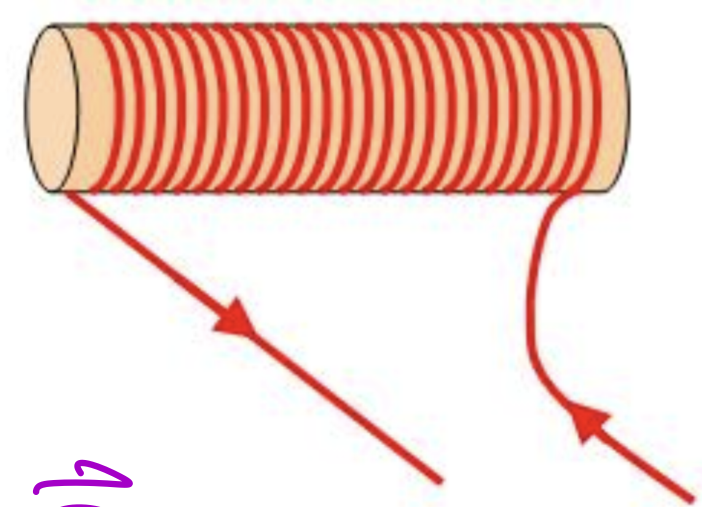
0. Ensure that you have printed your full name and student ID number, with **clear and neat handwriting**, on both the front page of this exam **AND** on your bubble sheet. Your student ID number is not written on your BuffOne Card. Bubble in **version (A)** on your bubble sheet. Failure to follow these instructions may result in the loss of one point on this exam.

1. The solenoid shown below carries a current of 3.00 A. It has 24 turns of radius 0.0120 m and a length of 0.120 m. What is the **magnetic field** at the center of the solenoid? [You may use the approximation we discussed for an infinitely long solenoid.]

   A. 7.53×10^{-4} A to the left
   B. 7.53×10^{-4} A to the right
   C. 9.05×10^{-5} A to the left
   D. 9.05×10^{-5} A to the right
   E. 7.53×10^{-3} A to the right

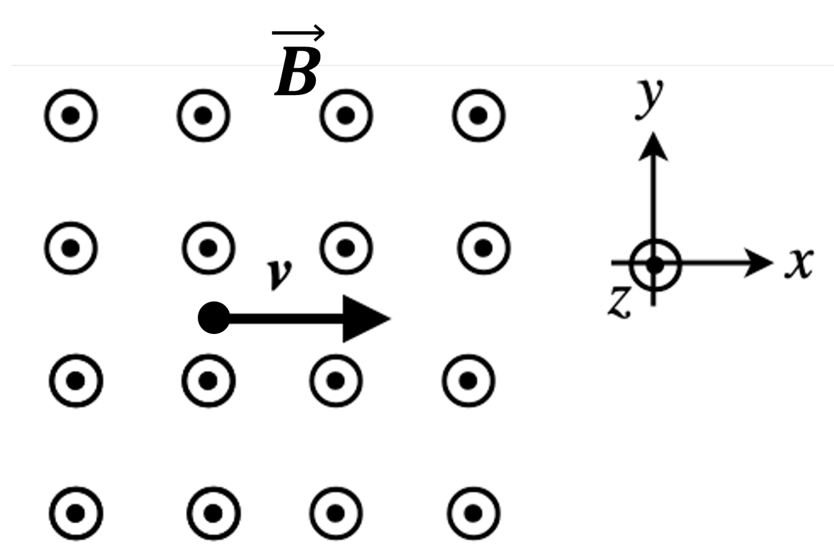


$B_{solenoid} = \mu_0 n I$

$n = \frac{\#\text{ turns}}{\text{length}} = \frac{24}{.12\text{m}}$

Use RHR #2 for direction of $\vec{B}$.

The next **two questions** refer to the situation below. A particle of charge q and mass m moves in a region of space where there is a uniform magnetic field of magnitude B in the $+z$ direction (out of the page).



2. At a given moment the particle is moving in the $+x$ direction. If q **is negative**, what is the direction of the force on the particle due to the magnetic field the instant shown?

   A. $+y$
   B. $-y$
   C. $+z$
   D. $-z$
   E. There is no force on the particle.

$B \odot \rightarrow v$ $\quad \vec{v} \times \vec{B} = \downarrow$

$\vec{F} = q\vec{v} \times \vec{B} = \uparrow$ if q is negative

3. Suppose that you add an electric field to the region so that the particle will travel in a straight line if it has a speed v. What magnitude of **electric field** is required?

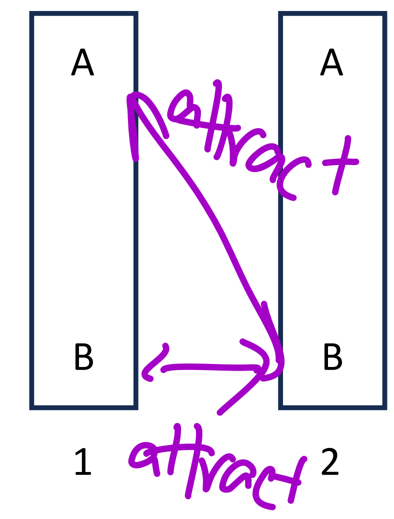
   A. There is no E-field that will allow it to travel undeflected.
   B. qvB
   C. vB
   D. vB/q
   E. $mv/(qB)$

$|\vec{F}_E| = |\vec{F}_B|$

$qE = q|\vec{v} \times \vec{B}|$ $\quad \sin\theta = \sin(90^\circ) = 1$

$E = vB$

4. Two metal bars, labeled 1 and 2, are marked A and B on either end as shown. The following observations are made by a student:



- End 1B attracts 2B
- End 1A attracts 2B

Case 1: $\boxed{\text{N S}}$ $\boxed{\text{mag material}}$ or Case 2: $\boxed{\text{mag material}}$ $\boxed{\text{N S}}$

Assuming the forces are only magnetic, what can we conclude for certain about the magnetic classes of the two bars?

A. Bar 1 is a permanent magnet, Bar 2 is magnetic material (but not a permanent magnet)
B. Bar 2 is a permanent magnet, Bar 1 is magnetic material (but not a permanent magnet)
C. Both bar 1 and bar 2 are permanent magnets
D. Not enough information to choose between answers A and B.

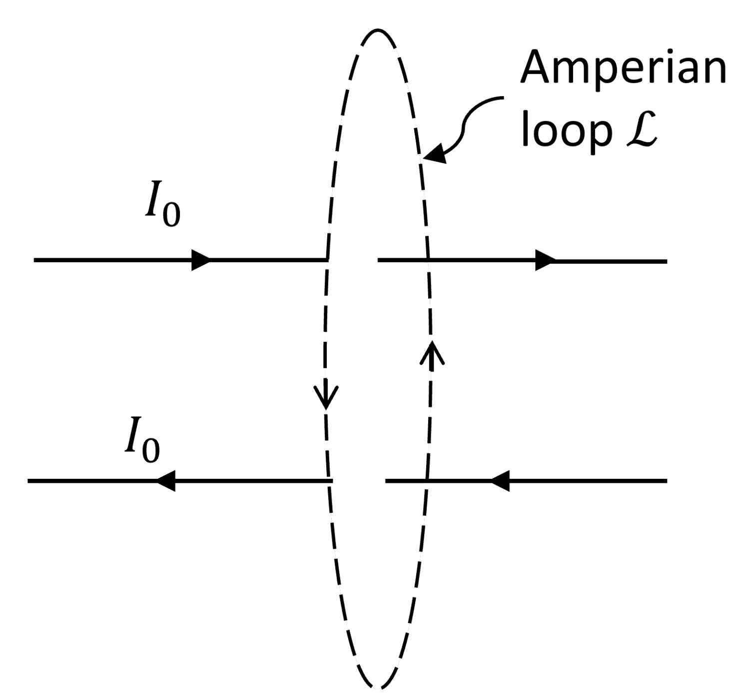
Either Case 1 or Case 2 works.

5. The figure shows two equal line currents of magnitude I_0 which are parallel, but in opposite directions. An imaginary Amperian loop is shown through which both currents pass. Find the value of the line integral of the magnetic field around the loop, $\oint_{\mathcal{L}} \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}}$.

A. $\oint_{\mathcal{L}} \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = 2\mu_0 I_0$
B. $\oint_{\mathcal{L}} \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 I_0$
C. $\oint_{\mathcal{L}} \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = 2I_0$
D. $\oint_{\mathcal{L}} \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = 0$
E. $\oint_{\mathcal{L}} \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}}$ depends on the size of the loop.

$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$

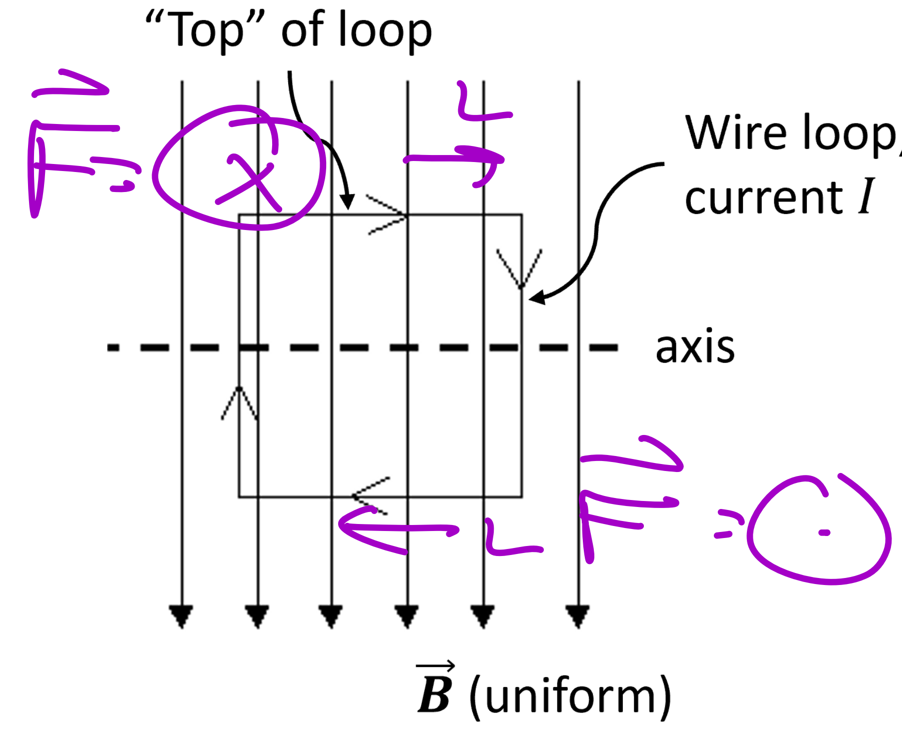
$I_{encl} = 0$ here



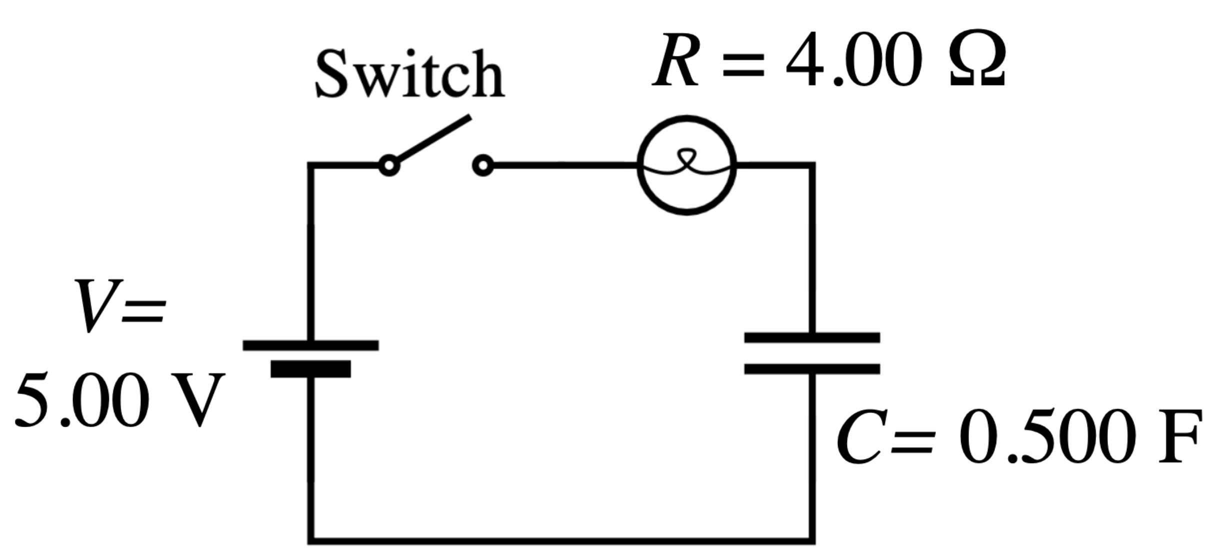
6. A square loop of wire carrying current I can rotate freely about an axis as shown. A uniform magnetic field (made by something not shown) is in the plane of the loop. If the loop is now released from rest, which way does it rotate? Answer in terms of the motion of the "Top" of the loop (see the figure).

A. "Top" of loop moves into the page
B. "Top" of loop moves out of the page
C. The loop will not rotate

$\vec{F} = I\vec{L} \times B$



The next two questions refer to the following figure. The circuit contains an ideal battery, an ideal bulb, a switch and a capacitor. The capacitor is initially uncharged and the switch is open (as shown in the figure). The switch is closed (connecting the circuit) at $t = 0$.



7. What is the initial current through the bulb **just after the switch is closed** (that is, at $t = 0 + \epsilon$)?

   A. 0.00 A
   B. 1.25 A
   C. 20.0 A
   D. 0.625 A
   E. 10.0 A

Initially $V_c = 0$. So $V_R = V_{Bat} = IR$

$I = \frac{V_{Bat}}{R} = \frac{5V}{4\Omega}$

8. In the circuit above, at what time will the current be **20%** of its initial value?

   A. 1.6 seconds
   B. 2.0 seconds
   C. 3.2 seconds
   D. 3.6 seconds
   E. 4.0 seconds

$I(t) = 0.20 I_0 = I_0 e^{-t/RC}$

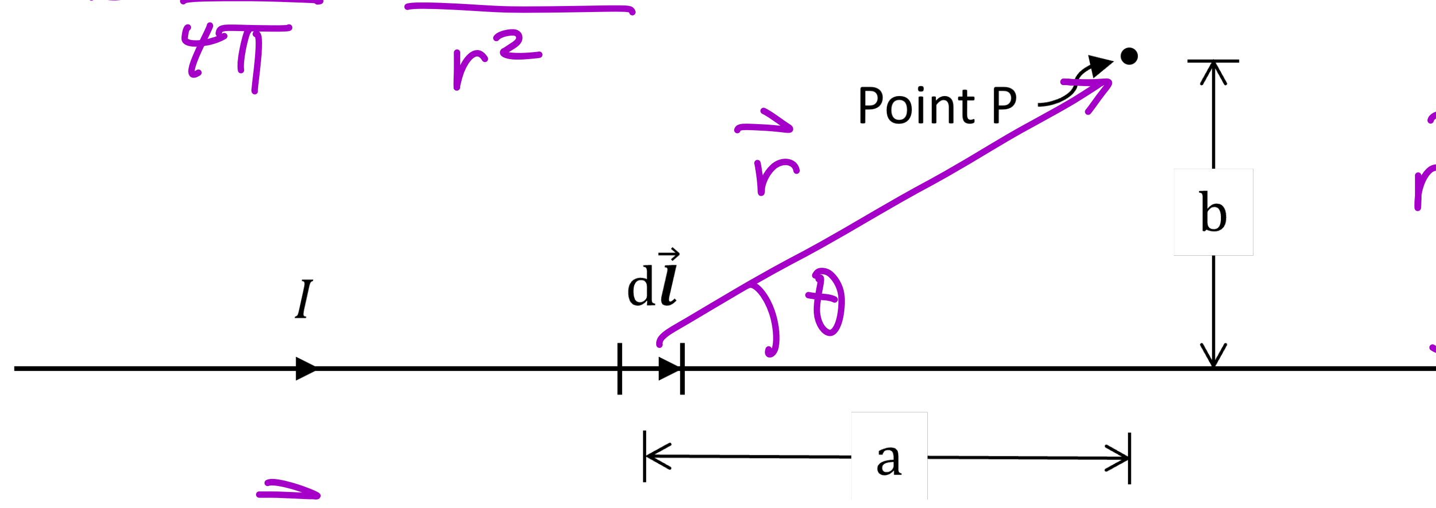
$\ln(0.20) = -t/RC$

$-RC\ln(0.20) = t$

9. A long straight wire carries current I. A small segment of the wire $\mathrm{d}\vec{\mathbf{l}}$ is shown. A point in empty space, point P, is also shown a horizontal distance a and vertical distance b from $\mathrm{d}\vec{\mathbf{l}}$. What is $|\mathrm{d}\vec{\mathbf{B}}|$, the magnitude of the small magnetic field at point P due to the small segment of current $\mathrm{d}\vec{\mathbf{l}}$?

   A. $|\mathrm{d}\vec{\mathbf{B}}| = \frac{\mu_0 I}{2b}$
   B. $|\mathrm{d}\vec{\mathbf{B}}| = \frac{\mu_0 I}{2\pi b}$
   C. $|\mathrm{d}\vec{\mathbf{B}}| = \frac{\mu_0}{4\pi}\frac{I\,\mathrm{d}l}{a^2+b^2}$
   D. $|\mathrm{d}\vec{\mathbf{B}}| = \frac{\mu_0}{4\pi}\frac{I\,\mathrm{d}l\,b}{(a^2+b^2)^{3/2}}$
   E. $|\mathrm{d}\vec{\mathbf{B}}| = \frac{\mu_0}{4\pi}\frac{I\,\mathrm{d}l\,a}{(a^2+b^2)^{3/2}}$

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



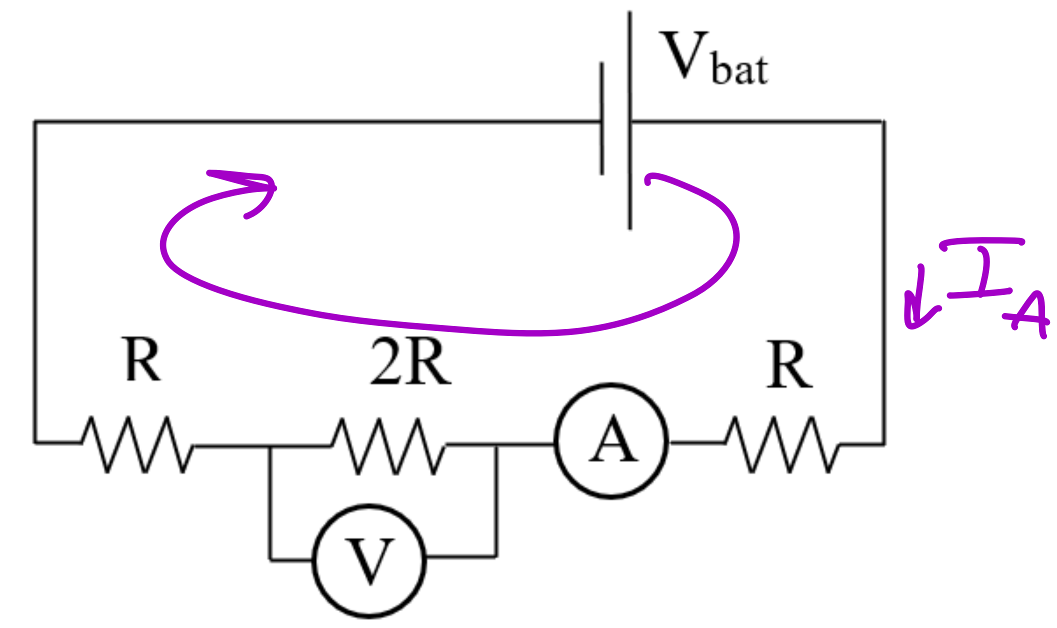
$r^2 = a^2 + b^2$

$\sin\theta = \frac{b}{r} = \frac{b}{\sqrt{a^2+b^2}}$

$d\vec{l}\times\hat{r} = dl\sin\theta$

$|d\vec{B}| = \frac{\mu_0}{4\pi}\frac{I\,dl}{(a^2+b^2)}\cdot\frac{b}{\sqrt{a^2+b^2}}$

The **next two** questions refer to the circuit shown, which contains an ideal battery of voltage V_{bat}, three resistors (R, $2R$, and R), an ideal voltmeter and an ideal ammeter.



10. What will the meters read?

A. Voltmeter reads $\frac{V_{bat}}{3}$. Ammeter reads $\frac{3V_{bat}}{4R}$.

B. Voltmeter reads $\frac{V_{bat}}{2}$. Ammeter reads $\frac{3V_{bat}}{4R}$.

C. Voltmeter reads $\frac{V_{bat}}{3}$. Ammeter reads $\frac{V_{bat}}{4R}$.

D. Voltmeter reads $\frac{V_{bat}}{2}$. Ammeter reads $\frac{V_{bat}}{4R}$.

E. Voltmeter reads V_{bat}. Ammeter reads $\frac{V_{bat}}{4R}$.

$V_{bat} - I_A R - I_A 2R - I_A R = 0$

$V_{bat} = I_A 4R$

$\frac{V_{bat}}{4R} = I_A$

$V_V = I_A \cdot 2R = \frac{V_{batt}}{4R} \cdot 2R = \frac{V_{batt}}{2}$

11. Now suppose the voltmeter and the ammeter **switch places**. What will the ammeter read after the switch?

A. Ammeter reads $\frac{V_{bat}}{4R}$.

B. Ammeter reads $\frac{V_{bat}}{2R}$.

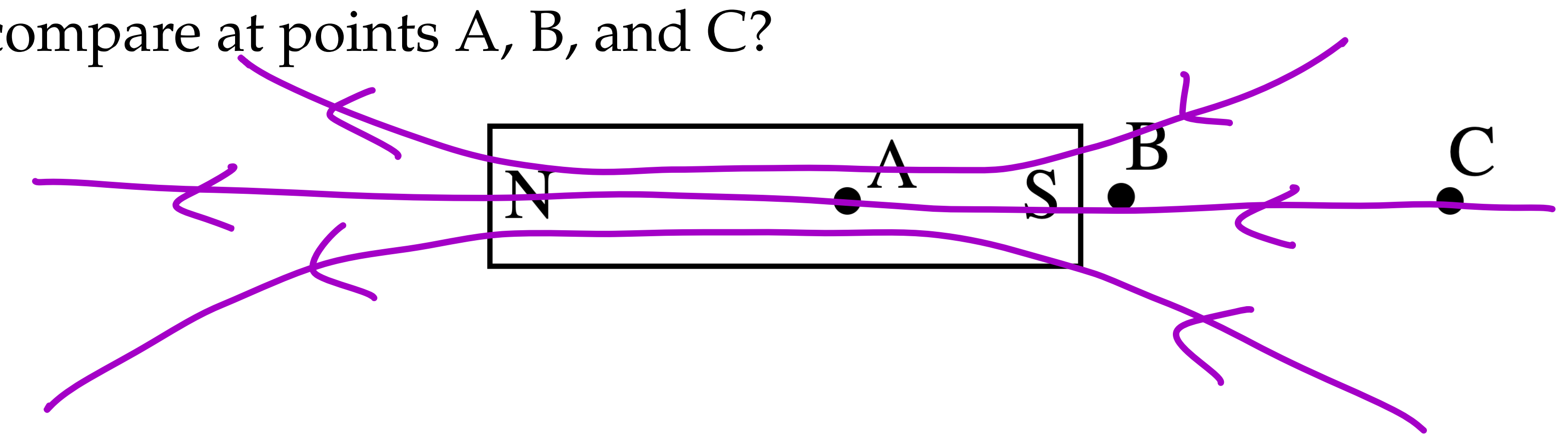
C. Ammeter reads $\frac{V_{bat}}{R}$.

D. Ammeter reads $\frac{V_{bat}}{8R}$.

E. Ammeter reads 0.

An ideal voltmeter has $R = \infty$. So no current will be able to flow around loop when A + V are switched.

12. A bar magnet is shown below. Its north and south poles are labeled "N" and "S". Points A, B, and C line in the plane of the magnet, with point A being inside the magnet. How does the **magnitude of the magnetic field** compare at points A, B, and C?



A. B > C > A

B. B > A > C

C. A > B > C

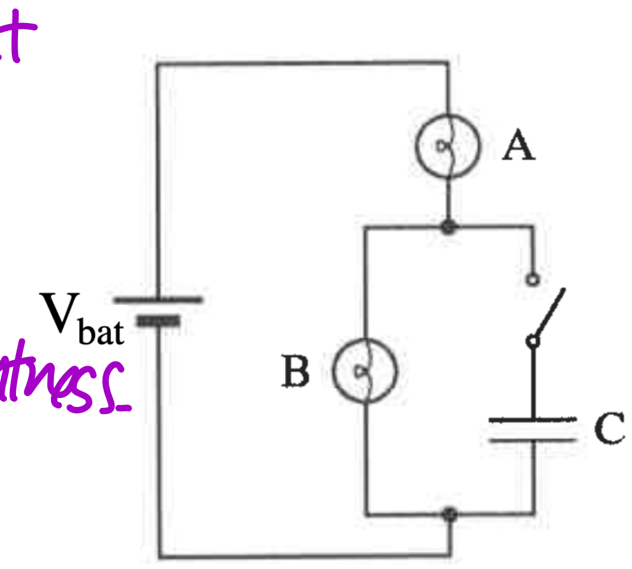
D. A = B = C

E. B = C > A

$|\vec{B}|$ is largest where density of field lines is greatest.

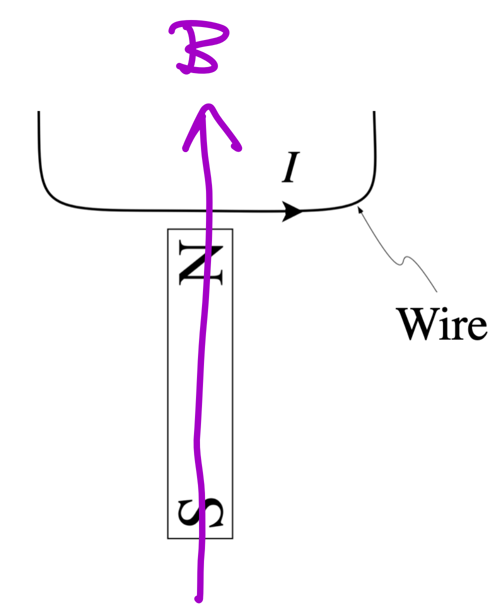
13. Two identical bulbs and a capacitor are connected to an ideal battery as shown. The capacitor is initially uncharged and the switch is open at the instant shown. Then the switch is closed, connecting the capacitor to the circuit. Describe the brightness of Bulb A and Bulb B a **long time after the switch is closed**.

After long time, no current flows through C. So A + B have same current & same brightness.



A. Both bulbs are off.
B. Both bulbs are on, and **Bulb A is brighter** than Bulb B.
C. Both bulbs are on, and **Bulb A is dimmer** than Bulb B.
D. Both bulbs are on, and **Bulb A is equally as bright** as Bulb B.
E. Only Bulb A is on.

14. A wire carrying a current I sits near a bar magnet as shown. The wire and the magnet lie in the same plane. What is the direction of the **magnetic force** on the wire due to the bar magnet?



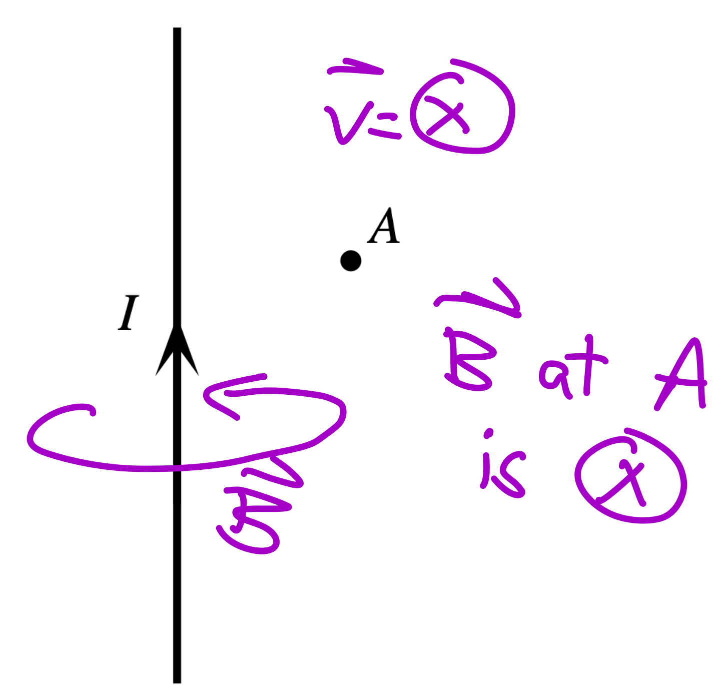
A. Into the page $\otimes$
B. Out of the page $\odot$
C. Up $\uparrow$
D. Down $\downarrow$
E. There is no magnetic force on the wire.

$\vec{B}$ $\vec{L}$

$\vec{F} = I\vec{L}\times\vec{B}$

= out of page

15. A **positively charged particle** is located at Point A, near a current carrying wire. At the instant shown below, the particle is in the plane of the wire and is **moving into the page**. What is the direction of the **magnetic force** on the charged particle at this instant?



Positively charged particle at A is moving into page

A. Into the page $\otimes$
B. Out of the page $\odot$
C. To the right $\rightarrow$
~~D.~~ Up $\uparrow$
E. There is no magnetic force on the particle.

$\vec{v}\times\vec{B} = 0$ since $\vec{v}$ and $\vec{B}$ are parallel.

$\vec{F} = q\vec{v}\times\vec{B} = 0$

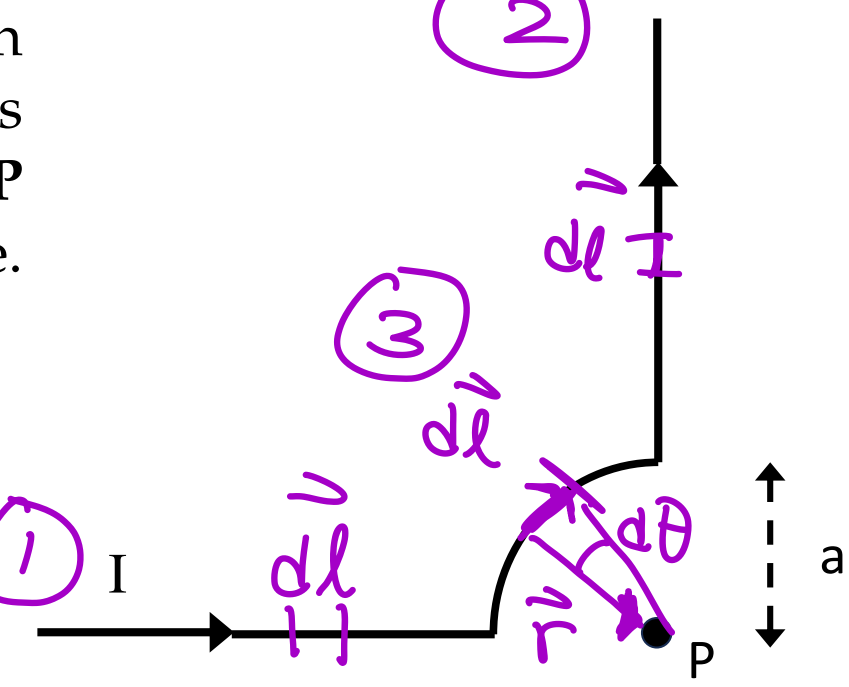
16. A charged particle with charge 3.2×10^{-19} C is injected with a speed of 100 m/s into a region containing a 0.04 T uniform magnetic field. The particle's injection velocity is perpendicular to the field. The **diameter** of the particle's subsequent orbit is measured and found to be 0.08 m. What is the mass of the particle?

A. 1.02×10^{-20} kg
B. 1.60×10^{-5} kg
C. 5.12×10^{-27} kg
~~D.~~ 1.02×10^{-23} kg
E. 5.12×10^{-24} kg

$r = \frac{mv}{|q|B}$ $\quad d = 2r = \frac{2mv}{|q|B}$

$\frac{dqB}{2v} = m$

17. A long straight wire makes a 90 degree change in direction with a small circular arc of radius a, as shown in the figure. Find the **magnetic field at Point P** at the center of the circular arc for a current I in the wire.



A. $\mu_0 I/(8\pi a)$
B. $\mu_0 I/(4a^2)$
C. $\mu_0 I a/2$
D. $\mu_0 I/(4a)$
E. $\mu_0 I/(8a)$

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

For ① + ③, $d\vec{l}$ and $\hat{r}$ are parallel so $d\vec{l} \times \hat{r} = 0$.

B only comes from circular arc.

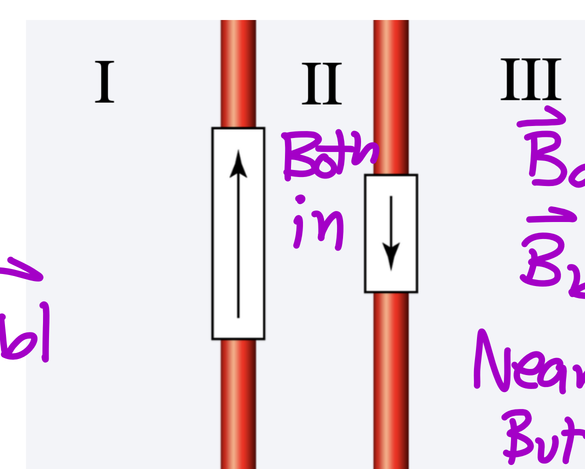
$dl = a\,d\theta$

$d\vec{l}$ + $\hat{r}$ are $\perp$ so $d\vec{l} \times \hat{r} = a\,d\theta$ into page

$\vec{B} = \frac{\mu_0}{4\pi}\int_0^{\pi/2} \frac{I a\,d\theta}{a^2} = \frac{\mu_0 I}{4\pi a}\theta\Big|_0^{\pi/2} = \frac{\mu_0 I}{4\pi a}\cdot\frac{\pi}{2} = \frac{\mu_0 I}{8a}$ into page

18. Consider the pair of long, parallel wires with **unequal currents** shown below. Arrows give the direction of the current in each wire, with the shorter arrow representing a smaller current than the longer one. In which of the regions is there a place where the **net magnetic field is zero**? Don't consider distances very far from the wires where the field goes to zero.

A. Region I only
B. Region II only
C. Region III only
D. Regions I and III
E. None of the regions



$\vec{B}_a$ = out
$\vec{B}_b$ = in
But $|\vec{B}_a|$ always $> |\vec{B}_b|$ so no 0.

Both in

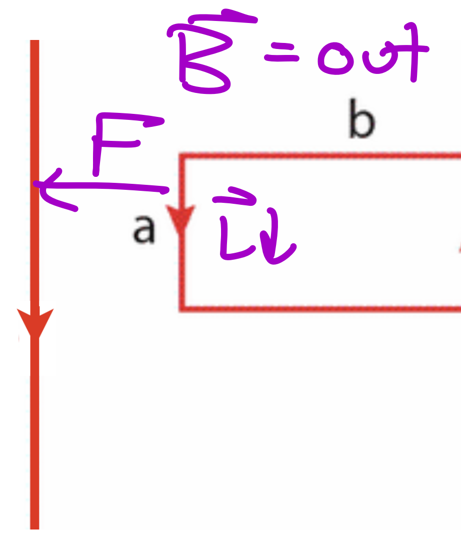
$\vec{B}_a$ = in
$\vec{B}_b$ = out
Near wire $|\vec{B}_b| > |\vec{B}_a|$
But farther away $|\vec{B}_a| > |\vec{B}_b|$. So there is a 0.

a b

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

19. A rectangular current-carrying loop of height a and width b is placed near a long straight current-carrying wire, as shown. The current directions are indicated by arrows. What is the direction of the **net force on the loop** due to the straight wire?

A. $\downarrow$
B. $\uparrow$
C. $\leftarrow$
D. $\rightarrow$
E. No net force on the loop.



$\vec{B}$ = out of page

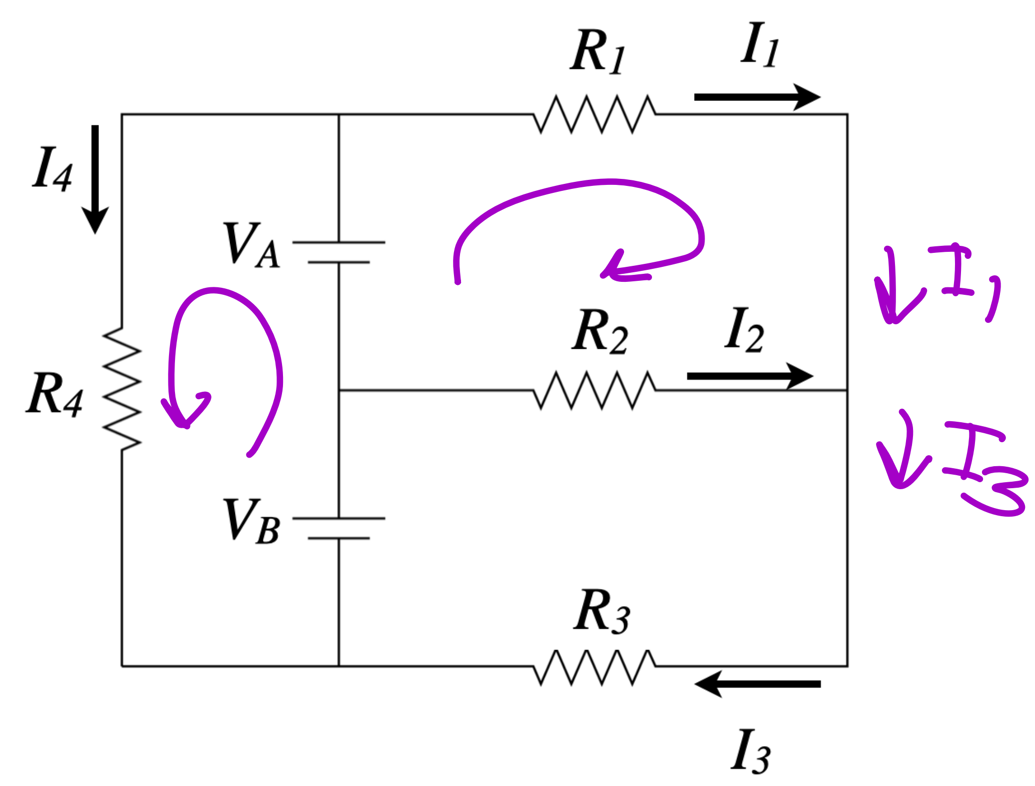
$\vec{F} = I\vec{L}\times\vec{B}$

left side: $\vec{F} = \leftarrow$
right side: $\vec{F} = \rightarrow$

B $F_{left} > F_{right}$, so $F_{net} = \leftarrow$

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

20. Which of the following equations are correct for the circuit below, given the current directions shown in the Figure?



× I. $I_1 = I_2 + I_3$ $\quad I_1 + I_2 = I_3$

× II. $V_A - I_1R_1 - I_2R_2 = 0$ $\quad V_A - I_1R_1 + I_2R_2 = 0$

× III. $V_B + V_A + I_4R_4 = 0$ $\quad V_B + V_A - I_4R_4 = 0$

A. I only

B. I and II

C. II only

D. II and III

E. None are correct

21. Two long straight wires each carry current I out of the page. They intersect the y axis a distance d above and below the origin as shown. What is the **net magnetic field** due to the two wires at Point P, which is on the x axis, a distance d from the origin?

A. $\frac{\mu_0 I}{2\pi d}$ to the right

B. $\frac{\mu_0 I}{2\pi d}$ upward ↑

C. $\frac{\mu_0 I}{\pi d}$ to the right

D. $\frac{\mu_0 I}{\pi\sqrt{2}d}$ to the right

E. $\frac{\mu_0 I}{\pi\sqrt{2}d}$ upward ↑

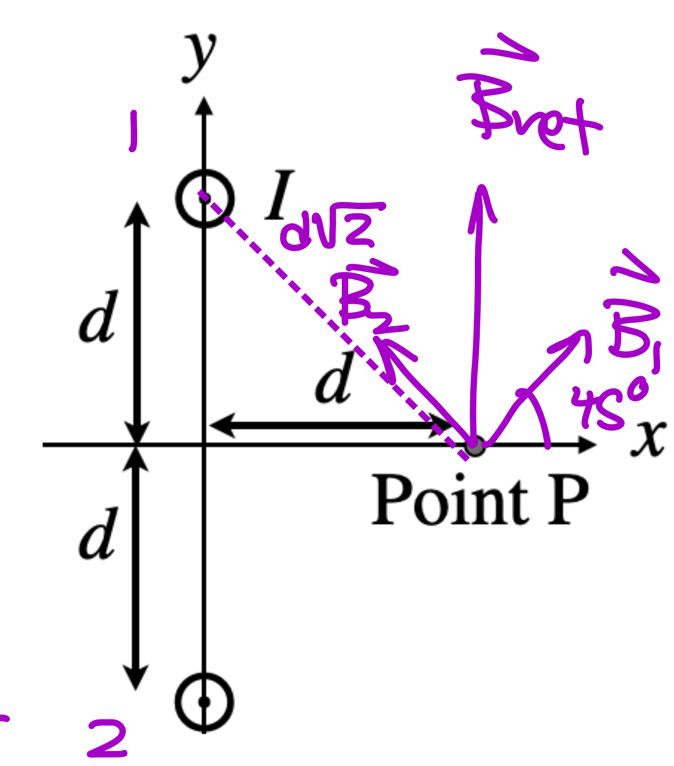
X-components cancel.
Y-components add.

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

$B_{1y} = B_{2y} = B_1 \cdot \sin 45^\circ = B_1 \cdot \frac{\sqrt{2}}{2}$

$B_{net_y} = B_{1y} + B_{2y} = \frac{\mu_0 I}{2\pi\sqrt{2}d} \cdot \frac{\sqrt{2}}{2} \cdot 2$

$B_{net} = \frac{\mu_0 I}{2\pi d}$ upward



22. A long straight cylindrical wire made of copper has radius a and carries current I. The current density in the wire is uniform. Find the magnitude of the magnetic field inside the wire at radius r ($r < a$).

A. $\mu_0 I r/(2\pi a^2)$

B. $\mu_0 I r^2/(2\pi a^3)$

C. $\mu_0 I/(2\pi r)$

D. $\mu_0 I/(2\pi a)$

E. $\mu_0 I a/(2\pi r^2)$

Use dashed Amperian loop

$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$

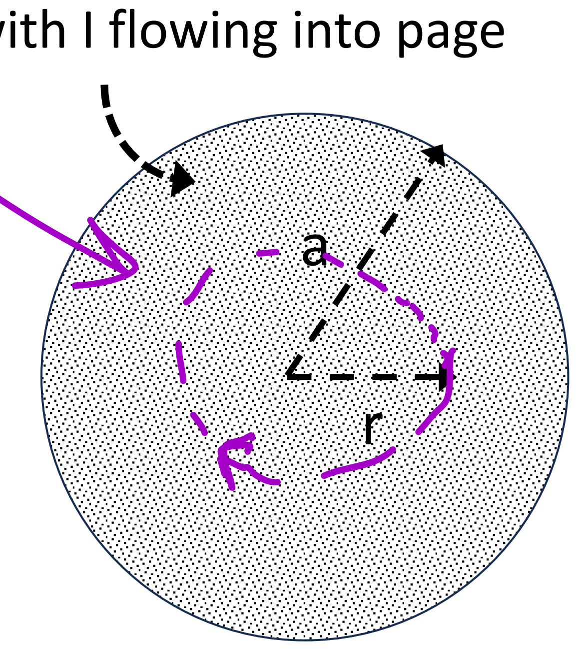
$B \cdot 2\pi r = \mu_0 J \cdot A_{encl}$

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

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

$J = \frac{I}{A} = \frac{I}{\pi a^2}$

Solid copper with I flowing into page



Zoomed in cross section view of wire