LAB 6 now after spring break!

Physics 212
Lecture 15

Tim Stelzer's office hour 4:00 March 10th is moved to 4:00 March 12th

Today's Concept:

Ampere's Law

$$\oint \vec{B} \bullet d\vec{\ell} = \mu_o I_{enclosed}$$

Your Comments

Hmm, not so bad. That's what I said about Gauss though too. Really, the concepts are not hard, I just needed more practice. Maybe seeing the concept applied again to this context will help me do better with both Gauss and Ampere.

THANK YOU FOR PUTTING "SORRY PROF, I DIDN'T THINK ABOUT THIS" AS AN OPTION.

Why does this class and 211 have office hours on only two days out of seven?

Ampere meets Coulumb at a cafe. Coulumb decides to call over his family. Ampere runs away, since he can only manage one Coulumb per second.

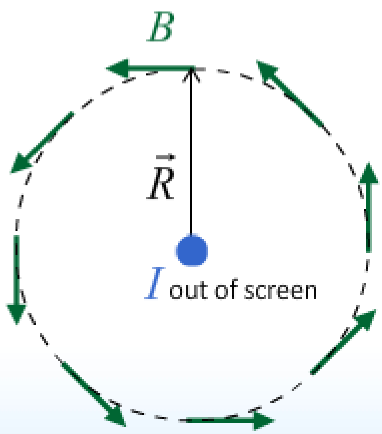
When the wire is wrapped around a tube, why is there B in the tube? Isn't it that the I enc is 0?

All hail the mighty space lizard of physics!!!

Methinks that Mr. Ampere copied Mr. Gauss.... I don't see any works cited

Ampere's Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_o I$$



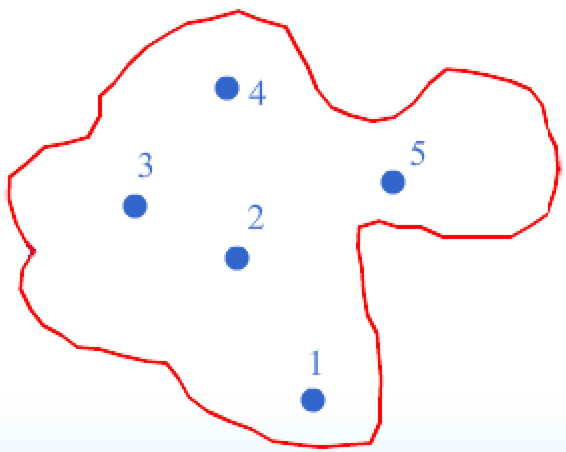
Infinite current-carrying wire

LHS: $\oint \vec{B} \bullet d\vec{\ell} = \oint B d\ell = B \oint d\ell = B \cdot 2\pi R$

RHS: $I_{enclosed} = I$

$$\longrightarrow B = \frac{\mu_o I}{2\pi R}$$

General Case



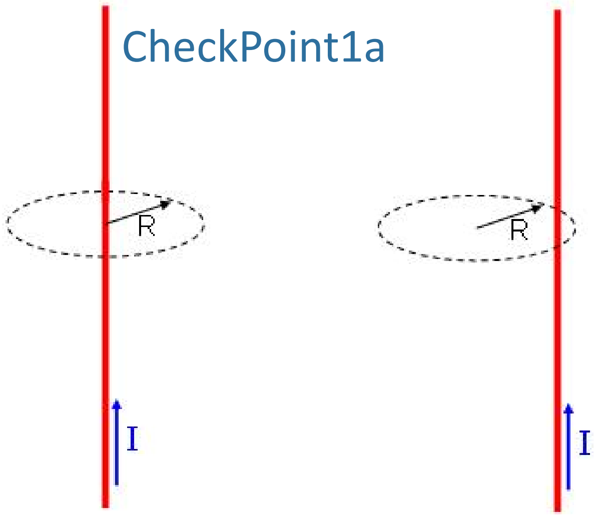
Ampere's Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_o I_{enclosed}$$

Practice on Enclosed Currents

$$\oint \vec{B}\cdot d\vec{l} = \mu_o I_{enclosed}$$

CheckPoint1a

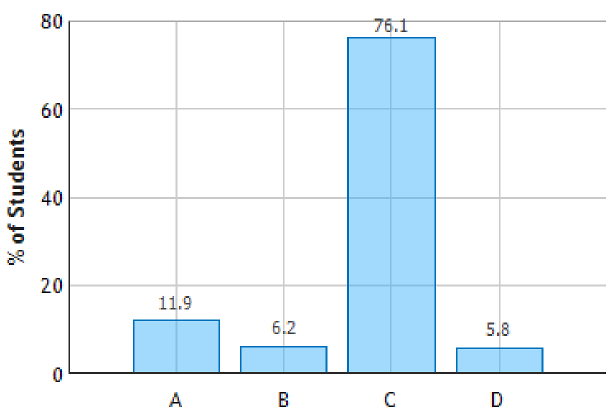


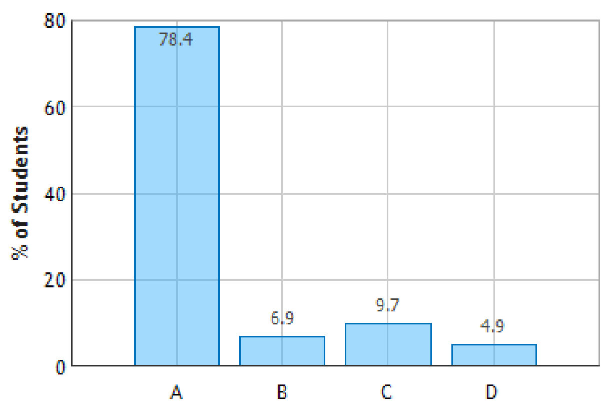
Case 1 $I_{enclosed} = I$

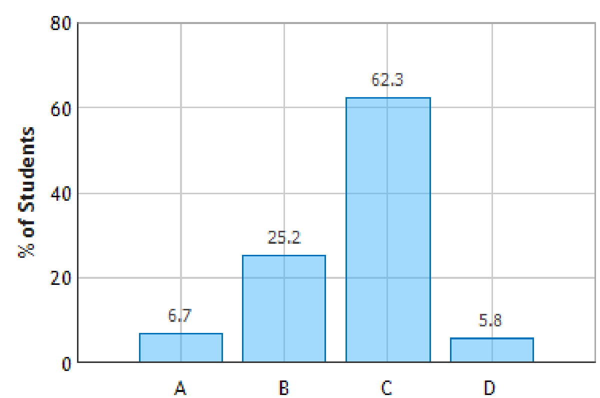
Case 2 $I_{enclosed} = I$

For which loop is ∫**B**·d**l** the greatest?

A. Case 1 ***B.*** Case 2 $\boxed{\textbf{\textit{C.}}\text{ Same}}$

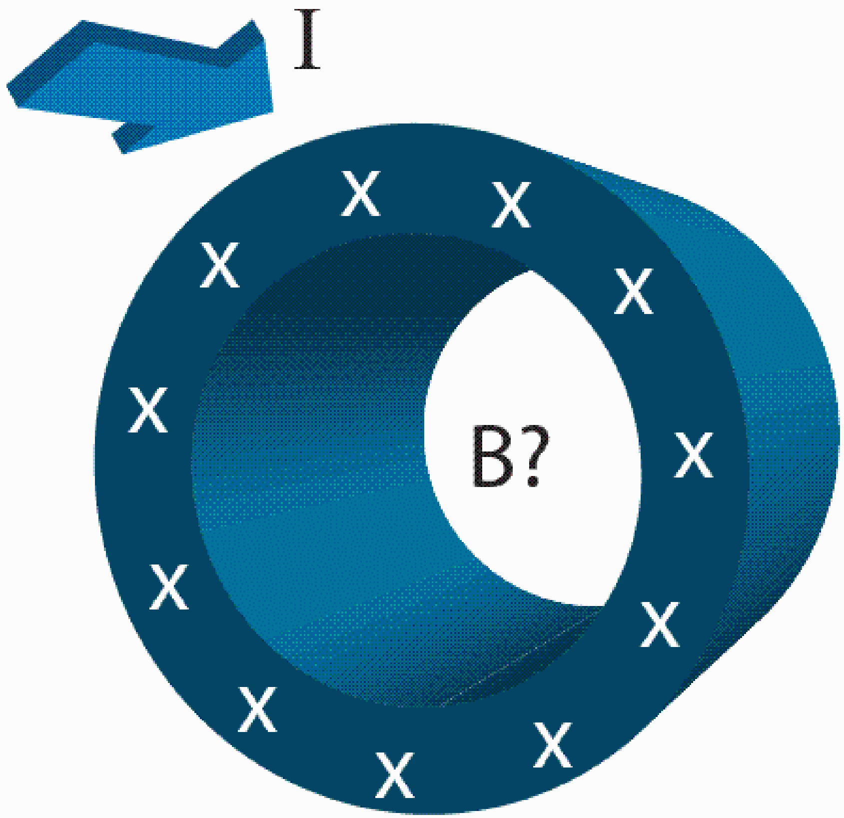






CheckPoint 2a

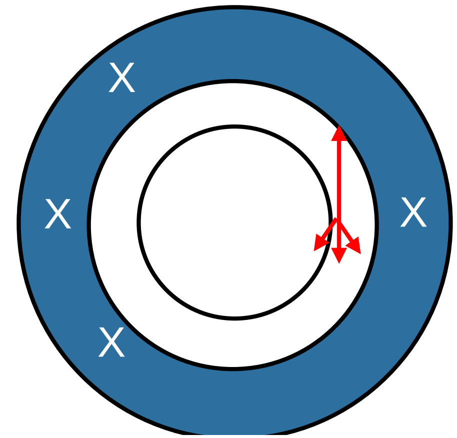
An infinitely long hollow conducting tube carries current I in the direction shown.



What is the direction of the magnetic field inside the tube?

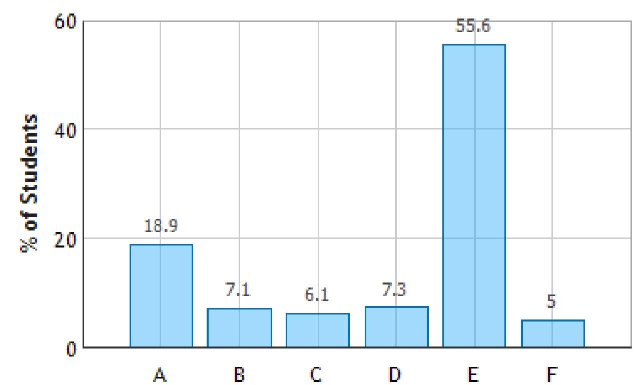
A. clockwise
B. counterclockwise
C. radially inward to the center
D. radially outward from the center
E. the magnetic field is zero

Cylindrical Symmetry



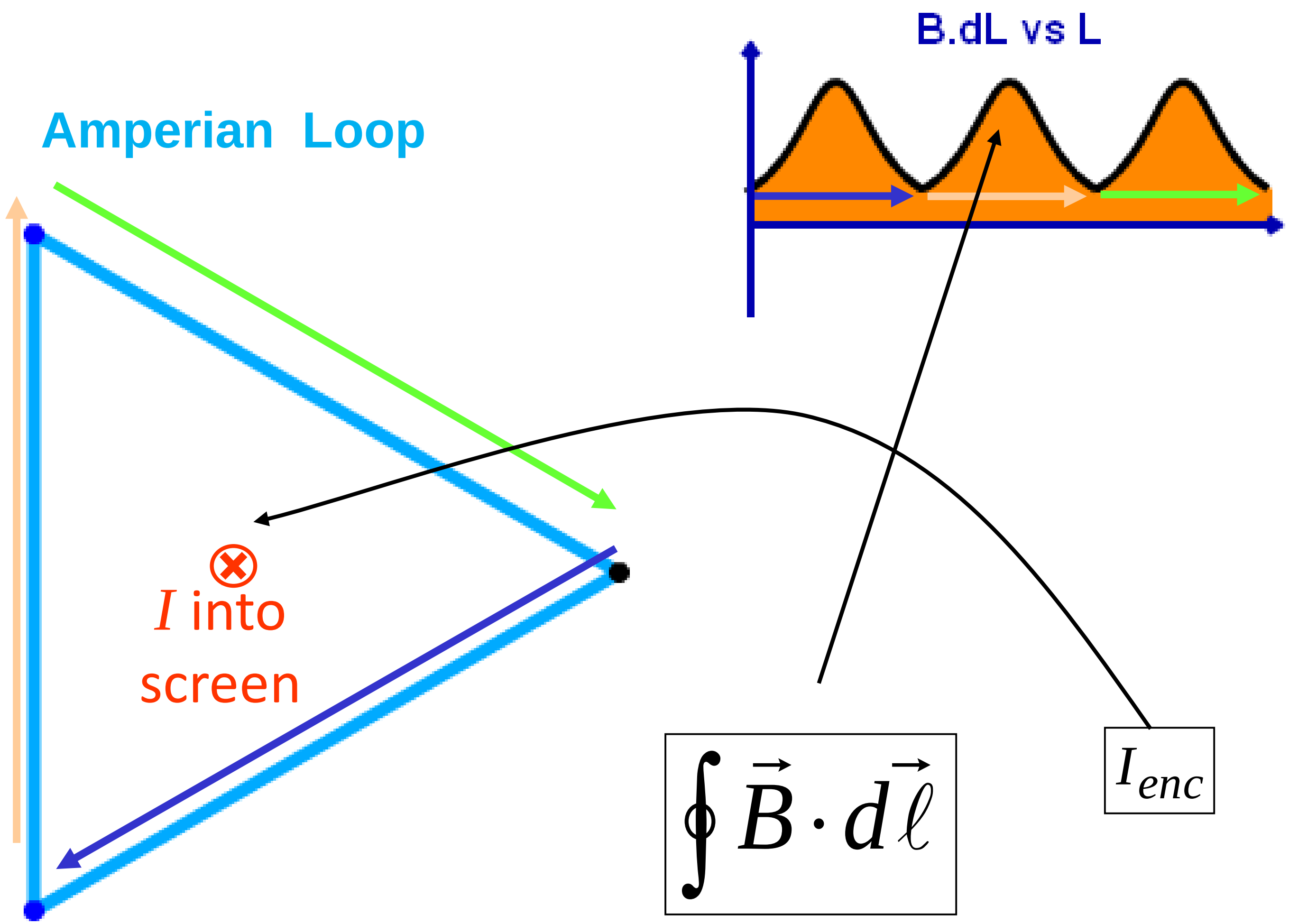
Enclosed Current = 0

Check cancellations



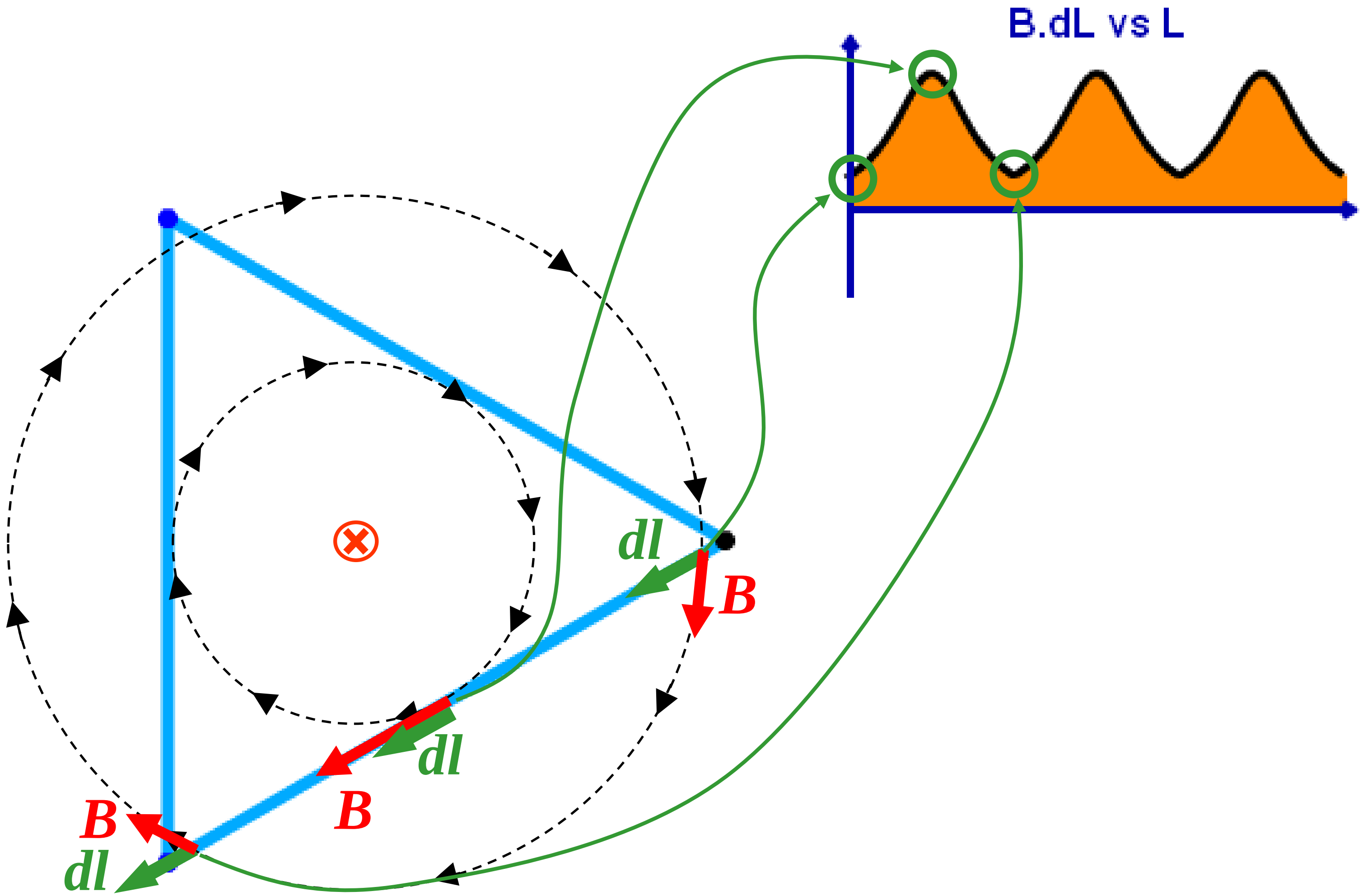
Ampere's Law

+integrals + magnetic field directinos



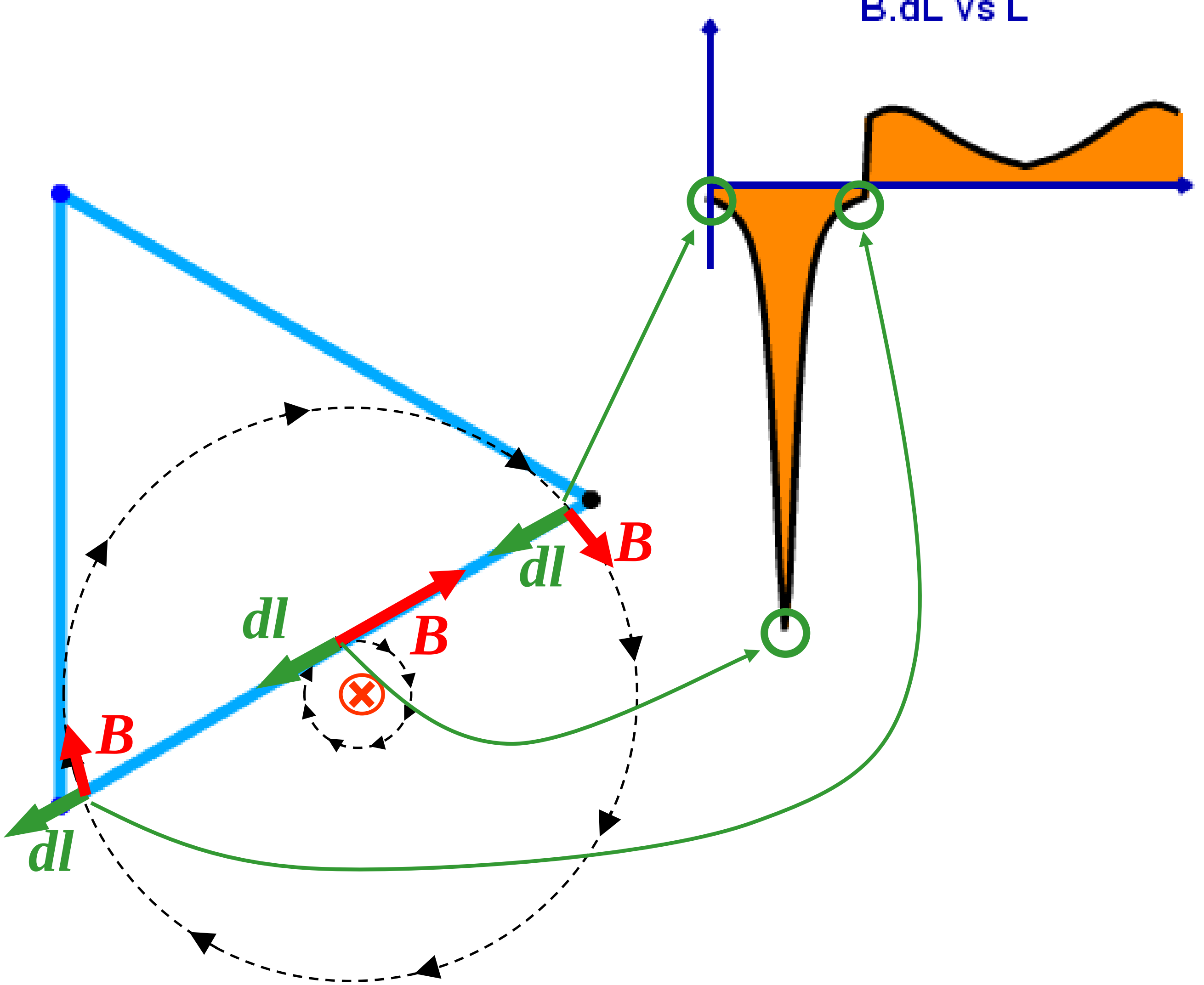
Ampere's Law

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{enc}$$



Ampere's Law

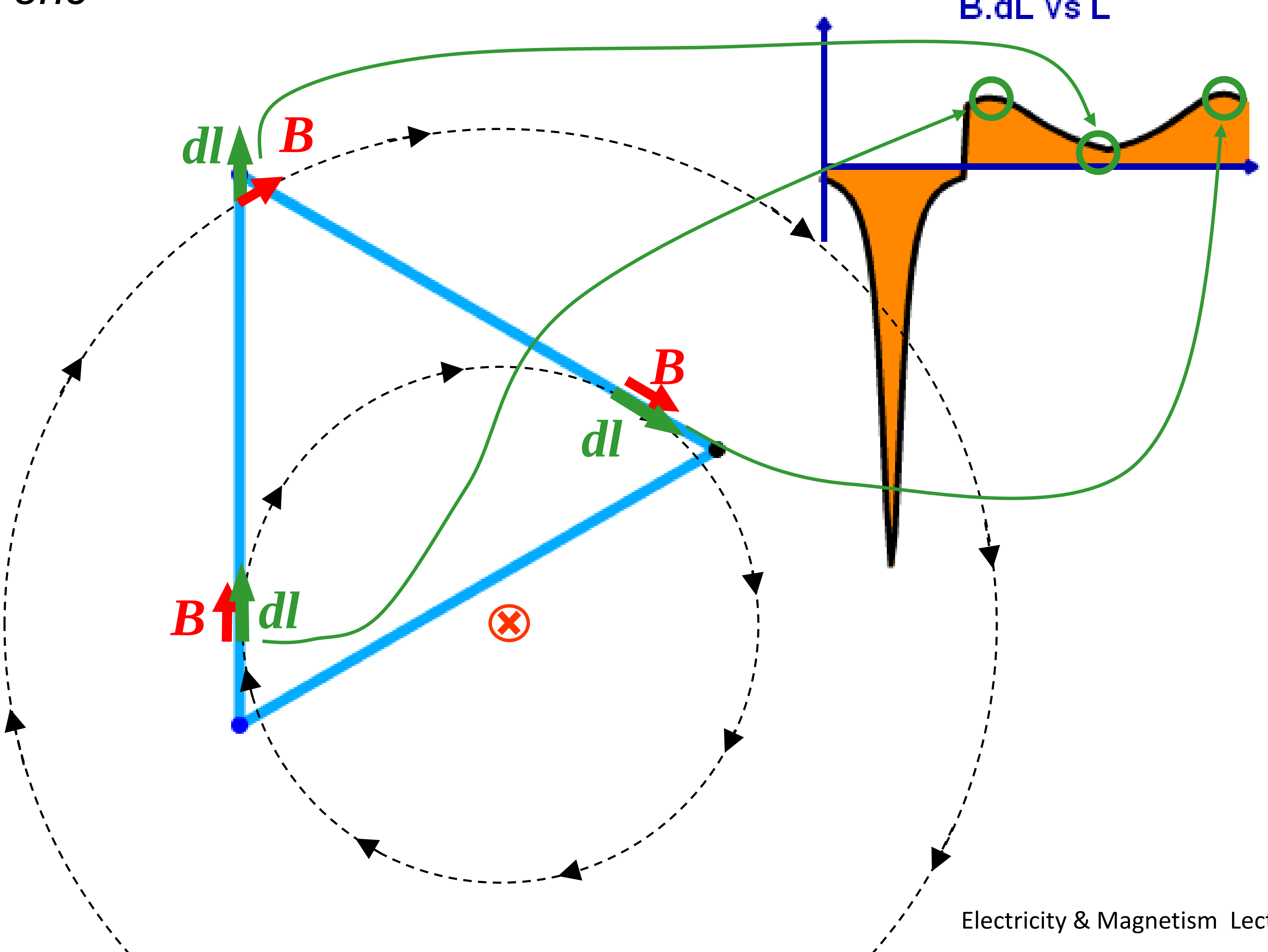
$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{enc}$$



Ampere's Law

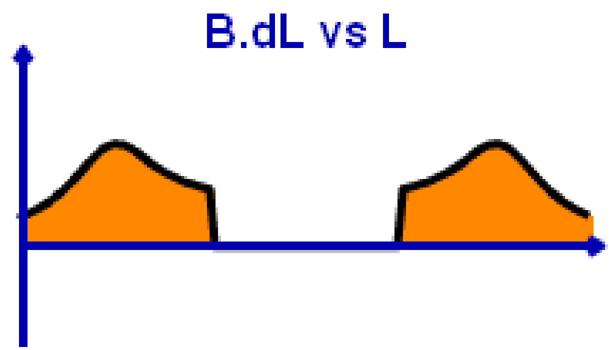
$$I_{enc} = 0!$$

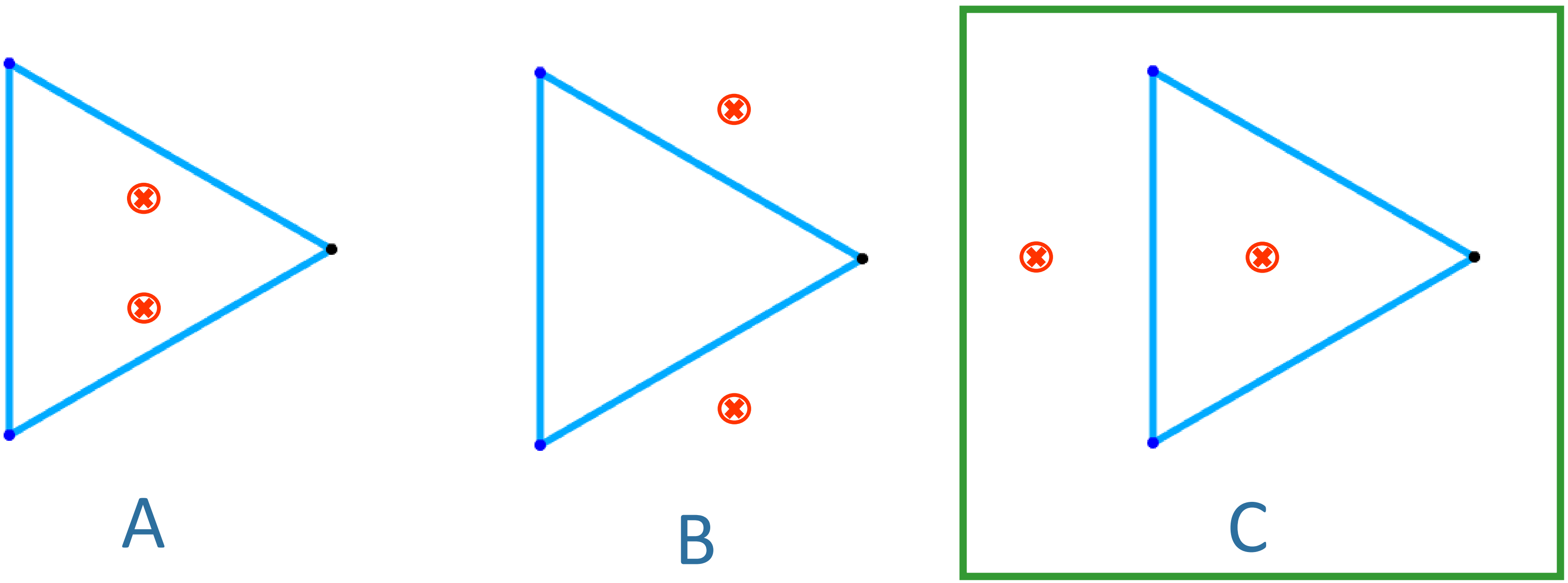
$$\oint \vec{B} \cdot d\vec{\ell} = \mu_o I_{enc}$$



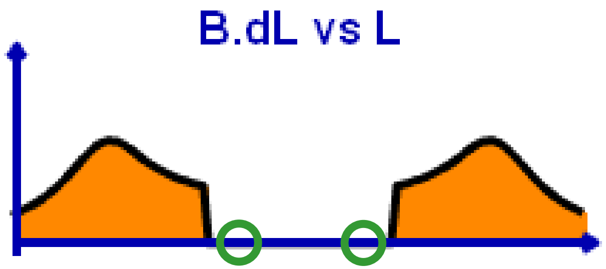
Ampere’s Law Clicker Question

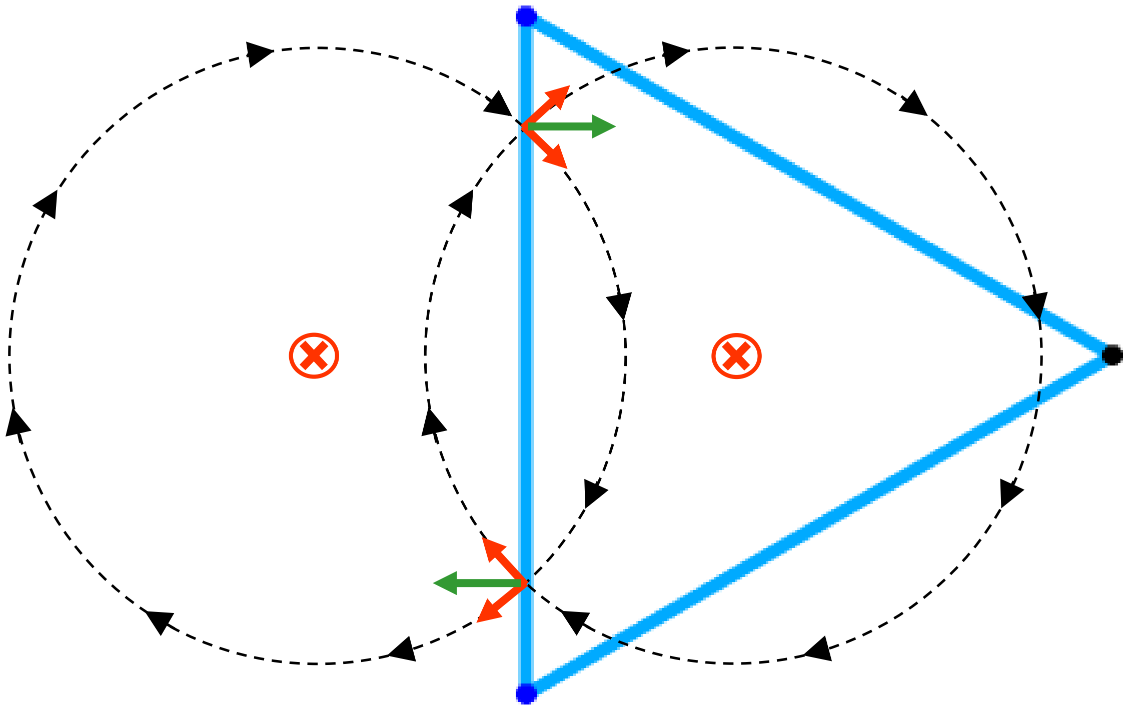
Which of the following current distributions would give rise to the $B \cdot dL$ distribution at the right?



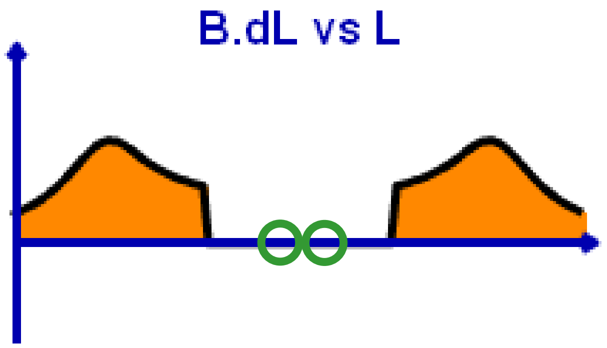


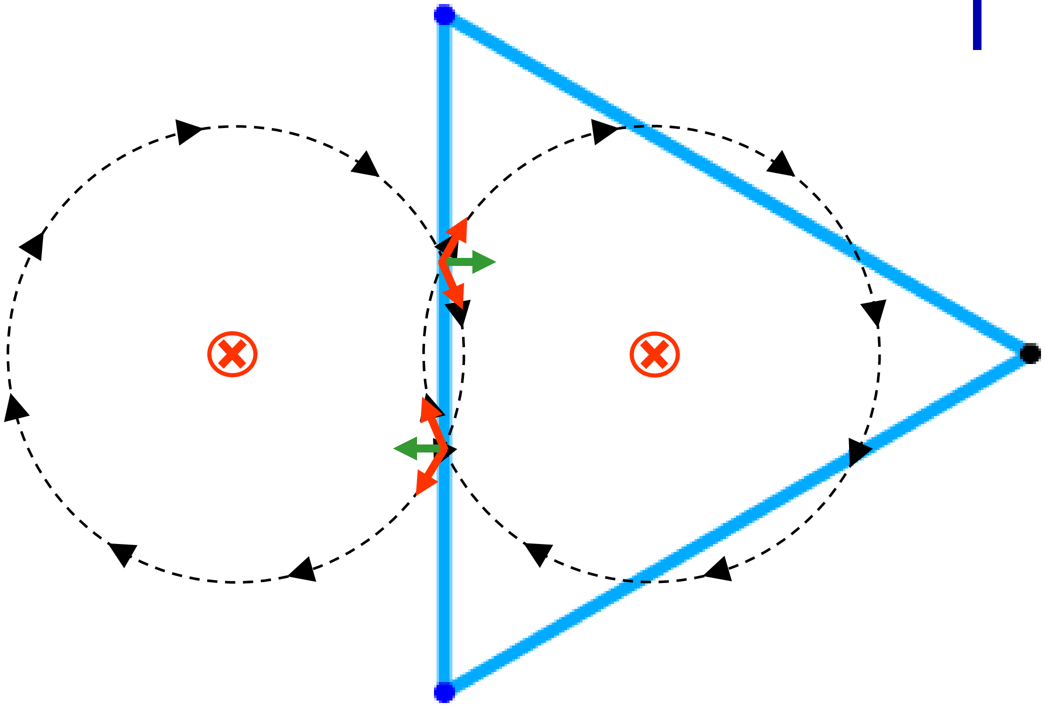
Ampere’s Law Clicker Question



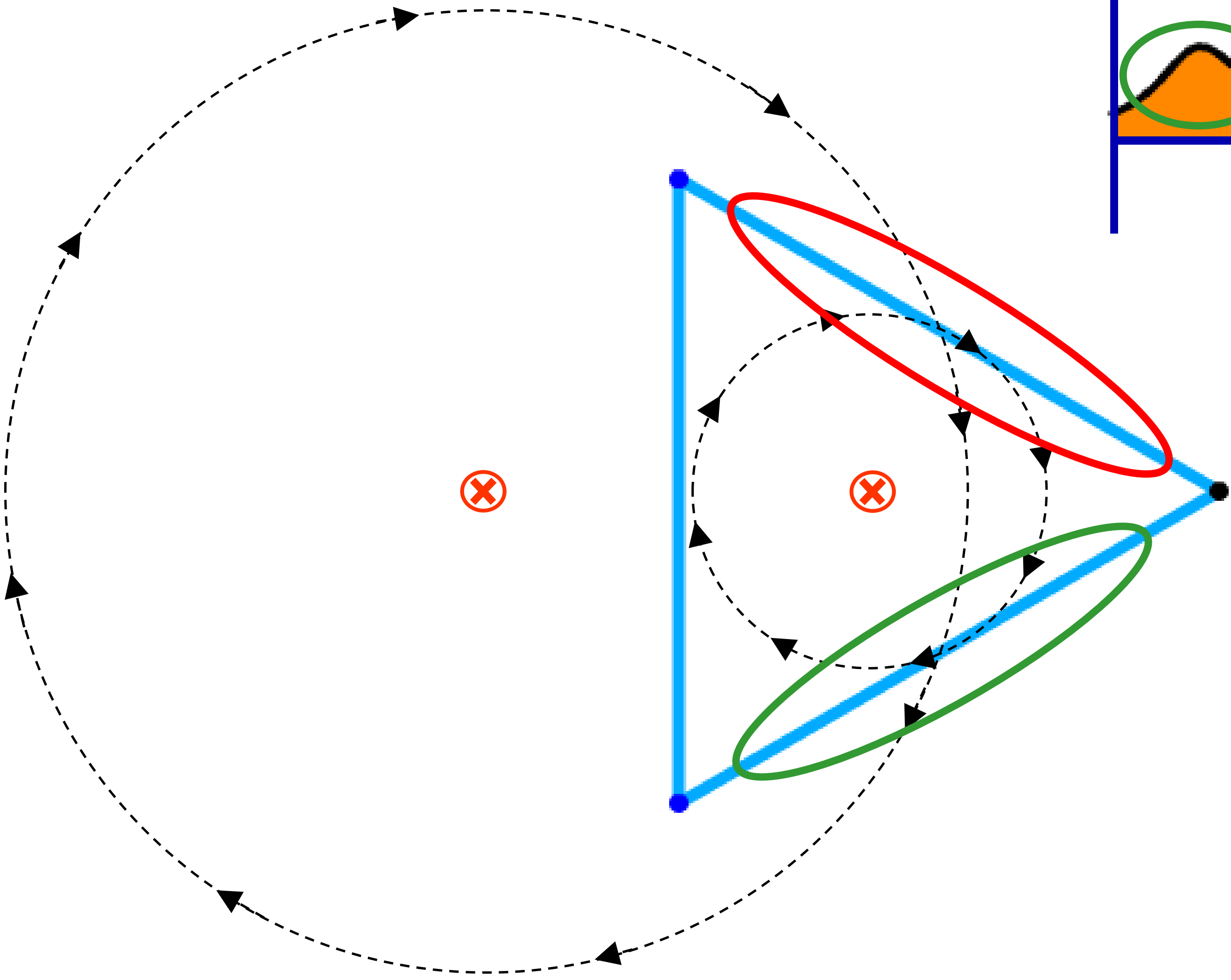


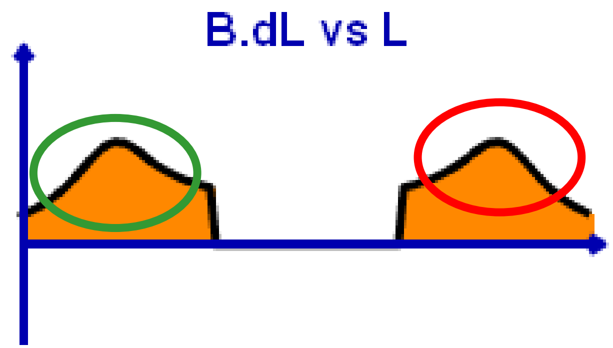
Ampere's Law Clicker Question



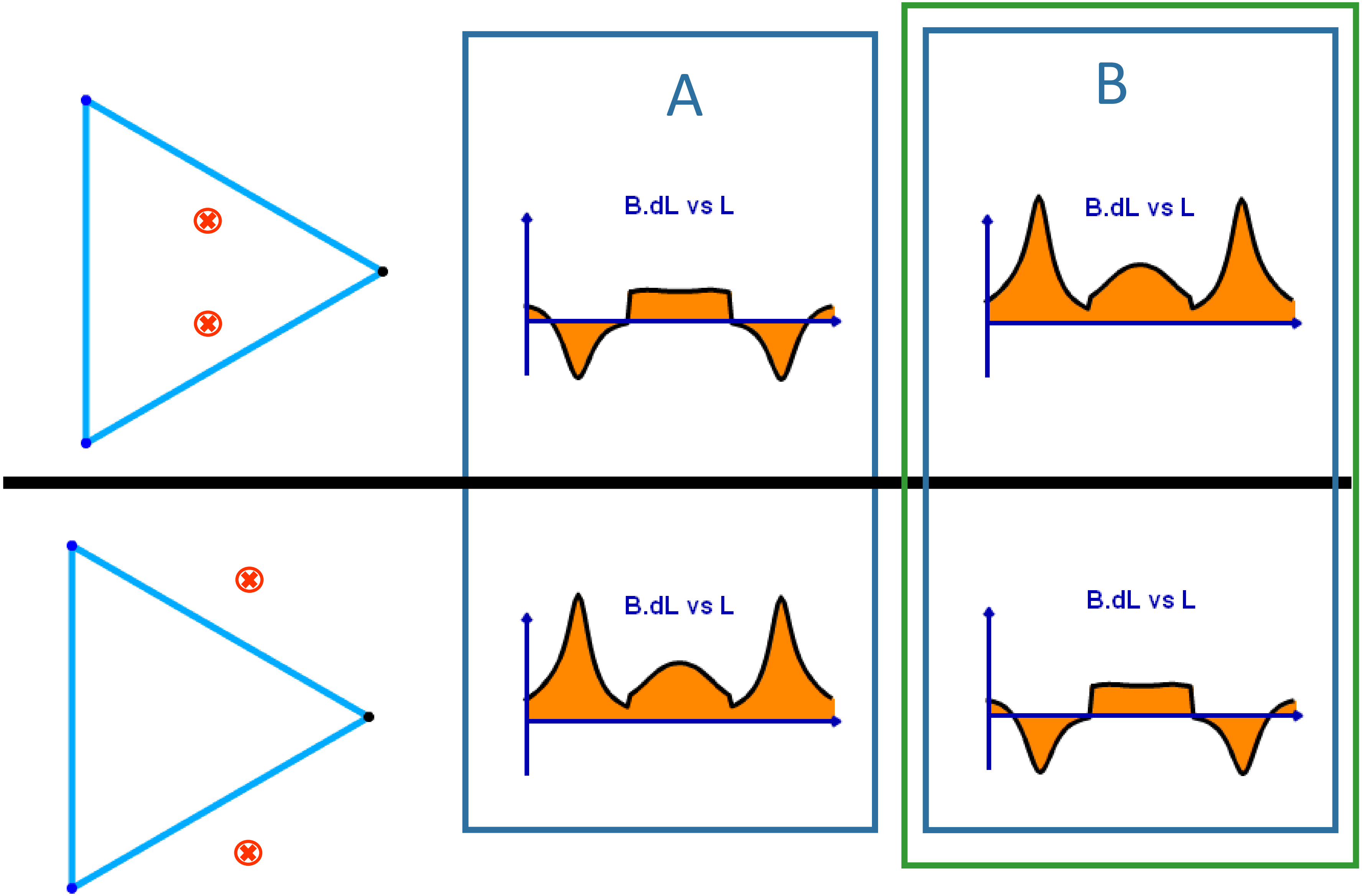


Ampere's Law Clicker Question



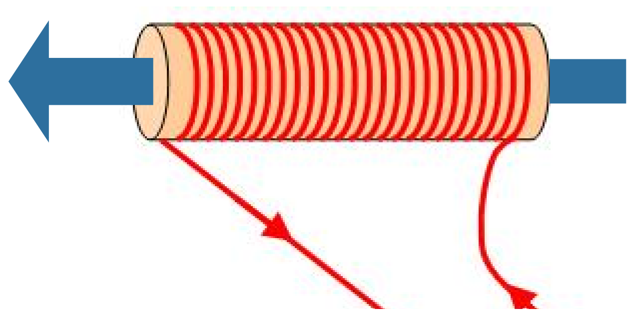


Match the other two:



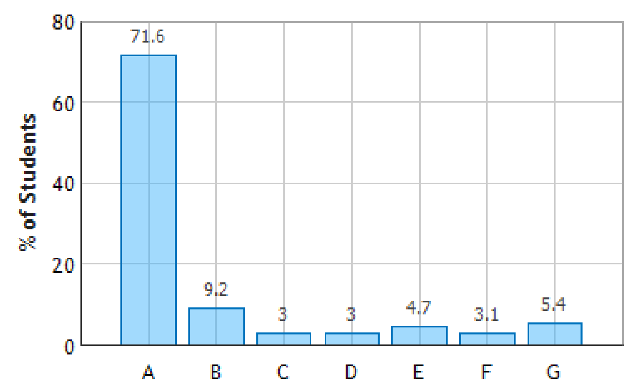
CheckPoint 2b

A current carrying wire is wrapped around cardboard tube as shown below.



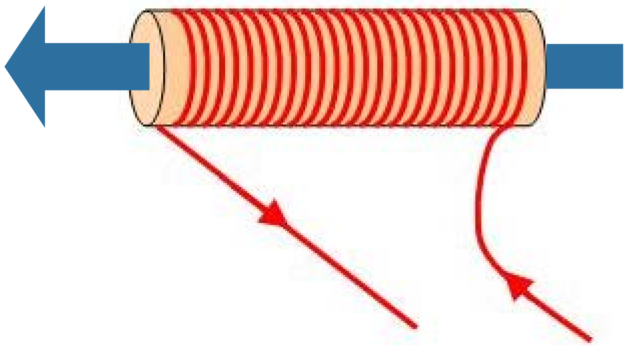
In which direction does the magnetic field point inside the tube?

A. Left **B.** Right **C.** Up **D.** Down **E.** Out of screen

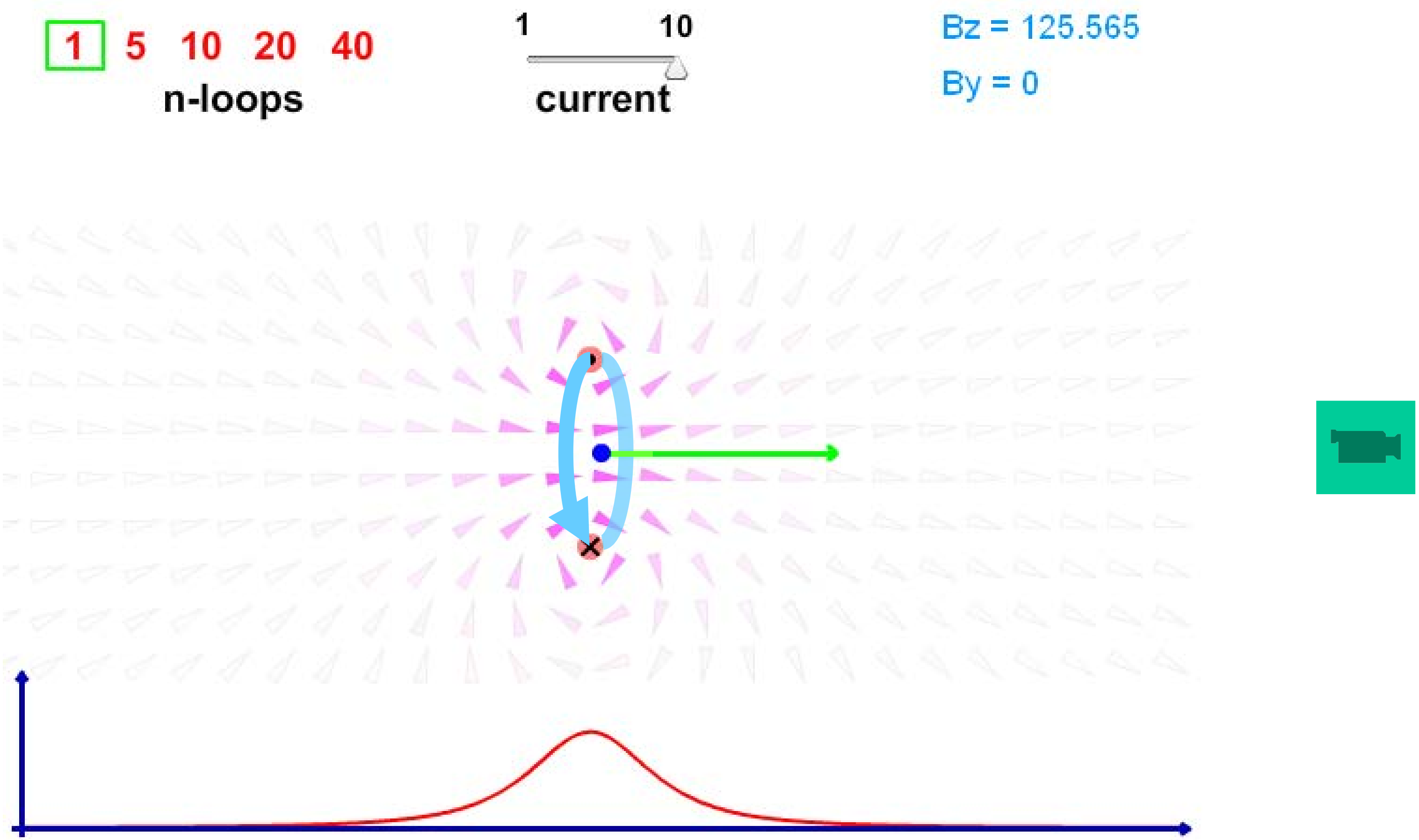


Use the right hand rule and curl your fingers along the direction of the current.

"When the wire is wrapped around a tube, why is there B in the tube? Isn't it that the I enc is 0?"

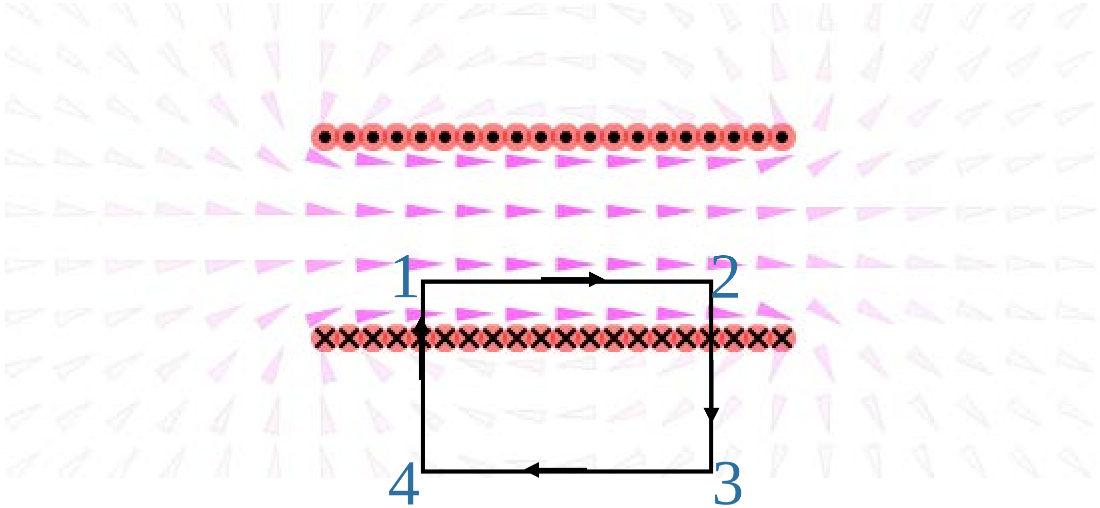


Simulation



Solenoid

Several loops packed tightly together form a uniform magnetic field inside, and nearly zero magnetic field outside.



From this simulation, we can assume a constant field inside the solenoid and zero field outside the solenoid, and apply Ampere's law to find the magnitude of the constant field inside the solenoid!

$$\oint \vec{B} \bullet d\vec{\ell} = \mu_o I_{enc} \longrightarrow \int_1^2 \vec{B} \bullet d\vec{\ell} + \int_2^3 \vec{B} \bullet d\vec{\ell} + \int_3^4 \vec{B} \bullet d\vec{\ell} + \int_4^1 \vec{B} \bullet d\vec{\ell} = \mu_o I_{enc}$$

$$BL + 0 + 0 + 0 = \mu_o I_{enc}$$

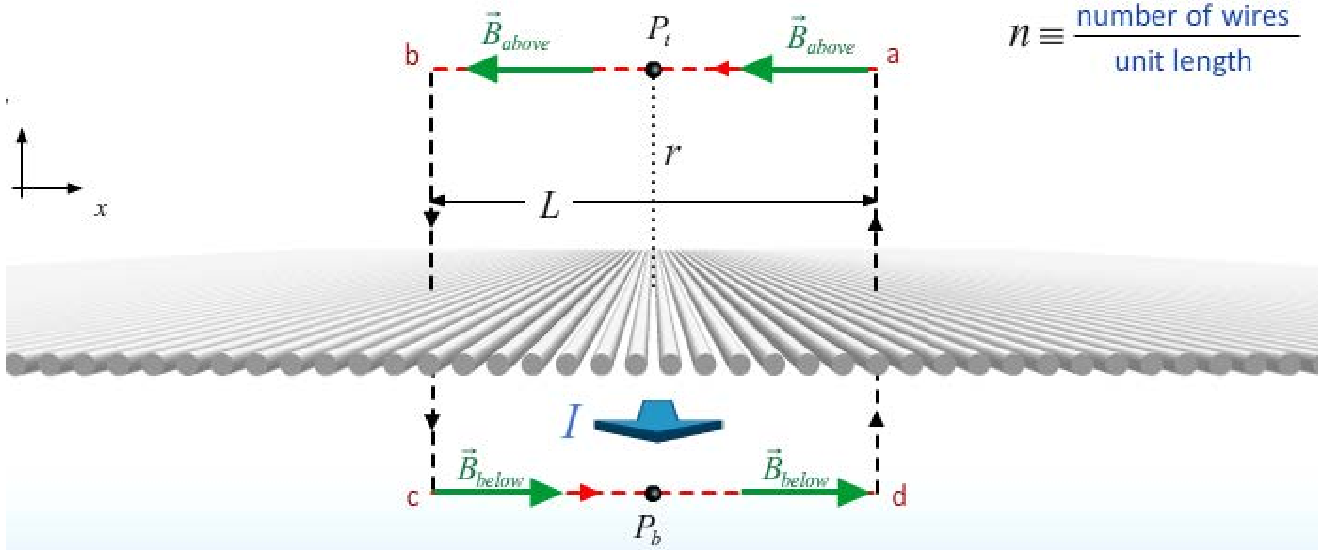
$$\longrightarrow BL = \mu_o nLI \longrightarrow B = \mu_o nI$$

n = # turns/length

Similar to the Current Sheet

Wire Density

$$n \equiv \frac{\text{number of wires}}{\text{unit length}}$$



$$\oint_{loop} \vec{B}\cdot d\vec{l} = \int_a^b \vec{B}\cdot d\vec{l} + \int_c^d \vec{B}\cdot d\vec{l}$$

$$= \quad BL \quad + \quad BL$$

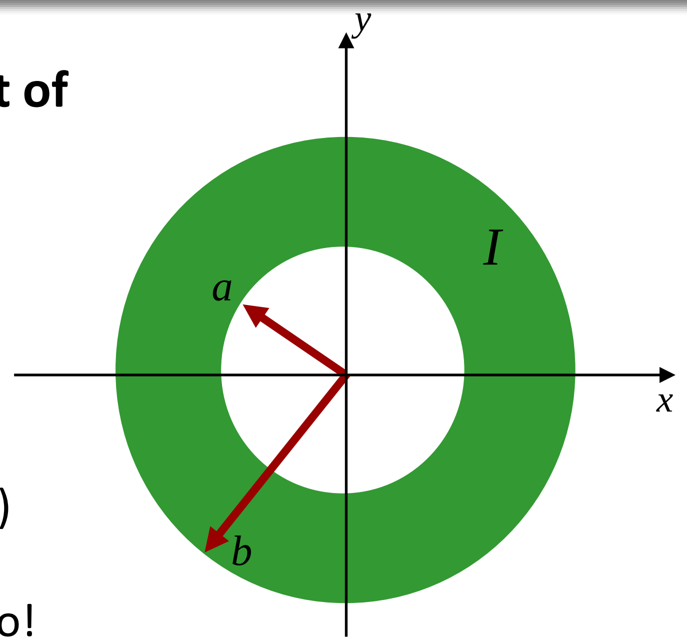
Total integral around the loop

$$\oint_{loop} \vec{B}\cdot d\vec{\ell} = 2BL = \mu_0 I_{enclosed}$$

$$\therefore B = \frac{\mu_0 N I}{2L} = \frac{\mu_0 n I}{2}$$

Example Problem

An infinitely long cylindrical shell with inner radius a and outer radius b carries a uniformly distributed current I **out of the screen.**



Sketch $|B|$ as a function of r.

Conceptual Analysis

Complete cylindrical symmetry (can only depend on r)

$\Rightarrow$ can use Ampere's law to calculate B

B field can only be clockwise, counterclockwise or zero!

$$\oint \vec{B} \bullet d\vec{\ell} = \mu_o I_{enc}$$

$$B \oint d\ell = \mu_o I_{enc}$$ For circular path concentric with shell.

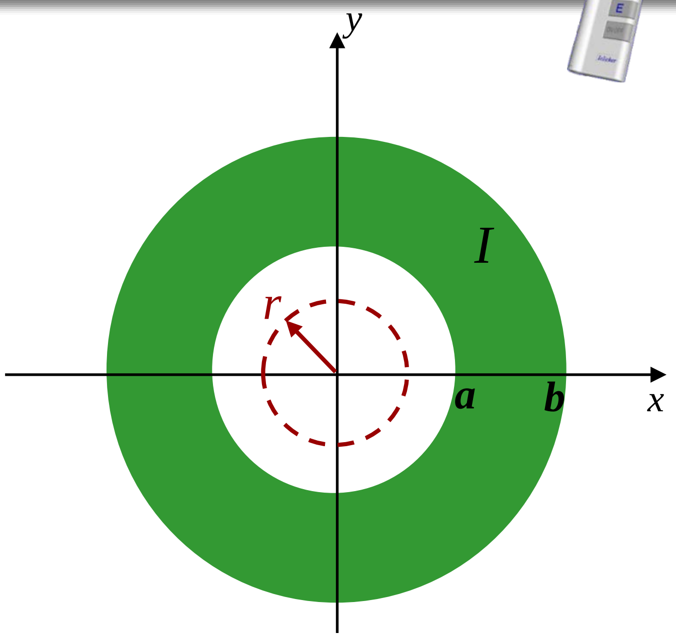
Strategic Analysis

Calculate B for the three regions separately:

1) $r < a$
2) $a < r < b$
3) $r > b$

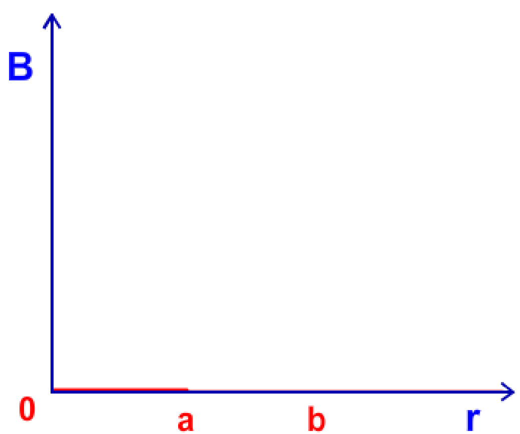
Example Problem

What does $|B|$ look like for $r < a$?

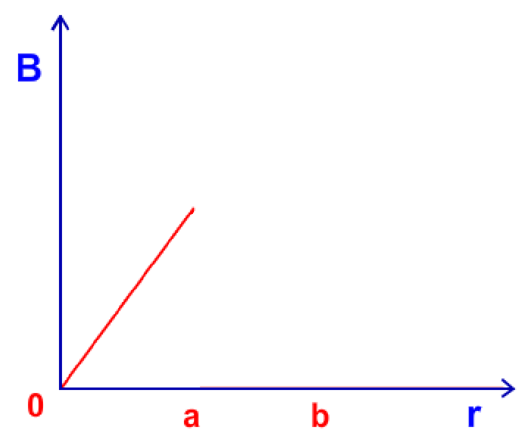


$$\oint \vec{B}\bullet d\vec{\ell} = \mu_o \underbrace{I_{enc}}_{0}$$

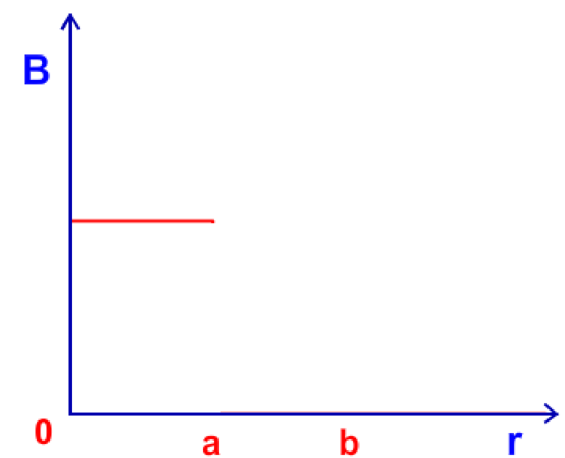
so $\vec{B} = 0$



A



B



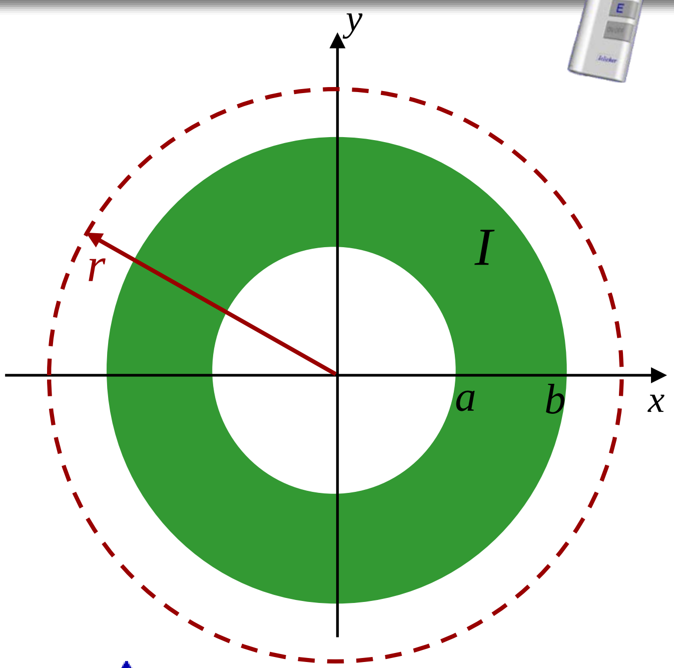
C

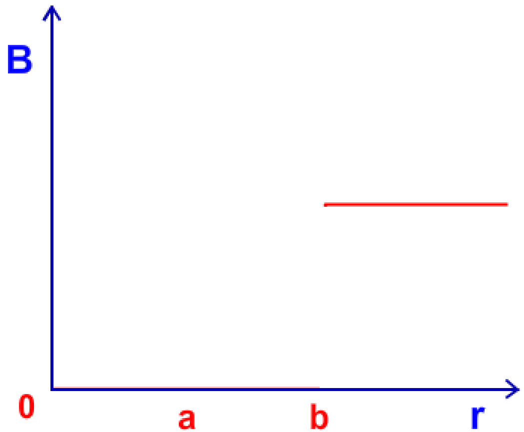
Example Problem

What does $|B|$ look like for $r > b$?

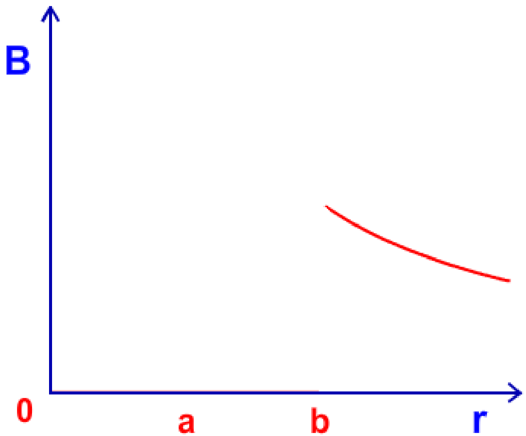
$$\oint \vec{B} \bullet d\vec{\ell} = \mu_o I_{inc}$$

I

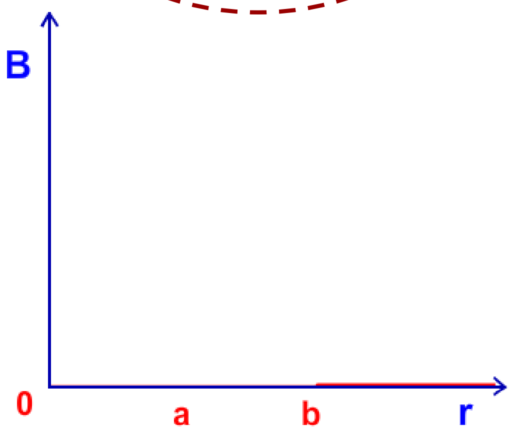




A



B



C

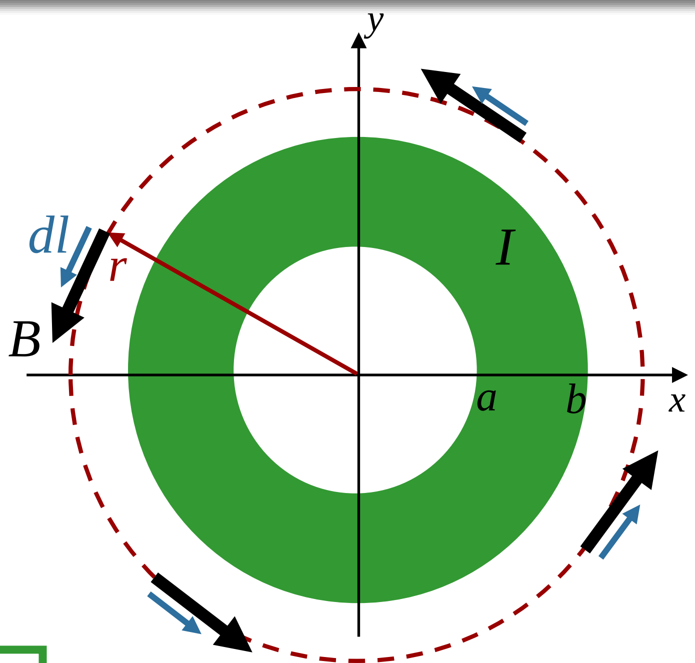
Example Problem

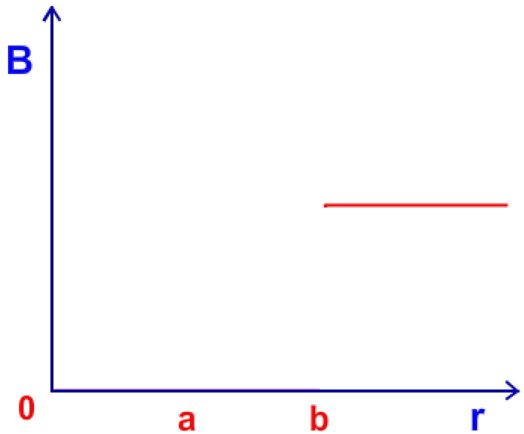
What does $|B|$ look like for $r > b$?

LHS: $\oint \vec{B} \bullet d\vec{\ell} = \oint B d\ell = B \oint d\ell = B \cdot 2\pi r$

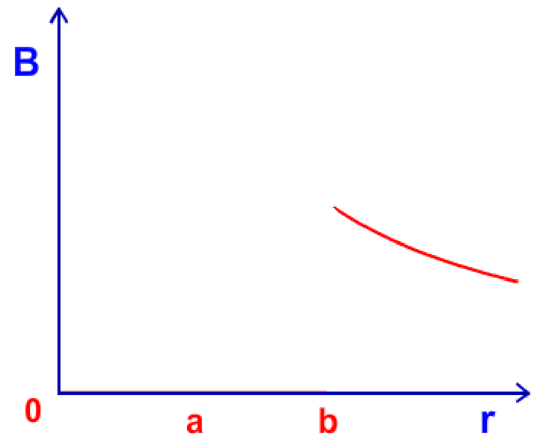
RHS: $I_{enclosed} = I$

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

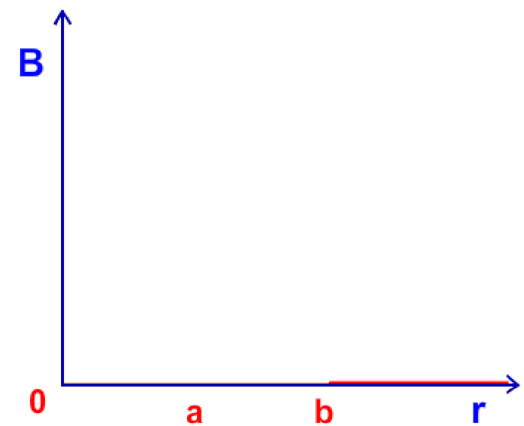




A



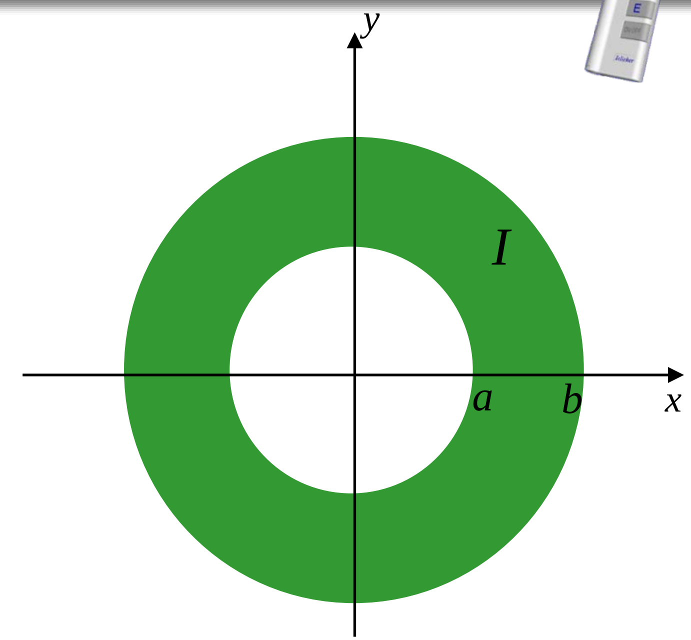
B



C

Example Problem

What is the current density j (Amp/m^2) in the conductor?



A) $j = \dfrac{I}{\pi b^2}$

B) $j = \dfrac{I}{\pi b^2 + \pi a^2}$

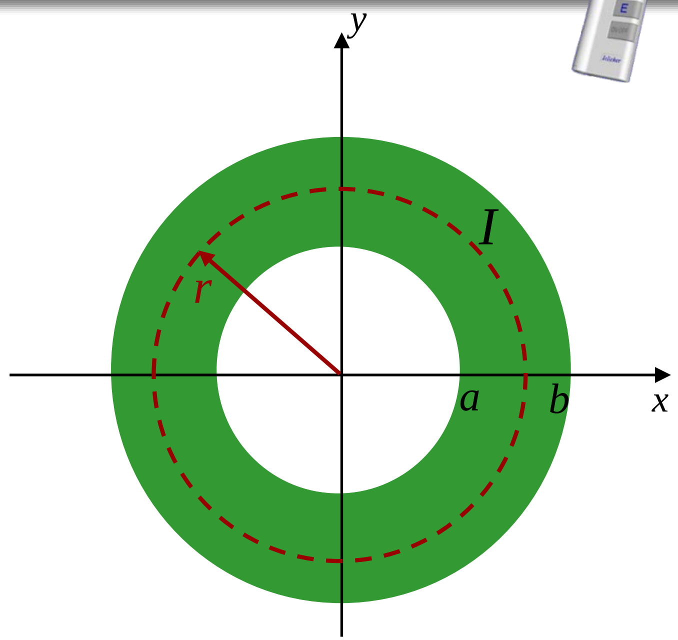
C) $\boxed{j = \dfrac{I}{\pi b^2 - \pi a^2}}$

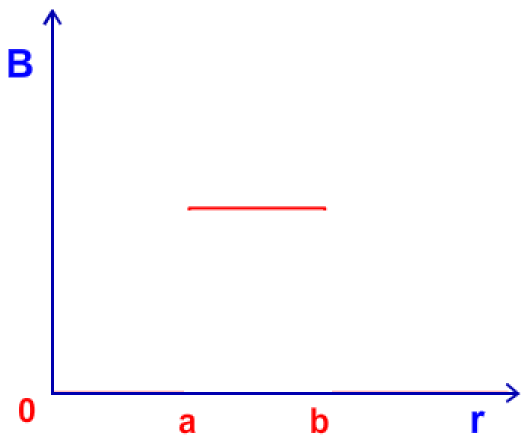
$$\underbrace{j = I / area \qquad area = \pi b^2 - \pi a^2}$$

$$j = \frac{I}{\pi b^2 - \pi a^2}$$

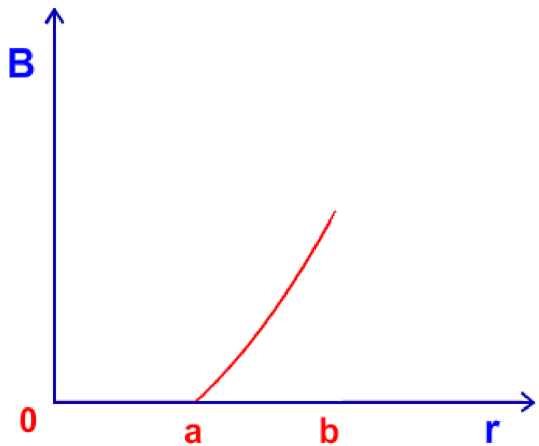
Example Problem

What does $|B|$ look like for $a < r < b$?

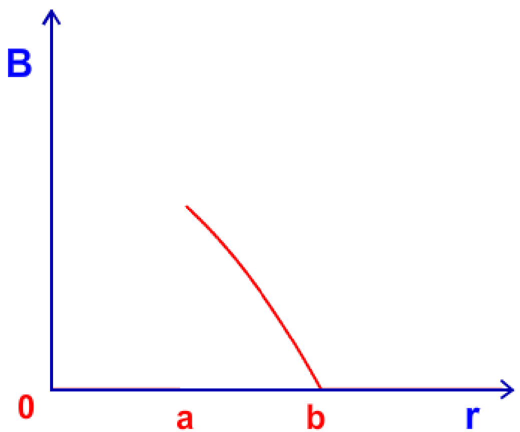




A



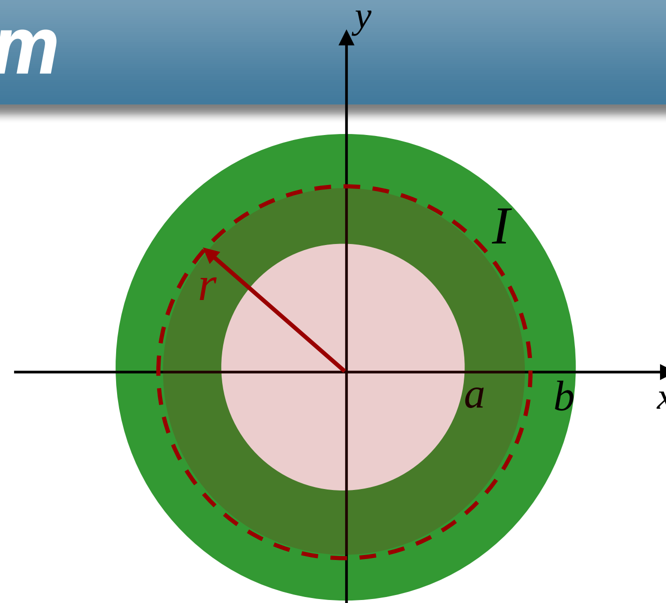
B



C

Example Problem

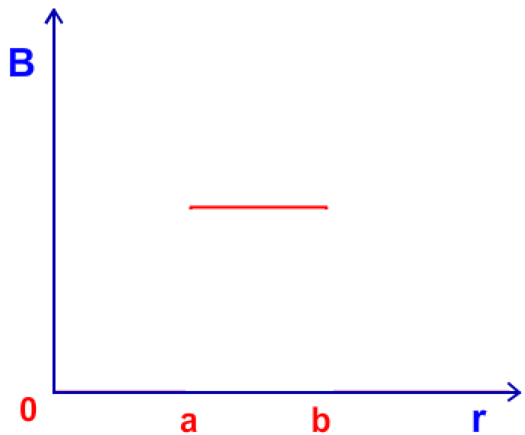
What does $|B|$ look like for $a < r < b$?



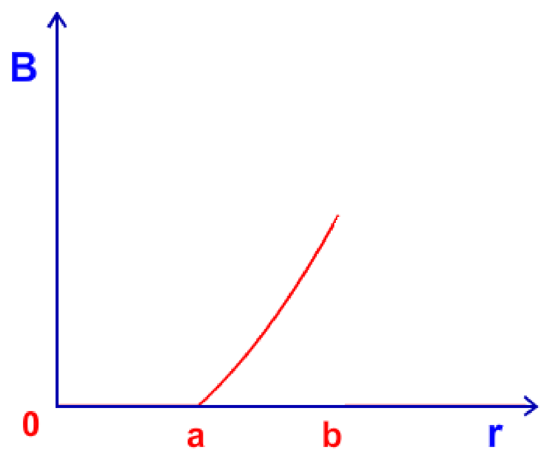
$$\oint \vec{B} \bullet d\vec{\ell} = \mu_o I_{enc} \;\longrightarrow\; B \cdot 2\pi r = \mu_o \cdot jA_{enc}$$

$$B \cdot 2\pi r = \mu_o \cdot \frac{I}{\pi(b^2 - a^2)} \cdot \pi(r^2 - a^2) \;\longrightarrow\; B = \frac{\mu_o I}{2\pi r} \cdot \frac{(r^2 - a^2)}{(b^2 - a^2)}$$

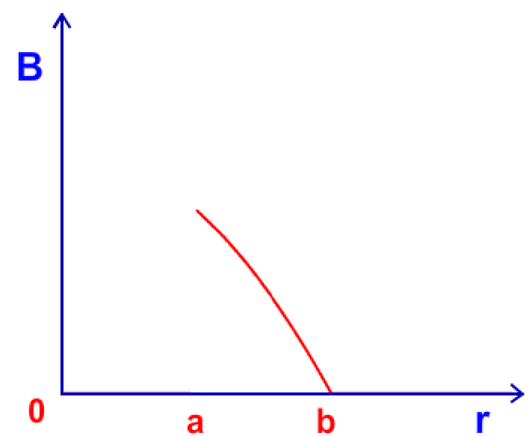
Starts at 0 and increases almost linearly



A



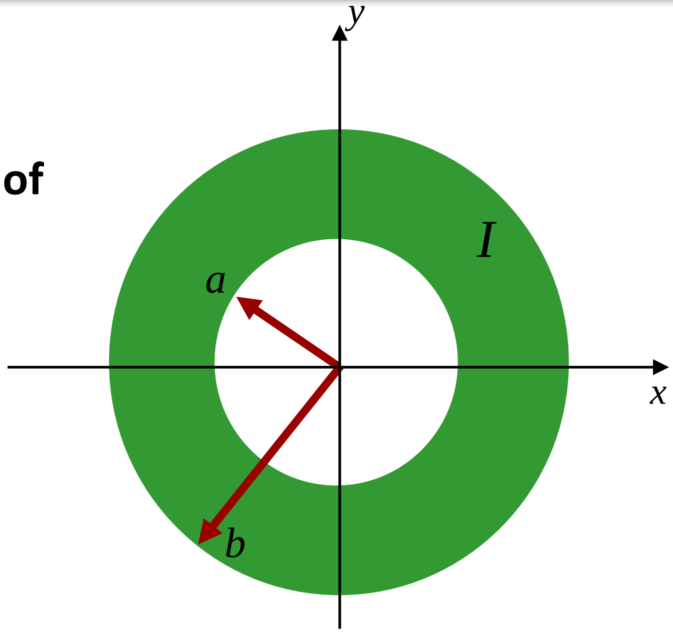
B



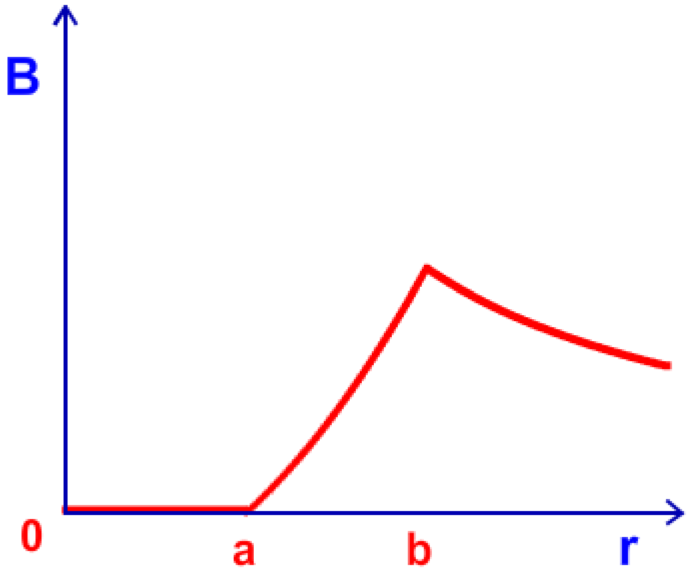
C

Example Problem

An infinitely long cylindrical shell with inner radius a and outer radius b carries a uniformly distributed current **I out of the screen.**

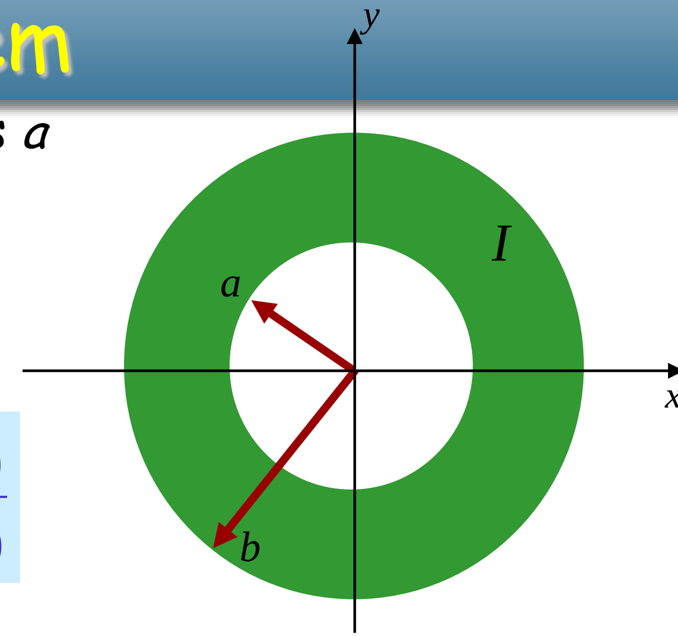


Sketch $|B|$ as a function of r.



Example Problem

An infinitely long cylindrical shell with inner radius *a* and outer radius *b* carries a uniformly distributed current I ***out of the screen***.

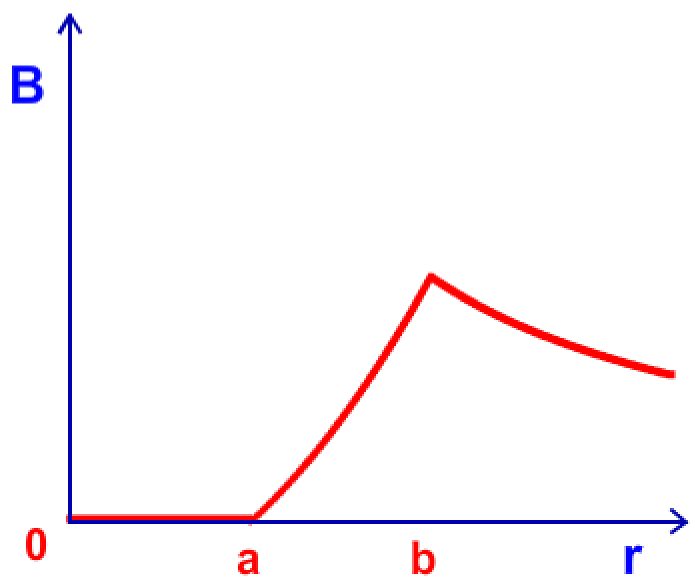


Sketch |B| as a function of *r*.

How big is B at *r* = *b*?

$$B = \frac{\mu_0 I}{2\pi r} \cdot \frac{(r^2 - a^2)}{(b^2 - a^2)}$$

Let I = 10 A, b = 1 mm



$$B(b) = \frac{\mu_o I}{2\pi b}$$

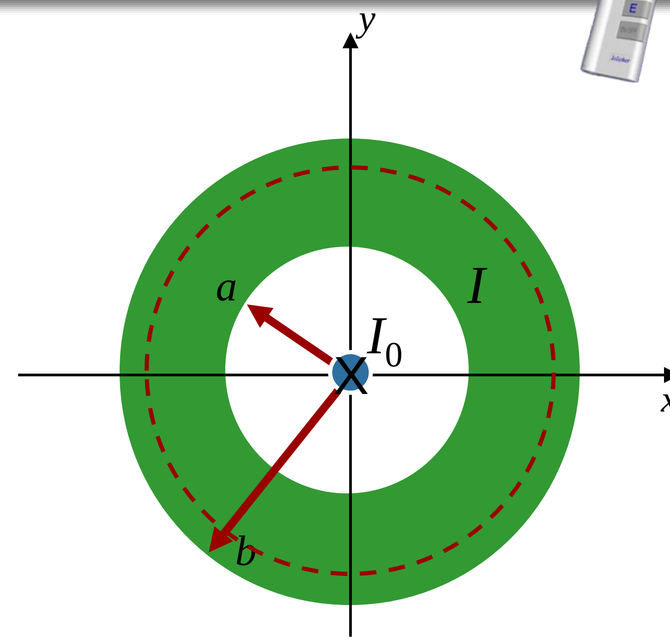
$$= \frac{4\pi x 10^{-7}\ \mathrm{Tm/A} \cdot 10\mathrm{A}}{2\pi \cdot 0.001\,\mathrm{m}}$$

$$= 2x10^{-3}\ \mathrm{T}$$

Follow-Up

Add an infinite wire along the z axis carrying current I_0.

What must be true about I_0 such that there is some value of r, $a < r < b$, such that $B(r) = 0$?



A) $|I_0| > |I|$ AND I_0 into screen

B) $|I_0| > |I|$ AND I_0 out of screen

C) $|I_0| < |I|$ AND I_0 into screen

D) $|I_0| < |I|$ AND I_0 out of screen

E) There is no current I_0 that can produce $B = 0$ there

B will be zero if total current enclosed $= 0$