

Question 2: Version J

2. A rotating, circular, conducting loop of area A and resistance R is in an external uniform magnetic field of magnitude B that is directed in the $-z$ -direction. At time $t = 0$, the magnetic field is perpendicular to the plane of the loop, as shown in Figure 1. The loop is rotating with constant angular speed ω and period T about the dashed line that is along the diameter of the loop. The value of the magnetic flux through the loop as a function of time t is $\Phi = BA \cos(\omega t)$.

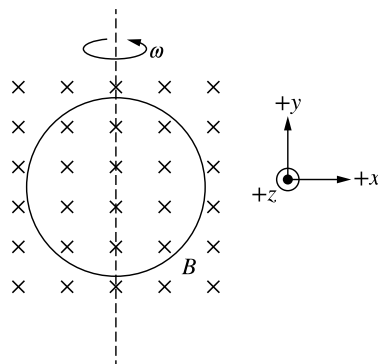


Figure 1

- A. The absolute value of the induced emf in the loop is $|\mathcal{E}|$. The partially completed bar chart in Figure 2 shows a bar that represents $|\mathcal{E}|$ at $t = \frac{3}{4}T$. In Figure 2, **draw** bars to represent $|\mathcal{E}|$ at times $t = 0$, $\frac{1}{4}T$, and $\frac{1}{2}T$ relative to $|\mathcal{E}|$ shown at $\frac{3}{4}T$. If $|\mathcal{E}| = 0$, **write** a “0” in that column.

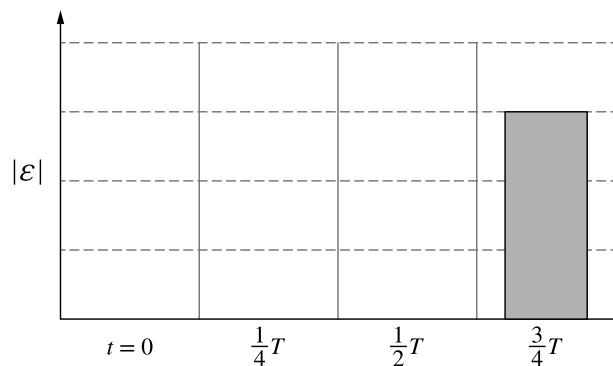


Figure 2

- B. **Derive** an expression for the maximum induced current in the loop in terms of A , R , B , ω , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.
- C. On the axes shown in Figure 3, **sketch** a graph of the instantaneous power P dissipated by the loop as a function of t during the time interval $0 \leq t \leq T$.

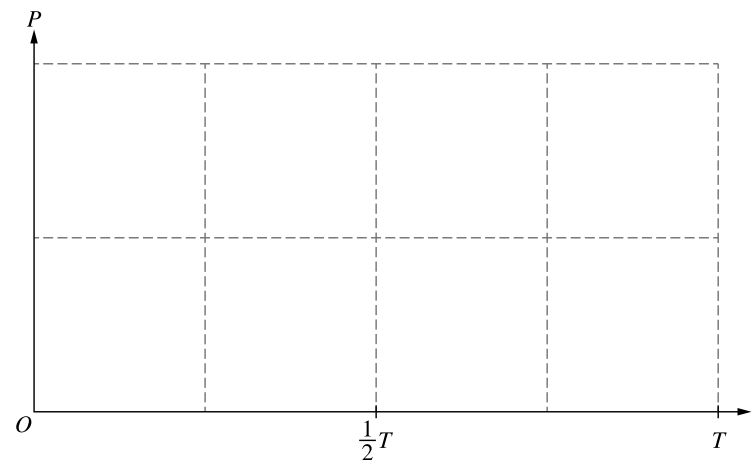


Figure 3

- D. **Indicate** whether the sketch you drew in part C is or is not consistent with the bars that you drew in part A. Briefly **justify** your answer by referencing the functional dependence between P and $|\mathcal{E}|$.

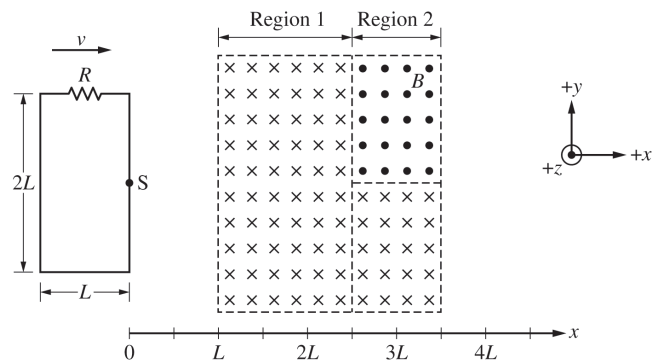
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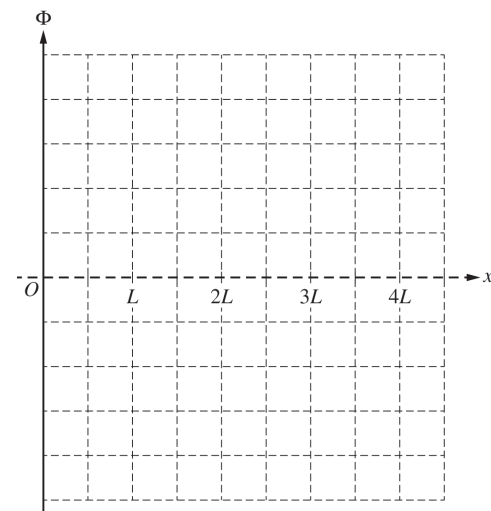
Figure 1

3. A wire is connected to a resistor of resistance R to form a rigid rectangular loop of width L and height $2L$. An external force is exerted on the loop so that the loop always moves with constant speed v in the $+x$ -direction, as shown in Figure 1. The loop then enters Region 1 of external uniform magnetic field of magnitude B that is directed in the $-z$ -direction. Region 1 has boundaries $x = L$ and $x = 2.5L$. The loop later enters Region 2 with two external, uniform magnetic fields, each of magnitude B , that are parallel but are directed in opposite z -directions. Region 2 has boundaries $x = 2.5L$ and $x = 3.5L$. Point S is the midpoint of the leading edge of the loop and is aligned with the horizontal boundary in Region 2 that separates the two magnetic fields.

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Continue your response to **QUESTION 3** on this page.

- (a) On the following axes, **sketch** a graph of the magnetic flux Φ through the rectangular loop as a function of the position x of Point S from $x = 0$ to $x = 4.5L$. The $+z$ -direction indicated in Figure 1 corresponds to $+\Phi$.



- (b) Consider the instant when Point S reaches $x = 1.5L$.

- i. **Indicate** whether the current I_R that is induced in the rectangular loop when Point S reaches $x = 1.5L$ is clockwise, counterclockwise, or zero.

_____ Clockwise _____ Counterclockwise _____ Zero

Briefly **justify** your answer.

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Continue your response to **QUESTION 3** on this page.

ii. **Derive** an expression for I_R when Point S reaches $x = 1.5L$. If $I_R = 0$, indicate how the derived expression shows that $I_R = 0$. Express your answer in terms of R , L , v , B , and physical constants, as appropriate.

iii. **Derive** an expression for the power P dissipated by the resistor when Point S reaches $x = 1.5L$. Express your answer in terms of R , L , v , B , and physical constants, as appropriate.

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Continue your response to **QUESTION 3** on this page.

The total energy dissipated by the resistor in the rectangular loop as Point S moves from $x = 0$ to $x = 4.5L$ is E_{original} .

The vertical boundary between regions 1 and 2 is now shifted to $x = 1.5L$. After the boundary is shifted, the rectangular loop again moves with speed v in the $+x$ -direction, as shown in Figure 2. The total energy dissipated by the resistor as Point S moves from $x = 0$ to $x = 4.5L$ is E_{new} .

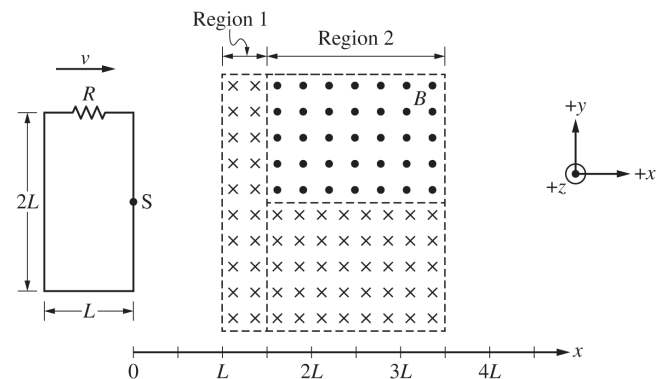


Figure 2

(c) **Indicate** whether E_{new} is greater than, less than, or equal to E_{original} .

_____ $E_{\text{new}} > E_{\text{original}}$ _____ $E_{\text{new}} < E_{\text{original}}$ _____ $E_{\text{new}} = E_{\text{original}}$

Briefly **justify** your answer.

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The original magnetic fields are modified so that the region $L < x < 3.5L$ contains an external uniform magnetic field of magnitude B that is directed in the $-z$ -direction.

A new wire is connected to a resistor of resistance R to form a rigid triangular loop with base length L and height $2L$. An external force is exerted on the loop so that the loop always moves with speed v in the $+x$ -direction, as shown in Figure 3. Point S represents the lower-leading corner of the loop.

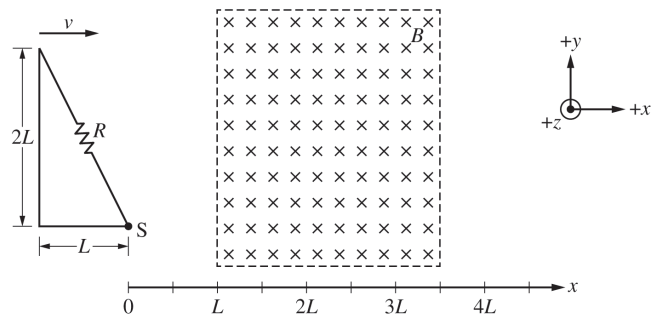
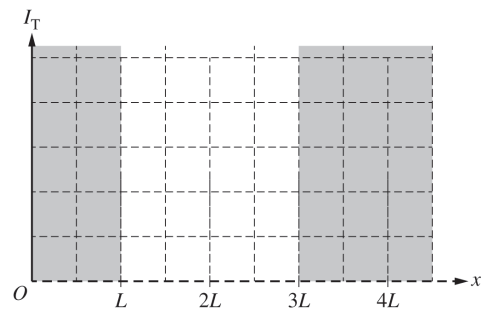


Figure 3

- (d) On the following axes, **sketch** a graph of the induced current I_T in the triangular loop as Point S moves from $x = L$ to $x = 3L$.



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END OF EXAM

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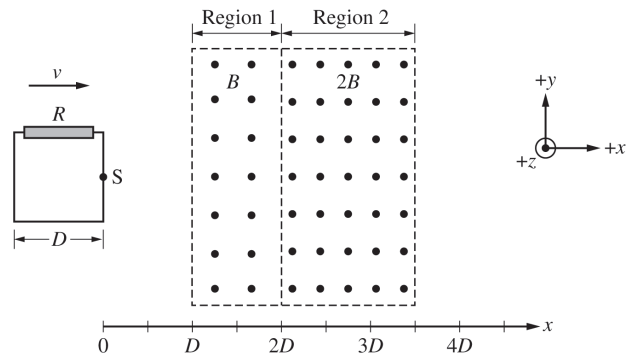


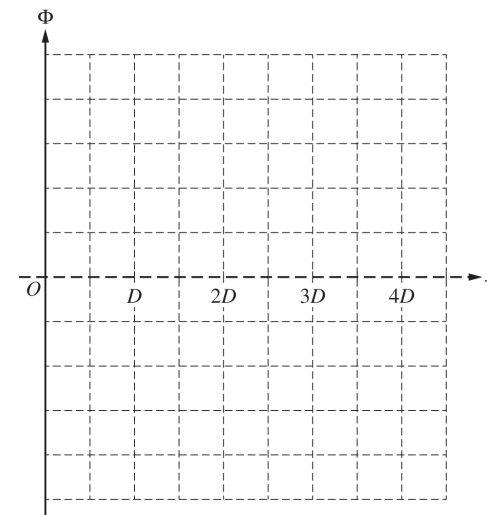
Figure 1

3. A wire is connected to a resistor of resistance R to form a rigid square loop of side length D . An external force is exerted on the loop so that the loop always moves with constant speed v in the $+x$ direction, as shown in Figure 1. The loop then enters Region 1 of external uniform magnetic field of magnitude B that is directed in the $+z$ -direction. Region 1 has boundaries $x = D$ and $x = 2D$. The loop later enters Region 2 of external uniform magnetic field of magnitude $2B$ that is directed in the $+z$ -direction. Region 2 has boundaries $x = 2D$ and $x = 3.5D$. Point S is the midpoint of the leading edge of the loop.

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Continue your response to **QUESTION 3** on this page.

- (a) On the following axes, **sketch** a graph of the magnetic flux Φ through the square loop as a function of the position x of Point S from $x = 0$ to $x = 4.5D$. The $+z$ -direction indicated in Figure 1 corresponds to $+\Phi$.



- (b) Consider the instant when Point S reaches $x = 1.5D$.

- i. **Indicate** whether the current I_S that is induced in the square loop when Point S reaches $x = 1.5D$ is clockwise, counterclockwise, or zero.

_____ Clockwise _____ Counterclockwise _____ Zero

Briefly **justify** your answer.

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Continue your response to **QUESTION 3** on this page.

ii. **Derive** an expression for I_S when Point S reaches $x = 1.5D$. If $I_S = 0$, indicate how the derived expression shows that $I_S = 0$. Express your answer in terms of R , D , v , B , and physical constants, as appropriate.

iii. **Derive** an expression for the power P dissipated by the resistor when Point S reaches $x = 1.5D$. Express your answer in terms of R , D , v , B , and physical constants, as appropriate.

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Continue your response to **QUESTION 3** on this page.

The total energy dissipated by the resistor in the square loop as Point S moves from $x = 0$ to $x = 4.5D$ is E_{original} .

The vertical boundary between regions 1 and 2 is now shifted to $x = 2.5D$. After the boundary is shifted, the square loop again moves with speed v in the $+x$ -direction, as shown in Figure 2. The total energy dissipated by the resistor as Point S moves from $x = 0$ to $x = 4.5D$ is E_{new} .

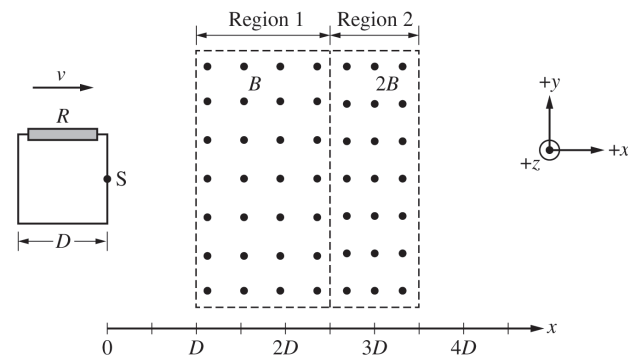


Figure 2

(c) **Indicate** whether E_{new} is greater than, less than, or equal to E_{original} .

_____ $E_{\text{new}} > E_{\text{original}}$ _____ $E_{\text{new}} < E_{\text{original}}$ _____ $E_{\text{new}} = E_{\text{original}}$

Briefly **justify** your answer.

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The original magnetic fields are modified so that the region $D < x < 3.5D$ contains an external uniform magnetic field of magnitude B that is directed in the $+z$ -direction.

A new wire is connected to a resistor of resistance R to form a rigid triangular loop with base length D and height D . An external force is exerted on the loop so that the loop always moves with speed v in the $+x$ -direction, as shown in Figure 3. Point S represents the upper-leading corner of the loop.

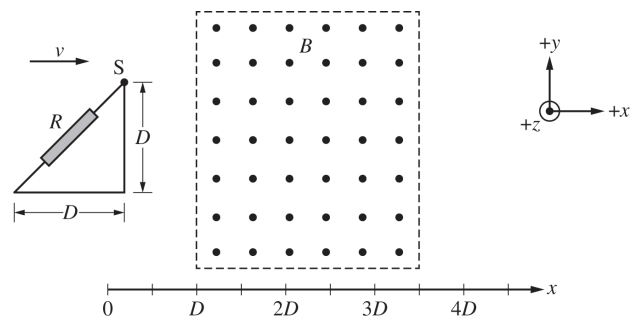
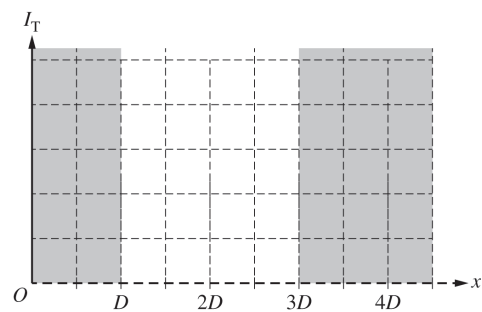


Figure 3

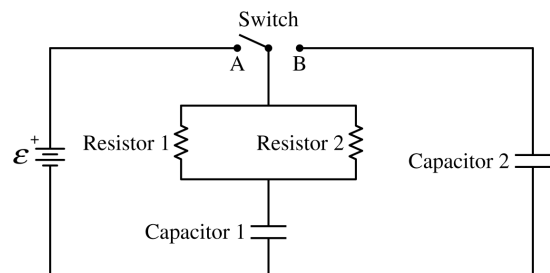
- (d) On the following axes, **sketch** a graph of the induced current I_T in the loop as Point S moves from $x = D$ to $x = 3D$.



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END OF EXAM



The circuit shown consists of a battery of emf $\mathcal{E}$, resistors 1 and 2 each with resistance R , capacitors 1 and 2 with capacitances C and $2C$, respectively, and a switch. The switch is initially open and both capacitors are uncharged.

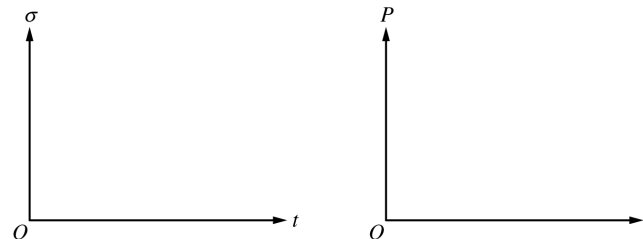
At time $t = 0$, the switch is closed to Position A.

- (a) Write, but do NOT solve, a differential equation that can be used to determine the charge Q on the positive plate of Capacitor 1 as a function of time t after the switch is closed to Position A. Express your answer in terms of $\mathcal{E}$, R , C , Q , t , and fundamental constants, as appropriate.

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Continue your response to **QUESTION 3** on this page.

- (b) On the axes shown, sketch graphs of the surface charge density σ on the positive plate of Capacitor 1 and the total power P dissipated by the resistors as functions of time t from time $t = 0$ until steady-state conditions are nearly reached.



A long time after the switch is closed to Position A, the charge on the positive plate of Capacitor 1 is Q_0 and Capacitor 2 is uncharged.

- (c) At time t_1 , the switch is closed to Position B.
- Immediately after time t_1 , is the direction of the current in the switch directed toward the left, directed toward the right, or is there no current? Briefly justify your answer.
 - Determine an expression for the total charge on the positive plate of Capacitor 2 a long time after t_1 . Express your answer in terms of Q_0 and fundamental constants, as appropriate.

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iii. Derive an expression for the total energy E_R dissipated by resistors 1 and 2 from immediately after time t_1 until new steady-state conditions have been reached. Express your answer in terms of C , Q_0 , and fundamental constants, as appropriate.

With the switch still closed to Position B, the parallel plates of Capacitor 2 are moved so that the separation distance increases by a factor of 2.

(d) Determine the ratio $\frac{U_2}{U_1}$ of the energy U_2 stored in Capacitor 2 to the energy U_1 stored in Capacitor 1 a long time after the plates of Capacitor 2 have been moved. Briefly justify your answer.

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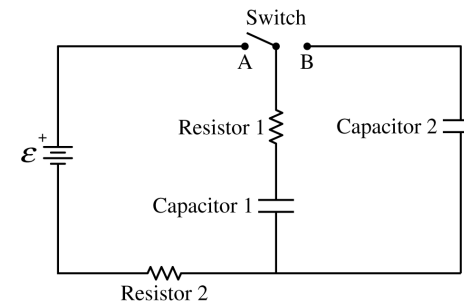
With the capacitors still charged as in part (d), the switch is now closed to Position A.

(e) Express your answers to part (e)(i) and part (e)(ii) in terms of R , C , Q_0 , and fundamental constants, as appropriate.

i. Derive an expression for the current I_0 from the battery immediately after the switch is closed to Position A.

ii. Determine the current I_∞ from the battery a long time after the switch is closed to Position A.

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STOP**END OF EXAM**

The circuit shown consists of an ideal battery of emf $\mathcal{E}$, resistors 1 and 2 each with resistance R , capacitors 1 and 2 each with capacitance C , and a switch. The switch is initially open and both capacitors are uncharged.

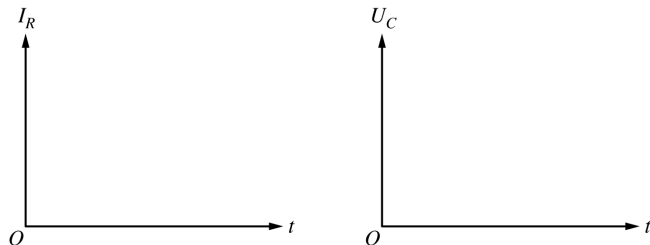
At time $t = 0$, the switch is closed to Position A.

- (a) Write, but do NOT solve, a differential equation that can be used to determine the charge Q on the positive plate of Capacitor 1 as a function of time t after the switch is closed to Position A. Express your answer in terms of $\mathcal{E}$, R , C , Q , t , and fundamental constants, as appropriate.

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Continue your response to Question 3 on this page.

- (b) On the axes shown, sketch graphs of the current I_R in Resistor 1 and the energy U_C stored in Capacitor 1 as functions of time t from time $t = 0$ until steady-state conditions are nearly reached.



A long time after the switch is closed to Position A, the total charge on the positive plate of Capacitor 1 is Q_0 and Capacitor 2 is uncharged.

- (c) At time t_1 , the switch is closed to Position B.

i. Immediately after t_1 , is the direction of the current in Resistor 1 directed up, directed down, or is there no current? Briefly justify your answer.

ii. Determine an expression for the total charge on the positive plate of Capacitor 2 a long time after t_1 . Express your answer in terms of Q_0 and fundamental constants, as appropriate.

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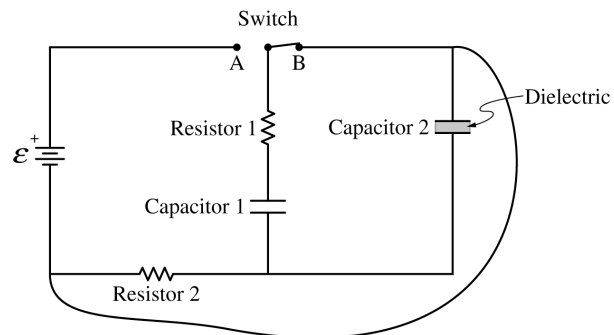
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- iii. Derive an expression for the total energy dissipated by Resistor 1 immediately after time t_1 until new steady-state conditions have been reached. Express your answer in terms of C , Q_0 , and fundamental constants, as appropriate.

With the switch still closed to Position B, a dielectric material with dielectric constant $\kappa = 2$ is inserted between the plates of Capacitor 2.

- (d) Determine the charge on the positive plate of Capacitor 2 a long time after the dielectric has been inserted. Express your answer in terms of Q_0 and fundamental constants, as appropriate.

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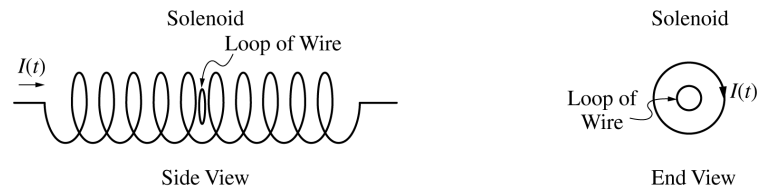
With the switch still closed to Position B, a wire of negligible resistance is connected between two corners of the circuit, as shown.

(e) Express your answers to part (e)(i) and part (e)(ii) in terms of R , C , Q_0 , and fundamental constants, as appropriate.

i. Derive an expression for the current in Resistor 2 immediately after the wire is connected to the circuit.

ii. Determine the current in Resistor 2 a long time after the wire is connected to the circuit.

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Begin your response to **QUESTION 3** on this page.Note: Figures not drawn to scale.

A single loop of wire with resistance $3.0\ \Omega$ and radius $0.10\ \text{m}$ is placed inside a solenoid, with the normal to the loop parallel to the axis of the solenoid. The solenoid has 500 turns, is $0.25\ \text{m}$ long, and is connected to a power supply that is not shown. At time $t = 0$, the power supply is turned on, and the current I in the solenoid as a function of t is given by the equation $I(t) = \beta t$, where $\beta = 5.0\ \text{A/s}$. The direction of the current in the solenoid is clockwise, as shown in the end view.

- (a) At time $t = 2.0\ \text{s}$, is the induced current in the loop, as seen from the end view shown, clockwise, counterclockwise, or zero?

☐ Clockwise ☐ Counterclockwise ☐ Zero

Justify your answer.

- (b) Calculate the current in the loop of wire at time $t = 2.0\ \text{s}$.

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Continue your response to **QUESTION 3** on this page.

- (c) Calculate the total energy dissipated by the loop of wire from time $t = 0$ to time $t = 2.0\ \text{s}$.

- (d) A group of students attempts to verify experimentally the calculation of the current from part (b). The current in the inner circular loop at time $t = 2.0\ \text{s}$ is measured to be less than the current calculated in part (b). Which of the following could explain this discrepancy? Select one answer.

- ☐ The experiment did not account for Earth's magnetic field.
☐ The plane of the loop is not perpendicular to the axis of the solenoid.
☐ The center of the loop is not on the axis of the solenoid.
☐ The resistance of the loop is less than the given value.
☐ The radius of the loop is actually larger than $0.10\ \text{m}$.

Justify your answer.

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Continue your response to **QUESTION 3** on this page.

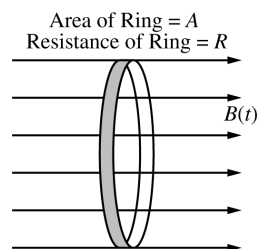
- (e) The power supply is now turned off. The original loop of wire is then replaced with a second loop made from wire that has the same thickness and is made from the same material as the original loop of wire. The second loop has radius 0.20 m, is placed in the same orientation as the original loop, and fits completely inside the solenoid. The power supply is turned on, and the current I in the solenoid as a function of t is again given by the equation $I(t) = \beta t$, where $\beta = 5.0 \text{ A/s}$. Which of the following expressions correctly indicates the ratio $\frac{I_2}{I_1}$ where I_1 represents the current induced in the original loop of wire in part (b) and I_2 represents the current induced in the second loop of wire?

$\frac{I_2}{I_1} = 1$ $1 < \frac{I_2}{I_1} < 2$ $\frac{I_2}{I_1} = 2$ $\frac{I_2}{I_1} > 2$

Justify your answer.

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3. A thin, conducting ring of area A and resistance R is aligned in a uniform magnetic field directed to the right and perpendicular to the plane of the ring, as shown. At time $t = 0$, the magnitude of the magnetic field is B_0 . At $t = 1$ s, the magnitude of the magnetic field begins to decrease according to the equation $B(t) = \frac{\beta}{t}$, where β has units of T·s.

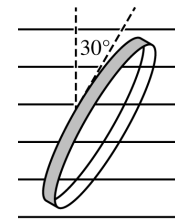
(a) Derive an equation for the magnitude of the induced current I in the ring as a function of t for $t > 1$ s. Express your answer in terms of β , A , R , t , and physical constants, as appropriate.

Assume $A = 0.50 \text{ m}^2$, $R = 2.0 \Omega$, and $\beta = 0.50 \text{ T} \cdot \text{s}$.

- (b) Calculate the electrical energy dissipated in the ring from $t = 1$ s to $t = 2$ s.

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The ring is then rotated so that the plane of the ring is aligned at a 30° angle to the magnetic field, as shown.

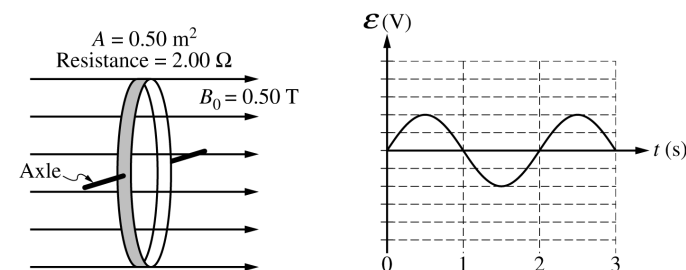
The magnitude of the magnetic field is reset to a magnitude of B_0 at a new time $t = 0$ and again begins to

decrease at $t = 1$ s according to the equation $B(t) = \frac{\beta}{t}$, where β has units of T·s.

- (c) Will the amount of energy dissipated in the ring from $t = 1$ s to $t = 2$ s be greater than, less than, or equal to the energy dissipated in part (b) ?

_____ Greater than _____ Less than _____ Equal to

Justify your answer.



The ring is now mounted on an axle that is perpendicular to the magnetic field. The magnitude of the magnetic field is now held at a constant $B_0 = 0.50 \text{ T}$, as shown. The ring rotates about the axle, and the emf $\mathcal{E}$ induced in the ring as a function of time t is shown on the graph.

- (d) Calculate the angular speed ω of the rotating ring in rad/s.

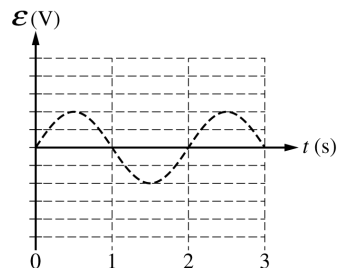
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(e) Calculate the magnitude of the maximum emf $\mathcal{E}_{\text{MAX}}$ induced in the ring.

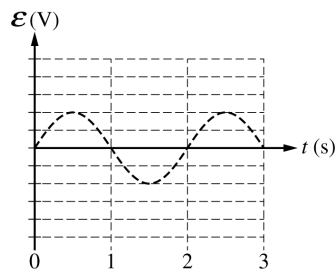
The ring now begins to rotate at an angular speed 2ω .

(f) On the graph below, draw a curve to indicate the new induced emf $\mathcal{E}$ in the ring. The dashed curve shows the emf induced under the original conditions.



Justify your sketch, specifically identifying and addressing any similarities or differences between the sketch and the original graph.

PRACTICE GRAPH - Use the graph below to practice your sketch for part (f). Any work shown on the graph below will NOT be graded.



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Use a pencil or pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

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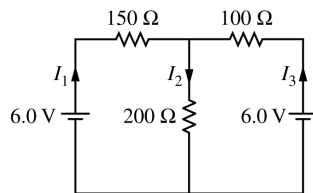


Figure 1

2. The circuit shown above is constructed with two 6.0 V batteries and three resistors with the values shown. The currents I_1 , I_2 , and I_3 in each branch of the circuit are indicated.

(a)

- Using Kirchhoff's rules, write, but DO NOT SOLVE, equations that can be used to solve for the current in each resistor.
- Calculate the current in the $200\ \Omega$ resistor.
- Calculate the power dissipated by the $200\ \Omega$ resistor.

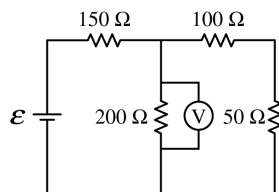


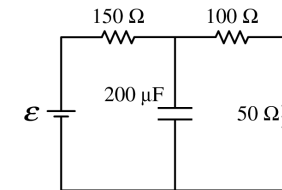
Figure 2

The two 6.0 V batteries are replaced with a battery with voltage $\mathcal{E}$ and a resistor of resistance $50\ \Omega$, as shown above. The voltmeter V shows that the voltage across the $200\ \Omega$ resistor is 4.4 V.

- Calculate the current through the $50\ \Omega$ resistor.
- Calculate the voltage $\mathcal{E}$ of the battery.

(d)

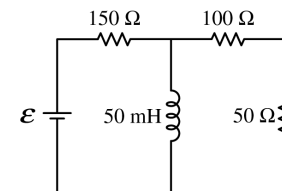
- The $200\ \Omega$ resistor in the circuit in Figure 2 is replaced with a $200\ \mu\text{F}$ capacitor, as shown on the right, and the circuit is allowed to reach steady state. Calculate the current through the $50\ \Omega$ resistor.

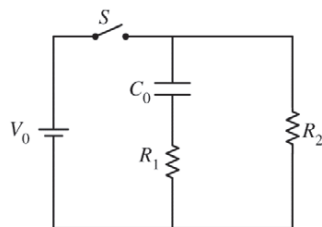


- The $200\ \Omega$ resistor in the circuit in Figure 2 is replaced with an ideal $50\ \text{mH}$ inductor, as shown on the right, and the circuit is allowed to reach steady state. Is the current in the $50\ \Omega$ resistor greater than, less than, or equal to the current calculated in part (b) ?

_____ Greater than _____ Less than _____ Equal to

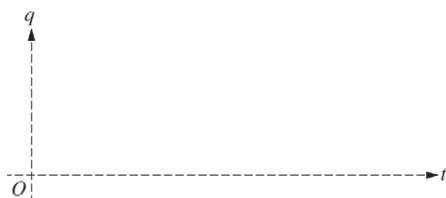
Justify your answer.



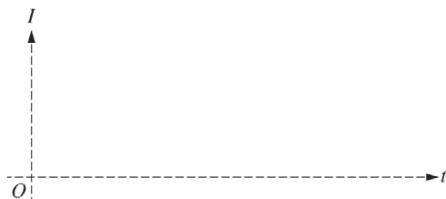


2. In the circuit above, an ideal battery of voltage V_0 is connected to a capacitor with capacitance C_0 and resistors with resistances R_1 and R_2 , with $R_1 > R_2$. The switch S is open, and the capacitor is initially uncharged.

- (a) The switch is closed at time $t = 0$. On the axes below, sketch the charge q on the capacitor as a function of time t . Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



- (b) On the axes below, sketch the current I through each resistor as a function of time t . Clearly label the two curves as I_1 and I_2 , the currents through resistors R_1 and R_2 , respectively. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



The circuit is constructed using an ideal 1.5 V battery, an $80 \mu\text{F}$ capacitor, and resistors $R_1 = 150 \Omega$ and $R_2 = 100 \Omega$. The switch is closed, allowing the capacitor to fully charge. The switch is then opened, allowing the capacitor to discharge.

- (c) The time it takes to charge the capacitor to 50% of its maximum charge is Δt_C . The time it takes for the capacitor to discharge to 50% of its maximum charge is Δt_D . Which of the following correctly relates the two time intervals?

_____ $\Delta t_C > \Delta t_D$ _____ $\Delta t_C = \Delta t_D$ _____ $\Delta t_C < \Delta t_D$

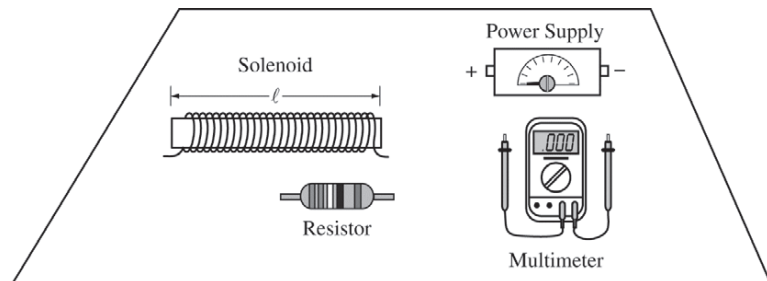
Justify your answer.

(d)

- i. Calculate the current through resistor R_2 immediately after the switch is opened.
- ii. Is the current through resistor R_2 increasing, decreasing, or constant immediately after the switch is opened?
- _____ Increasing _____ Decreasing _____ Constant
- Justify your answer.

(e)

- i. Calculate the energy stored in the capacitor immediately after the switch is opened.
- ii. Calculate the energy dissipated by resistor R_1 as the capacitor completely discharges.



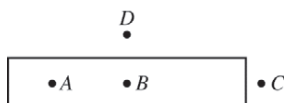
3. When studying Ampere's law, students collect data on the magnetic field of two different solenoids in order to determine the magnetic permeability of free space μ_0 . The solenoids are created by wrapping wire around a hollow plastic tube. The solenoids of length ℓ with N turns of wire will be connected in series to a power supply and resistor. A multimeter will be used as an ammeter to measure the magnitude of the current I through the solenoids. The main components for the setup with one of the solenoids are shown in the figure above.

(a)

- On the figure above, draw wire connections between the solenoid, power supply, resistor, and multimeter that will complete the circuit and allow students to measure the magnitude of the current through the solenoid.
- Using the connections you made in part (a)i above, what will be the direction of the magnetic field inside the solenoid?

_____ Toward the top of the page _____ To the left _____ Out of the page
 _____ Toward the bottom of the page _____ To the right _____ Into the page

The rectangle shown below represents the solenoid (the loops of wire are not shown). Points A , B , and C are along the central axis of the solenoid with point B at the middle of the solenoid. Point D is directly above point B .

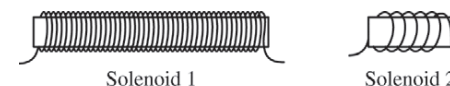


- From the choices below, select the point where you would place a magnetic field probe (a probe that can measure the magnitude of the magnetic field) to best measure the strength of the magnetic field of the solenoid in order to determine the magnetic permeability of free space μ_0 .

_____ A _____ B _____ C _____ D

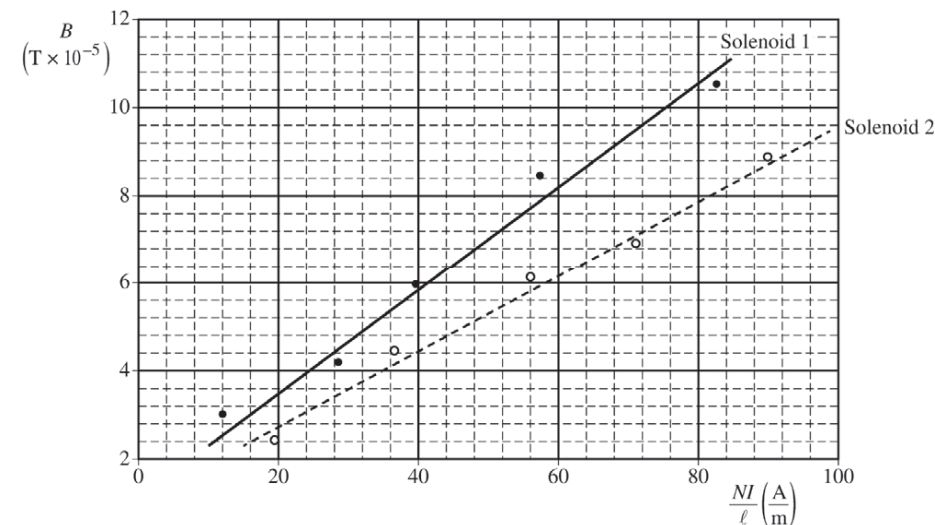
Justify your answer based on the model for a simple solenoid.

The figures below show two different solenoids that will be connected in the circuit above. Solenoid 1 has a length $\ell = 25$ cm with $N = 100$ turns. Solenoid 2 has a length $\ell = 5.0$ cm with $N = 5$ turns.



Note: Figures not drawn to scale.

A graph of the magnitude of the magnetic field B as a function of NI/ℓ is shown below. The best-fit lines for the data are shown as a solid line for solenoid 1 and as a dashed line for solenoid 2.



- Which solenoid's best-fit line would give the best results for determining a value for the magnetic permeability of free space μ_0 ?

_____ Solenoid 1 _____ Solenoid 2

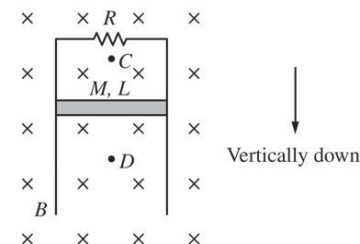
Justify your answer.

-

- Use the slope of the best-fit line for the solenoid chosen in part (b) to calculate the magnetic permeability of free space μ_0 .
- Calculate the percent error for the experimental value of the magnetic permeability of free space μ_0 determined in part (c)i.

- (d)
- What is a reasonable physical explanation for a best-fit line that does not pass through the origin?
 - Suppose a student connects the solenoid in a closed circuit similar to the circuit in part (a)i but without the resistor. The student notices the multimeter stops functioning after the power supply is turned on. Explain what causes the failure of the multimeter.

STOP
END OF EXAM



E&M.3.

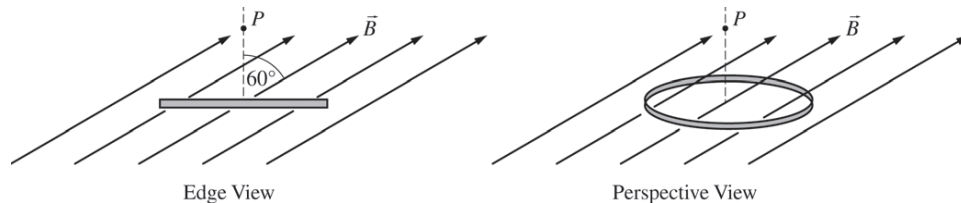
A conducting bar of mass M , length L , and negligible resistance is connected to two long vertical conducting rails of negligible resistance. The two rails are connected by a resistor of resistance R at the top. The entire apparatus is located in a magnetic field of magnitude B directed into the page, as shown in the figure above. The bar is released from rest and slides without friction down the rails.

- What is the direction of the current in the resistor?
 ____ Left ____ Right
- Is the magnitude of the net magnetic field above the bar at point C greater than, less than, or equal to the magnitude of the net magnetic field before the bar is released?
 ____ Greater than ____ Less than ____ Equal to
 Justify your answer.
 - While the bar is above point D , is the magnitude of the net magnetic field at point D greater than, less than, or equal to the magnitude of the net magnetic field before the bar is released?
 ____ Greater than ____ Less than ____ Equal to
 Justify your answer.

Express your answers to parts (c) and (d) in terms of M , L , R , B , and physical constants, as appropriate.

- Write, but do NOT solve, a differential equation that could be used to determine the velocity of the falling bar as a function of time t .
 - Determine an expression for the terminal velocity v_T of the bar.
- Express your answers to parts (e) and (f) in terms of v_T , M , L , R , B , and physical constants, as appropriate.
- Derive an expression for the power dissipated in the resistor when the bar is falling at terminal velocity.
 - Using your differential equation from part (c), derive an expression for the speed of the falling bar $v(t)$ as a function of time t .

STOP
END OF EXAM



E&M. 3.

A circular wire loop with radius 0.10 m and resistance $50\ \Omega$ is held in place horizontally in a magnetic field $\vec{B}$ directed upward at an angle of 60° with the vertical, as shown in the figure above. The magnetic field in the direction shown is given as a function of time t by $B(t) = a(1 - bt)$, where $a = 4.0\text{ T}$ and $b = 0.20\text{ s}^{-1}$.

- (a) Derive an expression for the magnetic flux through the loop as a function of time t .
- (b) Calculate the numerical value of the induced emf in the loop.
- (c)
 - i. Calculate the numerical value of the induced current in the loop.
 - ii. What is the direction of the induced current in the loop as viewed from point P ?
 ___ Clockwise ___ Counterclockwise
 Justify your answer.
- (d) Assuming the loop stays in its current position, calculate the energy dissipated in the loop in 4.0 seconds.
- (e) Indicate whether the net magnetic force and net magnetic torque on the loop are zero or nonzero while the loop is in the magnetic field.
 Net magnetic force: ___ Zero ___ Nonzero
 Net magnetic torque: ___ Zero ___ Nonzero
 Justify both of your answers.

STOP
END OF EXAM