AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2008 SCORING GUIDELINES

General Notes About 2008 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point and a student's solution contains the application of that equation to the problem, but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations such as those given on the AP Physics Exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is, of course, also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases, answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 2

15 points total | **Distribution of points**

(a)

(i) 4 points

For calculating the equivalent resistance of the parallel branch — 1 point

$$\frac{1}{R_{resP}} = \frac{1}{(100 + 50)\ \Omega} + \frac{1}{300\ \Omega} = \frac{3}{300\ \Omega}$$

$R_{resP} = 100\ \Omega$

For calculating the total resistance of the circuit — 1 point

$R_{resT} = R_1 + R_{resP} = 200\ \Omega + 100\ \Omega = 300\ \Omega$

For correctly using the total resistance to compute the current through the battery — 1 point

$I_{resT} = \mathcal{E}/R_{resT} = 1500\ \text{V}/300\ \Omega = 5\ \text{A}$

For correctly using the total current to calculate the voltage across R_2 — 1 point

$V_{1res} = I_{resT}R_1 = (5\ \text{A})(200\ \Omega) = 1000\ \text{V}$

$V_{2res} = \mathcal{E} - V_{1res} = 1500\ \text{V} - 1000\ \text{V}$

$V_{2res} = 500\ \text{V}$

Alternate solution — *Alternate points*

For the correct Kirchhoff junction equation — *1 point*

$I_1 = I_2 + I_3$

For one correct loop equation $(\Sigma V = 0)$ — *1 point*

For a second correct loop equation — *1 point*

$1500\ \text{V} - (200\ \Omega)I_1 - (300\ \Omega)I_2 = 0$

$1500\ \text{V} - (200\ \Omega)I_1 - (150\ \Omega)I_3 = 0$

Using these three equations to solve for I_2

$1500\ \text{V} - (200\ \Omega)I_1 - (300\ \Omega)I_2 = 1500\ \text{V} - (200\ \Omega)I_1 - (150\ \Omega)I_3$

$(300\ \Omega)I_2 = (150\ \Omega)I_3$

$2I_2 = I_3$

$I_1 = I_2 + 2I_2 = 3I_2$

$1500\ \text{V} - (200\ \Omega)3I_2 - (300\ \Omega)I_2 = 0$

$I_2 = 1.67\ \text{A}$

For correctly using the current I_2 *to calculate the voltage across* R_2 — *1 point*

$V_{2res} = (1.67\ \text{A})(300\ \Omega)$

$V_{2res} = 500\ \text{V}$

Question 2 (continued)

Distribution of points

(a) (continued)

(ii) 2 points

For indicating that the current in branch 3 is zero immediately after the switch is closed, either explicitly or by correctly calculating the total resistance at this instant — 1 point

$R_{indT} = R_1 + R_2 = 200\ \Omega + 300\ \Omega = 500\ \Omega$

For correctly using the total resistance to calculate the voltage across resistor R_2 — 1 point

$I_{indT} = \mathcal{E}/R_{indT} = 1500\ \text{V}/500\ \Omega = 3\ \text{A}$

$V_{2ind} = (3\ \text{A})(300\ \Omega) = 900\ \text{V}$

Alternate solution — *Alternate points*

For one correct Kirchhoff equation indicating knowledge that there is no current through resistor R_3 — *1 point*

$1500\ \text{V} - (200\ \Omega)I_{indT} - (300\ \Omega)I_{indT} = 0$

$I_{indT} = 3\ \text{A}$

For correctly using the current to calculate the voltage across resistor R_2 — *1 point*

$V_{2ind} = (3\ \text{A})(300\ \Omega)$

$V_{2ind} = 900\ \text{V}$

(iii) 3 points

For indicating that the voltage across the capacitor is zero immediately after the switch is closed, either explicitly or by correctly calculating the total resistance — 1 point

$$\frac{1}{R_{capP}} = \frac{1}{100\ \Omega} + \frac{1}{300\ \Omega} = \frac{4}{300\ \Omega}$$

$R_{capP} = 75\ \Omega$

$R_{capT} = R_1 + R_{capP} = 200\ \Omega + 75\ \Omega = 275\ \Omega$

For correctly using the total resistance to compute the current through the battery — 1 point

$I_{capT} = \mathcal{E}/R_{capT} = 1500\ \text{V}/275\ \Omega = 5.45\ \text{A}$

For correctly using the total current to compute the voltage across R_2 — 1 point

$V_{2cap} = I_{capT}R_{capP} = (5.45\ \text{A})(75\ \Omega)$

$V_{2cap} = 410\ \text{V}$ (rounded to two significant digits)

Question 2 (continued)

Distribution of points

(a) (continued)

(iii) (continued)

Alternate solution — *Alternate points*

For one correct Kirchhoff equation indicating the current flowing in R_3 — *1 point*

For a second correct Kirchhoff equation — *1 point*

$1500 \text{ V} - (200\ \Omega)I_1 - (100\ \Omega)I_3 = 0$

$1500 \text{ V} - (200\ \Omega)I_1 - (300\ \Omega)I_2 = 0$

Using a Kirchhoff junction equation and solving the three equations for I_2

$I_1 = I_2 + I_3$

$1500 \text{ V} - (200\ \Omega)I_1 - (100\ \Omega)I_3 = 1500 \text{ V} - (200\ \Omega)I_1 - (300\ \Omega)I_2$

$(100\ \Omega)I_3 = (300\ \Omega)I_2$

$I_3 = 3I_2$

$I_1 = I_2 + 3I_2 = 4I_2$

$1500 \text{ V} - (200\ \Omega)4I_2 - (300\ \Omega)I_2 = 0$

$I_2 = 1.36 \text{ A}$

For correctly using I_2 *to calculate the voltage across* R_2 — *1 point*

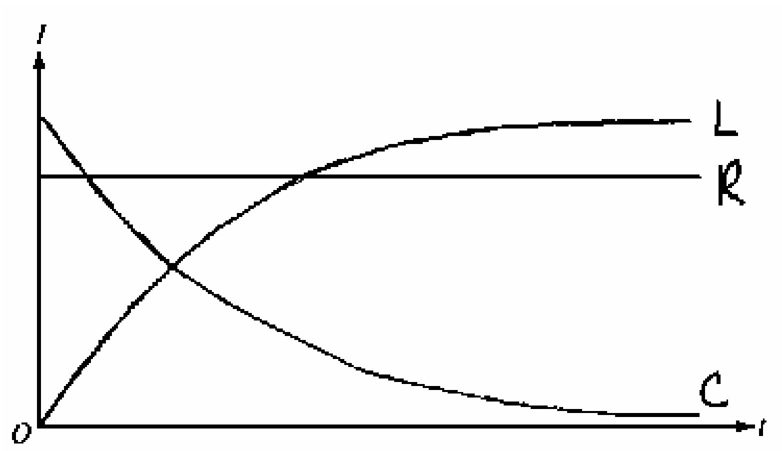
$V_2 = I_2R_2 = (1.36 \text{ A})(300\ \Omega)$

$V_2 = 410 \text{ V}$ (rounded to two significant digits)

Question 2 (continued)

Distribution of points

(b) 6 points



<u>Resistor graph</u>:

The current is constant with the resistor placed between points *A* and *B*. The resistance of that branch is more than when the capacitor and inductor are placed there, so the current will be less.

For drawing a horizontal line, indicating a constant current — 1 point

For having the value of the resistor graph less than the initial value of the capacitor graph or the steady state value of the inductor graph — 1 point

<u>Inductor graph</u>:

The inductor initially opposes the flow of current, so the initial current in that branch is zero. Eventually, the inductor acts like a wire and does not impede the flow of charge, as the rate of change of current decreases to zero.

For starting the graph at $I_3 = 0$ at time $t = 0$ — 1 point

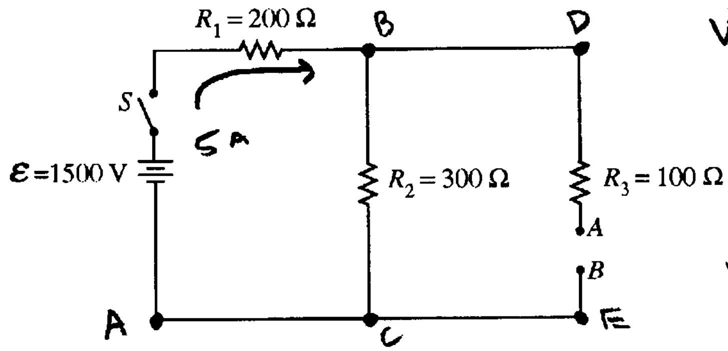
For a graph that is concave down and asymptotic to the initial current in the capacitor case — 1 point

<u>Capacitor graph</u>:

Initially, the capacitor is uncharged and current is a maximum in the branch containing R_3. As the capacitor charges the current in that branch decreases to zero.

For a finite, nonzero initial value for the current I_3 at $t = 0$ — 1 point

For a graph that is concave up and asymptotic to $I = 0$ — 1 point



$V_B = V_D$

$V_C = V_E = V_A = 0$

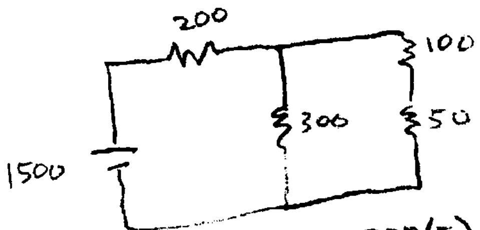
E&M. 2.

In the circuit shown above, A and B are terminals to which different circuit components can be connected.

(a) Calculate the potential difference across R_2 immediately after the switch S is closed in each of the following cases.

$\frac{1}{300} + \frac{1}{150} = \frac{1}{100}$

i. A 50 Ω resistor connects A and B.



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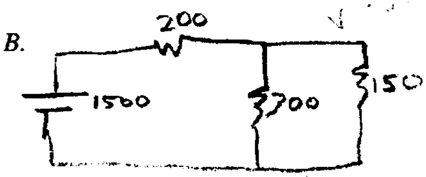

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$R_{eq} = 300$

$V = IR$
$1500 = 300 I$
$I_T = 5$ A

$V_A + 1500 - 200(5) = V_B$
$1500 - 1000 = V_B$
$500 = V_B$

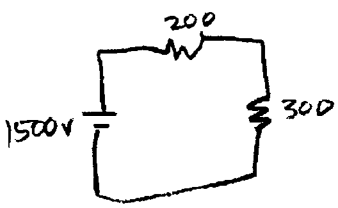
$V_C = 0$

$V_B - V_C = 500 - 0 = 500$ V

$V_{R_2} = 500$ V

ii. A 40 mH inductor connects A and B.

t=0 inductor acts as perfect insulator



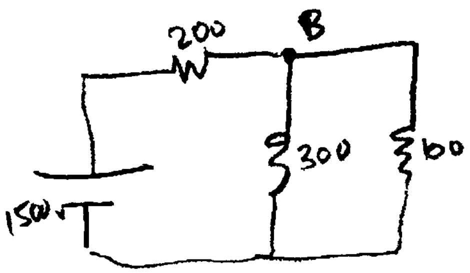
$R_{eq} = 500$
$1500 = 500 I$
$I = 3$

$V_{R_2} = I R_2 = 3(300) = 900$ V

$V_{R_2} = 900$ V

iii. An initially uncharged 0.80 μF capacitor connects A and B.

t=0 capacitor acts as perfect conductor



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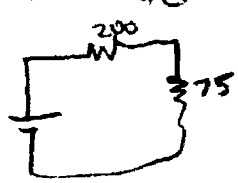

$R_{eq} = 275\ \Omega$
$1500 = 275 I$
$I_{Total} = 5.5$A

$1500 - 200(5.5) = 409$ V

$V_{R2} = 410$ V

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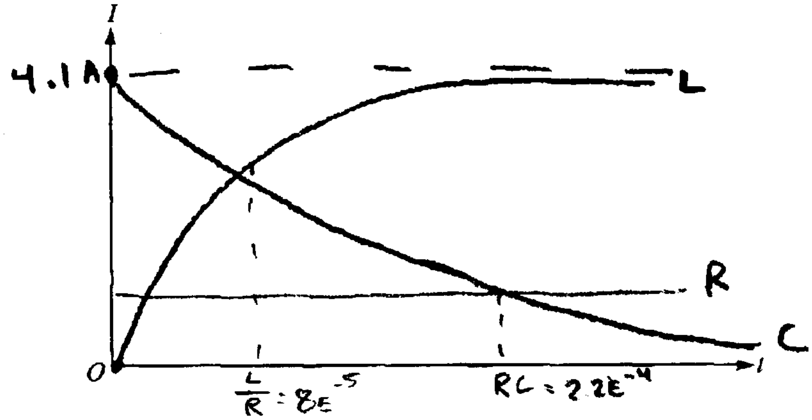
(b) The switch gets closed at time $t = 0$. On the axes below, sketch the graphs of the current in the 100 Ω resistor R_3 versus time t for the three cases. Label the graphs R for the resistor, L for the inductor, and C for the capacitor.



$I =$

$T = \frac{L}{R_{eq}} = \frac{.040}{500} = 8E^{-5}$ s

$I_f = 4.1$ A

$T = R_{eq}C = (.8E^{-6})(275) = 2.2E^{-4}$ s

V_0 $410 = 100\, I_0$

$I_0 = 4.1$ A

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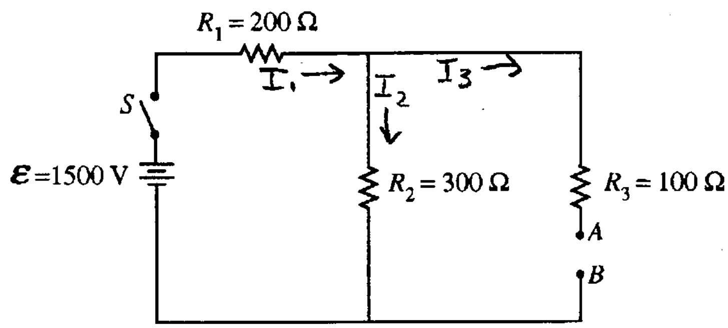


E&M. 2.

In the circuit shown above, A and B are terminals to which different circuit components can be connected.

(a) Calculate the potential difference across R_2 immediately after the switch S is closed in each of the following cases.

i. A 50 Ω resistor connects A and B.

$I_1 = I_2 + I_3$

$1500 - 200 I_1 - 150 I_3 = 0$

$1500 - 200 I_1 - 300 I_2 = 0$

$I_1 = 5\ A$

$I_2 = 1.67\ A$

$I_3 = 3.33\ A$

$\Delta V = IR = (1.67\ A)(300\ \Omega) = \boxed{500\ V}$

ii. A 40 mH inductor connects A and B.

no current flows in the AB part of circuit

$1500 - 500 I = 0$

$I = 3A$

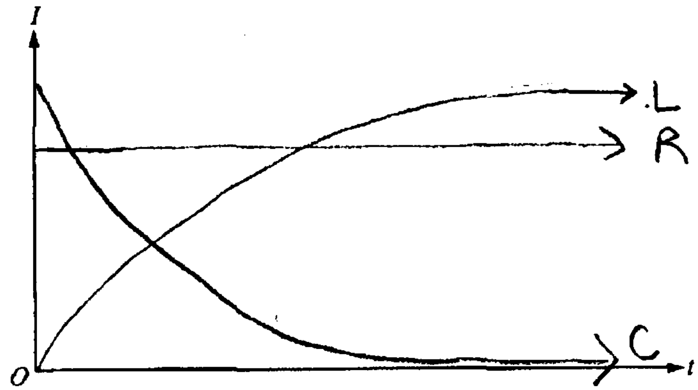
$\Delta V = IR_2 = (3\ A)(300\ \Omega) = \boxed{900\ V}$

iii. An initially uncharged 0.80 μF capacitor connects A and B.

no current flows through R_2

$\boxed{0\ V}$

(b) The switch gets closed at time $t = 0$. On the axes below, sketch the graphs of the current in the 100 Ω resistor R_3 versus time t for the three cases. Label the graphs R for the resistor, L for the inductor, and C for the capacitor.



R: constant

L: $I = I_0 (1 - e^{-t/(L/R)})$

C: $I = I_0 e^{-t/RC}$

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$\frac{1}{300} + \frac{1}{150} = \frac{1}{x}$

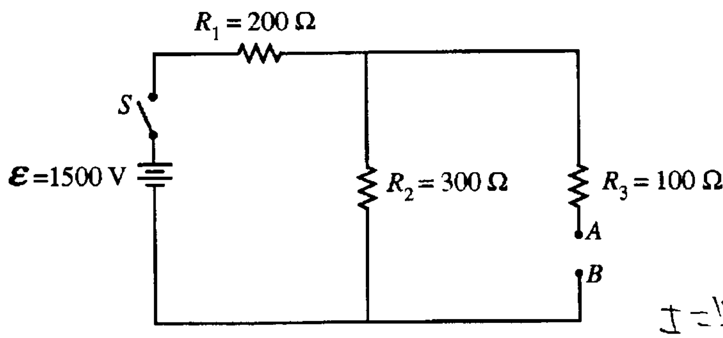
$\frac{3}{300} = \frac{1}{x}$

$\frac{1}{100} = \frac{1}{x}$

$100 + 200 = 300$

$I = \frac{1500}{300}$

$I = 5$



E&M. 2.

In the circuit shown above, A and B are terminals to which different circuit components can be connected.

(a) Calculate the potential difference across R_2 immediately after the switch S is closed in each of the following cases.

i. A 50 Ω resistor connects A and B.

$R_{total} = 300$

$I = 5$

$V = IR$

$V_2 = 5(300)$

$V_2 = \boxed{1500\ V}$

ii. A 40 mH inductor connects A and B.

$R_{total} = 275$

$I = 5.45$

$V_2 = IR$

$V_2 = 5.45(300)$

$V_2 = 1635$

iii. An initially uncharged 0.80 μF capacitor connects A and B.

$R_{total} = 275$

$I = 5.45$

$V_2 = IR$

$= 5.45(300)$

$V_2 = \boxed{1635\ V}$

$I = \frac{V}{R}$

$I = \frac{1500}{275}$

$I = 5.45$

$\frac{1}{300} + \frac{1}{100} = \frac{1}{total}$

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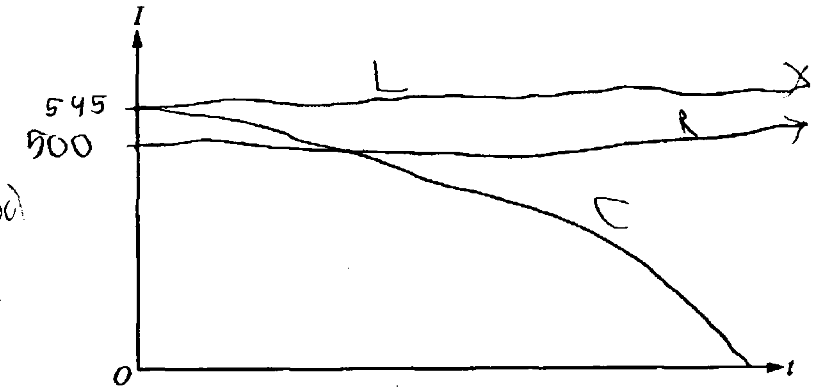
CE2C 2

(b) The switch gets closed at time $t = 0$. On the axes below, sketch the graphs of the current in the 100 Ω resistor R_3 versus time t for the three cases. Label the graphs R for the resistor, L for the inductor, and C for the capacitor.

$V = 5(100)$

500

$V = 5.45(100)$



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AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2008 SCORING COMMENTARY

Question 2

Overview

This question was intended to assess students' knowledge of circuits, including *RC* and *RL* circuits. In part (a)(i) students had to know how to determine voltages in a resistive network involving both series and parallel connections. In parts (a)(ii) and (a)(iii) students needed to understand how capacitors and inductors behave just after the power supply is connected. Part (b) required students to graph the current through the branch of the circuit containing the various replaceable elements. Students had to demonstrate understanding of how the capacitor, inductor, and resistor affected the time dependence of the current in that branch.

Sample: CE2A
Score: 15

In part (a) the student includes diagrams that are helpful in evaluating the work shown and explicitly describes the initial behavior of the inductor and capacitor. The graph includes labels with actual values not required when just a sketch is requested.

Sample: CE2B
Score: 12

The student correctly uses Kirchhoff's rules in part (a)(i) and received full credit for parts (a)(i) and (a)(ii). No points were earned in part (a)(iii); however, part (b) earned full credit.

Sample: CE2C
Score: 8

In part (a)(i) the student lost the last point because the final calculation of voltage is incorrect. In part (a)(ii) the student uses capacitor conditions for the inductor, so no points were earned. In part (a)(iii) the student uses the correct initial conditions but again makes an error in the final calculation of voltage, so only 2 points were earned. In part (b) the resistor graph earned 2 points, and the capacitor graph earned 1 point for its initial value.