AP® Physics C: Electricity and Magnetism
2006 Scoring Guidelines

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General Notes About 2006 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. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

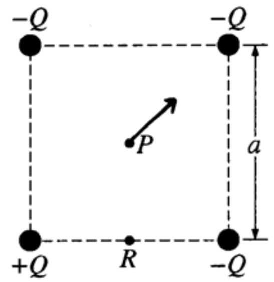
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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 1

15 points total **Distribution of points**

(a) 1 point



For a single arrow pointing toward the upper-right negative charge — 1 point

(b)
(i) 3 points

The fields at point P due to the upper left and lower right negative charges are equal in magnitude and opposite in direction so they sum to zero.

The fields at point P due to the other two charges are equal in magnitude and in the same direction so they add.

For determining the distance between each charge and point P — 1 point

$$r = \frac{a}{\sqrt{2}} \quad \text{OR} \quad r^2 = \frac{1}{2}a^2$$

For correctly summing the fields of the two contributing point charges — 1 point

$$E = 2\left(\frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}\right) = 2\frac{kQ}{r^2}$$

For substituting the distance relationship into an electric field relationship — 1 point

$$E = 2\left(\frac{1}{4\pi\epsilon_0}\frac{Q}{\left(a/\sqrt{2}\right)^2}\right) = 2\frac{kQ}{\left(a/\sqrt{2}\right)^2}$$

Note: Use of the equation above with all substitutions overtly included earned full credit.

$$E = \frac{Q}{\pi\epsilon_0 a^2} = \frac{4kQ}{a^2}$$

Note: Because of the use of the word "derive" in the question stem, no credit was awarded for a final answer equation with no supporting work.

Question 1 (continued)

Distribution of points

(b) (continued)

(ii) 3 points

For a correct expression for the potential of a point charge or charges which is subsequently applied — 1 point

$$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i} = k\sum_i \frac{q_i}{r_i}$$

For indicating the scalar sum of the four charges or potentials — 1 point

$$V = \frac{1}{4\pi\epsilon_0 r}(-Q - Q - Q + Q) = -\frac{2Q}{4\pi\epsilon_0 r} = -\frac{2kQ}{r}$$

For substituting the correct distance relationship into an electric potential relationship — 1 point

$$V = \frac{-2Q}{4\pi\epsilon_0\left(a/\sqrt{2}\right)} = \frac{-2kQ}{\left(a/\sqrt{2}\right)}$$

$$V = -\frac{Q}{\sqrt{2}\pi\epsilon_0 a} = -\frac{2\sqrt{2}kQ}{a}$$

<u>Note</u>: *Because of use of the word "derive" in the question stem, 2 points were awarded for the final expression with no supporting work.*

(c) 3 points

For checking "Negative" — 1 point

For relating the motion of the charge to either a field direction or the potential difference — 2 points

Examples:

The field is directed generally from R to P and the charge moves in the opposite direction. Thus, the field does negative work on the charge.

The potential difference between P and R is positive and the charge moves through the positive potential difference. Thus, the field does negative work on the charge.

<u>Notes</u>:

Only indicating the direction of the field or sign of the potential difference without relating that to the charge motion earned 1 point.

Any obviously incorrect statement within an otherwise correct answer resulted in a 1 point deduction. Examples: "The charges cancelled," or "The field is a scalar," or "The voltage is a vector."

Question 1 (continued)

Distribution of points

(d)

(i) 2 points

For replacing the top right negative charge with a positive charge OR replacing the bottom left positive charge with a negative charge	1 point
For an appropriate justification	1 point

Example:
The vector fields/forces all cancel from oppositely located same charge pairs.
<u>Note</u>: *Any obviously incorrect statement resulted in a 1 point deduction.*
Examples: "The charges cancelled," or "The field is a scalar," or "The voltage is a vector."

(ii) 3 points

For replacing the top left negative charge with a positive charge OR replacing the bottom right negative charge with a positive charge	1 point
For an appropriate justification for zero electric potential	1 point

Example:
The scalar potentials all cancel from equidistant located opposite charge pairs.

For indicating the direction of the resultant nonzero field using words or diagram	1 point

<u>Note</u>: *Any obviously incorrect statement resulted in a 1 point deduction.*
Examples: "The charges cancelled," or "The field is a scalar," or "The voltage is a vector."

Question 2

15 points total | **Distribution of points**

(a) 4 points

From Kirchhoff's loop rule, the sum of the potential differences around the circuit is zero.
For any statement of the loop rule — 1 point

$$\mathcal{E} - V_R - V_C = 0$$

For correct substitution of the potential differences across both resistor and capacitor — 1 point

$$\mathcal{E} - iR_1 - \frac{q}{C} = 0$$

For substituting the differential definition of current — 1 point

$$i = \frac{dq}{dt}$$

For a correct answer including correct signs (a correct answer with no supporting work was awarded full credit) 1 point

$$\mathcal{E} - R_1\frac{dq}{dt} - \frac{q}{C} = 0$$

Alternate solution — *Alternate points*

For a correct exponential expression for current as a function of time — *1 point*

$$I = I_0 e^{-t/R_1C}$$

For applying Ohm's law to determine the initial current — *1 point*

$$I_0 = \frac{\mathcal{E}}{R_1}$$

For substituting the differential definition of current — *1 point*

$$I = \frac{dq}{dt}$$

For a correct answer (a correct answer with no supporting work was awarded full credit) *1 point*

$$\frac{dq}{dt} = \frac{\mathcal{E}}{R_1}e^{-t/R_1C}$$

Question 2 (continued)

Distribution of points

(b) 3 points

Using the differential equation from part (a)

$$\mathcal{E} - \frac{dq}{dt}R_1 - \frac{q}{C} = 0$$

For separating the variables of the differential equation — 1 point

$$\frac{dq}{\mathcal{E}C - q} = \frac{dt}{R_1 C}$$

$$\int_0^q \frac{dq}{q - \mathcal{E}C} = \int_0^t -\frac{dt}{R_1 C}$$

For integrating the expression — 1 point

$$\ln(q - \mathcal{E}C)\Big|_0^q = -\frac{t}{R_1 C}\Big|_0^t$$

$$\ln(q - \mathcal{E}C) - \ln(-\mathcal{E}C) = \ln\frac{q - \mathcal{E}C}{-\mathcal{E}C} = -\frac{1}{R_1 C}(t - 0)$$

$$\frac{q - \mathcal{E}C}{-\mathcal{E}C} = e^{-t/R_1 C}$$

$$q - \mathcal{E}C = -\mathcal{E}Ce^{-t/R_1 C}$$

For a correct answer (a correct answer without supporting work in parts (a) or (b) was awarded 1 point) — 1 point

$$q = \mathcal{E}C\left(1 - e^{-t/R_1 C}\right)$$

Alternate solution — *Alternate points*

Using the differential equation from part (a) (alternate)

$$\frac{dq}{dt} = \frac{\mathcal{E}}{R_1}e^{-t/R_1 C}$$

For separating the variables of the differential equation — *1 point*

$$dq = \frac{\mathcal{E}}{R_1}e^{-t/R_1 C}dt$$

$$\int_0^q dq = \int_0^t \frac{\mathcal{E}}{R_1}e^{-t/R_1 C}dt$$

For integrating the expression — *1 point*

$$q\Big|_0^q = \frac{\mathcal{E}}{R_1}\left(-R_1 C e^{-t/R_1 C}\right)\Big|_0^t$$

$$q = -R_1 C\left(\frac{\mathcal{E}}{R_1}e^{-t/R_1 C} - \frac{\mathcal{E}}{R_1}\right)$$

For a correct answer (a correct answer without supporting work in parts (a) or (b) was awarded 1 point) — *1 point*

$$q = \mathcal{E}C\left(1 - e^{-t/R_1 C}\right)$$

Question 2 (continued)

Distribution of points

(c) 3 points

Using the charge on the capacitor in terms of potential difference and capacitance

$q = CV$

For setting the expression for charge from part (b) equal to the charge on the capacitor — 1 point

$\mathcal{E}C\left(1 - e^{-t/R_1C}\right) = CV$

Solving for the time

$t = R_1 C \ln\left(\dfrac{\mathcal{E}}{\mathcal{E} - V}\right)$

Substituting given values into the time expression

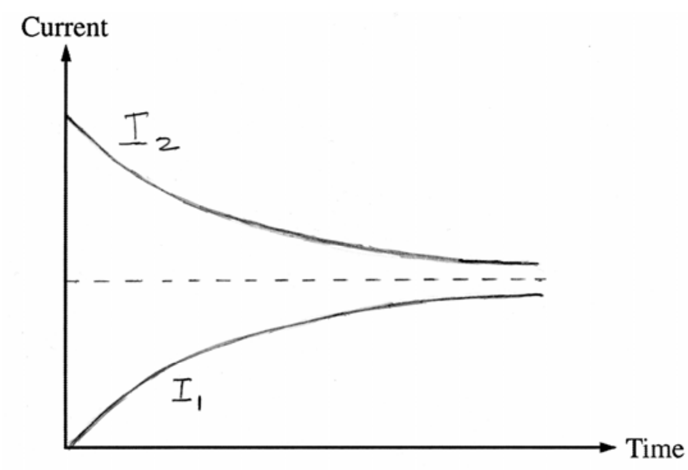
$t = (4700\ \Omega)(0.060\ \text{F})\ln\left(\dfrac{12\ \text{V}}{12\ \text{V} - 4\ \text{V}}\right)$

For the correct answer with units (a correct answer with units with no supporting work was awarded full credit) — 2 points

$t = 114\ \text{s}$ (or equivalent such as $t = 282\ln(3/2)\ \text{s}$)

<u>Note</u>: An incorrect value of time greater than 0 s and less than 282 s (the time constant, R_1C) with correct units earned 1 point.

(d) 5 points

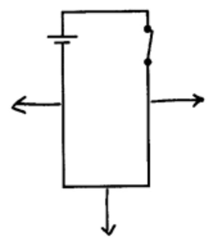


For having I_2 start at a positive, nonzero value	1 point
For sketching I_2 as exponentially decreasing to a horizontal asymptote	1 point
For having I_1 starting at zero	1 point
For sketching I_1 as exponentially increasing to a horizontal asymptote	1 point
For showing the I_1 and I_2 converging at the same horizontal asymptote	1 point

Question 3

15 points total | **Distribution of points**

(a) 2 points



For indicating at least one of the magnetic forces shown, perpendicular to any of the three lower arms and in the plane of the loop, and no forces on the upper arm — 1 point

For correctly indicating all three forces shown — 1 point

(b) 3 points

For recognizing the equilibrium condition with the upward spring force balancing the downward magnetic force and NO inclusion of the gravitational force on the loop — 1 point

$F_S = F_M$ or $kx = I\ell B$

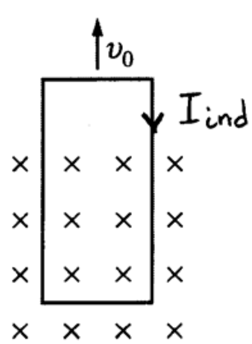
For explicitly solving for the initial magnetic field strength B_0, using the correct expressions for F_S and F_M — 1 point

$$B_0 = \frac{kx}{I\ell}$$

For substituting the width w of the loop bottom for the length ℓ in the magnetic force — 1 point

$$B_0 = \frac{kx}{Iw}$$

(c)
(i) 2 points



For indicating the clockwise induced current direction in the loop — 2 points

Question 3 (continued)

Distribution of points

(c) (continued)

(ii) 3 points

For noting that the potential difference around the loop results from the changing magnetic flux through the loop area — 1 point

$$\mathcal{E} = -\frac{d\phi_m}{dt} = -B_0\frac{dA}{dt} = -B_0\ell\frac{dy}{dt} = -B_0\ell\upsilon_0$$

For explicitly and correctly solving for the current using Ohm's law and the induced emf — 1 point

$$I_{ind} = \frac{\mathcal{E}}{R} \quad \text{or} \quad I_{ind} = \frac{d\phi_m}{dt}\Big/R \quad \text{or equivalent}$$

For identifying the length ℓ in the motional emf relationship as the width w of the loop bottom — 1 point

$$I_{ind} = \frac{B_0 w\upsilon_0}{R}$$

(d) 2 points

For recognizing that the current from part (c) (ii) is the appropriate current — 1 point

For using the current from part (c) (ii) in an algebraically correct expression for power — 1 point

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

$$P = \left(\frac{B_0 w\upsilon_0}{R}\right)^2 R = \frac{B_0^2 w^2\upsilon_0^2}{R}$$

Alternate solution: — *Alternate points*

The external force must balance the force on the current carrying wire in a magnetic field.

$$F_{\text{ext}} = F_B = B_0 w I_{ind}$$

For substituting the current from (c) (ii) into the expression for force — *1 point*

$$F_{ext} = F_B = B_0 w\left(\frac{B_0 w\upsilon_0}{R}\right) = \frac{B_0^2 w^2\upsilon_0}{R}$$

For using the expression for power in terms of constant force and constant speed and substituting the correct expressions for force and speed. — *1 point*

$$P = F\upsilon$$

$$P = \left(\frac{B_0^2 w^2\upsilon_0}{R}\right)\upsilon_0 = \frac{B_0^2 w^2\upsilon_0^2}{R}$$

Question 3 (continued)

	Distribution of points
(e) 3 points	
For choosing "Increases"	1 point
For a clear and complete justification indicating that the magnetic field affects the force directly through the relationship $F_M = B_0 I_{ind} \ell$ and also through the induced current $I_{ind} = B_0 w v_0 / R$	2 points

Example:

An increased magnetic field causes the magnetic force on the loop bottom to be larger for a given current and wire length. The larger field also increases the size of the induced current. Thus, the motion must be balanced by a larger applied force to keep the loop moving at the same constant speed v_0 through a larger field with a larger induced current.

<u>Note</u>: *A partially complete or unclear justification was awarded 1 point.*