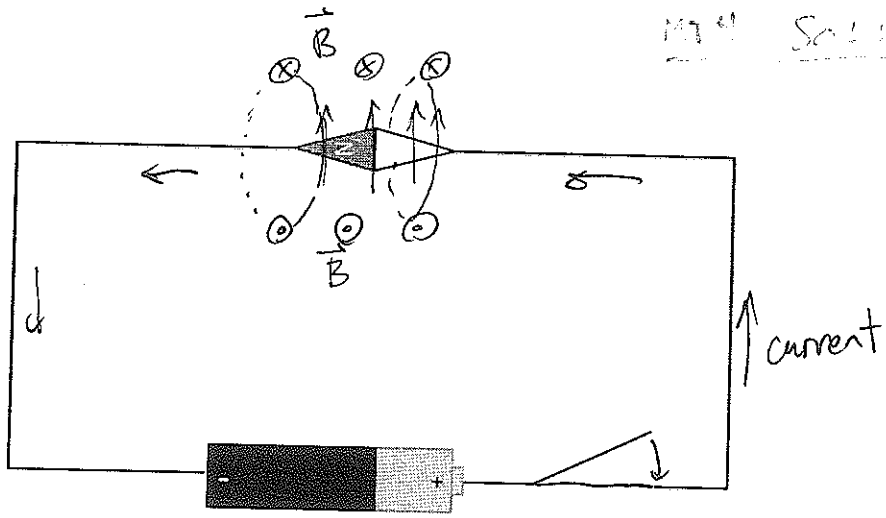
SOLUTIONS

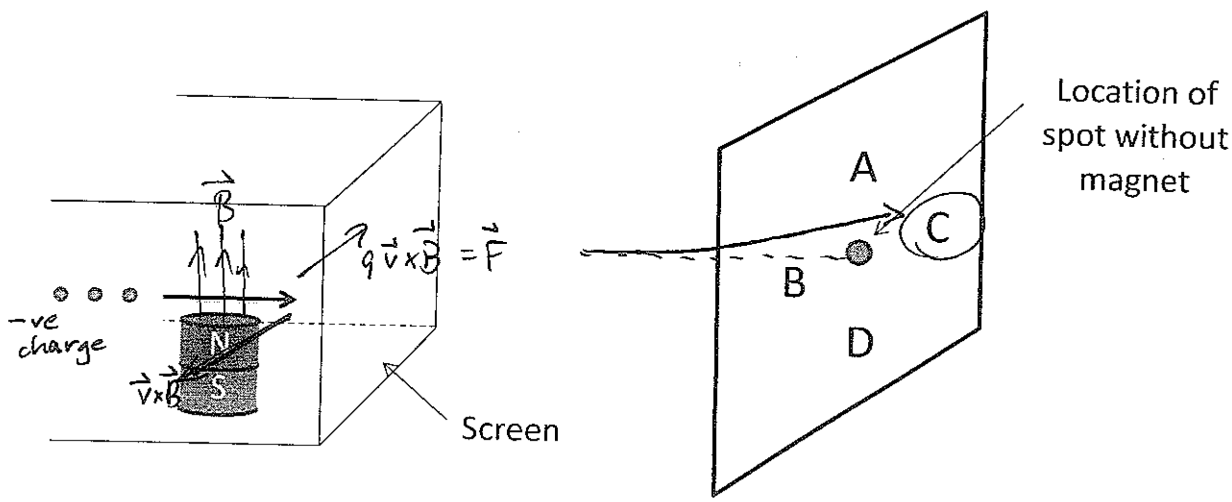



**Question 1:** In the picture, a compass needle sits directly above a wire that passes 1cm below it (we are looking down from the top). When the switch is closed,

$\vec{B}$ points ↑

A) the compass needle will rotate clockwise.
B) the compass needle will rotate counterclockwise.
C) the compass needle will try to rotate so the N side points toward the wire.
D) the compass needle will try to rotate so the S side points toward the wire.
E) the compass needle will not rotate.

N wants to point in $\vec{B}$ direction

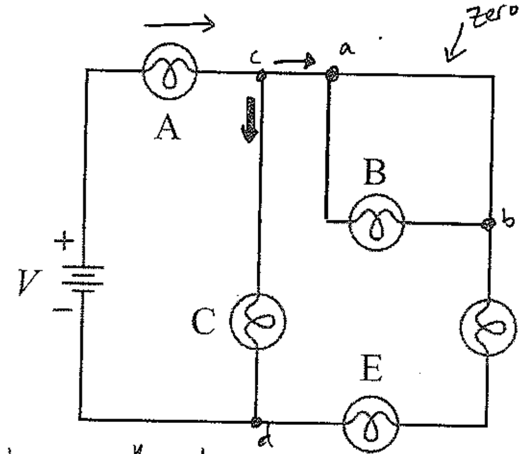



**Question 2:** In a cathode ray tube, a beam of electrons is sent towards a screen, resulting in a bright spot on the screen. If we now place a magnet under the beam as shown, what will be the final position of the dot on the screen? Choose A, B, C, D, or

E) The dot will stay in the original location $\boxed{C}$

Brightness ∝ current.

**Question 3:** Five identical light bulbs are connected to a potential as shown in the figure. What is the order from the brightest bulb to dimmest?

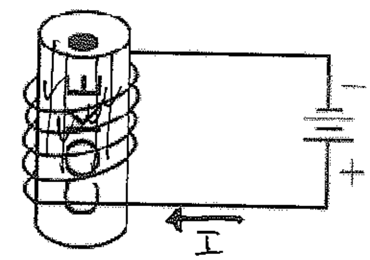



zero resistance so voltage drop = 0 between a & b ⇒ $I_B = 0$

$I_D = I_E$

a) A = D = E > B = C
b) A > B > C = D > E
c) B > A > C > D = E
d) A > C = D > E > B
e) A > C > E = D > B

- all current goes through A
- more current goes through C than D & E since $R_D + R_E > R_C$




**Question 4:** The circuit initially has a huge current running through it. A pop can is placed in the middle of the coil. Choose the best answer that describes what happens when the coil is detached from the voltage source so that the current rapidly drops to zero.

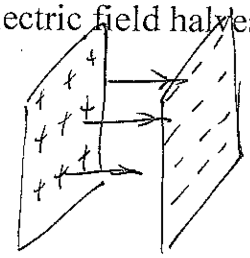
- Big downward flux
- This decreases
- Current flows in can to try to maintain this downward flux!

a) The pop can shoots upwards.
b) The pop can shoots downwards.
c) The pop can gets crushed.
d) The pop can balloons outwards.
e) Nothing.

- $\vec{v} \times \vec{B}$ is outwards
-

**Question 5:** You use a battery to fully charge a parallel plate capacitor. You then disconnect the capacitor from the battery and double the distance between the plates. What happens to the electric field between the plates and the capacitance?

a) The electric field doubles and the capacitance halves.
b) The electric field doubles and the capacitance doubles.
c) The electric field stays the same and the capacitance halves.
d) The electric field stays the same and the capacitance doubles.
e) The electric field halves and the capacitance halves.
f) The electric field halves and the capacitance doubles.

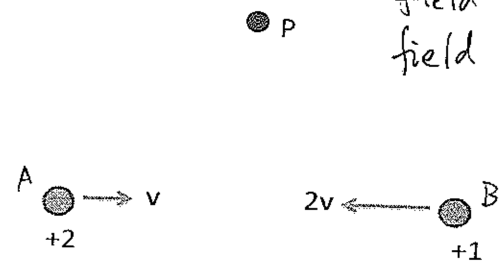


charge/charge density stays the same

⇒ E stays the same.

$V = E \cdot d$ increases

$C = \frac{Q}{V}$ decreases.



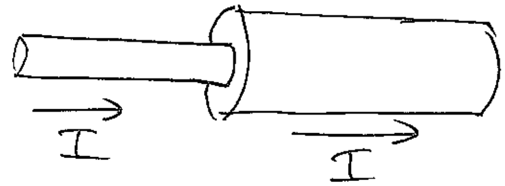

field from A: into page
field from B: out of page
$|\vec{B}| \propto q \cdot v$
same for both.
$\therefore$ net field = 0.

**Question 6:** The charges shown approach each other with the indicated speeds. The net magnetic field at the point P is

a) zero.
b) into the page.
c) out of the page.
d) None of the above.

**Question 7:** A narrow copper wire of length $L$ and radius $b$ is attached to a wide copper wire of length $L$ and radius $2b$, forming one long wire of length $2L$. This long wire is attached to a battery and current runs through it. If the drift speed in the wide section of the wire is $v$, then the drift speed in the narrow section is:

a) $v/4$
b) $v/2$
c) $v$
d) $2v$
e) $4v$

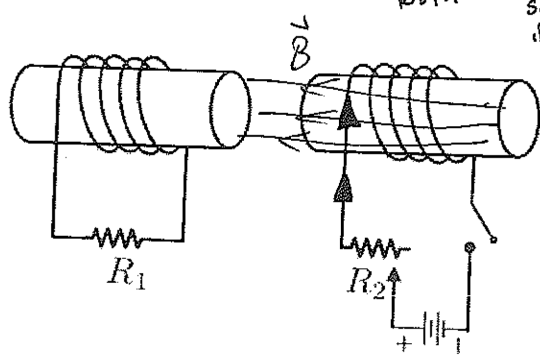



I same in both parts.

$I = e n_e A v_d$

same for both; $4\times$ smaller in narrow part; $4\times$ bigger in narrow part.

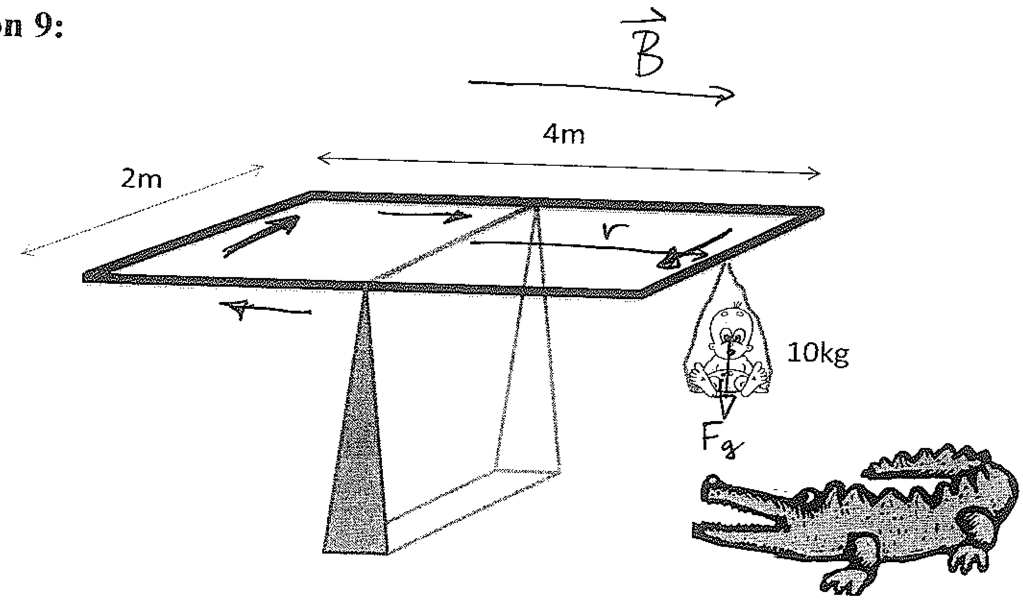
**Question 8:** Find the direction of the current through the resistor $R_1$ when the following steps are taken in the order given. Circle the correct answers.




Step:

| | | | Current is to the |
|---|---|---|---|
| a) The switch is closed | B increasing to left | Bind to right. | left/ right/ none |
| b) The variable resistor, R2, is decreased | $I = \frac{V}{R} \uparrow$ | $B_{left} \uparrow$ | left/ right/ none |
| c) The circuit containing R2 is moved to the right | $B_{left}$ decreases | $\Rightarrow$ Bind is to left | left/ right/ none |
| d) The switch is opened | $B_{left}$ decreases | Bind to left | left/ right/ none |

**Question 9:**




A uniform 0.1T magnetic field points to the right. How much current do we need in the rectangular loop to keep the baby from being eaten? Indicate the direction of the current on the diagram. *Note: the baby is also afraid of heights and is likely to make an unpleasant whining noise if he goes any higher.* **(3 points)**

- Want upward force on right & downward force on left

$\therefore$ current flows as shown.

Torque of baby on loop $= r \cdot F_{grav}$

$= 2m \cdot 10kg \cdot g$

$= 196 \ kg \ m^2/s^2$

Need torque from $\vec{B}$ to cancel this.

$|\tau_B| = |\vec{\mu} \times \vec{B}| = |\vec{\mu}| \cdot |\vec{B}|$

$= I \cdot A \cdot B$

$\therefore$ Want $\quad I \cdot (\text{Area}) \cdot B = 196 \ kg \ m^2/s^2$

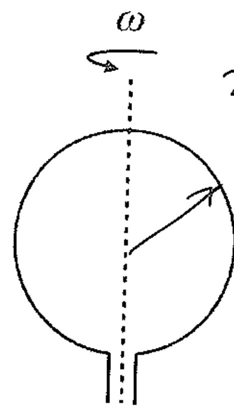
need. $\quad I = \dfrac{196 \ kg \ m^2/s^2}{8m^2 \cdot 0.1T} = 245 \ A.$

* no actual babies were harmed in preparing this question

**Question 10:** Suppose you have 10 m of wire and you want to use the Earth's magnetic field to make a generator that can light a light bulb from the Science One storage room.

The light bulb needs 1 V across it to light. The strength of the magnetic field in Vancouver is about 50 μT (micro = $10^{-6}$). You can assume the wire has no resistance and take resistance of the bulb to be 10 Ω.

If you make the wire into a big circular loop that can be rotated, what is the minimum angular velocity at which you have to spin your loop in order to light the bulb? **(3 points)**




$2\pi R = 10m$

The voltage across the bulb will be the induced EMF

$$\mathcal{E} = \frac{d\Phi}{dt}$$

$\Phi$ oscillates from $+B\cdot A$ to $-B\cdot A$ with frequency $\omega$:

$$\Phi(t) = B\cdot(\pi R^2)\cdot \sin(\omega t)$$

Have: $$\mathcal{E} = \frac{d\Phi}{dt} = B\cdot(\pi R^2)\cdot \omega \cos(\omega t)$$

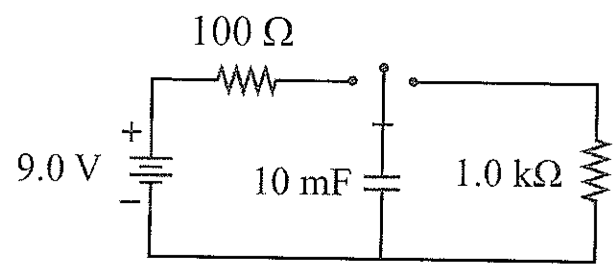
So $$\text{MAX } \mathcal{E} = B\cdot\omega\cdot\pi R^2$$

We need this to be 1V, so

$$\omega = \frac{1V}{B\pi R^2}$$

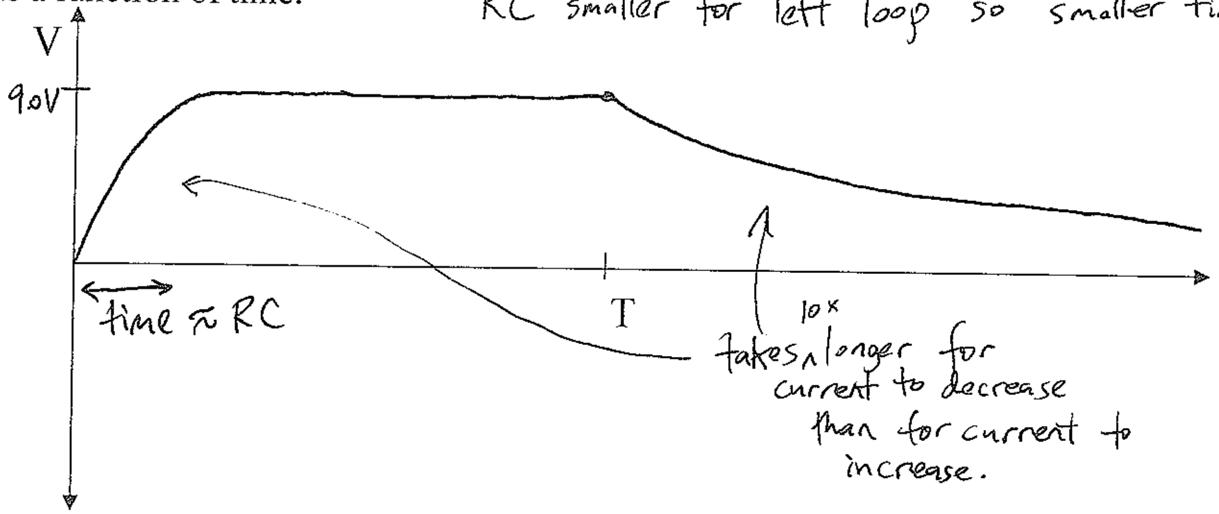
$$= \frac{1V}{(5\times10^{-5}T)\cdot\pi\left(\frac{10m}{2\pi}\right)^2} = 2.5\times10^3\ s^{-1}$$

**Question 11:** The circuit shown has a switch with three possible positions: left, right, and middle. The switch is initially in the middle position, which isn't connected to anything. **(3 points)**




a) At t = 0 the switch is flipped to the left and remains there until the voltage across the capacitor stops changing significantly. The switch is then flipped to the right (at time T). Plot the voltage across the capacitor (potential difference between top and bottom) as a function of time.

RC smaller for left loop so smaller time constant.




b) It turns out that the capacitor is actually the Not-Explodatron 9000, a device that, once charged, needs at least 7 V potential difference at all times, or the world will explode. How long after time T does humanity have to realize the folly of moving the switch to the right and move it back to the left?

The charge on the capacitor decays exponentially after time T.

$$Q = Q_0 e^{-\frac{t}{RC}}$$

$t$ ← time after time T.

The potential is

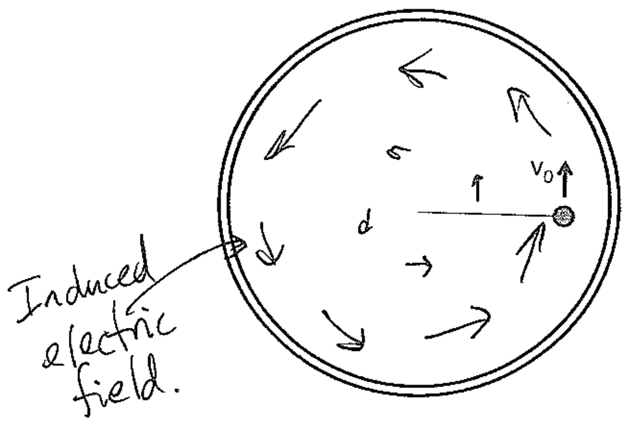
$$V = \frac{Q}{C} = \frac{Q_0}{C} e^{-\frac{t}{RC}} = V_0 e^{-\frac{t}{RC}}$$

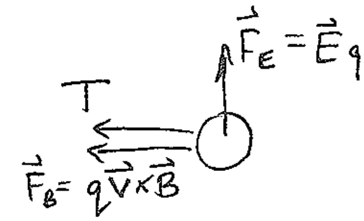
V will be 7V when

$$7V = 9V e^{-\frac{t}{RC}}$$

$$\Rightarrow t = RC \ln\left(\frac{9}{7}\right)$$

$$= 10^3 \Omega \cdot 10^{-2} F \cdot \ln\left(\frac{9}{7}\right) \boxed{= 2.5 s}$$




**Question 12:**

A positively charged object of mass M swings around at speed $v_0$ on a rope of length R. Suddenly a big solenoid appears around the swinging object as shown in the figure. At time t=0, the current in the solenoid starts increasing, resulting in a uniform magnetic field into the page with strength B = H t for t > 0. The object is observed to start swinging faster, but then at some time T starts spiraling towards the middle.

a) Explain why this occurs. (*there is no gravity, friction, or air drag in this problem).*
**(2 points)**

b) Determine the time T in terms of $v_0$, R, $Q_1$, M, and H. **(Happy Bonus Points™)**
(*Hint: something from the formula sheet may be useful)*

a) The increasing magnetic field results in an increasing inward force on the object. Initially, this doesn't make the object move inward; rather, it results in a decrease in tension of the rope. The object will only move inward when the inward acceleration due to B is larger than the acceleration for circular motion:

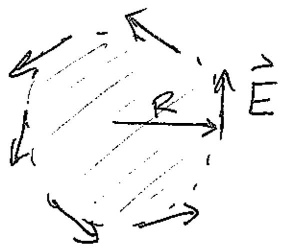
$$a_B > \frac{V^2}{R}$$

The magnetic force can't explain the increase in speed of the object, since its force is perpendicular to the velocity. This speed increase is due to the electric field induced by the changing magnetic field – this acts to increase the "current" (i.e. speed up the particle) so the magnetic field from the orbiting particle will counteract the increasing flux.

b) The quantitative way to figure out what the electric field is at the location of the object is to use Faraday's

Law in the form

$$\left| \oint \vec{E} \cdot d\vec{s} \right| = \frac{d\Phi_B}{dt}$$




We have:

$$\oint \vec{E} \cdot d\vec{s} = 2\pi R \cdot E$$

$$\Phi_B = \pi R^2 \cdot B = \pi R^2 \cdot H \cdot t$$

$$\frac{d\Phi_B}{dt} = \pi R^2 \cdot H.$$

So Faraday's Law gives:

$$2\pi R E = \pi R^2 \cdot H$$

$$\Rightarrow E = \frac{R}{2} \cdot H$$

The electric field increases the velocity in the $\theta$ direction by:

$$\frac{dV_\theta}{dt} = \frac{1}{m} F_E$$

$$= \frac{1}{m} \cdot Q\left(\frac{R}{2} \cdot H\right)$$

So: $V_\theta(t) = V_0 + \frac{QRH}{2M} \cdot t$

The object starts to spiral inward when:

$$a_B = \frac{V^2}{R}$$

$$\frac{QV_\theta B}{M} = \frac{V_\theta^2}{R} \Rightarrow V_\theta = \frac{QBR}{M} \Rightarrow V_0 + \frac{QRH}{2M} t = \frac{QR}{M} \cdot Ht$$

$$\Rightarrow V_0 = \frac{QRH}{2M} t \quad \Rightarrow \quad \boxed{t = \frac{2MV_0}{QRH}}$$