Begin your response to **QUESTION 2** on this page.

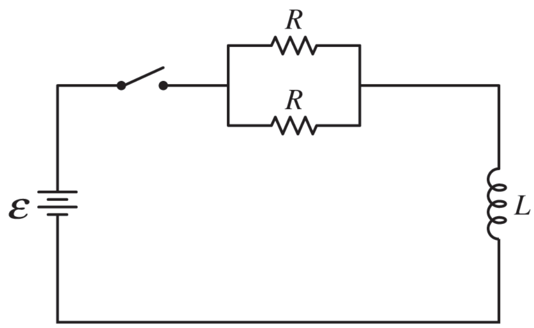


Figure 1

2. Students are asked to determine the resistance R of two identical resistors. The resistors are in parallel with each other and are connected in series to a battery of known emf $\mathcal{E}$, an inductor of known inductance L, and a switch, as shown in Figure 1. The students have access to a voltmeter that can measure potential difference as a function of time. The students are required to measure a quantity that <u>decreases</u> with time to determine R.

(a)

i. On the circuit diagram shown in Figure 1, **draw** the voltmeter, using the following symbol, with connections that would allow the students to correctly measure a potential difference that <u>decreases</u> with time.

Voltmeter Symbol

ii. **Describe** a procedure for collecting data that would allow the students to graphically determine the experimental value for R using the measured quantity that <u>decreases</u> with time. Provide enough detail so that another student could replicate the experiment.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

(b)

i. On the axes shown in Figure 2, produce a graph that represents the expected trend of the data by completing the following tasks.

- **Label** the quantities graphed on the vertical and horizontal axes.
- **Sketch** a line or curve that represents the expected trend of the collected data.
- **Label** any appropriate intercepts and/or asymptotes in terms of the quantities provided.

Figure 2

ii. **Describe** how the information from the graph in part (b)(i) would be used to determine the experimental value for R.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

(c) Starting with an appropriate application of Kirchhoff's loop rule, **derive**, but do NOT solve, a differential equation that can be used to determine the current I in the inductor at time t after the switch is closed. Express your answer in terms of R, $\mathcal{E}$, L, t, and physical constants, as appropriate.

After reaching steady state, the absolute value of the potential difference across the inductor is $|\Delta V_1|$. The students replace the original inductor with a new inductor that has nonnegligible resistance. The experiment is repeated. After a long time, the absolute value of the potential difference across the new inductor is $|\Delta V_2|$.

(d) **Indicate** whether $|\Delta V_2|$ is greater than, less than, or equal to $|\Delta V_1|$.

_____ $|\Delta V_2| > |\Delta V_1|$ _____ $|\Delta V_2| < |\Delta V_1|$ _____ $|\Delta V_2| = |\Delta V_1|$

Justify your answer.

GO ON TO THE NEXT PAGE.

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

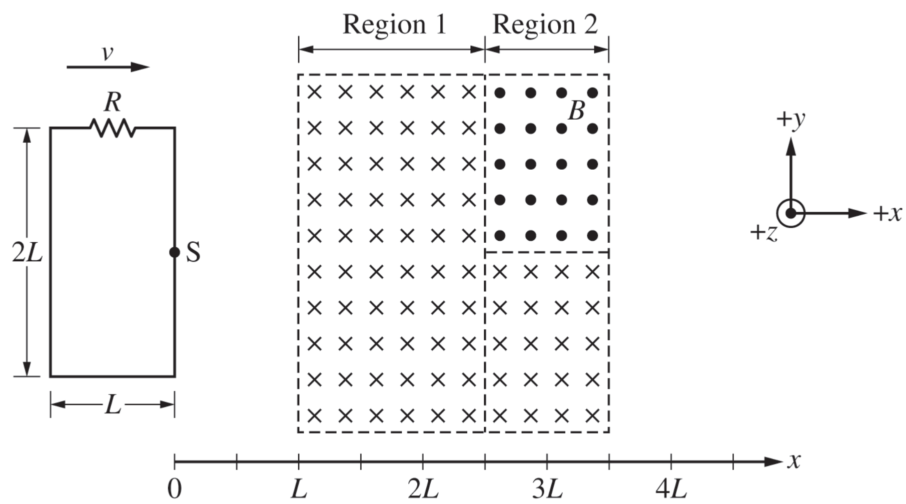


Figure 1

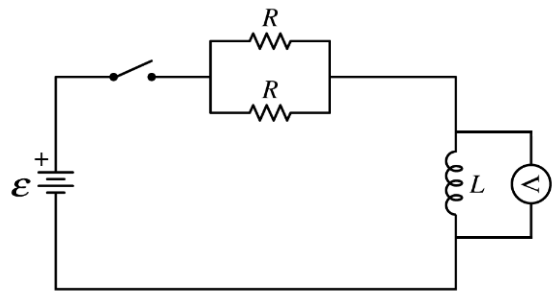
3. A wire is connected to a resistor of resistance R to form a rigid rectangular loop of width L and height $2L$. An external force is exerted on the loop so that the loop always moves with constant speed v in the $+x$-direction, as shown in Figure 1. The loop then enters Region 1 of external uniform 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.

GO ON TO THE NEXT PAGE.

Question 2: Free-Response Question — 15 points

(a)(i)	For correctly placing the voltmeter in parallel with the inductor	**1 point**

Example Response



(a)(ii)	For a procedure that indicates that the voltmeter should be used to measure the potential difference for at least one time	**1 point**
	For measuring the potential difference from immediately after the switch is closed to when steady-state conditions have been established or during a time interval that would allow the time constant to be determined	**1 point**

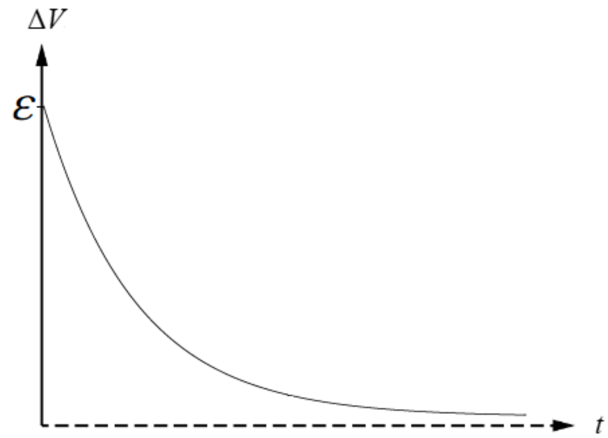
Example Response

Close the switch. Using the voltmeter, record the potential difference as a function of time until steady-state conditions are established.

Total for part (a) 3 points

(b)(i)	For correctly labeling potential difference on the vertical axis and time on the horizontal axis	**1 point**
	For a concave-up and decreasing curve	**1 point**
	For a curve that asymptotically approaches zero, or a curve that starts at the origin and approaches a horizontal asymptote that is consistent with the placement of the voltmeter in the response in part (a)(i)	**1 point**
	For including a vertical intercept or a horizontal asymptote that is consistent with the placement of the voltmeter in the response in part (a)(i) that is correctly labeled as $\mathcal{E}$	**1 point**

Example Response



(b)(ii) For indicating that a curve fit to the graph is that of an exponential function or for correctly relating the area under the curve to the current in the circuit **1 point**

Alternate Solution

For indicating the time on the graph where the potential difference is approximately $0.37\mathcal{E}$, or $0.63\mathcal{E}$ for a curve that starts at the origin and approaches a horizontal asymptote that is consistent with the placement of the voltmeter in the response in part (a)(i)

For indicating that the coefficient in front of the t of the curve-fit equation is equal to $\frac{R}{2L}$ or for correctly relating R to L and the current **1 point**

Alternate Solution

For indicating that the time constant is equal to $\frac{2L}{R}$

Example Response

The data in the graph should be fit with an exponential function for the equation $V_L = \mathcal{E}\left(e^{-t\frac{R}{2L}}\right)$. Because $\mathcal{E}$ and L are known, R can be calculated.

Alternate Example Response

The potential difference at $0.37\mathcal{E}$ along the vertical axis corresponds to the time constant along the horizontal axis. Because the time constant is equal to $\frac{2L}{R}$, and L is known, R can be calculated.

Total for part (b) **6 points**