AP® Physics C: Electricity and Magnetism
2007 Scoring Guidelines

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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 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) 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)

Note: *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*

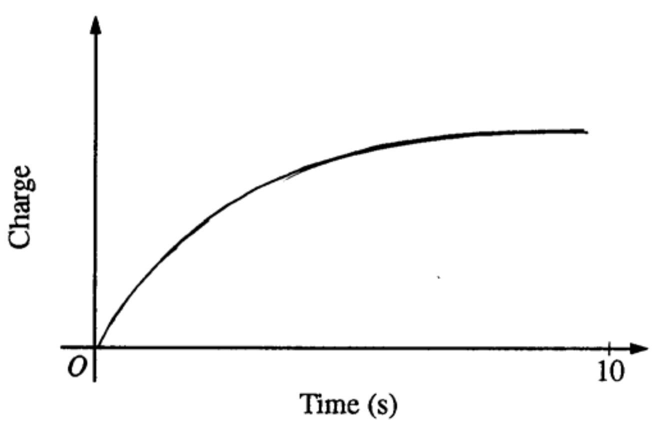
$Q = \left(4000 \times 10^{-6} \text{ F}\right)(1.24 \text{ V})\left(1 - e^{-1.82}\right)$

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

$P = \left(0.35\times10^{-3}\ \text{A}\right)(0.19\ \text{V})$ or $\left(0.35\times10^{-3}\ \text{A}\right)^2(550\ \Omega)$ or $(0.19\ \text{V})^2/(550\ \Omega)$

$P = 6.7\times10^{-5}\ \text{W}$ (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 $Q_{\kappa=3}(t = 4\ \text{s}) = 6.7\times10^{-3}\text{C}$ earned both justification points.

Question 2

15 points total | **Distribution of points**

(a)

(i) 2 points

$\oint \mathbf{E} \cdot d\mathbf{A} = \dfrac{Q_{enc}}{\epsilon_0}$, where Q_{enc} is the charge enclosed by the Gaussian surface

Use a concentric sphere of radius $r < a$ as the Gaussian surface.

For correctly calculating Q_{enc} — 1 point

$$Q_{enc} = \rho V = \left(\frac{Q}{\frac{4}{3}\pi a^3}\right)\left(\frac{4}{3}\pi r^3\right) = \frac{Qr^3}{a^3}$$

E is normal to the surface everywhere, so applying Gauss's law,

$$E\left(4\pi r^2\right) = \frac{1}{\epsilon_0}\left(\frac{Qr^3}{a^3}\right)$$

For the correct answer (This point was not awarded if no supporting work was shown.) — 1 point

$$E = \frac{1}{4\pi\epsilon_0}\frac{Qr}{a^3} \quad \text{or} \quad E = \frac{kQr}{a^3}$$

(ii) 2 points

Use a concentric sphere of radius $a < r < 2a$ as the Gaussian surface.

For correctly identifying Q_{enc} — 1 point

$$Q_{enc} = Q$$

E is normal to the surface everywhere, so applying Gauss's law,

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

For the correct answer (This point was not awarded if no supporting work was shown.) — 1 point

$$E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2} \quad \text{or} \quad E = \frac{kQ}{r^2}$$

Question 2 (continued)

	Distribution of points
(iii) 4 points	
Use a concentric sphere of radius $2a < r < 3a$ as the Gaussian surface.	
For recognizing that Q_{enc} is the sum of two charges (or that E_{total} is the sum of two components)	1 point
$Q_{enc} = Q - \rho_0 V_0$, where ρ_0 is the charge density of the outer sphere and V_0 is the volume of the outer sphere enclosed by the Gaussian surface	
$\rho_0 = \dfrac{Q}{\frac{4}{3}\pi(3a)^3 - \frac{4}{3}\pi(2a)^3} = \dfrac{Q}{\frac{4}{3}\pi a^3 (19)}$	
$V_0 = \frac{4}{3}\pi r^3 - \frac{4}{3}\pi(2a)^3 = \frac{4}{3}\pi\left(r^3 - 8a^3\right)$	
For correctly calculating Q_{enc} or just the charge enclosed by the shell	1 point
$Q_{enc} = Q - \left(\dfrac{Q}{\frac{4}{3}\pi a^3(19)}\right)\left(\frac{4}{3}\pi\left(r^3 - 8a^3\right)\right) = Q - \dfrac{Qr^3}{19a^3} + \dfrac{8Q}{19} = \dfrac{Q}{19}\left(27 - \dfrac{r^3}{a^3}\right)$	
Gauss's law, $\oint \mathbf{E} \cdot d\mathbf{A} = \dfrac{Q_{enc}}{\epsilon_0}$, is applied with **E** normal to the surface everywhere.	
For recognizing that $\oint \mathbf{E} \cdot d\mathbf{A} = E\left(4\pi r^2\right)$	1 point
For correctly substituting Q_{enc} into Gauss's law to find E	1 point
$E\left(4\pi r^2\right) = \dfrac{1}{\epsilon_0}\left(\dfrac{Q}{19}\left(27 - \dfrac{r^3}{a^3}\right)\right)$	
$E = \dfrac{Q}{76\pi\epsilon_0 r^2}\left(27 - \dfrac{r^3}{a^3}\right)$ or equivalent	
(iv) 2 points	
Use a concentric sphere of radius $3a < r$ as the Gaussian surface.	
For correctly calculating Q_{enc}	1 point
$Q_{enc} = +Q - Q = 0$	
Applying Gauss's law	
$E\left(4\pi r^2\right) = \dfrac{Q_{enc}}{\epsilon_0} = 0$	
For the correct answer (This point was not awarded if no supporting work was shown.) $E = 0$	1 point

Question 2 (continued)

Distribution of points

(b) 3 points

For correctly identifying that $V = 0$ — 1 point

For a correct, complete explanation — 2 points

Examples:

$V = -\int_{\infty}^{3a} \mathbf{E} \cdot d\mathbf{r}$, and since $E = 0$ and $V_\infty = 0$, it follows that $V = 0$

<u>OR</u> Work to bring a charge from ∞ to the outer surface is 0 since $E = 0$, so
$W = q(V_{3a} - V_\infty) = q(V_{3a} - 0) = 0$. Thus $V_{3a} = 0$.

<u>Note</u>: 1 point only was awarded for a correct but incomplete explanation such as $\sum q = 0$ or $E = 0$.

(c) 2 points

Let V_0 be the potential inside the outer sphere due to charge on the outer sphere. Use superposition of the potentials resulting from the charges on inner and outer spheres.

For correctly identifying V_X — 1 point

$$V_X = V_0 + \frac{Q}{4\pi\epsilon_0 a}$$

For correctly identifying V_Y — 1 point

$$V_Y = V_0 + \frac{Q}{4\pi\epsilon_0 (2a)}$$

$$V_X - V_Y = \left(V_0 + \frac{Q}{4\pi\epsilon_0 a}\right) - \left(V_0 + \frac{Q}{4\pi\epsilon_0 (2a)}\right) = \frac{Q}{4\pi\epsilon_0}\left(\frac{1}{a} - \frac{1}{2a}\right)$$

$$V_X - V_Y = \frac{Q}{8\pi\epsilon_0 a}$$

Alternate solution — *Alternate points*

$$E = -\frac{dV}{dr}$$

$$\Delta V = \int E\, dr$$

For setting up a correct integral with proper limits and sign (limits could be switched from those shown below if the integral had a positive sign) — *1 point*

For correct substitution of E in to the integral — *1 point*

$$V_X - V_Y = -\int_{2a}^{a} \frac{Q}{4\pi\epsilon_0 r^2}\, dr = -\frac{Q}{4\pi\epsilon_0}\left(-\frac{1}{r}\bigg|_{2a}^{a}\right) = \frac{Q}{4\pi\epsilon_0}\left(\frac{1}{a} - \frac{1}{2a}\right)$$

$$V_X - V_Y = \frac{Q}{8\pi\epsilon_0 a}$$

Question 3

15 points total | **Distribution of points**

(a) 3 points

For marking the "Counterclockwise" choice — 1 point

For explaining that there must be opposition to a change in magnetic flux — 1 point

For explaining that, in order to oppose the increase in magnetic flux, the induced magnetic field must be out of the paper. Therefore, the induced current must be counterclockwise to produce the induced field. — 1 point

Alternate solution — *Alternate points*

For marking the "Counterclockwise" choice — *1 point*

For correctly explaining that positive charge carriers in the rod experience a force toward the top of the page. (for example, by using the "right-hand rule," or by using $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$*, since* $\mathbf{v}$ *is to the right and* $\mathbf{B}$ *is into the paper)* — *2 points*

(b) 4 points

For correctly identifying V in Ohm's law as the induced emf (ignoring the sign from Faraday's law) — 1 point

$IR = V = \mathcal{E} = \dfrac{d\phi_m}{dt}$ or $B\dfrac{dA}{dt}$ or $B\ell\dfrac{dx}{dt}$ or $B\ell\upsilon$

For a correct expression for the resistance of the loop — 1 point

$R = \lambda(L + 2\upsilon t)$ or $\lambda(L + 2x)$

For a correct expression for $\mathcal{E}$ — 1 point

$\mathcal{E} = B\ell\upsilon$ or $BL\upsilon$

For correctly substituting the expressions for R and V from above into Ohm's law, with no explicit negative sign — 1 point

$$I = \frac{BL\upsilon}{\lambda(L + 2\upsilon t)}$$

Note*: The substitutions had to be in terms of the given quantities only in order to earn the substitution points.*

(c) 2 points

For a correct expression for the magnetic force, using L and not including $\sin\theta$ — 1 point

$F_B = ILB$

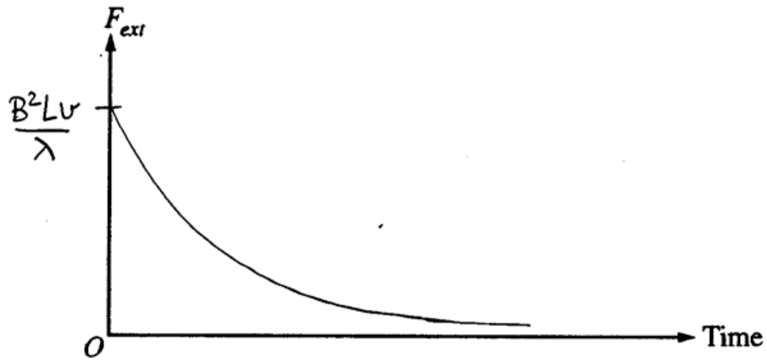
For a correct substitution of the expression for I from part (b) — 1 point

$$F_B = \frac{B^2L^2\upsilon}{\lambda(L + 2\upsilon t)}$$

Question 3 (continued)

Distribution of points

(d) 3 points



For recognizing that $F_{ext} = F_B$ — 1 point

For labeling the y-intercept, consistent with the result from part (c) — 1 point

$F_{ext}(t = 0) = \dfrac{B^2L\upsilon}{\lambda}$

For a graph shape that is consistent with the expression found in part (c) — 1 point

(e) 3 points

For marking the “Decreases” choice — 1 point

For a correct, clear, and complete justification — 2 points

Example: If $F_{ext} = 0$, then the only force on the rod is F_B. Since F_B is in the opposite direction of the velocity, the acceleration of the rod is opposite the velocity and therefore the velocity decreases.

<u>Note</u>: *Partial credit of 1 point was awarded for the justification if the justification was only partially correct, clear, or complete.*