AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2007 SCORING GUIDELINES

General Notes About 2007 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 one 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 and 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 $g = 9.8 \text{ m}/\text{s}^2$, but use of $10 \text{ m}/\text{s}^2$ 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 1

15 points total — **Distribution of points**

(a) 3 points

Writing the general loop rule for the circuit
$\mathcal{E} = IR + V_C$
$V_C = 0$ at time = 0, so $\mathcal{E} = I_0 R$

For correct substitution of a value for I_0 and a value for R into Ohm's law or the loop rule with the recognition that $V_C = 0$ at time = 0	1 point
For correctly reading the magnitude of I_0 from the graph and using it in a valid equation	1 point

$2.2 \le I_0 \le 2.3$

For correctly using the current in mA — 1 point

$2.2\text{ mA} \le I_0 \le 2.3\text{ mA}$

$\mathcal{E} = \left(2.25 \times 10^{-3}\text{ A}\right)(550\ \Omega) = 1.24\text{ V}$

(b) 3 points

For a correct loop rule equation — 1 point

$\mathcal{E} = IR + V_C$

For correctly reading $I(t = 4\text{ s})$ from the graph — 1 point

$0.3\text{ mA} \le I(t = 4\text{ s}) \le 0.4\text{ mA}$

For correct substitution of $\mathcal{E}$ from part (a) into a correct equation — 1 point

$V_C = 1.24\text{ V} - \left(0.35 \times 10^{-3}\text{ A}\right)(550\ \Omega)$, using the middle of the range of acceptable values for I

$V_C = 1.05\text{ V}$ (or value consistent with the value of I chosen within the acceptable range)

<u>Note</u>: Use of a value for current that was not correctly expressed in mA was acceptable if the mA point was not awarded in part (a) (either for using an incorrectly expressed value or no value at all).

Alternate solution — *Alternate points*

For correctly using an expression for V_C — *1 point*

$V_C = \mathcal{E}\left(1 - e^{-t/\tau}\right)$ *or equivalent*

For correct substitution for the time and the time constant — *1 point*

$$\frac{t}{\tau} = \frac{t}{RC} = \frac{4.0\text{ s}}{(550\ \Omega)\left(4000 \times 10^{-6}\text{ F}\right)} = \frac{4.0\text{ s}}{2.2\text{ s}} = 1.82$$

For correct substitution of $\mathcal{E}$ from part (a) into a correct equation — *1 point*

$V_C = (1.24\text{ V})\left(1 - e^{-1.82}\right)$

$V_C = 1.04\text{ V}$

Question 1 (continued)

Distribution of points

(c) 2 points

For using V_C from part (b) in a correct equation — 1 point

$Q = CV = C(1.05\text{ V})$

For correct substitution of C — 1 point

$Q = \left(4000 \times 10^{-6}\text{ F}\right)(1.05\text{ V})$

$Q = 4.20 \times 10^{-3}\text{ C}$ or $4200 \times 10^{-6}\text{ C}$ (or value consistent with V_C from part (b))

Alternate solution — *Alternate points*

For a correct substitution of $\mathcal{E}$ or I_0 into a correct equation — *1 point*

$Q = C\mathcal{E}\left(1 - e^{-t/\tau}\right) = C(1.24\text{ V})\left(1 - e^{-t/\tau}\right)$

OR $Q = \int_0^4 \left(2.25 \times 10^{-3}\text{A}\right)\left(e^{-t/\tau}\right)dt$

For a correct substitution of C or τ into a correct equation — *1 point*

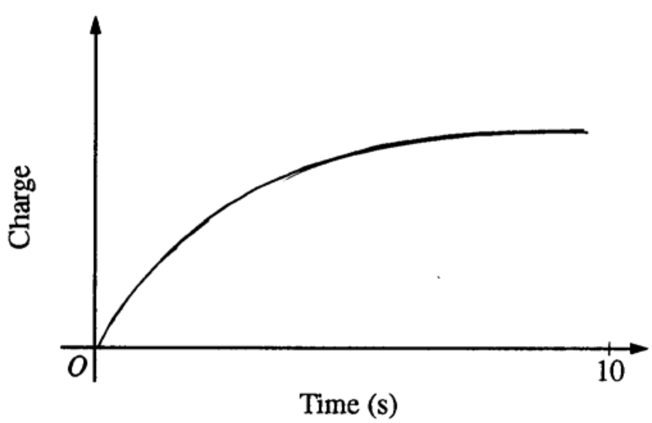
$Q = \left(4000 \times 10^{-6}\text{ F}\right)(1.24\text{ V})\left(1 - e^{-1.82}\right)$

OR $Q = \int_0^4 \left(2.25 \times 10^{-3}\text{A}\right)\left(e^{-t/(2.2\text{s})}\right)dt$

$Q = 4.16 \times 10^{-3}\text{ C}$ *or* $4160\ \mu\text{C}$

<u>Note</u>: *If the answer to (c) was correct using one of the exponential equations, it could be substituted into $V = Q/C$ in part (b) for full credit.*

(d) 2 points



For starting the graph at the origin — 1 point

For a sketch that is approximately exponential and approaching an asymptote — 1 point

Question 1 (continued)

Distribution of points

(e) 2 points

$P = IV_R$ or I^2R or V_R^2/R, where $V_R = \mathcal{E} - V_C$

For the substitution of one correct quantity into a correct equation for the instantaneous power — 1 point

For the substitution of the second correct quantity into a correct equation for the instantaneous power — 1 point

$P = (0.35 \times 10^{-3}\ \text{A})(0.19\ \text{V})$ or $(0.35 \times 10^{-3}\ \text{A})^2 (550\ \Omega)$ or $(0.19\ \text{V})^2/(550\ \Omega)$

$P = 6.7 \times 10^{-5}\ \text{W}$ (or value consistent with earlier values of I and V_C)

<u>Note</u>: Use of a value for current that was not correctly expressed in mA was acceptable if the mA part was not awarded in part (a) (either by using an incorrectly expressed value or no value at all), or if the value used in part (e) was consistent with the value used in part (b).

(f) 3 points

For marking the "Greater than" choice — 1 point

For any indication that C increases — 1 point

$C = \kappa\varepsilon_0 A/d$ or $C_{\text{new}} = 3C_0$

For explicitly and correctly addressing time dependence — 1 point

$$\frac{Q_{\kappa=3}(t = 4\ \text{s})}{Q_{\kappa=1}(t = 4\ \text{s})} = \frac{\kappa C\mathcal{E}\left(1 - e^{-t/\kappa\tau}\right)}{C\mathcal{E}\left(1 - e^{-t/\tau}\right)} = \frac{3\left(1 - e^{-0.61}\right)}{\left(1 - e^{-1.82}\right)} = 1.63\ ,\ \tau_{\kappa=3} = 3RC\ ,\ \text{or equivalent}$$

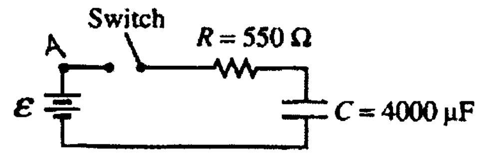
<u>Notes</u>:

If "Greater than" was not checked, no points were awarded for part (f) regardless of the justification.

If "Greater than" was checked, a correct value of $Q_{\kappa=3}(t = 4\ \text{s}) = 6.7 \times 10^{-3}\text{C}$ earned both justification points.

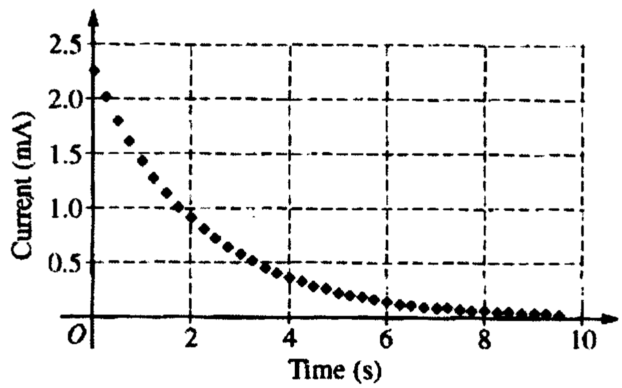
PHYSICS C: ELECTRICITY AND MAGNETISM
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



E&M 1.

A student sets up the circuit above in the lab. The values of the resistance and capacitance are as shown, but the constant voltage $\mathcal{E}$ delivered by the ideal battery is unknown. At time $t = 0$, the capacitor is uncharged and the student closes the switch. The current as a function of time is measured using a computer system, and the following graph is obtained.



(a) Using the data above, calculate the battery voltage $\mathcal{E}$.

$I_0 = 2.25\text{A}$

$\mathcal{E} = IR$

$\mathcal{E} = (2.25\text{A})(550\Omega) = \boxed{1240\text{V}}$

(b) Calculate the voltage across the capacitor at time $t = 4.0$ s.

$V_c = \mathcal{E}_0(1 - e^{-\frac{t}{RC}})$

$V_c = 1240\text{V}\left(1 - e^{\frac{-4.0\text{s}}{(550\Omega)(4000\mu F)}}\right)$

$\boxed{V_c = 1040\text{V}}$

GO ON TO THE NEXT PAGE.

(c) Calculate the charge on the capacitor at $t = 4.0$ s.

$C = \frac{Q}{V}$

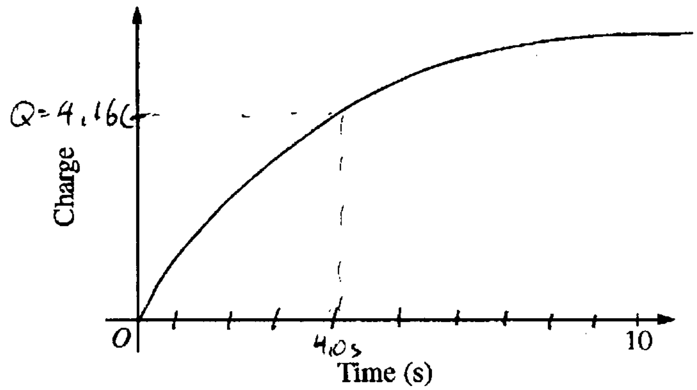
$4000\mu F = \frac{Q}{1040V}$

$\boxed{Q = 4.16C}$

(d) On the axes below, sketch a graph of the charge on the capacitor as a function of time.

$Q = VC$

$Q = \mathcal{E}_0(1 - e^{-\frac{t}{RC}})C$



(e) Calculate the power being dissipated as heat in the resistor at $t = 4.0$ s.

$P = IV$

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

$P = \frac{V^2}{R}$

LOOP AA

$1240V - 1040V - V_R = 0$

$V_c = 1040V$

$\hookrightarrow V_R = 200V$

$P = \frac{(200V)^2}{(550\Omega)} = \boxed{72.7 \text{ Watts}}$

(f) The capacitor is now discharged, its dielectric of constant $\kappa = 1$ is replaced by a dielectric of constant $\kappa = 3$, and the procedure is repeated. Is the amount of charge on one plate of the capacitor at $t = 4.0$ s now greater than, less than, or the same as before? Justify your answer.

X Greater than ____ Less than ____ The same

$C = \frac{kA\epsilon_0}{d}$ → Because k increased, C also increased, and since $C = \frac{Q}{V}$, and V remains constant, Q must have increased

GO ON TO THE NEXT PAGE.

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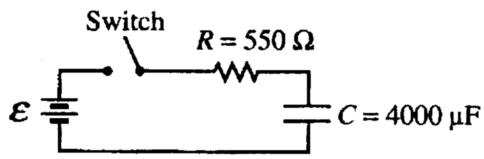
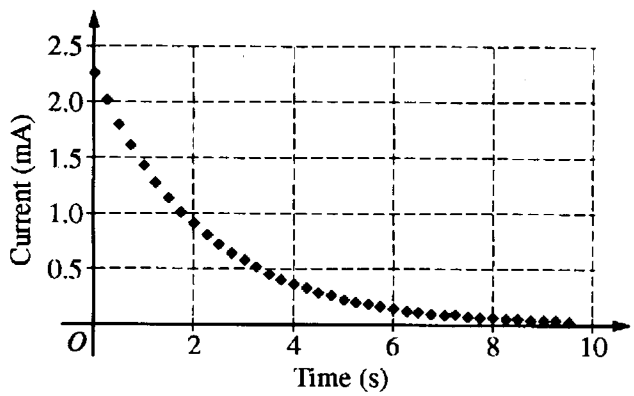


E&M 1.

A student sets up the circuit above in the lab. The values of the resistance and capacitance are as shown, but the constant voltage $\mathcal{E}$ delivered by the ideal battery is unknown. At time $t = 0$, the capacitor is uncharged and the student closes the switch. The current as a function of time is measured using a computer system, and the following graph is obtained.



(a) Using the data above, calculate the battery voltage $\mathcal{E}$.

$C = \frac{Q}{V}$ $V = \frac{Q}{C}$

$\tau = R \cdot C$

$V = V_0 - e^{t/\tau}$

~~[illegible]~~ $V_0 = \mathcal{E}$

$V = IR$

$V = 2.25 \times 550 = 1237.5\,V$

$\mathcal{E} = -\frac{d\Phi}{dt}$

$\mathcal{E} = -L\frac{dI}{dt}$

(b) Calculate the voltage across the capacitor at time $t = 4.0$ s.

$V = .4 \cdot 550 = 220\,V$

GO ON TO THE NEXT PAGE.

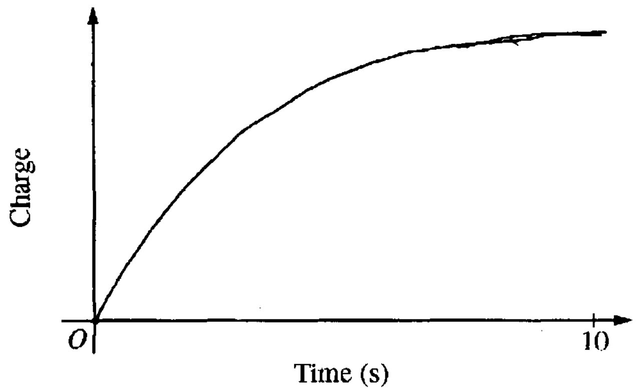
(c) Calculate the charge on the capacitor at $t = 4.0$ s.

$C = \frac{Q}{V}$

$Q = CV$

$Q = 4000 \mu F \times 220V = 880000\ V\mu F$

(d) On the axes below, sketch a graph of the charge on the capacitor as a function of time.



(e) Calculate the power being dissipated as heat in the resistor at $t = 4.0$ s.

$P = IV$

(f) The capacitor is now discharged, its dielectric of constant $\kappa = 1$ is replaced by a dielectric of constant $\kappa = 3$, and the procedure is repeated. Is the amount of charge on one plate of the capacitor at $t = 4.0$ s now greater than, less than, or the same as before? Justify your answer.

X Greater than ____ Less than ____ The same

$C = \frac{K \varepsilon_0 A}{d}$

ε_0, A, d remain same

only K increases so C increases

GO ON TO THE NEXT PAGE.

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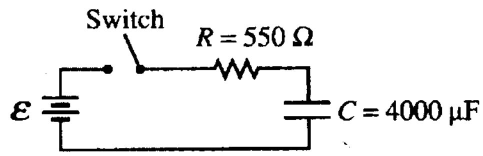
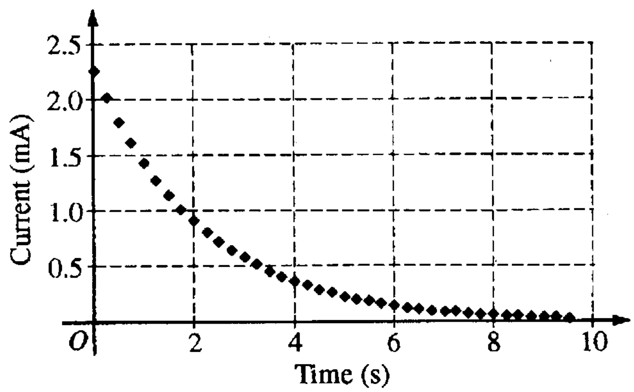


E&M 1.

A student sets up the circuit above in the lab. The values of the resistance and capacitance are as shown, but the constant voltage $\mathcal{E}$ delivered by the ideal battery is unknown. At time $t = 0$, the capacitor is uncharged and the student closes the switch. The current as a function of time is measured using a computer system, and the following graph is obtained.



(a) Using the data above, calculate the battery voltage $\mathcal{E}$.

$V = IR$

$= (2.25)(550)$

$= 1237.5\ V$

(b) Calculate the voltage across the capacitor at time $t = 4.0$ s.

$I = \frac{dQ}{dt}$ $\quad C = \frac{Q}{V}$

$.4 = \frac{dQ}{4}$ $\quad 4000 \cdot 10^{-6} = \frac{1.6}{V}$ $\quad V = 400\ V$

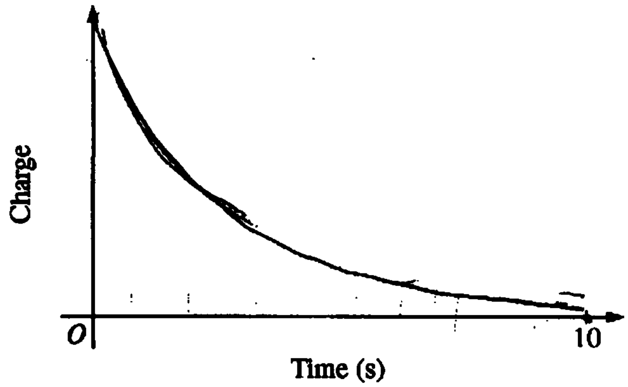
$dQ = 1.6$

GO ON TO THE NEXT PAGE.

(c) Calculate the charge on the capacitor at $t = 4.0$ s.

1.6 C

(d) On the axes below, sketch a graph of the charge on the capacitor as a function of time.



time ↑ increases
Q ↓ decreases

(e) Calculate the power being dissipated as heat in the resistor at $t = 4.0$ s.

$P = IV$
$= (.4)(400)$
$P = 160$ watts

(f) The capacitor is now discharged, its dielectric of constant $\kappa = 1$ is replaced by a dielectric of constant $\kappa = 3$, and the procedure is repeated. Is the amount of charge on one plate of the capacitor at $t = 4.0$ s now greater than, less than, or the same as before? Justify your answer.

____Greater than ____Less than __X__The same

C - greater

Although K caused the capacitance to increase the current did not increase. Therefore in the same amount of time the same charge will be on the plate.

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Question 1

Overview

This question was designed to assess students' ability to interpret and utilize information presented graphically, as well as their understanding of the charging of a simple RC circuit, including the dissipation of energy in the resistor and the consequences of changing the capacitance.

Sample: E1A
Score: 14

This clearly written response lost only 1 point in the justification in part (f) for failing to consider the time dependence of the charge on the capacitor as it is charged.

Sample: E1B
Score: 10

Part (a) received full credit. In part (b) the voltage across the resistor is computed, so only 1 point for the correct value of I at 4 seconds was earned. In part (c) only 1 point was awarded for the correct substitution of the time constant into the equation, but the substitution for the maximum value of Q is incorrect, so the other point was not awarded. Part (d) received full credit. Part (e) earned only 1 point for using the correct value of I at 4 seconds in the correct equation; the use of the voltage from part (b) is incorrect. Part (f) lost 1 point for not addressing time dependence.

Sample: E1C
Score: 4

Part (a) received 2 points but lost the final point for not using milliamps as the unit for current, substituting for the current as if the unit were amperes. Part (b) was awarded only the point for using a value for the current at 4 seconds that is within the acceptable range. Since the point for not expressing the current in milliamps was lost in part (a), there was no further penalty for the same error in part (b). No credit was given for part (c), and in part (d) the graph must start at the origin to receive the second point, so no credit was given for part (d) either. In part (e) 1 point was given for a correct substitution for the current into a valid equation, but the voltage is incorrect. In part (f) the wrong box is checked, so no points were awarded.