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

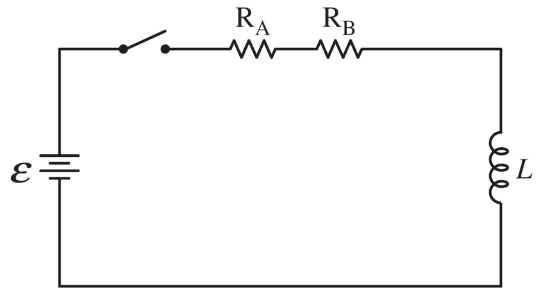

Figure 1

2. Students are asked to determine the resistance R of identical resistors R_A and R_B. The resistors are connected in series with each other, 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 increases 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 increases 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 a measured quantity that increases with time. Provide enough detail so that another student could replicate the experiment.

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(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.

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(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 R_A 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 R_A 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.

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

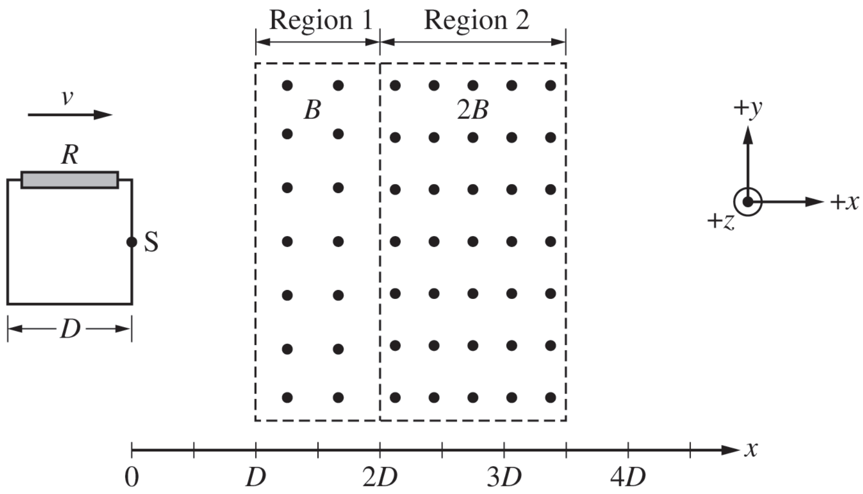

Figure 1

3. A wire is connected to a resistor of resistance R to form a rigid 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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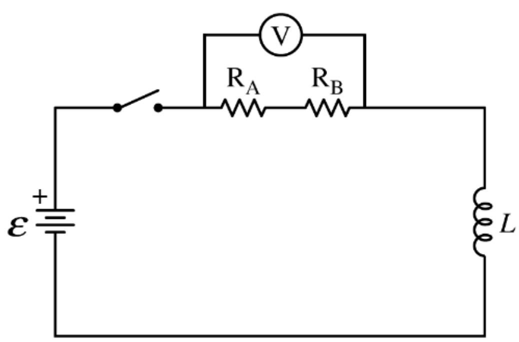
Question 2: Free-Response Question — 15 points

(a)(i)	For correctly placing the voltmeter in parallel with Resistor A, Resistor B, or the combination of resistors A and B	**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 until a time at which the time constant can 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-down and increasing curve	**1 point**
	For a curve that starts at the origin and asymptotically approaches a nonzero potential difference value	**1 point**
	For correctly labeling the horizontal asymptote that is consistent with the indication of the connection of the voltmeter in the response in part (a)(i)	**1 point**

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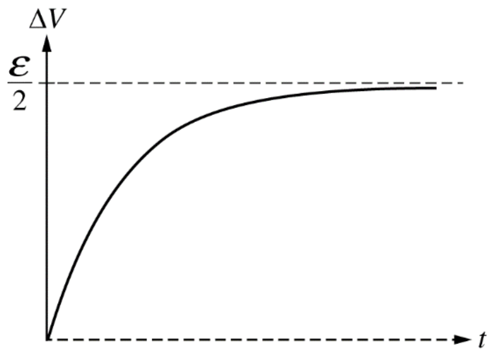
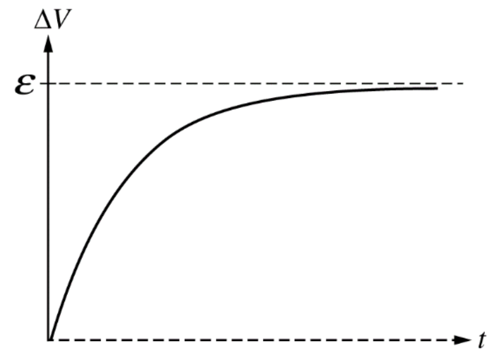
Example Responses



One Resistor

OR



Combination of Resistors

(b)(ii) For indicating that a curve fit to the graph is that of an exponential function **1 point**

Alternate Solution

For indicating the time on the graph where the potential difference across Resistor A *or Resistor* B *is approximately* $\frac{0.63\mathcal{E}}{2}$ *or that the potential difference across the combination of resistors* A *and* B *is approximately* $0.63\mathcal{E}$

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

Alternate Solution

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

Example Response

The data in the graph should be fit with an exponential function for the equation $V_R = \mathcal{E}\left(1 - e^{-t\frac{2R}{L}}\right)$. *Because* $\mathcal{E}$ *and* L *are known,* R *can be calculated.*

Alternate Example Response

The potential difference at $0.63\mathcal{E}$ *along the vertical axis corresponds to the time constant along the horizontal axis. Because the time constant is equal to* $\frac{L}{2R}$*, and* L *is known,* R *can be calculated.*

Total for part (b) 6 points