

This print-out should have 41 questions. Multiple-choice questions may continue on the next column or page – find all choices before answering.

001 0.0 points

Four copper wires of equal length are connected in series. Their cross-sectional areas are 1.4 cm^2 , 2.9 cm^2 , 3.1 cm^2 , and 6 cm^2 .

If a voltage of 87 V is applied to the arrangement, determine the voltage across the 2.9 cm^2 wire.

Correct answer: 19.3753 V.

Explanation:

$$\begin{aligned} \text{Let : } A_1 &= 1.4 \text{ cm}^2, \\ A_2 &= 2.9 \text{ cm}^2, \\ A_3 &= 3.1 \text{ cm}^2, \\ A_4 &= 6 \text{ cm}^2, \quad \text{and} \\ V_{tot} &= 87 \text{ V}. \end{aligned}$$

The resistance of the copper wire is proportional to the length of the wire and inversely proportional to the cross sectional area of the wire. Since the lengths are the same, and the current i is the same for all resistors connected in series, taking $r \propto \frac{1}{A}$, etc, we have

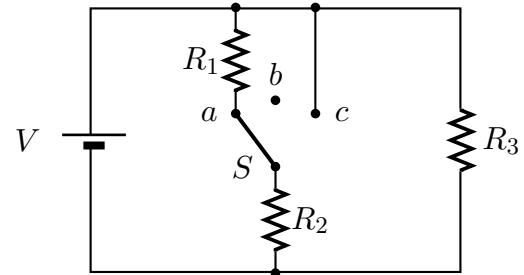
$$i = \frac{V_{tot}}{r_1 + r_2 + r_3 + r_4} = \frac{V_2}{r_2},$$

where V_{tot} is the difference in voltage across all for wires and V_2 is the difference in voltage across the second wire only. Solving for V_2 , we have

$$\begin{aligned} V_2 &= \frac{r_2}{r_1 + r_2 + r_3 + r_4} V_{tot} \\ &= \frac{\frac{1}{A_2}}{\frac{1}{A_1} + \frac{1}{A_2} + \frac{1}{A_3} + \frac{1}{A_4}} V_{tot} \\ &= \frac{\frac{1}{2.9 \text{ cm}^2}}{\frac{1}{1.4 \text{ cm}^2} + \frac{1}{2.9 \text{ cm}^2} + \frac{1}{3.1 \text{ cm}^2} + \frac{1}{6 \text{ cm}^2}} \times (87 \text{ V}) \\ &= \boxed{19.3753 \text{ V}}. \end{aligned}$$

002 (part 1 of 2) 0.0 points

In the figure below the switch S is initially in position **a**.



What happens to the current through R_3 when the switch is moved to the open position **b**? $R_1 = R_2 = R_3$. Neglect the internal resistance of the battery.

1. The current through R_3 remains the same. **correct**
2. The current through R_3 is reduced to one-half its original value.
3. The current through R_3 increases to three-halves its original value.
4. The current through R_3 decreases to two-thirds its original value.
5. The current through R_3 increases to twice its original value.

Explanation:

The voltage across R_3 is the $\mathcal{E}$ of the battery, and is unchanged. The current through R_3 remains the same, $\frac{\mathcal{E}}{R_3}$.

003 (part 2 of 2) 0.0 points

What happens when switch S is moved to position **c**, leaving R_2 and R_3 parallel?

1. The current through R_3 increases.
2. The current through R_2 remains the same as when R_1 was in the circuit.

3. The current through R_3 decreases.

4. The current through R_2 is half what it was with R_1 in the circuit.

5. The current through R_2 and R_3 are now the same. **correct**

Explanation:

Since R_2 and R_3 have the same terminal voltage and resistance, the current through R_2 and R_3 must now be the same.

004 0.0 points

Consider a silver wire with a cross-sectional area of 1 mm^2 carrying 0.4 A of current. The conductivity of silver is $6.3 \times 10^7 \text{ (A/m}^2\text{)(V/m)}$. Calculate the magnitude of the electric field required to drive this current through the wire.

Correct answer: 0.00634921 V/m .

Explanation:

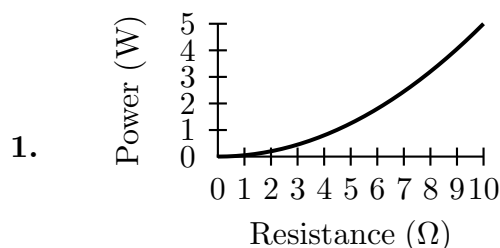
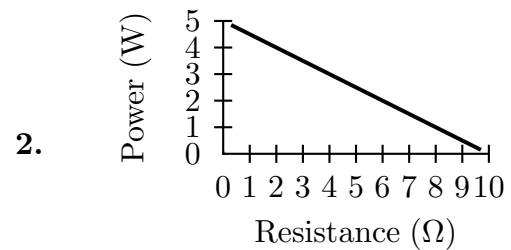
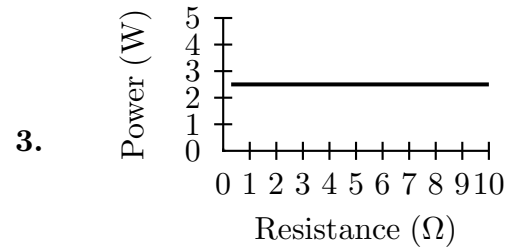
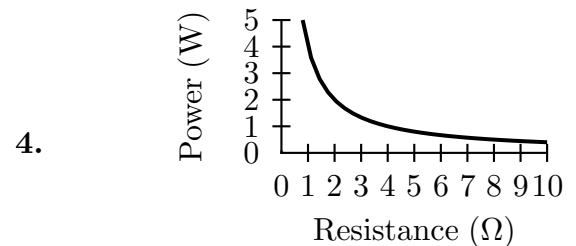
Let J be the current density. We can write

$$\begin{aligned} J &= \frac{I}{A} \\ \Rightarrow E &= \frac{J}{\sigma} = \frac{I/A}{\sigma} \\ &= \frac{0.4 \text{ A}}{(1 \text{ mm}^2)(6.3 \times 10^7 \text{ (A/m}^2\text{)(V/m)})} \\ &= \boxed{0.00634921 \text{ V/m}}. \end{aligned}$$

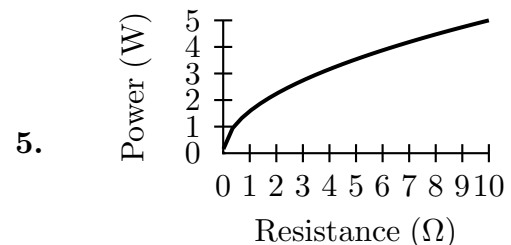
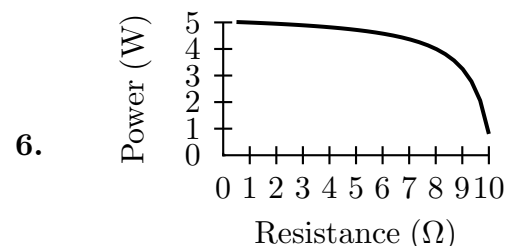
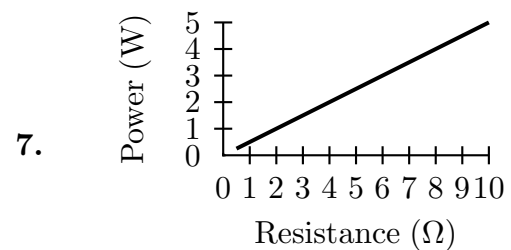
005 0.0 points

A variable resistor is connected across a constant voltage source.

Which of the following graphs represents the power P dissipated by the resistor as a function of its resistance R ?



correct



Explanation:

The power dissipated in the resistor has

several expressions

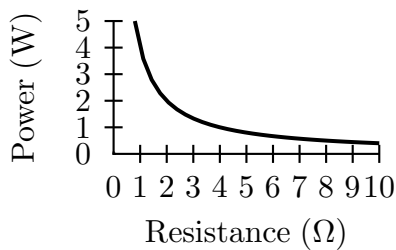
$$P = \mathcal{E} I = \frac{\mathcal{E}^2}{R} = I^2 R,$$

where the last two are simply derived from the first equation together with the application of the Ohm's law.

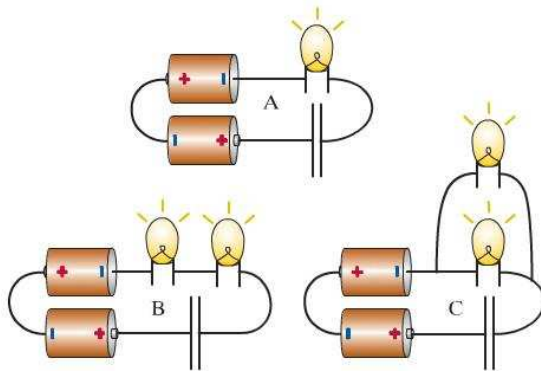
Since the resistor is connected to a constant voltage source $\mathcal{E} = \text{constant}$

$$P = \frac{\mathcal{E}^2}{R} = \frac{\text{constant}}{R},$$

tells us that the power is inversely proportional to the resistance $\left(P \propto \frac{1}{R}\right)$.



006 0.0 points



Figure

Figure above shows 3 circuits labeled A, B and C. All the light bulbs, batteries and the capacitors are identical. Denote the time constants of the circuits by T_A , T_B and T_C . The charges after the capacitors are fully charged by Q_A , Q_B and Q_C . Choose from among the following statements:

- Ia. $T_B = \frac{T_A}{2}$.
 Ib. $T_B = 2T_A$.

- IIa. $T_C = \frac{T_A}{2}$.
 IIb. $T_C = 2T_A$.

- IIIa. $Q_A = Q_B = Q_C$.
 IIIb. $Q_A < Q_B$, $Q_A > Q_C$.

1. Ia, IIa, IIIa
2. Ia, IIb, IIIb
3. Ib, IIb, IIIa
4. Ib, IIa, IIIa **correct**
5. Ia, IIa, IIIb
6. Ib, IIa, IIIb
7. Ib, IIb, IIIb
8. Ia, IIb, IIIa

Explanation:

For circuit A, $T_A = RC$.

For circuit B, the two bulbs are in series. It has a resistance $2R$. So $T_B = 2RC$.

For circuit C, the two bulbs are in parallel. It has a resistance $\frac{R}{2}$. So $T_C = \frac{RC}{2}$.

Put all together, we have $T_B = 2T_A$, and $T_C = \frac{T_A}{2}$. So Ib and IIa are correct.

After waiting for a long time, for all three cases $Q = \mathcal{E}C$. So $Q_A = Q_B = Q_C$. Hence, IIIa is correct.

007 0.0 points

An $18 \mu\text{F}$ capacitor is first charged to a potential 18 V , then connected in parallel with a $5 \mu\text{F}$ capacitor that had been charged to the half the initial potential of the other capacitor, i.e. 9 V .

What is the the final potential difference V_f across the capacitors?.

Correct answer: 16.0435 V .

Explanation:

Let : $C_1 = 18 \mu\text{F}$,
 $C_2 = 5 \mu\text{F}$, and
 $V_1 = 18 \text{ V}$.

Initially, before C_2 is connected in parallel to C_1 , the total charge in the system is

$$Q_i = C_1 V_1 + (0.5 C_2) V_1 = V_1 (C_1 + 0.5 C_2) .$$

When they are connected in parallel, the potential V_f is the same on both capacitors, so by conservation of charge

$$Q_i = Q_f$$

$$V_1 (C_1 + 0.5 C_2) = (C_1 + C_2) V_f .$$

$$V_f = V_1 \frac{C_1 + 0.5 C_2}{C_1 + C_2}$$

$$= (18 \text{ V}) \frac{18 \mu\text{F} + 0.5 * 5 \mu\text{F}}{18 \mu\text{F} + 5 \mu\text{F}}$$

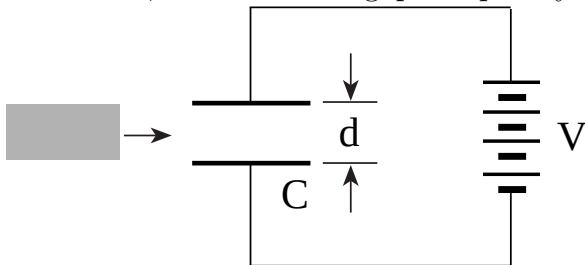
$$= \boxed{16.0435 \text{ V}} .$$

008 0.0 points

Consider the setup shown, where a capacitor with a capacitance C is connected to a battery with emf V and negligible internal resistance.

Before the insertion of the dielectric slab with dielectric constant κ , the charge on the capacitor is $Q = C V$ and the energy density is $u = \frac{1}{2} \epsilon_0 E^2$.

Now, keeping the battery connected, insert the dielectric, which fills the gap completely.



Suppose the battery remains connected during the insertion of the slab. Determine the energy density u' within the gap in the presence of the dielectric.

1. $u' = u \kappa^2$

2. $u' = \frac{u}{\kappa}$

3. $u' = u \kappa$ **correct**

4. $u' = \frac{u}{\kappa^2}$

5. $u' = u$

Explanation:

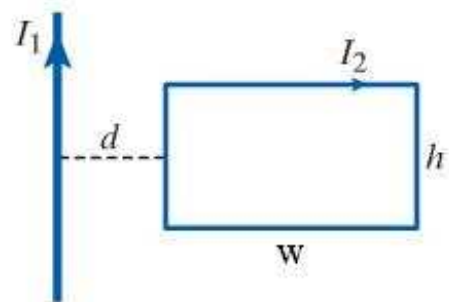
We are trying to find u' , the energy density after the insertion of the dielectric, in terms of u , the energy density before. The increase of C to $C' = \kappa C$, with V unchanged, draws more charge from the battery to the capacitor. Then we can calculate

$$U' = \frac{1}{2} C' V^2 = \frac{1}{2} \kappa C V^2 = \kappa U .$$

Since U changes and the volume doesn't, u must change by the same factor.

009 0.0 points

A long wire carries a current $I_1 = 1 \text{ A}$ upward, and a rectangular loop of height $h = 0.2 \text{ m}$ and width $w = 0.1 \text{ m}$ carries a current $I_2 = 6 \text{ A}$ clockwise as shown in Figure below. The loop is a distance $d = 1 \text{ cm}$ away from the long wire. The long wire and the rectangular loop are in the same plane.



Figure

Find the magnitude of the net magnetic force exerted by the long wire on the rectangular loop.

Correct answer: $2.18 \times 10^{-5} \text{ N}$.

Explanation:

$$\begin{aligned} \text{let : } I_1 &= 1 \text{ A}, \\ I_2 &= 6 \text{ A}, \\ d &= 1 \text{ cm} = 0.01 \text{ m}, \\ h &= 0.2 \text{ m}, \quad \text{and} \\ w &= 0.1 \text{ m}. \end{aligned}$$

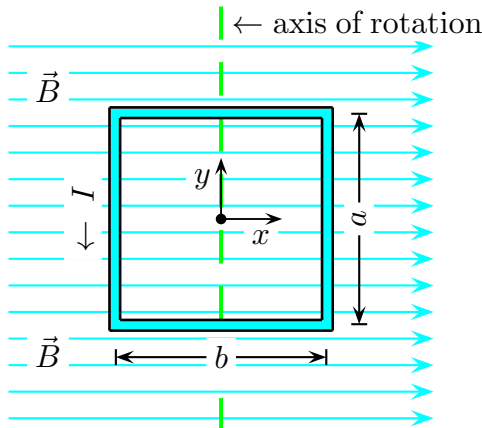
The forces on the top and bottom wires cancel each other. The force on the left wire is $F_B = I_2 h B = I_2 h \frac{\mu_0 I_1}{2\pi d}$ to the left. The force on the right wire is similarly $F_B = I_2 h \frac{\mu_0 I_1}{2\pi (d+w)}$ to the right.

The net force exerted by the long wire on the loop is

$$\begin{aligned} F_{\text{net}} &= I_2 h \frac{\mu_0 I_1}{2\pi d} - I_2 h \frac{\mu_0 I_1}{2\pi (d+w)} \\ &= I_2 h \mu_0 I_1 \left(\frac{1}{2\pi d} - \frac{1}{2\pi (d+w)} \right) \\ &= (1 \text{ A})(6 \text{ A})(0.2 \text{ m})(2 \times 10^{-7} \text{ N} \cdot \text{A}^{-2}) \\ &\quad \left(\frac{1}{0.01 \text{ m}} - \frac{1}{0.01 \text{ m} + 0.1 \text{ m}} \right) \\ &= 2.18 \times 10^{-5} \text{ N}. \end{aligned}$$

010 (part 1 of 3) 0.0 points

Consider a rectangular current loop lying in the xy -plane. A constant magnetic field $\vec{B}$ is parallel to the x -axis. In the figure, the z -axis points out of the page.



Determine the magnitude ($\|\vec{F}\| \equiv F$) of the net magnetic force on the loop.

$$1. F = 2 I b B$$

$$2. F = 2 I a B$$

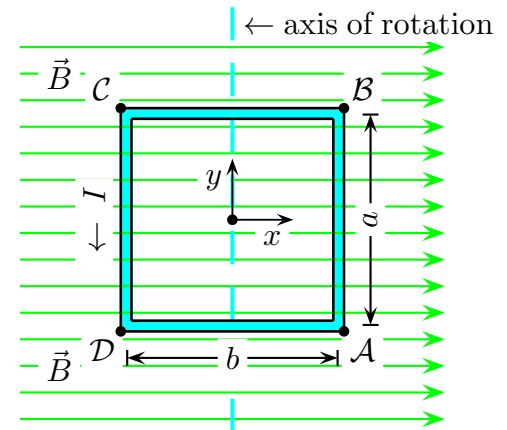
$$3. F = I a B$$

$$4. F = I \left(\frac{a+b}{2} \right) B$$

$$5. F = I b B$$

$$6. F = I (a+b) B$$

$$7. F = 0 \text{ correct}$$

Explanation:

Basic Concepts: Force on a current-carrying wire in a magnetic field

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

Torque on a current-carrying loop in a magnetic field

$$\vec{\tau} = \vec{\mu} \times \vec{B}. \quad (1)$$

Solution: Net magnetic force

$$\begin{aligned} \vec{F} &= \sum_i I \vec{L}_i \times \vec{B} = \left(\sum I \vec{L}_i \right) \times \vec{B} \\ &= i (\overline{AB} + \overline{BC} + \overline{CD} + \overline{DA}) \times \vec{B}. \end{aligned}$$

The segments $\overline{DA}$ and $\overline{BC}$ are parallel to the magnetic field and give no contribution to the force, so

$$\vec{F} = I (\overline{AB} + \overline{CD}) \times \vec{B}.$$

The segments $\overline{AB}$ and $\overline{CD}$ are perpendicular to $\vec{B}$ but opposite in direction ($\overline{AB} = -\overline{CD}$) so the net force is

$$\vec{F} = 0.$$

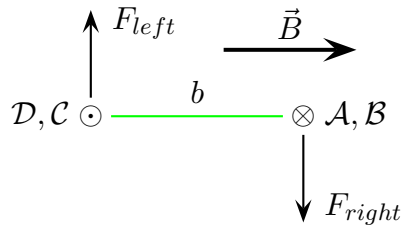
011 (part 2 of 3) 0.0 points

Determine the magnitude of the magnetic torque τ on the loop when the loop is in the position shown in the figure.

1. $\tau = I a^2 B$
2. $\tau = \frac{1}{\sqrt{2}} I a B$
3. $\tau = \frac{1}{\sqrt{2}} I b B$
4. $\tau = I b^2 B$
5. $\tau = \frac{1}{\sqrt{2}} I b^2 B$
6. $\tau = I a b B$ **correct**
7. $\tau = I \frac{a}{b} B$
8. $\tau = I a B$
9. $\tau = I b B$
10. $\tau = \frac{1}{\sqrt{2}} I a^2 B$

Explanation:

When viewed from below



The magnitude of the force is $F = I \ell B$, so

$$F_{right} = F_{left} = I a B,$$

since the length of segments AC and DB are a . The lever arm of each is $\frac{b}{2}$, but both forces try to rotate the loop clockwise so the magnitudes of the torques add

$$\begin{aligned} \tau &= \tau_{right} + \tau_{left} \\ &= I a B \frac{b}{2} + I a B \frac{b}{2} \\ &= I a b B. \end{aligned}$$

We could also immediately have applied equation (1) with a magnetic moment magnitude $\mu = I \mathcal{A}$ ($\mathcal{A}$ is the area of the loop) so that

$$\tau = \mu B = I a b B,$$

since $\vec{\mu}$ and $\vec{B}$ are perpendicular.

012 (part 3 of 3) 0.0 points

Determine the direction of the magnetic torque $\hat{\tau}$ on the loop when the loop is in the position shown in the figure.

1. $\hat{\tau} = \hat{k}$
2. $\hat{\tau} = -\hat{j}$
3. $\hat{\tau} = -\hat{k}$
4. $\hat{\tau} = \hat{j}$ **correct**
5. $\hat{\tau} = \hat{i}$
6. $\hat{\tau} = -\hat{i}$

Explanation:

The magnetic moment points along the normal of the loop, which is out of the paper in the first figure.

$$\vec{\mu} = I \mathcal{A} \hat{n} = I a b \hat{k},$$

where $\hat{k}$ is the unit vector in the z -direction (out of the paper). The magnetic field is $\vec{B} = B \hat{i}$. Again, equation (1) gives

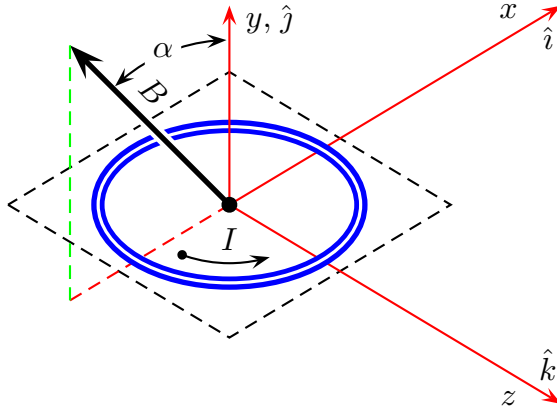
$$\begin{aligned} \vec{\tau} &= \vec{\mu} \times \vec{B} = I a b B (\hat{k} \times \hat{i}) \\ &= I a b B \hat{j}, \end{aligned}$$

so the torque vector points in the y -direction, in accordance with the right-hand rule. A torque vector signifies a rotation through the screwdriver-rule – if free to rotate, the loop will begin to rotate clockwise in the from-below figure, which verifies what we found in Part 2.

013 (part 1 of 3) 0.0 points

A circular current loop of radius R is placed in a horizontal plane and maintains a current

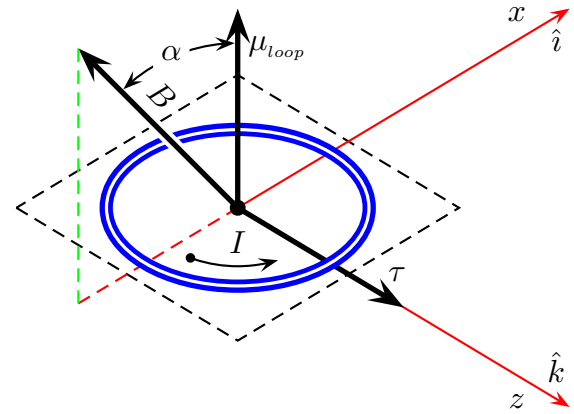
I . There is a constant magnetic field $\vec{B}$ in the xy -plane, with the angle α ($\alpha < 90^\circ$) defined with respect to y -axis. The current in the loop flows counterclockwise as seen from above.



What is the direction of the magnetic moment $\vec{\mu}$?

1. $-\cos \alpha \hat{j} + \sin \alpha \hat{i}$
2. $+\hat{i}$
3. $+\hat{k}$
4. $-\hat{i}$
5. $+\hat{j}$ **correct**
6. $\sin \alpha \hat{j} + \cos \alpha \hat{i}$
7. $-\hat{k}$
8. $\cos \alpha \hat{j} - \sin \alpha \hat{i}$
9. $-\sin \alpha \hat{j} - \cos \alpha \hat{i}$
10. $-\hat{j}$

Explanation:



According to the right-hand rule, the magnetic moment is upward.

014 (part 2 of 3) 0.0 points

If the current in the loop is 0.276 A and its radius is 2.31 cm, what is the magnitude of the magnetic moment of the loop?

Correct answer: 0.000462682 A · m².

Explanation:

$$\text{Let : } I = 0.276 \text{ A, and} \\ R = 2.31 \text{ cm.}$$

The magnetic dipole moment is

$$\begin{aligned} \mu &= I A = I \pi R^2 \\ &= (0.276 \text{ A}) (3.15) (2.31 \text{ cm})^2 \\ &= \boxed{0.000462682 \text{ A} \cdot \text{m}^2} \end{aligned}$$

015 (part 3 of 3) 0.0 points

What is the direction of the torque vector $\vec{\tau}$?

1. $\cos \alpha \hat{j} - \sin \alpha \hat{i}$
2. $-\hat{j}$
3. $-\hat{k}$
4. $\sin \alpha \hat{j} + \cos \alpha \hat{i}$
5. $-\cos \alpha \hat{j} + \sin \alpha \hat{i}$
6. $+\hat{i}$
7. $+\hat{j}$

8. $-\sin \alpha \hat{j} - \cos \alpha \hat{i}$

9. $-\hat{i}$

10. $+\hat{k}$ correct

Explanation:

The torque is

$$\begin{aligned}\vec{\tau} &= \vec{\mu} \times \vec{B} \\ &= \mu (\hat{j}) \times [B_x (-\hat{i}) + B_y (+\hat{j})]\end{aligned}$$

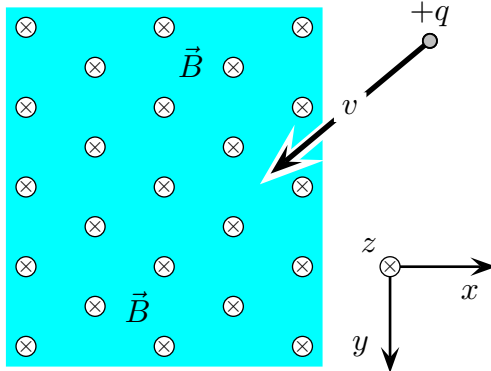
and $\hat{j} \times \hat{j} = 0$ and $+\hat{j} \times (-\hat{i}) = \hat{k}$, so

$$\vec{\tau} = \mu B_x \hat{k}$$

so the direction of the torque is $+\hat{k}$, which agrees with the answer based on the right-hand rule.

016 0.0 points

A positively charged particle moving at 45° angles to both the x -axis and y -axis enters a magnetic field (pointing into of the page), as shown. $\hat{i}$ is in the x -direction, $\hat{j}$ is in the y -direction, and $\hat{k}$ is in the z -direction.



What is the initial direction of deflection?

1. $\hat{F} = \frac{1}{\sqrt{2}} (+\hat{j} + \hat{k})$

2. $\hat{F} = \frac{1}{\sqrt{2}} (+\hat{k} + \hat{i})$

3. $\hat{F} = \frac{1}{\sqrt{2}} (-\hat{j} + \hat{k})$

4. $\hat{F} = \frac{1}{\sqrt{2}} (-\hat{j} + \hat{i})$

5. $\vec{F} = 0$; no deflection

6. $\hat{F} = \frac{1}{\sqrt{2}} (-\hat{k} - \hat{i})$

7. $\hat{F} = \frac{1}{\sqrt{2}} (-\hat{j} - \hat{i})$

8. $\hat{F} = \frac{1}{\sqrt{2}} (-\hat{k} + \hat{i})$

9. $\hat{F} = \frac{1}{\sqrt{2}} (-\hat{j} - \hat{k})$

10. $\hat{F} = \frac{1}{\sqrt{2}} (+\hat{j} + \hat{i})$ correct

Explanation:

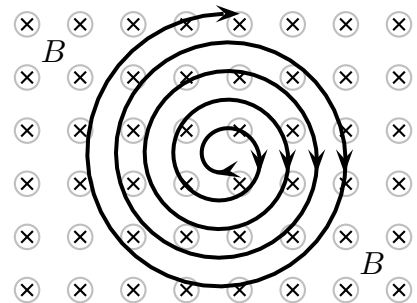
The force is $\vec{F} = q \vec{v} \times \vec{B}$, $\vec{B} = B (+\hat{i})$, $\vec{v} = \frac{1}{\sqrt{2}} v (-\hat{i} + \hat{j})$, and $q > 0$, so

$$\begin{aligned}\vec{F} &= +|q| \vec{v} \times \vec{B} \\ &= +|q| \frac{1}{\sqrt{2}} v B [(-\hat{i} + \hat{j}) \times (+\hat{k})] \\ &= +|q| \frac{1}{\sqrt{2}} v B (+\hat{j} + \hat{i})\end{aligned}$$

$$\hat{F} = \boxed{\frac{1}{\sqrt{2}} (+\hat{j} + \hat{i})}.$$

017 0.0 points

A static uniform magnetic field is directed into the page. A charged particle moves in the plane of the page following a clockwise spiral of increasing radius as shown.



Neglect the effect due to gravity.

What is a reasonable explanation?

1. The charge is positive and slowing down.

2. The charge is neutral and with a constant speed.

3. The charge is neutral and speeding up.

4. The charge is negative and speeding up.
correct

5. The charge is negative and slowing down.

6. The charge is neutral and slowing down.

7. The charge is negative and with a constant speed.

8. The charge is positive and speeding up.

9. None of these

10. The charge is positive and with a constant speed.

Explanation:

We know that when a charged particle moves in a uniform magnetic field with a constant speed, it undergoes a circular motion with the centripetal force provided by the magnetic force, namely

$$m \frac{v^2}{r} = q v B ,$$

so we know that the radius is in fact proportional to the speed,

$$r = \frac{m}{qB} v .$$

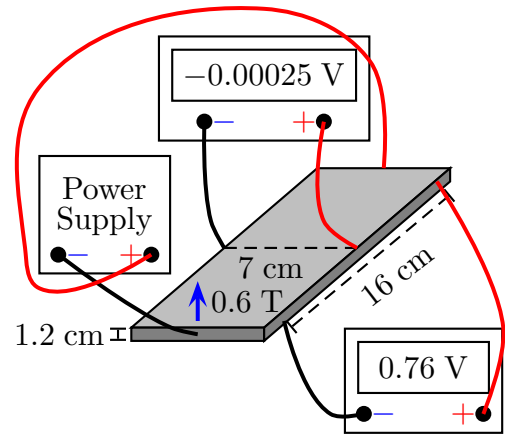
Since the particle follows a spiral of increasing radius, we can judge that it is speeding up.

The magnetic force $\vec{F} = q \vec{v} \times \vec{B}$ must be in the direction for the centripetal force $-\hat{r}$ (pointed inward) of this particle in clockwise circular motion. Since $\vec{v} \times \vec{B}$ is in the positive $\hat{r}$ direction, the particle has a negative charge.

018 (part 1 of 3) 0.0 points

A slab made of unknown material is connected to a power supply as shown in the figure below. There is a uniform magnetic field of 0.6 T pointing upward throughout this region (perpendicular to the horizontal slab). Two voltmeters are connected to the slab and read steady voltages as shown. The connections

across the slab are carefully placed directly across from each other. Assume that there is only one kind of mobile charge in this material, but we don't know whether they are positive or negative.



Determine the (previously unknown) sign of the mobile charges.

1. Not enough information

2. Negative

3. Positive **correct**

Explanation:

The voltmeter reading of -0.00025 V indicates that the back side of the slab is at a higher potential than the front side, so there is a Hall-effect transverse electric field E_H . That means that there must be extra $+$ charge on the back side (and extra $-$ charge on the front).

The conventional current flow and the main electric field E point as shown, and the 0.76 V reading is consistent: the potential is dropping in the direction of E and the conventional current. Positive carriers move in the direction of conventional current, and experience a magnetic force toward the backside, which would lead to $+$ charge buildup on the back side, which is what is observed.

Negative carriers move opposite to the conventional current, and would also experience a magnetic force toward the back side, which would lead to $-$ charge buildup on the back side, which is not observed. So the charge

carriers are positive.

019 (part 2 of 3) 0.0 points

What is the drift speed v of the mobile charges?

Correct answer: 0.00595238 m/s.

Explanation:

In the steady state, the transverse electric and magnetic forces must balance, so

$$q E_H = q v B \sin 90^\circ = q v B.$$

So $E_H = v B$. The drift speed v is uniform throughout the slab (current conservation and constant cross-sectional area), and the magnetic field B is uniform throughout this region. So $E_H = v B$ must be uniform along the 7 cm path across the slab, and we can write

$$\begin{aligned} |\Delta V| &= 0.00025 \text{ V} \\ &= E_H w \\ &= E_H (7 \text{ cm}) \\ \Rightarrow E_H &= \frac{0.00025 \text{ V}}{7 \text{ cm}} \\ &= 0.00357143 \text{ V/m}. \end{aligned}$$

And

$$\begin{aligned} v &= \frac{E_H}{B} \\ &= \frac{0.00357143 \text{ V/m}}{0.6 \text{ T}} \\ &= \boxed{0.00595238 \text{ m/s}}. \end{aligned}$$

Note that we have experimentally determined the drift speed v , independent of the carrier charge q and the density of charge carriers n .

020 (part 3 of 3) 0.0 points

What is the mobility u of the mobile charges?

Correct answer: 0.00125313 (m/s)/(V/m).

Explanation:

We know that $v = u E$, so $u = \frac{v}{E}$, where E is the electric field in the direction of the current. Since v is uniform, E must be uniform, and we can write

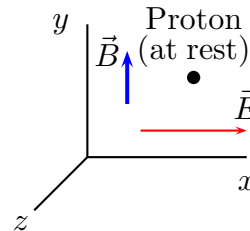
$$\begin{aligned} |\Delta V| &= E L \\ \Rightarrow E &= \frac{0.76 \text{ V}}{16 \text{ cm}} \\ &= 4.75 \text{ V/m}. \end{aligned}$$

Knowing E and v , we can now find the mobility:

$$\begin{aligned} u &= \frac{v}{E} \\ &= \frac{0.00595238 \text{ m/s}}{4.75 \text{ V/m}} \\ &= \boxed{0.00125313 \text{ (m/s)/(V/m)}}. \end{aligned}$$

021 (part 1 of 4) 0.0 points

Consider the situation in the figure below, in which there is a uniform electric field in the x direction and a uniform magnetic field in the y direction.



At time $t = 0$ when the proton is at rest, what is the direction of the magnetic force on the proton?

1. $\vec{F}_B = \langle -F_B, 0, 0 \rangle$
2. $\vec{F}_B = \langle 0, -F_B, 0 \rangle$
3. $\vec{F}_B = \langle 0, 0, F_B \rangle$
4. $\vec{F}_B = \langle 0, 0, -F_B \rangle$
5. $\vec{F}_B = \langle 0, 0, 0 \rangle$ **correct**
6. $\vec{F}_B = \langle F_B, 0, 0 \rangle$
7. $\vec{F}_B = \langle 0, F_B, 0 \rangle$

Explanation:

Since the expression for the magnetic force is dependent upon velocity, $F = q \vec{v} \times \vec{B}$, the

magnetic force is zero because the proton is not moving.

022 (part 2 of 4) 0.0 points

Immediately after the proton is released (i.e. *just* after $t = 0$), what is the direction of the magnetic force on the proton?

1. $\vec{F}_B = \langle 0, -F_B, 0 \rangle$
2. $\vec{F}_B = \langle F_B, 0, 0 \rangle$
3. $\vec{F}_B = \langle 0, F_B, 0 \rangle$
4. $\vec{F}_B = \langle 0, 0, 0 \rangle$
5. $\vec{F}_B = \langle 0, 0, -F_B \rangle$
6. $\vec{F}_B = \langle -F_B, 0, 0 \rangle$
7. $\vec{F}_B = \langle 0, 0, F_B \rangle$ **correct**

Explanation:

Immediately after the proton is released, it is accelerated by E in the $+x$ direction. Since the proton now has a velocity in the $+x$ direction,

$$F_B = q\vec{v} \times \vec{B} = qvB(\hat{x} \times \hat{y}) = F_B\hat{z}.$$

023 (part 3 of 4) 0.0 points

Will the proton ever acquire a velocity in the $\pm\hat{y}$ direction?

1. unable to determine
2. yes
3. no **correct**

Explanation:

E will always exert a force in the $+x$ direction, while acceleration due to B must be in the xz plane (perpendicular to B). There is no field capable of generating $\pm\hat{y}$ acceleration, so the answer is no.

024 (part 4 of 4) 0.0 points

Letting $v_x(t)$ and $v_z(t)$ denote the (time-dependent) velocities of the proton in the x

and z directions, what is the equation of motion for the proton?

1. $F_{e+} = q[(E - Bv_z)\hat{z} + Bv_x\hat{x}]$
2. $F_{e+} = q[(E + Bv_z)\hat{x} + Bv_x\hat{z}]$
3. $F_{e+} = q[(E - Bv_x)\hat{z} + Bv_z\hat{x}]$
4. $F_{e+} = q[(E - Bv_x)\hat{x} + Bv_z\hat{z}]$
5. $F_{e+} = q[(E + Bv_z)\hat{x} - Bv_x\hat{z}]$
6. $F_{e+} = q[(E + Bv_x)\hat{z} - Bv_z\hat{x}]$
7. $F_{e+} = q[(E - Bv_z)\hat{x} + Bv_x\hat{z}]$ **correct**

Explanation:

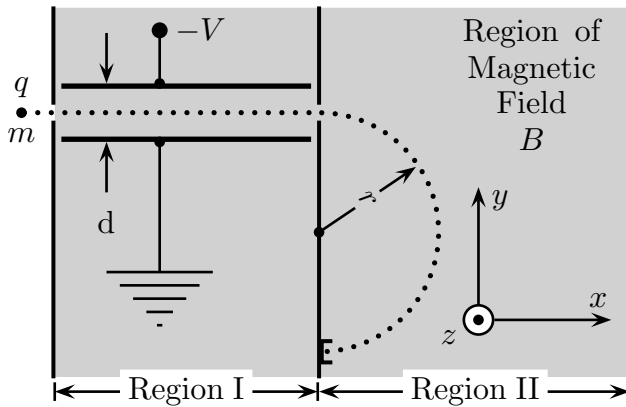
The Lorentz force law tells us that

$$\begin{aligned} F_{e+} &= q(\vec{E} + \vec{v} \times \vec{B}) \\ &= q[E\hat{x} + (v_x\hat{x} + v_z\hat{z}) \times B\hat{y}] \\ &= q[E\hat{x} + Bv_x\hat{z} - Bv_z\hat{x}] \\ &= q[(E - Bv_z)\hat{x} + Bv_x\hat{z}]. \end{aligned}$$

025 (part 1 of 3) 0.0 points

A device (“source”) emits a bunch of charged ions (particles) with a range of velocities. Some of these ions pass through the left slit and enter “Region I” in which there is a vertical uniform electric field E (in the $-\hat{y}$ direction) and a B uniform magnetic field (aligned with the $\pm\hat{k}$ -direction) as shown by the shaded area. $\hat{i}$ is in the direction $+x$ (to the right), $\hat{j}$ is in the direction $+y$ (up the page), and $\hat{k}$ is in the direction $+z$ (out of the page).

The ions that make it into “Region II” are observed to be deflected downward and then follow a circular path with a radius of r .



In which direction (relative to the coordinate system above) should the magnetic field point in order for positively charged ions to move along the path shown by the dotted line in the diagram?

1. $\|\vec{B}\| = 0$; direction undetermined
2. $\frac{\vec{B}}{\|\vec{B}\|} = -\hat{k}$
3. $\frac{\vec{B}}{\|\vec{B}\|} = +\hat{k}$ **correct**

Explanation:

To obtain a straight orbit, the upward and downward forces need to cancel. The force on a charged particle is

$$\vec{F} = \vec{F}_E + \vec{F}_B = q(\vec{E} + \vec{v} \times \vec{B}).$$

For the force to be zero, we need

$$\begin{aligned}\vec{F}_E + \vec{F}_B &= 0 \\ \vec{F}_E &= -\vec{F}_B.\end{aligned}$$

Therefore, the forces are equal and opposite and the magnitude of forces are equal; i.e., $\|\vec{F}_E\| = \|\vec{F}_B\|$.

The force due to the magnetic field provides the centripetal force that causes the negative ions to move in the semicircle.

As the positively charged ion exits the region of the electric field, $\vec{F}_B = q \vec{v} \times \vec{B}$, so by the right-hand rule the magnetic field must point out of the page (or in the $+z$ -direction $+\hat{k}$), since the force $\vec{F}$ is in the direction up the page; i.e., “ $+\hat{j}$.”

$$\begin{aligned}\frac{q}{|q|} &= +, \quad \frac{\vec{v}}{\|\vec{v}\|} = +\hat{i}, \quad \frac{\vec{B}}{\|\vec{B}\|} = ?, \\ \frac{\vec{F}_B}{\|\vec{F}_B\|} &= -\hat{j}, \quad \hat{i} \times \hat{k} = -\hat{j}, \quad \text{and the force} \\ \vec{F} &= q \vec{v} \times \vec{B} = \|\vec{F}\| (-\hat{j}), \text{ so}\end{aligned}$$

$$\begin{aligned}\frac{\vec{F}}{\|\vec{F}\|} &= \frac{q}{|q|} \left[\frac{\vec{v}}{\|\vec{v}\|} \times \frac{\vec{B}}{\|\vec{B}\|} \right] \\ &= + \left[(+\hat{i}) \times (+\hat{k}) \right] \\ &= -\hat{j} \\ \frac{\vec{B}}{\|\vec{B}\|} &= +\hat{k}.\end{aligned}$$

026 (part 2 of 3) 0.0 points

In “Region I”, the electric potential between the plates is V , the distance between the plates is d , which gives rise to an electric field E . The magnetic field in both “Regions I and II” is B .

What is the velocity of the ion?

1. $v = \frac{B}{E}$
2. $v = \sqrt{EB}$
3. $v = \frac{E}{B}$ **correct**
4. $v = \frac{E^2}{B}$
5. $v = \left(\frac{B}{E}\right)^2$
6. $v = \frac{E}{B^2}$
7. $v = EB$
8. $v = \left(\frac{E}{B}\right)^2$
9. $v = \frac{B^2}{E}$
10. $v = \frac{B}{E^2}$

Explanation:

Since the electric and magnetic forces on the ion are equal,

$$qE = qvB$$

$$v = \frac{E}{B}.$$

027 (part 3 of 3) 0.0 points

The ions that make it into “Region II” are observed to be deflected downward and then follow a circular path with a radius of r .

If the charge on each ion is q , what is the mass of the ions?

1. $m = \frac{qE^2}{rB}$
2. $m = \frac{qB}{rE}$
3. $m = \frac{qE}{rB}$
4. $m = \frac{qEr}{B^2}$
5. $m = \frac{qBr}{E}$
6. $m = \frac{qBr}{E^2}$
7. $m = \frac{qB^2r}{E}$ correct
8. $m = \frac{qEr}{B}$
9. $m = \frac{qE^2r}{B}$
10. $m = \frac{qB^2}{rE}$

Explanation:

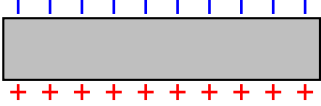
The radius of a circular path taken by a charged particle in a magnetic field is given by

$$r = \frac{mv}{qB}$$

$$m = q \frac{Br}{v} = q \frac{Br}{\frac{E}{B}} = \frac{qB^2r}{E}.$$

028 0.0 points

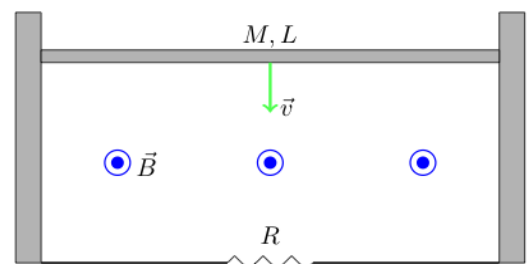
A neutral copper bar oriented horizontally moves upward through a region where there is a magnetic field out of the page. Which diagram correctly shows the distribution of charge on the bar?

1. 
2. 
3. 
4. 
5.  correct

Explanation:

According to the right-hand rule, the magnetic force on the negatively charged mobile electrons is to the left, causing negative charge to pile up on the left end of the bar and positive charge to pile up on the right end of the bar.

029 0.0 points



A Metal bar of mass M and length L slides down with negligible friction but good electrical contact between two vertical metal posts. The bar falls at a constant speed v . The bar

and posts have negligible electrical resistance, but the posts are connected at the bottom by a resistor of resistance R . The apparatus sits in a uniform magnetic field of magnitude B coming out of the page.

In terms of the given quantities and physical constants, determine the speed v of the bar.

1. $\frac{gR}{LB}$
2. $\frac{mg}{(LB)^2}$
3. $\sqrt{\frac{MgR}{LB}}$
4. $\frac{MgR}{(LB)^2}$ **correct**
5. $\frac{Mg(LB)^2}{R}$
6. $LB\sqrt{\frac{Mg}{R}}$
7. MgR
8. $\frac{\sqrt{MgR}}{LB}$

Explanation:

Since we are told the speed is constant, the magnetic and gravitational forces must balance, so

$$ILB = Mg \Rightarrow I = \frac{Mg}{LB}$$

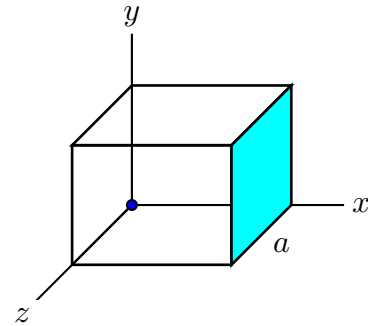
and I flows counterclockwise. Then, using the expression

$$\Delta V = \text{emf} = vBL$$

for a “battery” with negligible internal resistance, we can apply a loop rule $\Delta V - IR = 0$ and solve the resulting equation for v .

$$\begin{aligned}\Delta V &= IR \\ vBL &= \frac{Mg}{LB}R \\ v &= \frac{MgR}{(LB)^2}.\end{aligned}$$

Consider a charge q located at the origin and at the corner of a cube as shown in the figure. The sides of the cube have length a .



Find the total flux due to the charge q . (The total flux refers to the total flux emitted in all directions regardless of whether the cube is there.)

1. None of these
2. $4\pi a^2 q$
3. $\epsilon_0 q$
4. $\frac{q}{4\pi\epsilon_0}$
5. $\frac{4\pi q}{\epsilon_0}$
6. $\pi a q$
7. $2\pi a q$
8. $4\pi\epsilon_0 q$
9. $\frac{q}{\epsilon_0}$ **correct**

Explanation:

By Gauss' Law the **total** electric flux from q is

$$\Phi = \frac{q}{\epsilon_0}.$$

In other words, if we wrap the charge with a surface S , then the **total** electric flux through the surface is given by

$$\Phi = \Phi_S = \frac{q}{\epsilon_0}.$$

cube. Treat the charge as a small sphere located at the origin and consider then number of quadrants in three dimensional space.

{Hints: 1) use a symmetry argument together with the total flux due to q ; 2) remember, $\Phi_E = \vec{E} \bullet \vec{A}$ — in this case, $\vec{A}$ is the sum of the area vectors of the cube faces.}

1. $\frac{4q}{\epsilon_0}$
2. $\frac{q}{8\epsilon_0}$ **correct**
3. $\frac{4q}{\pi\epsilon_0}$
4. $8\pi a q$
5. $\frac{8q}{\epsilon_0}$
6. $\frac{8\pi q}{\epsilon_0}$
7. $\frac{8q}{\pi\epsilon_0}$
8. $\frac{4\pi q}{\epsilon_0}$
9. $4\pi a q$

10. $\pi a^2 q$

Explanation:

Using hint one, consider a Gaussian cube *completely* enclosing the charge — i.e. a cube of side length $2a$ centered on the origin. The flux through this larger cube is the total flux, and the smaller cube in question forms $1/8$ of the large cube. Using hint 2, the flux through the faces of the small cube that are bordered by the coordinate axes is 0. By symmetry, the flux through the outer faces of the small cube (and therefore the entire small cube) must be $1/8$ of the total flux:

$$\Phi_{cube} = \frac{1}{8} \Phi = \frac{q}{8\epsilon_0}.$$

032 (part 3 of 3) 0.0 points

If the charge is 2.23 C and the cube length is 1.99 m , find the flux through the shaded area. The permittivity of a vacuum is $8.8542 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$. Consider the symmetry properties of the cube.

Correct answer: $1.04941 \times 10^{10} \text{ N} \cdot \text{m}^2/\text{C}$.

Explanation:

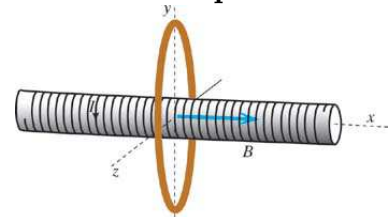
$$\begin{aligned} \text{Let : } q &= 2.23 \text{ C}, \\ a &= 1.99 \text{ m}, \quad \text{and} \\ \epsilon_0 &= 8.8542 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2. \end{aligned}$$

The electric field of a point charge is directed radially outward. The flux is zero if $\vec{E}$ is parallel to the surface; $\vec{E}$ is parallel to three of the sides of the cube, so the total flux $\Phi_{cube} = \frac{q}{8\epsilon_0}$ is due to the other three sides.

By symmetry, the flux through each of the 3 sides is identical, so the flux through one of the these sides is

$$\begin{aligned} \Phi_{shaded} &= \frac{1}{3} \Phi_{cube} = \frac{1}{3} \frac{q}{8\epsilon_0} = \frac{q}{24\epsilon_0} \\ &= \frac{2.23 \text{ C}}{24(8.8542 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2)} \\ &= \boxed{1.04941 \times 10^{10} \text{ N} \cdot \text{m}^2/\text{C}}. \end{aligned}$$

033 0.0 points



In the above figure, the radius of the solenoid (r_1) is 2 cm and the radius of the ring (r_2) is 10 cm .

The magnetic flux through the outer ring is

- Ia) $\pi r_1^2 B$
- Ib) $\pi r_2^2 B$

Now consider the case where I is increasing.

Direction of the induced current in the ring with radius r_2 , as viewed from the right is

- IIa) clockwise

IIb) counterclockwise

Direction of the induced magnetic dipole of the outer ring is

IIIa) to the right

IIIb) to the left

1. Ia, IIa, IIIa

2. Ib, IIa, IIIb

3. Ia, IIb, IIIb

4. Ia, IIa, IIIb **correct**

5. Ib, IIb, IIIb

6. Ia, IIb, IIIa

7. Ib, IIb, IIIa

8. Ib, IIa, IIIa

Explanation:

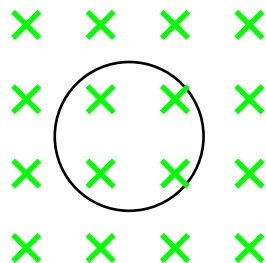
Ia: The magnetic flux encircled by the big ring is: $\pi r_1^2 B$

IIa: With B increasing, B_{ind} of the big loop is pointing to the left, so from the RHR the induced current is clockwise as viewed from the right.

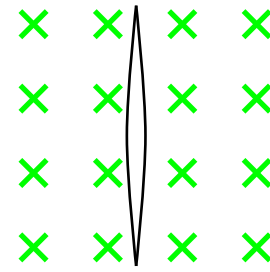
IIIb: The direction of the induced magnetic dipole is to the left.

034 0.0 points

A flexible loop of conducting wire has a radius of 20 cm and is in a magnetic field of strength of 0.28 T.



The loop is grasped at opposite ends and stretched until it closes to an area of 0.005 m^2 .



If it takes 0.32 s to close the loop, find the magnitude of the average induced emf in it during this time.

Correct answer: 105.581 mV.

Explanation:

$$\begin{aligned} \text{Let : } N &= 1, \\ r_i &= 20 \text{ cm} = 0.2 \text{ m}, \\ A_f &= 0.005 \text{ m}^2, \\ B &= 0.28 \text{ T}, \\ \Delta t &= 0.32 \text{ s}, \quad \text{and} \\ \theta &= 0^\circ. \end{aligned}$$

The change of the area which the flux penetrates is

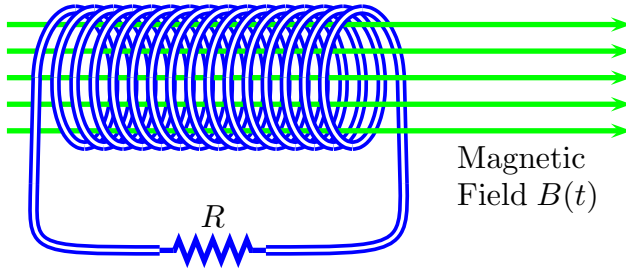
$$\begin{aligned} \Delta A &= A_f - A_i = A_f - \pi r_i^2 \\ &= 0.005 \text{ m}^2 - \pi (0.2 \text{ m})^2 \\ &= -0.120664 \text{ m}^2, \end{aligned}$$

so the average induced $emf \langle \mathcal{E} \rangle$ is

$$\begin{aligned} \langle \mathcal{E} \rangle &= -N \frac{\Delta A B (\cos \theta)}{\Delta t} \\ &= \frac{-N B (\cos \theta) \Delta A}{\Delta t} \\ &= -(1) (0.28 \text{ T}) (\cos 0^\circ) \\ &\quad \times \frac{-0.120664 \text{ m}^2}{0.32 \text{ s}} \cdot \frac{10^3 \text{ mV}}{\text{V}} \\ &= \boxed{105.581 \text{ mV}}. \end{aligned}$$

035 0.0 points

A circular coil is made of N turns of copper wire as shown in the figure. When viewed from the right the coil is wound counterclockwise. A resistor R is inserted in the copper wire. Initially, a uniform magnetic field of magnitude B_i points horizontally from left-to-right through the perpendicular plane of the coil.



During a time interval t the field uniformly changes at a constant rate, until a reversed field is reached equal in magnitude to the initial field.

The current in the resistor R

1. flows in a direction that cannot be determined from the information given.
2. flows from left to right. **correct**
3. is zero.
4. flows from right to left.

Explanation:

As the left-to-right magnetic field decreases (and eventually flipping sign and increasing in magnitude) it follows from Lenz's law (opposition to the change in magnetic field will tend to keep the current constant and flowing in the same direction) that the induced *emf* will produce a left-to-right magnetic field arising from induced currents in the coil.

By the right hand rule, the induced current flows counter-clockwise when viewed from the right and the coils are wound counter-clockwise as the wire goes from the right to left terminals. The current must enter the loop from the right terminal and exit at the left terminal.

Since the current is continuous, the current must flow through the resistor in the left-to-right direction.

036 0.0 points

In an RL series circuit, an inductor of 4.64 H and a resistor of $8.29\ \Omega$ are connected to a 29 V battery. The switch of the circuit is initially open. Next close the switch and wait for a long time. Eventually the current reaches its

equilibrium value.

At this time, what is the corresponding energy stored in the inductor?

Correct answer: 28.3906 J.

Explanation:

$$\begin{aligned} \text{Let : } L &= 4.64\ \text{H}, \\ R &= 8.29\ \Omega, \quad \text{and} \\ \mathcal{E} &= 29\ \text{V}. \end{aligned}$$

The current in an RL circuit is

$$I = \frac{\mathcal{E}}{R} \left(1 - e^{-Rt/L} \right).$$

The final equilibrium value of the current, which occurs as $t \rightarrow \infty$, is

$$I_0 = \frac{\mathcal{E}}{R} = \frac{29\ \text{V}}{8.29\ \Omega} = 3.49819\ \text{A}.$$

The energy stored in the inductor carrying a current 3.49819 A is

$$\begin{aligned} U &= \frac{1}{2} L I^2 \\ &= \frac{1}{2} (4.64\ \text{H}) (3.49819\ \text{A})^2 \\ &= \boxed{28.3906\ \text{J}}. \end{aligned}$$

037 (part 1 of 2) 0.0 points

The current in a 76 mH inductor changes with time as $I = bt^2 - at$.

With $a = 20\ \text{A/s}$ and $b = 2\ \text{A/s}^2$, find the magnitude of the induced *emf*, $|\mathcal{E}|$, at $t = 1\ \text{s}$.

Correct answer: 1.216 V.

Explanation:

$$\begin{aligned} \text{Let : } L &= 76\ \text{mH} = 0.076\ \text{H}, \\ b &= 2\ \text{A/s}^2, \\ a &= 20\ \text{A/s}, \quad \text{and} \\ t &= 1\ \text{s}. \end{aligned}$$

From Faraday's Law, the induced *emf* $\mathcal{E}$ is proportional to the rate of change of the

magnetic flux, which in turn is proportional to the rate of change of the current. This is expressed as

$$\begin{aligned}\mathcal{E} &= L \frac{dI}{dt} \\ &= L \frac{d}{dt} (bt^2 - at) \\ &= L(2bt - a)\end{aligned}$$

At 1 s, the magnitude of the induced *emf* is

$$\begin{aligned}|\mathcal{E}| &= (0.076 \text{ H}) |2(2 \text{ A/s}^2)(1 \text{ s}) - 20 \text{ A/s}| \\ &= \boxed{1.216 \text{ V}}.\end{aligned}$$

038 (part 2 of 2) 0.0 points

At what time is the *emf* zero?

Correct answer: 5 s.

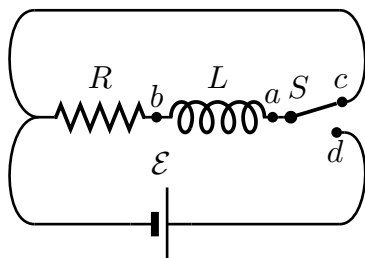
Explanation:

From Part 1, the induced *emf* is zero when

$$\begin{aligned}\frac{dI}{dt} &= 0 \\ 2bt_0 - a &= 0 \\ t_0 &= \frac{(20 \text{ A/s})}{2(2 \text{ A/s}^2)} \\ &= \boxed{5 \text{ s}}.\end{aligned}$$

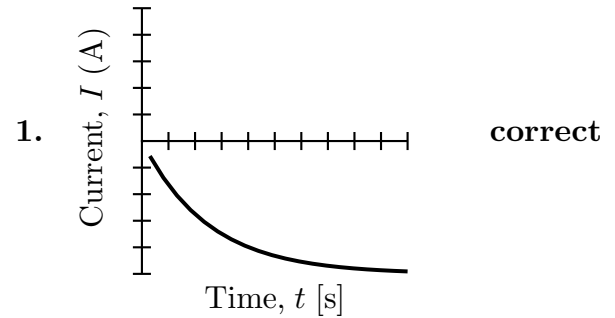
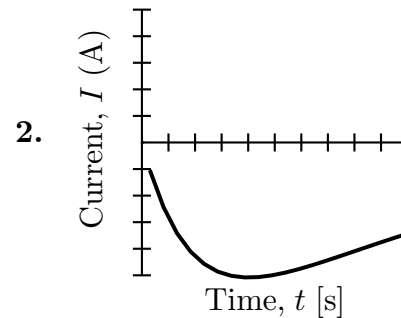
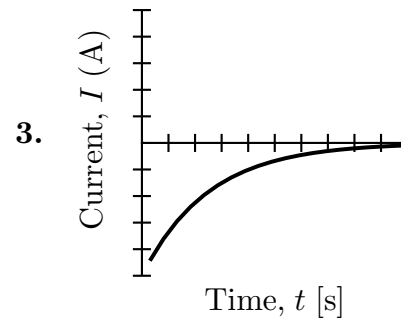
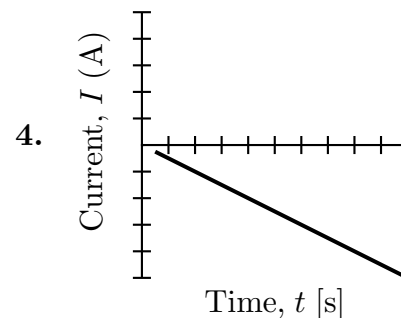
039 (part 1 of 3) 0.0 points

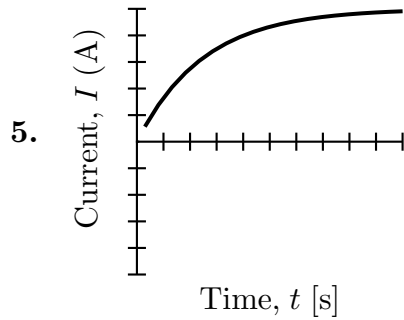
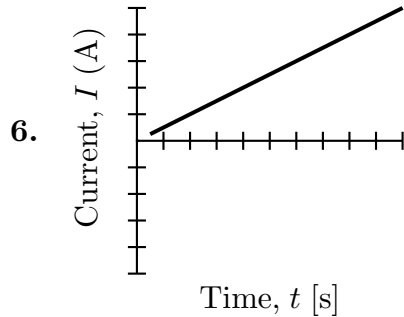
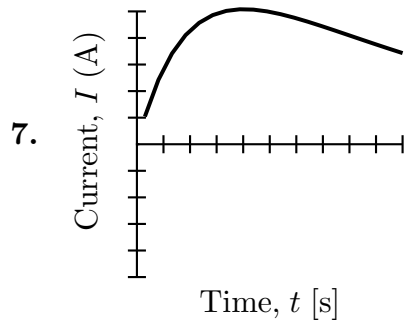
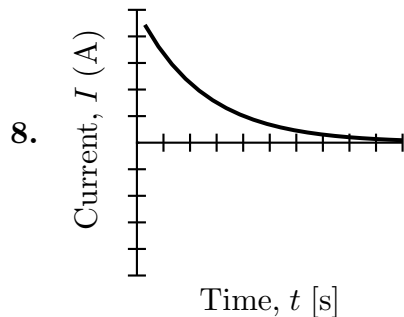
Consider the circuit shown in the figure where the switch has been initially in position **c** for a long period of time. Then, at time $t = 0$ the switch is set to position **d**.



Considering the current and electric potential (voltage drop) from **b** to **a**, which graph

represents the time dependence of the current; i.e., for I vs t ?



**Explanation:**

At $t = 0$, $I = 0$.

At $t = \infty$, the loop voltage equation gives with V_L the voltage drop across the inductor, and the current I circulates in the lower loop in the clockwise direction, so that the current I formally goes from **b** to **a**. Therefore

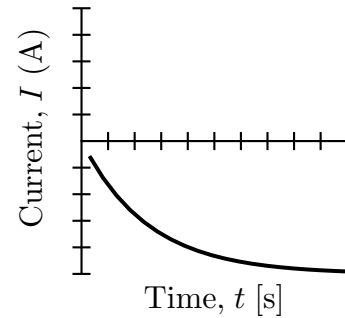
$$\mathcal{E} + IR + V_L = 0$$

$$I = \frac{-\mathcal{E} - V_L}{R}.$$

In steady state,

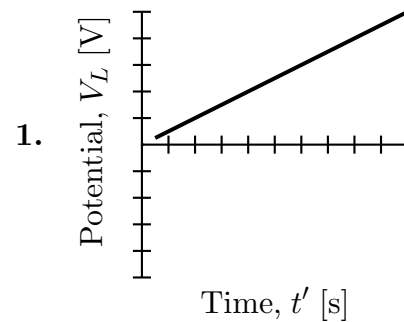
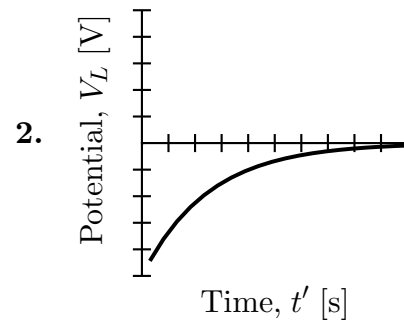
$$V_L = L \frac{dI}{dt} = 0.$$

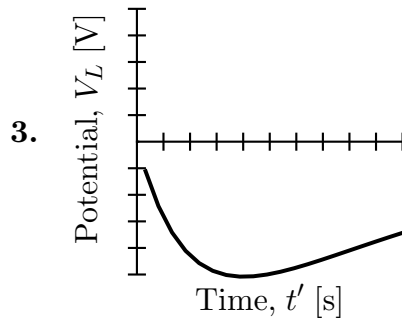
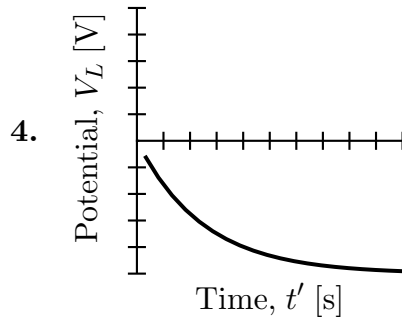
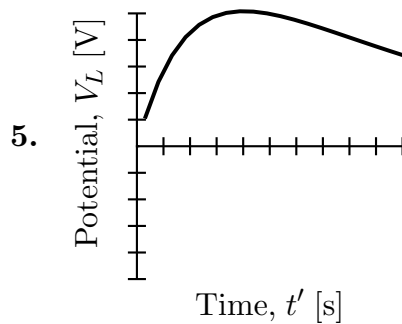
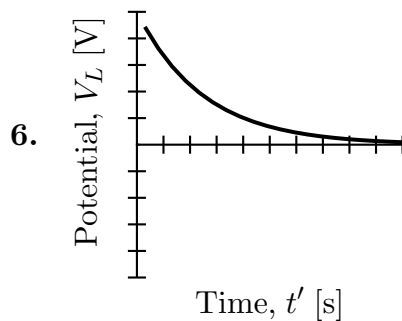
Thus, $I = \frac{-\mathcal{E}}{R}$ at $t = \infty$. Finally, the current is $I(t) = I_0 \left(1 - e^{-t/\tau}\right)$, with $I_0 = \frac{-\mathcal{E}}{R}$ and the graph for $I(t) = \frac{-\mathcal{E}}{R} \left(1 - e^{-t/\tau}\right)$ is

**040 (part 2 of 3) 0.0 points**

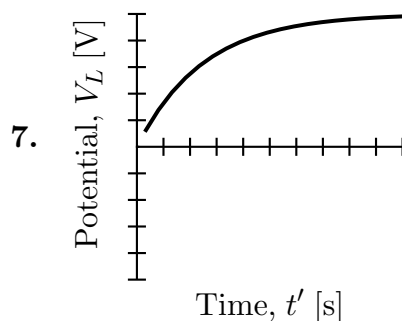
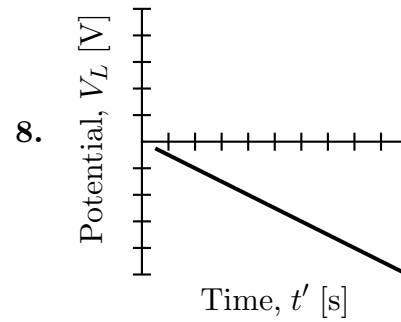
After being at position **d** for a long time, at $t' = 0$ the switch is set instantaneously to position **c**.

Which graph represents the t' dependence of the electric potential drop $V_L(t')$; i.e., for $(V_a - V_b)$ vs t' ?





correct

**Explanation:**

At $t' = 0$, the top loop voltage equation, when circulating in the counter-clockwise direction (so that the current formally goes from **b** to **a**) is given by

$$V_L + I R = 0$$

$$V_L = -I R = |I| R > 0.$$

041 (part 3 of 3) 0.0 points

Consider an inductance of 10 H, resistance of 26.2 Ω , and initial current of 6.9 A at $t' = 0$.

For the last case, find total energy dissipated through the resistor during the time interval $t' = 0$ to ∞ .

Correct answer: 238.05 J.

Explanation:

$$\begin{aligned} \text{Let : } L &= 10 \text{ H,} \\ R &= 26.2 \Omega, \quad \text{and} \\ I_0 &= 6.9 \text{ A.} \end{aligned}$$

After switching to **c**, the total stored energy is the magnetic energy at $t' = 0$:

$$U_L \Big|_{t'=0} = \frac{1}{2} L I_0^2,$$

which will be dissipated in the resistor between $0 < t' < \infty$. Applying conservation of energy,

$$\begin{aligned} U_R \Big|_{t'=0 \rightarrow \infty} &= U_L \Big|_{t'=0} = \frac{1}{2} L I_0^2 \\ &= \frac{1}{2} (10 \text{ H}) (6.9 \text{ A})^2 = \boxed{238.05 \text{ J}}. \end{aligned}$$