2017

AP CollegeBoard

AP Physics C: Electricity and Magnetism

Scoring Guidelines

General Notes About 2017 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. The requirements that have been established for the paragraph length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. 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.

4. 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 embeds the application of that equation to the problem in other work, 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 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.

5. 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.

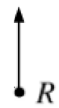
6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences 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**

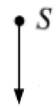
(a)

i. 1 point



For correctly drawing a single vector pointing upward at point *R* — 1 point

ii. 1 point



For correctly drawing a single vector pointing downward at point *S* — 1 point

(b)

i. 2 points

For using Gauss's law to calculate the electric flux — 1 point

$$\Phi = \frac{Q}{\varepsilon_0} = \frac{\rho V}{\varepsilon_0}$$

For a correct answer — 1 point

$$\Phi = \frac{\rho_0 A h}{\varepsilon_0}$$

ii. 3 points

For correctly applying Gauss's law to the slab — 1 point

$$\frac{Q}{\varepsilon_0} = \oint \vec{E} \bullet d\vec{A} = EA_{top} + EA_{bottom}$$

For substituting the flux from part (b)(i) into equation above and for including the contributions of the top and bottom parts of the Gaussian surface — 1 point

$$\frac{\rho_0 A h}{\varepsilon_0} = 2EA$$

For correctly relating h to $2z$ — 1 point

$$\frac{\rho_0 A(2z)}{\varepsilon_0} = 2EA$$

$$E = \frac{\rho_0 z}{\varepsilon_0}$$

Question 1 (continued)

Distribution of points

(c)

i. 1 point

Selecting "$z_0 < 0$"

For a correct justification — 1 point

Example: The electric field due to the plates alone is directed toward the top of the page. Therefore, the net electric field can only be zero where the electric field of the slab is directed toward the bottom of the page. So the net electric field can only be zero when $z_0 < 0$.

ii. 3 points

For setting the net electric field between the plates equal to zero and relating it to the sum of the electric fields of the plates and the slab — 1 point

$$E_{total} = 0 = E_{plate} + E_{slab}$$

For using the correct formula for the electric field between the plates regardless of sign — 1 point

$$\frac{\sigma}{\varepsilon_0} = -\frac{\rho_0 z_0}{\varepsilon_0}$$

$$z_0 = -\frac{\sigma}{\rho_0}$$

Substitute into equation above

$$z_0 = -\frac{\left(2.0 \times 10^{-6}\ \mathrm{C/m^2}\right)}{\left(1.0 \times 10^{-3}\ \mathrm{C/m^3}\right)}$$

For an answer that is consistent with the formula provided by the student above (must include units) — 1 point

$$z_0 = -2.0 \times 10^{-3}\ \mathrm{m}$$

Question 1 (continued)

Distribution of points

(d) 4 points

For using the sum of the electric potential of the slab and the plates as the total potential difference between the center and top of the slab — 1 point

$$\Delta V = \Delta V_{slab} + \Delta V_{plate}$$

$$\Delta V = \int E_{total}\,dr = \int \left(E_{slab} + E_{plate}\right) dr$$

$$\Delta V = \int E_{slab} dr + \int E_{plate}\,dr$$

For integrating with proper limits or constants of integration — 1 point

$$\Delta V = \int_{z=0}^{z=0.005} \frac{\rho_0 z}{\varepsilon_0} dz + \int_{z=0}^{z=0.005} \frac{\sigma}{\varepsilon_0} dz$$

For correctly integrating each term regardless of whether they contain the correct expressions — 1 point

$$\Delta V = \frac{\rho_0}{\varepsilon_0}\left[\frac{z^2}{2}\right]_{z=0}^{z=0.005} + \frac{\sigma}{\varepsilon_0}[z]_{z=0}^{z=0.005} = \frac{\rho_0}{2\varepsilon_0}\left(0.005^2 - 0\right) + \frac{\sigma}{\varepsilon_0}(0.005 - 0)$$

$$\Delta V = \frac{\rho_0 z^2}{2\varepsilon_0} + \frac{\sigma z}{\varepsilon_0}$$

$$\Delta V = \frac{\left(1.0 \times 10^{-3}\ \text{C/m}^3\right)\left(5.0 \times 10^{-3}\ \text{m}\right)^2}{(2)\left(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\bullet\text{m}^2\right)} + \frac{\left(2.0 \times 10^{-6}\ \text{C/m}^2\right)\left(5.0 \times 10^{-3}\ \text{m}\right)}{\left(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\bullet\text{m}^2\right)}$$

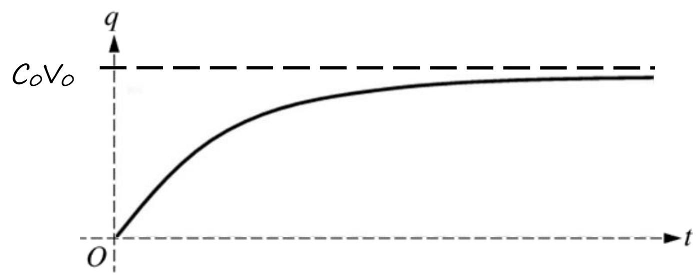
For a correct answer — 1 point

$$\Delta V = 2540\ \text{V}$$

Question 2

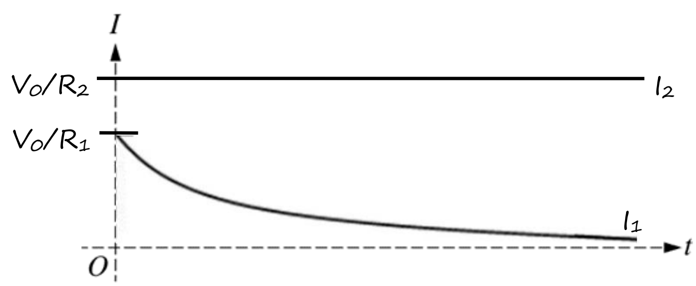
15 points total **Distribution of points**

(a) 3 points



For a concave down curve starting at the origin 1 point
For a horizontal asymptote 1 point
For properly labeling the horizontal asymptote 1 point

(b) 4 points



For showing that I_2 is horizontal with the correct vertical intercept 1 point
For showing that I_1 is concave up and asymptotic to I = 0 1 point
For correctly labeling the vertical intercept of the I_1 graph 1 point
For drawing the I_2 graph always above the I_1 graph 1 point

(c) 2 points

Select "$\Delta t_C < \Delta t_D$"
For indicating that the equivalent resistance during discharging is greater than during charging 1 point
For a statement relating the greater resistance to the greater time constant, or to a smaller current 1 point
Example: Because the resistance as the capacitor discharges is greater than when it charges, the time constant is larger for discharging. Therefore, the time to charge to 50% of its maximum charge is less than the time to discharge to 50% of its maximum charge.

Question 2 (continued)

Distribution of points

(d)

i. 2 points

For using a correct statement of Ohm's law or loop rule with the switch open — 1 point

$V = IR$

$I = \dfrac{V_C}{R_{tot}} = \dfrac{V_0}{R_1 + R_2}$

Substitute correct values into equation above

$I = \dfrac{(1.5\ \text{V})}{(100\ \Omega + 150\ \Omega)}$

For a correct answer — 1 point

$I = 6.0\ \text{mA}$ with units, or 0.006 without units

ii. 1 point

For a correct justification — 1 point

Example: Once the capacitor begins to discharge, the charge stored in the capacitor will decrease and the potential difference across the capacitor decreases. Therefore, the current through resistor R_2 decreases.

(e)

i. 1 point

For correctly substituting into an equation for the energy stored in a capacitor, including units for numerical values — 1 point

$U = \dfrac{1}{2}CV^2 = \dfrac{1}{2}(80\ \mu\text{F})(1.5\ \text{V})^2 = 90\ \mu\text{J}$

ii. 2 points

For setting up a valid equation or argument to calculate the energy dissipated by resistor R_1 — 1 point

$E_{dis} = Pt = I^2Rt \therefore E_{dis} \sim R \therefore E_{dis,1} = E_{dis,tot}\dfrac{R_1}{(R_1 + R_2)}$

For correctly substituting into the equation above — 1 point

$E_{dis,1} = (90\ \mu\text{J})\dfrac{(150\ \Omega)}{(150\ \Omega + 100\ \Omega)} = 54\ \mu\text{J}$

Alternate Solution on next page.

Question 2 (continued)

Distribution of points

(e)(ii) continued

Alternate Solution — *Alternate Points*

Derive an equation for the current through resistor R_1 *as a function of time*

$$I(t) = I_{MAX}e^{-t/\tau} = \frac{V_{MAX}}{(R_1 + R_2)}e^{-t/(R_1+R_2)C} = \frac{(1.5\text{ V})}{(250\ \Omega)}e^{-t/(250\ \Omega)(80\ \mu\text{F})}$$

$$I(t) = (6.0\text{ mA})e^{-t/(0.02)}$$

For using a correct formula with integral calculus to calculate the energy dissipated by resistor R_1 — 1 point

$$E = \int Pdt = \int I^2Rdt = \int I(t)^2 R_1dt = \int\left((6.0\text{ mA})e^{-t/(0.02)}\right)^2(150\ \Omega)dt$$

For integrating the above equation with correct limits or constants of integration — 1 point

$$E = (0.0054)\int_{t=0}^{t=\infty}\left(e^{-t/(0.02)}\right)^2dt = (0.0054)\int_{t=0}^{t=\infty}e^{-100t}dt = (0.0054)\left[\frac{e^{-100t}}{(-100)}\right]_{t=0}^{t=\infty}$$

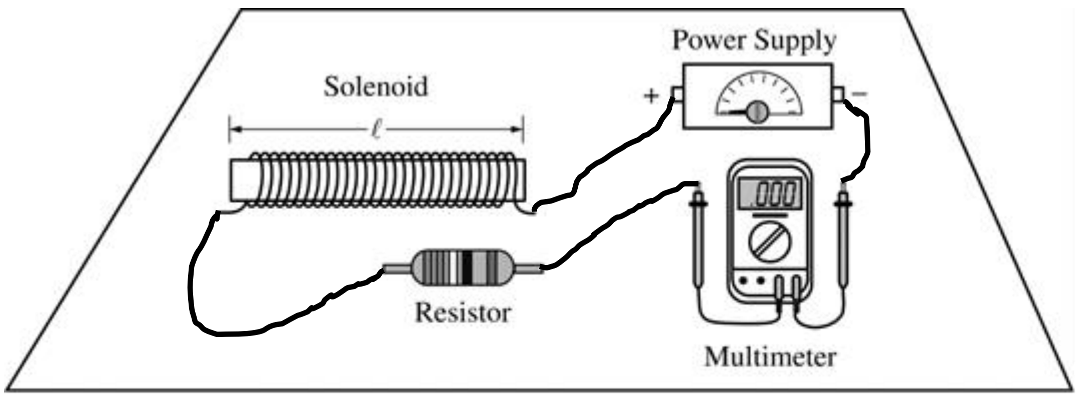
$$E = \left(-5.4\times10^{-5}\right)\left(e^{-\infty} - e^{0}\right) = 54\ \mu\text{J}$$

Question 3

15 points total | **Distribution of points**

(a)

i. 2 points



For connections that create a circuit with the power supply, solenoid, and resistor in series with each other — 1 point

For connections that create a circuit with the multimeter in series with the inductor/resistor combination — 1 point

ii. 1 point

For selecting the answer consistent with the answer in part (a)(i) — 1 point

iii. 3 points

For selecting point *B* — 1 point

For any indication that the magnetic field outside the solenoid is less than inside the solenoid — 1 point

For any indication that the closer you are to the center of the solenoid, the better the approximation of an ideal solenoid due to the lack of edge effects — 1 point

Example: The equation for the magnetic field for a solenoid is for an ideal solenoid. This does not work outside the solenoid (this eliminates *C* and *D*). In addition, as you approach the edge of the solenoid, the ideal approximation is not as accurate (this eliminates *A*). Thus, point *B* gives the best approximation of an ideal solenoid.

Question 3 (continued)

Distribution of points

(b) 2 points

For any indication that Solenoid 1 has more turns per unit length — 1 point

For any indication that Solenoid 1 is longer and therefore more like an ideal solenoid — 1 point

Examples:

The equation for the magnetic field of a solenoid $(B = \mu_0 nI)$ is based on an ideal solenoid in which you can ignore edge effects. Because Solenoid 1 has more turns per unit length, it is a better approximation of an ideal solenoid and thus its slope will give a better value for the permeability of free space.

The slope for Solenoid 1 is closer to the accepted value than the slope for Solenoid 2; therefore, the graph for Solenoid 1 is better.

(c)

i. 3 points

For correctly calculating the slope for the solenoid chosen in part (b) using the best-fit line and not the data points — 1 point

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(10-4)\left(\text{T}\times 10^{-5}\right)}{(75-24)(\text{A/m})} = 1.17 \times 10^{-6}\ \text{T}\bullet\text{m/A}$$

For correctly relating the magnetic permittivity of free space to the slope — 1 point

$\mu_0 = \text{slope}$

For correct units — 1 point

$\mu_0 = 1.17 \times 10^{-6}\ \text{T}\bullet\text{m/A}$

For Solenoid 2

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(8-4)\left(\text{T}\times 10^{-5}\right)}{(82-35)(\text{A/m})} = 8.51 \times 10^{-7}\ \text{T}\bullet\text{m/A}$$

ii. 1 point

For using a correct equation for % error including the substitution of the accepted and the measured values — 1 point

$$\%\ \text{error} = \frac{|\text{acc} - \text{exp}|}{\text{acc}} \times 100\% = \frac{\left|\left(1.26\times 10^{-6}\right) - \left(1.18\times 10^{-6}\right)\right|}{\left(1.26\times 10^{-6}\right)} \times 100\% = 6.35\%$$

For Solenoid 2

$$\%\ \text{error} = \frac{|\text{acc} - \text{exp}|}{\text{acc}} \times 100\% = \frac{\left|\left(1.26\times 10^{-6}\right) - \left(8.51\times 10^{-7}\right)\right|}{\left(1.26\times 10^{-6}\right)} \times 100\% = 32.4\%$$

Question 3 (continued)

	Distribution of points
(d)	
i. 1 point	
For a correct explanation involving any extraneous *B* fields	1 point
Example: A component of Earth's magnetic field is in the direction of the inductor's magnetic field.	
ii. 2 points	
For stating that either the solenoid or the circuit has near zero resistance	1 point
For stating that as a result of near zero resistance the current becomes very high	1 point
Example: The inductor has near zero resistance. Therefore, without the resistor in series with it, the inductor will draw a near infinite current that the multimeter cannot handle.	