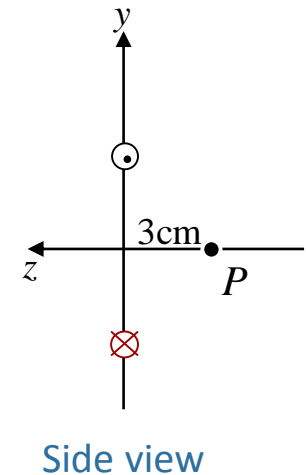
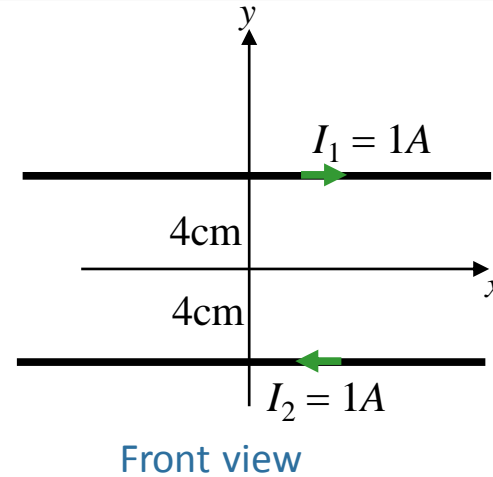
- 1) Like currents attract
- 2) Look like bar magnets



# Calculation

Two parallel horizontal wires are located in the vertical  $(x,y)$  plane as shown. Each wire carries a current of  $I = 1A$  flowing in the directions shown.

What is the  $B$  field at point  $P$ ?



## Conceptual Analysis

Each wire creates a magnetic field at  $P$

$$B \text{ from infinite wire: } B = \frac{\mu_0 I}{2\pi r}$$

Total magnetic field at  $P$  obtained from superposition

## Strategic Analysis

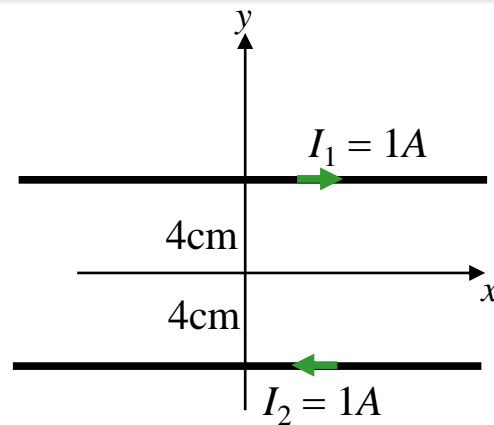
Calculate  $B$  at  $P$  from each wire separately

Total  $B$  = vector sum of individual  $B$  fields

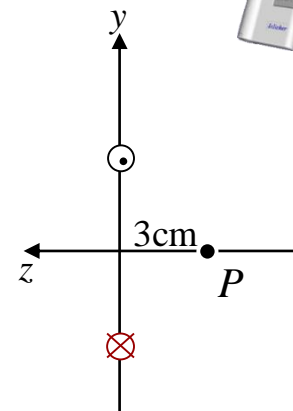
# Calculation



Two parallel horizontal wires are located in the vertical  $(x,y)$  plane as shown. Each wire carries a current of  $I = 1A$  flowing in the directions shown.



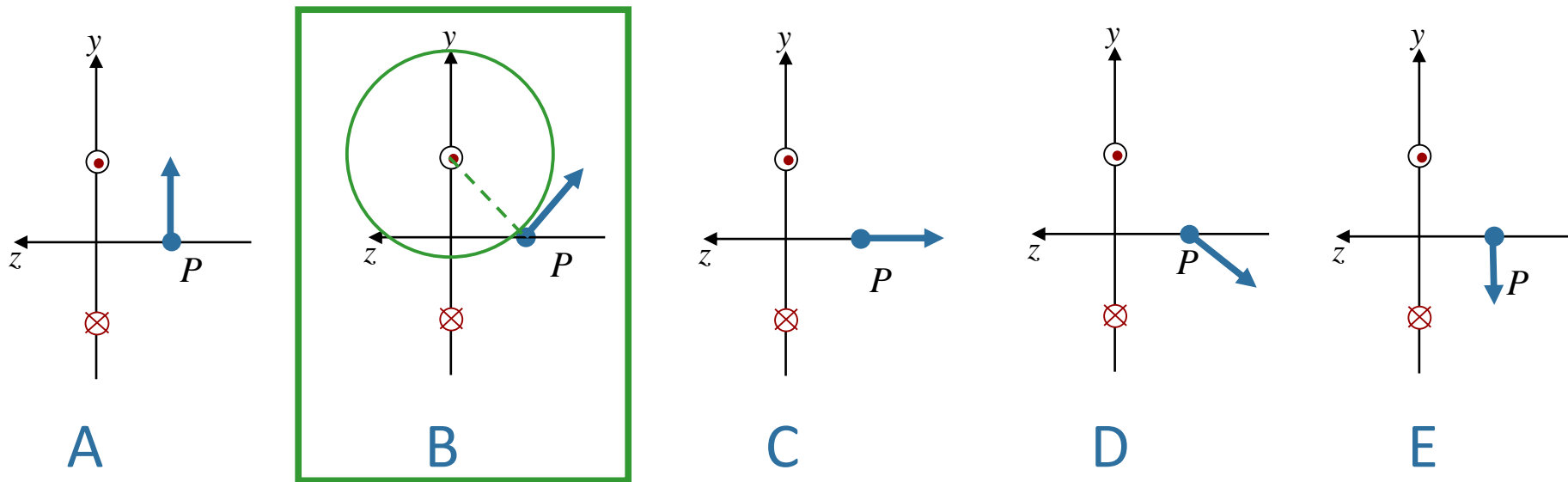
Front view



Side view

What is the  $B$  field at point  $P$ ?

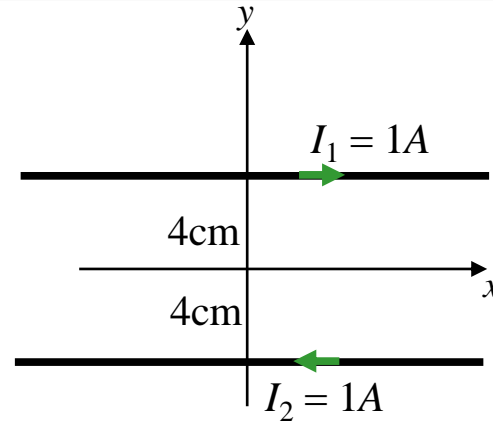
What is the direction of  $B$  at  $P$  produced by the top current  $I_1$ ?



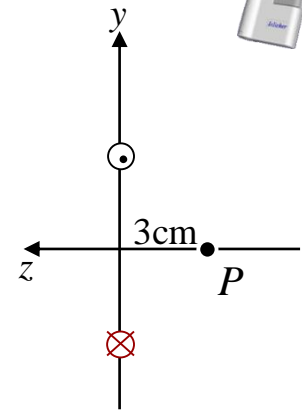
# Calculation



Two parallel horizontal wires are located in the vertical  $(x,y)$  plane as shown. Each wire carries a current of  $I = 1A$  flowing in the directions shown.



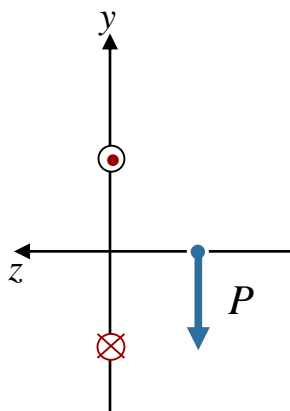
Front view



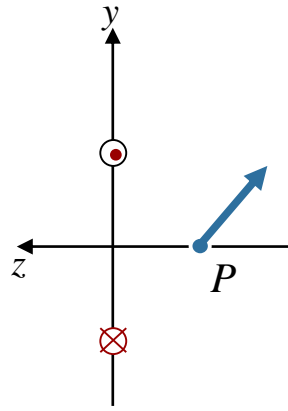
Side view

What is the  $B$  field at point  $P$ ?

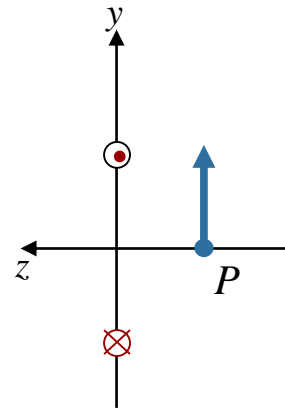
What is the direction of  $B$  at  $P$  produced by the bottom current  $I_2$ ?



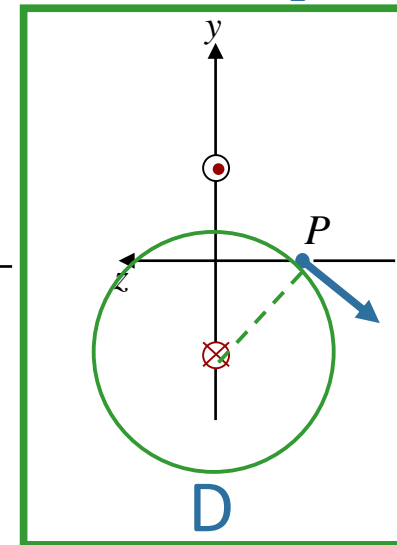
A



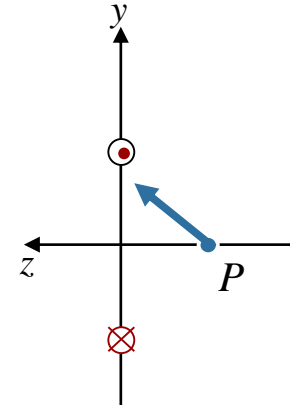
B



C



D

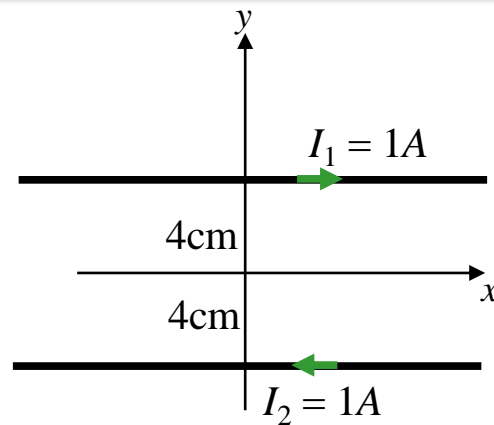


E

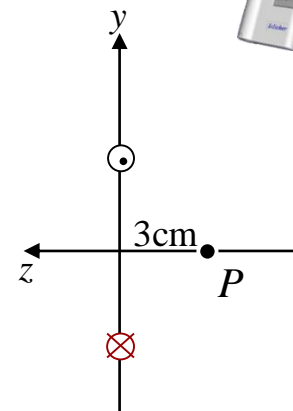
# Calculation



Two parallel horizontal wires are located in the vertical  $(x,y)$  plane as shown. Each wire carries a current of  $I = 1A$  flowing in the directions shown.



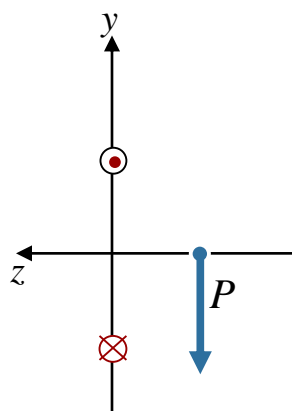
Front view



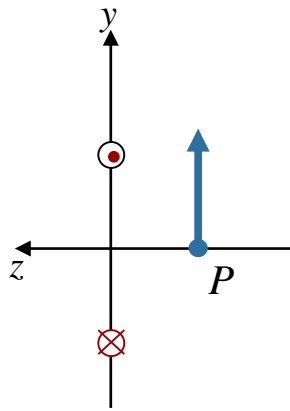
Side view

What is the  $B$  field at point  $P$ ?

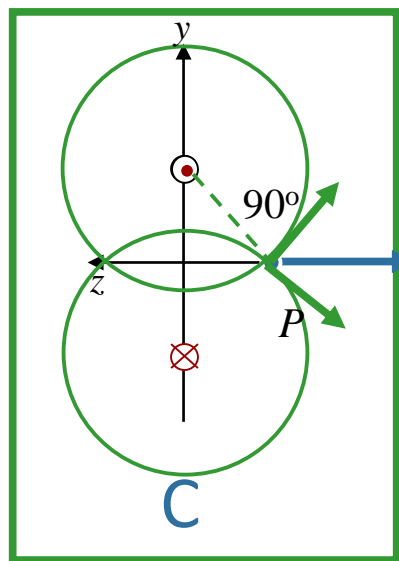
What is the direction of  $B$  at  $P$ ?



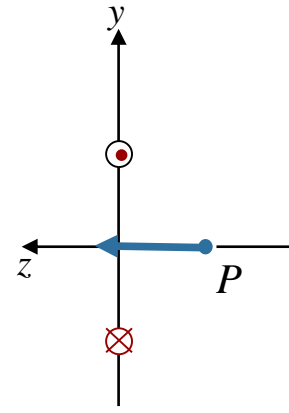
A



B



C

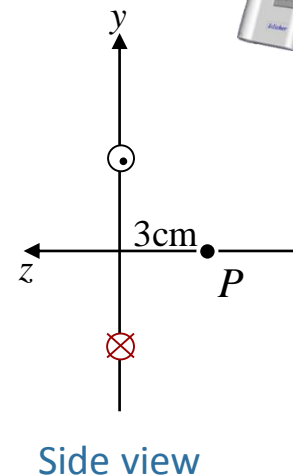
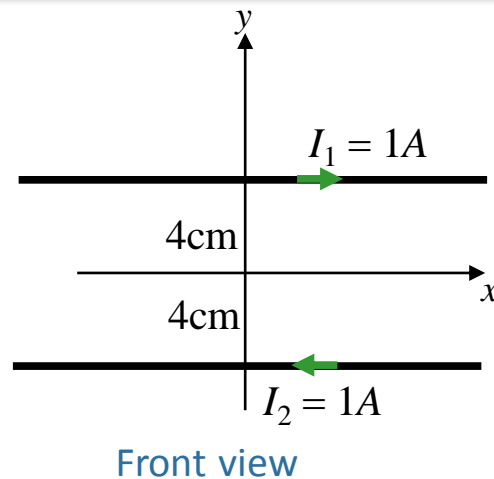


D

# Calculation



Two parallel horizontal wires are located in the vertical  $(x,y)$  plane as shown. Each wire carries a current of  $I = 1A$  flowing in the directions shown.



What is the  $B$  field at point  $P$ ?

$$B = \frac{\mu_0 I}{2\pi r}$$

What is the magnitude of  $B$  at  $P$  produced by the top current  $I_1$ ?

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

**A)  $4.0 \times 10^{-6} \text{ T}$**

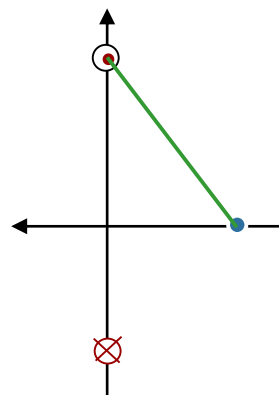
B)  $5.0 \times 10^{-6} \text{ T}$

C)  $6.7 \times 10^{-6} \text{ T}$

What is  $r$ ?

$r$  = distance from wire axis to  $P$

$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}) \times 1}{2\pi r} = 40 \times 10^{-7}$$

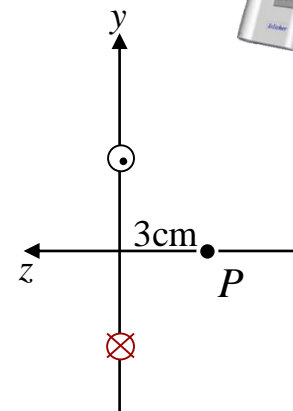
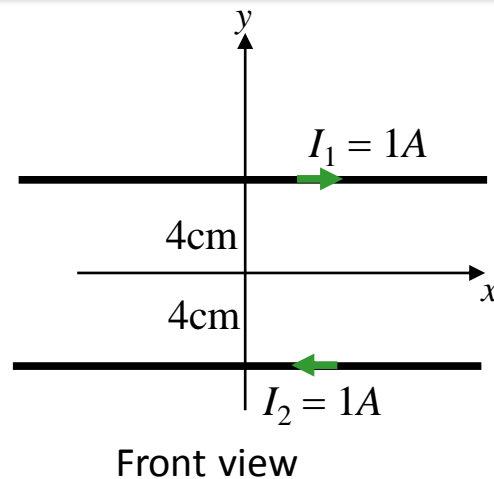


$$r = \sqrt{3^2 + 4^2} = 5 \text{ cm}$$

# Calculation



Two parallel horizontal wires are located in the vertical  $(x,y)$  plane as shown. Each wire carries a current of  $I = 1A$  flowing in the directions shown.



What is the  $B$  field at point  $P$ ?

$$B_{top} = 4 \times 10^{-6} T$$

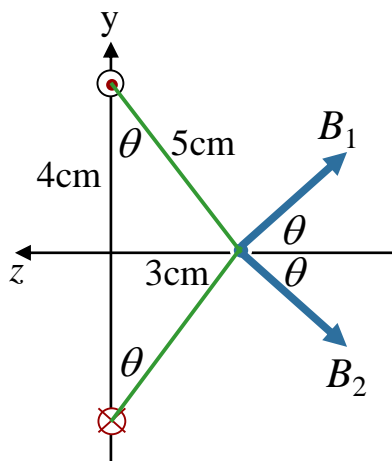
What is the magnitude of  $B$  at  $P$ ? ( $\mu_0 = 4\pi \times 10^{-7} T - m/A$ )

A)  $3.2 \times 10^{-6} T$

B)  $4.8 \times 10^{-6} T$

C)  $6.4 \times 10^{-6} T$

D)  $8.0 \times 10^{-6} T$



$$B_{1x} = B_1 \cos \theta$$

$$B_{2x} = B_2 \cos \theta$$

$$\rightarrow B_x = 2B_1 \cos \theta = 2 \times 4 \times 10^{-6} \times \left(\frac{4}{5}\right) = 6.4 \times 10^{-6}$$