Question 1: Free-Response Question — 15 points

(a) For using a correct equation for electric flux — **1 point**

Example Response

$$\Phi_E = \frac{Q}{\varepsilon_0}$$

For the correct numerical answer — **1 point**

Scoring Note: This point can be earned if a negative sign is included in the final answer or if units are missing and/or the units are incorrect.

Example Response

$$|\Phi_E| = 226\,\frac{\mathrm{N \cdot m^2}}{\mathrm{C}}$$

Example Solution

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$$

$$\Phi_E = \frac{Q}{\varepsilon_0}$$

$$\Phi_E = \frac{-2.0 \times 10^{-9}\ \mathrm{C}}{8.85 \times 10^{-12}\ \dfrac{\mathrm{C^2}}{\mathrm{N \cdot m^2}}}$$

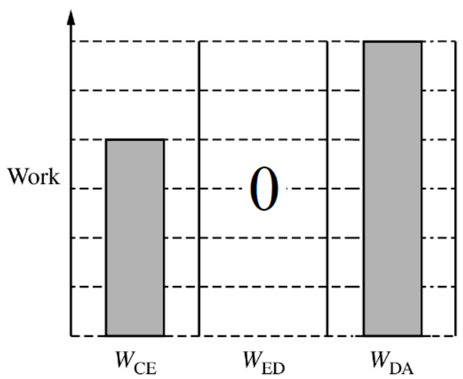
$$|\Phi_E| = 226\,\frac{\mathrm{N \cdot m^2}}{\mathrm{C}}$$

Total for part (a) — 2 points

(b)(i) For indicating that $W_{\mathrm{ED}} = 0$ — **1 point**

For drawing a bar representing W_{DA} that has a height of six units — **1 point**

Example Response



(b)(ii) For using an equation that relates the electric field to potential difference **1 point**

Scoring Note: This point can be earned if the response begins with a correct relationship between electric field and potential difference in which numerical values are already substituted.

Example Responses

$E_x = -\frac{dV}{dx}$ **OR** $|E_x| = \left|-\frac{dV}{dx}\right|$ **OR** $|E_x| = \left|-\frac{\Delta V}{\Delta x}\right|$ **OR** $\Delta V = -\int \vec{E} \cdot d\vec{r}$

For correct substitutions of values of electric potential and the distance between equipotential lines that can be used to calculate the approximate magnitude of the electric field at Position B **1 point**

Example Response

$$|E_x| = \left|-\frac{20.0\text{ V} - 0.0\text{ V}}{0.65\text{ m}}\right|$$

Example Solution

$$E_x = -\frac{dV}{dx}$$
$$|E_x| = \left|-\frac{dV}{dx}\right|$$
$$|E_x| = \left|-\frac{\Delta V}{\Delta x}\right|$$
$$|E_x| = \left|-\frac{20.0\text{ V} - 0.0\text{ V}}{0.65\text{ m}}\right|$$
$$|E_x| = 31\,\frac{\text{V}}{\text{m}}$$

Total for part (b) 4 points

(c)	For selecting only $+y$ with an attempt at a relevant justification	**1 point**
	For indicating that the direction of the electric field vector is perpendicular to a line that is tangent to the equipotential line at Position D	**1 point**
	For indicating one of the following: • The test charge moves from a higher electric potential to a lower electric potential. • The test charge and the sphere have charges of opposite sign. • The test charge moves in the direction of the electric field, which is directed upward.	**1 point**

Example Response

$+y$. The direction of an electric field vector is perpendicular to an equipotential line. Because the test charge has a positive charge, the test charge would move from a position of higher electric potential to a position of lower electric potential when an electric force is exerted on the test charge. Therefore, at Position D, the electric force is upward because that is the direction that is perpendicular to the equipotential line and in the direction of decreasing electric potential.

Total for part (c) 3 points

(d)(i)	For using an appropriate equation for determining the electric potential from a line of uniform charge	**1 point**

Example Responses

$$V = \frac{1}{4\pi\varepsilon_0}\sum\frac{q_i}{r_i} \quad \textbf{OR} \quad V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r} \quad \textbf{OR} \quad \Delta V = -\int\vec{E}\cdot d\vec{r}$$

For a correct determination of r, the distance between Point P and a point on the line of uniform charge **1 point**

Example Responses

$$V_P = k\sum\frac{Q}{x_P - x} \quad \textbf{OR} \quad V_P = k\int\left(\frac{1}{x_P - x}\right)dq$$

For a correct integral with λdx substituted for dq **1 point**

Example Response

$$V_P = k\lambda\int\left(\frac{1}{x_P - x}\right)dx$$

For the correct limits of integration **1 point**

Example Response

$$V_P = k\lambda\int_0^{4L}\left(\frac{1}{x_P - x}\right)dx$$

Example Solutions

$$V = \frac{1}{4\pi\varepsilon_0}\sum\frac{q_i}{r_i}$$

$$V_P = k\int\left(\frac{1}{x_P - x}\right)dq$$

$$dq = \lambda\, dx$$

$$V_P = k\lambda\int\left(\frac{1}{x_P - x}\right)dx$$

$$V_P = k\lambda\int_0^{4L}\left(\frac{1}{x_P - x}\right)dx$$

$$V_P = -k\lambda\ln(x_P - x)\,\Big|_0^{4L} = k\lambda\ln(x_P - x)\,\Big|_{4L}^{0}$$

$$V_P = k\lambda\ln\left(\frac{x_P}{x_P - 4L}\right)$$

OR

$$\Delta V = -\int\vec{E}\cdot d\vec{r}$$

$$E(x) = \int\frac{k}{r^2}\,dq$$

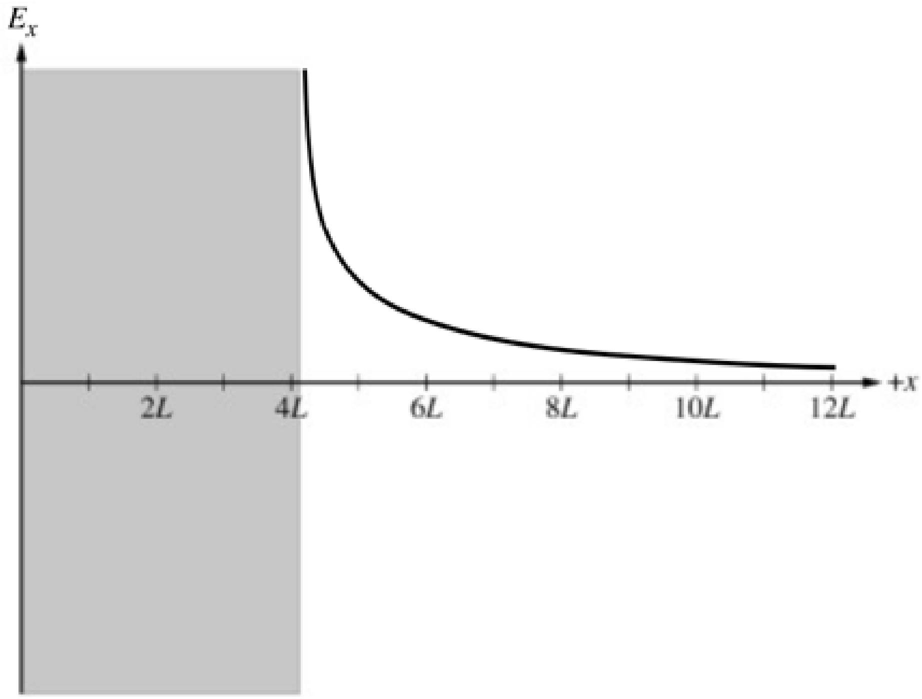
$$E(x) = \int_0^{4L}\frac{k\lambda}{(x - x')^2}\,dx' = k\lambda\left(\frac{1}{x - 4L} - \frac{1}{x}\right)$$

$$V_P = -\int_\infty^{x_P}E(x)\,dx = -k\lambda\int_\infty^{x_P}\left(\frac{1}{x - 4L} - \frac{1}{x}\right)dx$$

$$V_P = k\lambda\ln\left(\frac{x_P}{x_P - 4L}\right)$$

(d)(ii)	For sketching a curve or line that continually approaches the horizontal axis as position increases	**1 point**
	For sketching a concave up curve that is always positive	**1 point**

Example Response



Total for part (d) **6 points**

Total for question 1 **15 points**

Question 1: Free-Response Question — 15 points

(a) For using a correct equation for electric flux — **1 point**

Example Response

$$\Phi_E = \frac{Q}{\varepsilon_0}$$

For the correct numerical answer — **1 point**

Scoring Note: Correct units are not required to earn this point.

Example Response

$$\Phi_E = 113\,\frac{\mathrm{N \cdot m^2}}{\mathrm{C}}$$

Example Solution

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$$

$$\Phi_E = \frac{Q}{\varepsilon_0}$$

$$\Phi_E = \frac{1.0 \times 10^{-9}\ \mathrm{C}}{8.85 \times 10^{-12}\ \dfrac{\mathrm{C^2}}{\mathrm{N \cdot m^2}}}$$

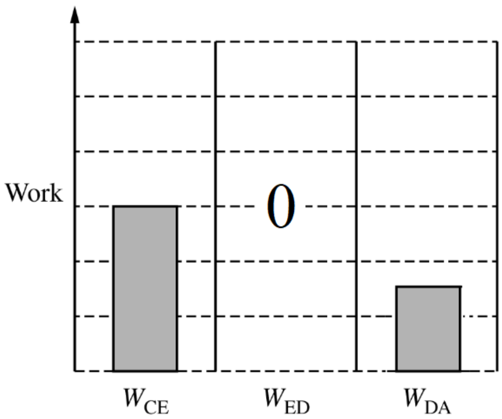
$$\Phi_E = 113\,\frac{\mathrm{N \cdot m^2}}{\mathrm{C}}$$

Total for part (a) — 2 points

(b)(i) For indicating that $W_{\mathrm{ED}} = 0$ — **1 point**

For drawing a bar representing W_{DA} that has a height of approximately one and a half units — **1 point**

Example Response



(b)(ii)	For using an equation that relates the electric field to potential difference	**1 point**

Scoring Note: This point can be earned if the response begins with a correct relationship between electric field and potential difference in which numerical values are already substituted.

Example Responses

$$E_y = -\frac{dV}{dy} \quad \textbf{OR} \quad \left|E_y\right| = \left|-\frac{dV}{dy}\right| \quad \textbf{OR} \quad \left|E_y\right| = \left|-\frac{\Delta V}{\Delta y}\right| \quad \textbf{OR} \quad \Delta V = -\int \vec{E} \cdot d\vec{r}$$

For correct substitutions of values of electric potential and the distance between equipotential lines that can be used to calculate the approximate magnitude of the electric field at Position B — **1 point**

Example Response

$$\left|E_y\right| = \left|-\frac{-20.0 \text{ V} - (-10.0 \text{ V})}{1.4 \text{ m}}\right|$$

Example Solution

$$E_y = -\frac{dV}{dy}$$

$$\left|E_y\right| = \left|-\frac{dV}{dy}\right|$$

$$\left|E_y\right| = \left|-\frac{\Delta V}{\Delta y}\right|$$

$$\left|E_y\right| = \left|-\frac{-20.0 \text{ V} - (-10.0 \text{ V})}{1.4 \text{ m}}\right|$$

$$\left|E_y\right| = 7.1 \frac{\text{V}}{\text{m}}$$

Total for part (b) — 4 points

(c)	For selecting only $-y$ with an attempt at a relevant justification	**1 point**

For indicating that the direction of the electric field vector is perpendicular to a line that is tangent to the equipotential line at Position C — **1 point**

For indicating one of the following: — **1 point**

- The test charge moves from a higher electric potential to a lower electric potential.
- The test charge and the rod have charges of the opposite sign.
- The test charge and the sphere have charges of the same sign.

Example Response

$-y$. The direction of an electric field vector is perpendicular to an equipotential line. Because the test charge has a positive charge, the test charge would move from a position of higher electric potential to a position of lower electric potential when an electric force is exerted on the test charge. Therefore, at Position C, the electric force is downward because that is the direction that is perpendicular to the equipotential line and in the direction of decreasing electric potential.

Total for part (c) — 3 points

(d)(i)	For using an appropriate equation for determining the electric potential from a line of uniform charge	**1 point**

Example Responses

$$V = \frac{1}{4\pi\varepsilon_0}\sum\frac{q_i}{r_i} \quad \textbf{OR} \quad V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r} \quad \textbf{OR} \quad \Delta V = -\int\vec{E}\cdot d\vec{r}$$

For a correct determination of r, the distance between Point P and a point on the line of uniform charge — **1 point**

Example Responses

$$V_\text{P} = k\sum\frac{Q}{y_\text{P} - y} \quad \textbf{OR} \quad V_\text{P} = k\int\left(\frac{1}{y_\text{P} - y}\right)dq$$

For a correct integral with $\lambda\, dy$ substituted for dq — **1 point**

Example Response

$$V_\text{P} = -k\lambda\int\left(\frac{1}{y_\text{P} - y}\right)dy$$

For the correct limits of integration — **1 point**

Example Response

$$V_\text{P} = -k\lambda\int_0^{2L}\left(\frac{1}{y_\text{P} - y}\right)dy$$

Example Solutions

$$V = \frac{1}{4\pi\varepsilon_0}\sum\frac{q_i}{r_i}$$
$$V_\text{P} = k\int\left(\frac{1}{y_\text{P} - y}\right)dq$$

$$dq = -\lambda\, dy$$

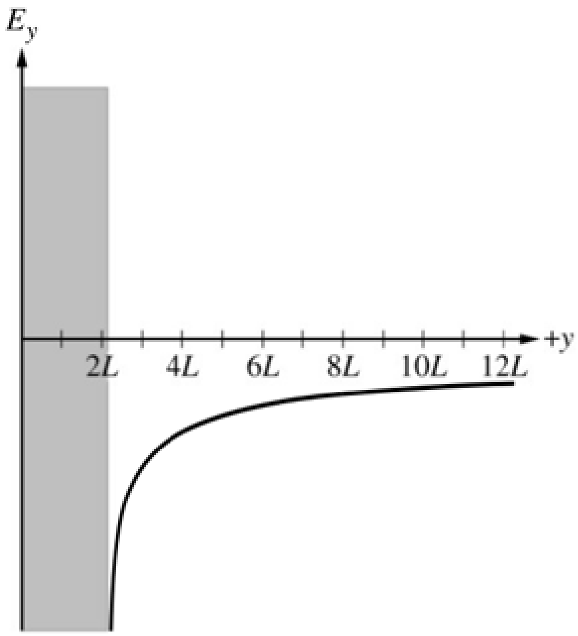
$$V_\text{P} = -k\lambda\int\left(\frac{1}{y_\text{P} - y}\right)dy$$
$$V_\text{P} = -k\lambda\int_0^{2L}\left(\frac{1}{y_\text{P} - y}\right)dy$$
$$V_\text{P} = k\lambda\ln(y_\text{P} - y)\,\Big|_0^{2L} = -k\lambda\ln(y_\text{P} - y)\,\Big|_{2L}^{0}$$
$$V_\text{P} = -k\lambda\ln\left(\frac{y_\text{P}}{y_\text{P} - 2L}\right)$$

OR

$$\Delta V = -\int\vec{E}\cdot d\vec{r}$$
$$E(y) = \int\frac{k}{r^2}\,dq$$
$$E(y) = \int_0^{2L}\frac{k\lambda}{(y - y')^2}\,dy' = k\lambda\left(\frac{1}{y - 2L} - \frac{1}{y}\right)$$
$$V_\text{P} = -\int_\infty^{y_\text{P}}E(y)\,dy = -k\lambda\int_\infty^{y_\text{P}}\left(\frac{1}{y - 2L} - \frac{1}{y}\right)dy$$
$$V_\text{P} = k\lambda\ln\left(\frac{y_\text{P}}{y_\text{P} - 2L}\right)$$

(d)(ii)	For sketching a curve or line that continually approaches the horizontal axis as position increases	**1 point**
	For sketching a concave down curve that is always negative	**1 point**

Example Response



Total for part (d) **6 points**

Total for question 1 **15 points**

2017

AP Physics C: Electricity and Magnetism

Scoring Guidelines

AP® PHYSICS
2017 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 $10\ \text{m/s}^2$ 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.

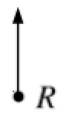
2017 SCORING GUIDELINES

Question

15 points total | **Distribution of ints**

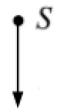
(a)

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

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

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

2017 SCORING GUIDELINES

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

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

2017 SCORING GUIDELINES

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

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

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

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

For a correct answer — 1 point

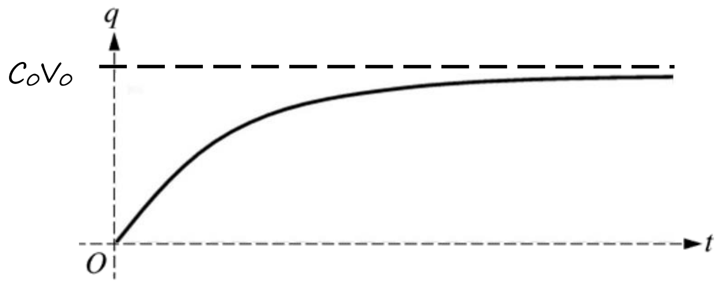
$$\Delta V = 2540\ \mathrm{V}$$

2017 SCORING GUIDELINES

Question

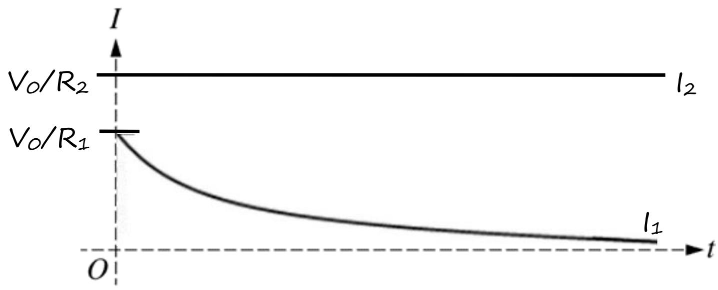
15 points total **Distribution of points**

(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.

2017 SCORING GUIDELINES

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

$V = IR$

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

Substitute correct values into equation above

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

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

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

ii. 2 points

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

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

For correctly substituting into the equation above — 1 point

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

Alternate Solution on next page.

2017 SCORING GUIDELINES

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

$$E = \int P dt = \int I^2 R dt = \int I(t)^2 R_1 dt = \int \left((6.0\ \text{mA})e^{-t/(0.02)}\right)^2 (150\ \Omega)\, dt$$

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

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

$$E = \left(-5.4\times 10^{-5}\right)\left(e^{-\infty} - e^{0}\right) = 54\ \mu\text{J}$$

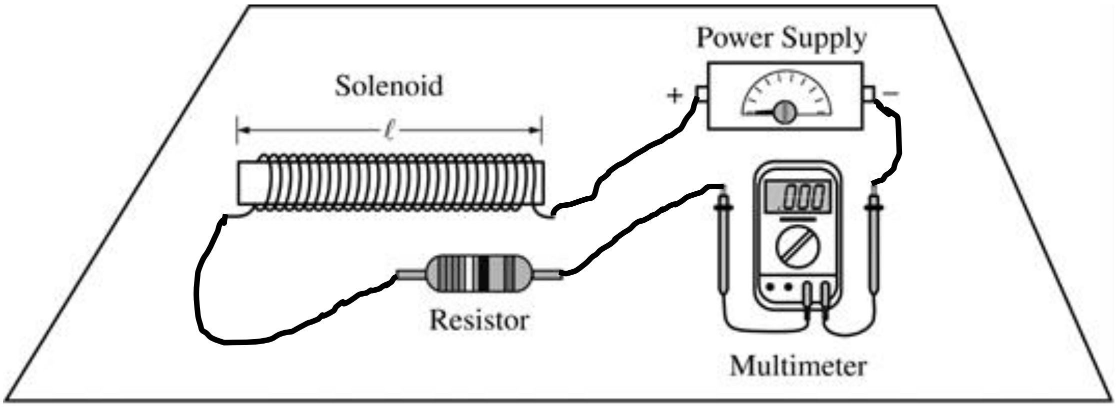
2017 SCORING GUIDELINES

Question

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

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(10-4)\left(\text{T}\times10^{-5}\right)}{(75-24)(\text{A/m})} = 1.17\times10^{-6}\ \text{T}\bullet\text{m/A}$$

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

$\mu_0 =$ slope

For correct units — 1 point

$\mu_0 = 1.17\times10^{-6}\ \text{T}\bullet\text{m/A}$

For Solenoid 2

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(8-4)\left(\text{T}\times10^{-5}\right)}{(82-35)(\text{A/m})} = 8.51\times10^{-7}\ \text{T}\bullet\text{m/A}$$

ii. 1 point

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

$$\%\ \text{error} = \frac{|\text{acc} - \text{exp}|}{\text{acc}}\times100\% = \frac{\left|\left(1.26\times10^{-6}\right) - \left(1.18\times10^{-6}\right)\right|}{\left(1.26\times10^{-6}\right)}\times100\% = 6.35\%$$

For Solenoid 2

$$\%\ \text{error} = \frac{|\text{acc} - \text{exp}|}{\text{acc}}\times100\% = \frac{\left|\left(1.26\times10^{-6}\right) - \left(8.51\times10^{-7}\right)\right|}{\left(1.26\times10^{-6}\right)}\times100\% = 32.4\%$$

2017 SCORING GUIDELINES

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.	

AP® Physics C: Electricity and Magnetism 2016 Scoring Guidelines

SCORING GUIDELINES

Question

15 points total | **Distribution of points**

3 points

For indicating that the total potential is the sum of the potential from individual point charges — 1 point

ample using point B: $V_B = 0 = V_1 + V_2$

orrectly substituting into the above equation (signs are ignored at this step) — 1 point

$-V_1 = V_2$

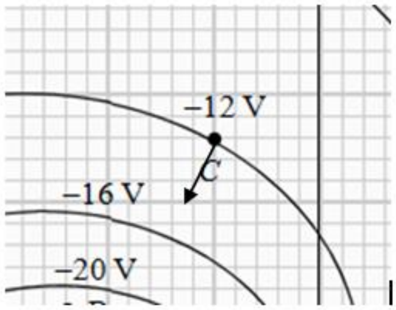
$-\frac{kq_1}{r_1} = \frac{kq_2}{r_2}$

$-\frac{q_1}{(5 \times 0.5m)} = \frac{(2.0\text{ nC})}{(2 \times 0.5\text{ m})}$

For a correct answer with correct sign and units — 1 point

$q_1 = -5.0\text{ nC}$

2 points



For drawing a vector perpendicular to the equipotential line for C — 1 point

For drawing a vector in the direction of the -16 V line — 1 point

2 points

For using the equation relating the electric field to potential difference — 1 point

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

$|E| \simeq \frac{\Delta V}{\Delta x}$

For substituting values from the figure — 1 point

$E = \frac{(-20\text{ V} - (-24\text{ V}))}{(2 \times 0.1\text{ m})}$

$E = 20\text{ N/C}$

SCORING GUIDELINES

Question 1 (continued)

Distribution of points

2 points

For using a correct equation for the electric flux — 1 point

$$\Phi_E = \frac{q_{enc}}{\varepsilon_0}$$

$$\Phi_E = \frac{(2.0 \text{ nC})}{\left(8.85 \times 10^{-12} \text{ C}^2/\left(\text{N}\bullet\text{m}^2\right)\right)}$$

For a correct answer with units — 1 point

$$\Phi_E = 226 \left(\text{N}\bullet\text{m}^2\right)/\text{C}$$

(

2 points

sing an equation that relates the work done to the change in potential energy — 1 point

$$W = -q\Delta V = -(1.6 \times 10^{-19} \text{ C})(-4 \text{ V} - (4 \text{ V}))$$

For a correct answer including sign and units — 1 point

$$W = 1.28 \times 10^{-18} \text{ J} = 8.0 \text{ eV}$$

2 points

ndicating that the kinetic energy of the proton at E will be equal to the work done — 1 point

$$W = \Delta K = \frac{1}{2}mv^2$$

orrectly substituting the answer from part (e) i. into the above equation — 1 point

$$\left(1.28 \times 10^{-18} \text{ J}\right) = \left(\frac{1}{2}\right)\left(1.67 \times 10^{-27} \text{ kg}\right)v^2$$

$$v = 3.92 \times 10^4 \text{ m/s}$$

) 2 points

correctly selecting Left — 1 point

For a correct justification — 1 point

Example: Electrons accelerate in the direction perpendicular to equipotential surfaces and toward higher potential. Therefore, at point B, an electron would accelerate toward the left.

No points are earned if the wrong answer is selected.

;CORING GUIDELINES

Question

15 points total | **Distribution of points**

2 points

For selecting "It is the same through both." — 1 point

For a correct justification — 1 point

Example: The sample of wire and the resistor are in series with each other and therefore will have the same current.

Note: Because the voltmeter is ideal, it will have no effect on the result.

No points are earned if the wrong answer is selected.

2 points

For selecting "It will depend on the resistance of the sample." — 1 point

For a correct justification including argument using Ohm's law, voltage drop across resistors, etc. — 1 point

Example: Because the sample of wire has resistance, it cannot be known whether the wire of the resistor has the greatest resistance and which has the higher potential difference across it. Therefore, it will depend on the resistance of the wire sample.

No points are earned if the wrong answer is selected.

(1 point

ndicating the correct quantities for each axis — 1 point

Horizontal axis: I_R

Vertical axis: $V_r = \mathcal{E} - V_R$

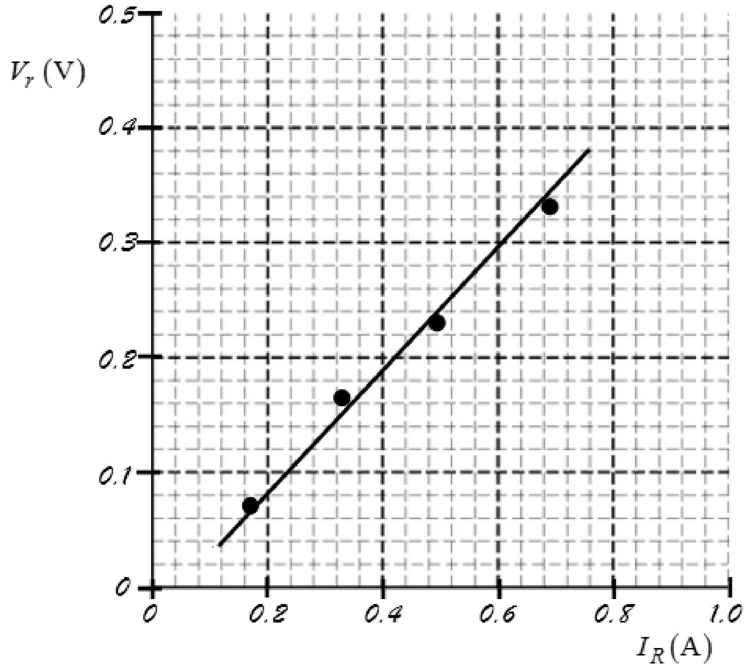
Note: Credit is received if the axes are reversed.

SCORING GUIDELINES

Question 2 (continued)

Distribution of points

3 points



For a correct scale that uses more than half the grid and for correctly labeling the axes including units — 1 point

For correctly plotting given data — 1 point

For drawing a straight line consistent with the given data — 1 point

(2 points

For correctly calculating slope using the best-fit straight line and not data points — 1 point

$$\text{slope} = \frac{(V_2 - V_1)}{(I_2 - I_1)} = \frac{(0.30 - 0.10)\ \text{V}}{(0.60 - 0.22)\ \text{A}} = 0.526\ \text{V/A}$$

Note: Linear regression gives $\text{slope} = 0.485\ \text{V/A}$. (Student must indicate that the value comes from a linear regression from the calculator, and the equation of the line must be present.)

For correctly relating r to the slope — 1 point

$V_r = I_R r$, therefore the slope equals r

$r = 0.526\ \Omega$

Note: Linear regression gives $r = 0.485\ \Omega$.

;CORING GUIDELINES

Question 2 (continued)

Distribution of points

) 1 point

For using the equation relating resistance to resistivity with the correct or consistent substitutions — 1 point

$$R = \frac{\rho L}{A} \text{ so } \rho = \frac{AR}{L}$$

$$\rho = \frac{(\pi)\left(1.00 \times 10^{-3} \text{ m}\right)^2 (0.526\ \Omega)}{(3.00 \text{ m})}$$

$$\rho = 5.51 \times 10^{-7}\ \Omega \bullet \text{m}$$

Note: Linear regression gives $\rho = 5.08 \times 10^{-7}\ \Omega \bullet \text{m}$.

2 points

electing "Less than" with an attempt at a justification — 1 point

For a correct justification — 1 point

Example: The resistance calculated from the graph is the sum of the sample resistance plus the ammeter resistance because it is not ideal. The actual resistance is the calculated resistance minus the ammeter resistance, and therefore less than the calculated resistance.

oints are earned if the wrong answer is selected.

2 points

For selecting "Greater than" with an attempt at a justification — 1 point

For a correct justification — 1 point

Example: If the voltmeter is not ideal, that would add an additional resistor in parallel. A parallel resistor reduces the total resistance of the circuit. This would lead to an increase in current and a higher reading on the ammeter.

No points are earned if the wrong answer is selected.

;CORING GUIDELINES

Question

15 points total | **Distribution of points**

1 point

For selecting "Left" — 1 point

2 points

For selecting "Less than" — 1 point
For a correct justification — 1 point
Example: Because as the bar falls the flux at point C is increasing, the emf generated must create a magnetic field to oppose this change. Therefore, it will create a magnetic field to decrease the flux and thus decrease the magnetic field.
No points are earned if the wrong answer is selected.

2 points

For selecting "Greater than" — 1 point
For a correct justification — 1 point
Example: The field at point C, which is above the bar, is less than the original magnetic field, and point D is on the other side of the bar. Therefore, the direction of the magnetic field from the bar at point D is the opposite of the direction at point C, so the net magnetic field at D when the bar is falling must be greater than the original magnetic field.
No points are earned if the wrong answer is selected.

(4 points

For correctly applying Newton's second law to the motion of the bar — 1 point

$F_{net} = Mg - F_M = Mg - BIL$

$I = \mathcal{E}/R$

For attempting to use Faraday's law to obtain an expression for the emf in the bar — 1 point

$\mathcal{E} = d\Phi/dt = BL(dx/dt)$

For correctly using the expression for emf to obtain an expression for the current — 1 point

$$I = \frac{BL(dx/dt)}{R} = \frac{BLv}{R}$$

$$Ma = Mg - B\frac{BLv}{R}L$$

$$a = g - \frac{B^2L^2v}{MR}$$

vriting the acceleration as dv/dt — 1 point

$$\frac{dv}{dt} = g - \frac{B^2L^2v}{MR}$$

;CORING GUIDELINES

Question 3 (continued)

Distribution of points

2 points

For setting the net force at terminal velocity equal to zero — 1 point

$$0 = Mg - \frac{B^2L^2v_T}{R}$$

$$\frac{B^2L^2v_T}{R} = Mg$$

ın answer consistent with part (c) — 1 point

$$v_T = \frac{MgR}{B^2L^2}$$

(1 point

For a correct or consistent substitution in an appropriate power equation — 1 point

$P = I^2R$ or $V = IR$

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

$$P = \frac{B^2L^2{v_T}^2}{R}$$

Alternate Solution — *Alternate points*

For a correct or consistent substitution in an appropriate power equation — *1 point*

$$P = I^2R$$

$$Mg = BIL$$

$$I = \frac{Mg}{BL}$$

$$P = \frac{M^2g^2R}{B^2L^2}$$

;CORING GUIDELINES

Question 3 (continued)

Distribution of points

) 3 points

Using the equation from part (c)

$$\frac{dv}{dt} = g - \frac{B^2L^2v}{MR}$$

$$\frac{dv}{dt} = \frac{-B^2L^2}{MR}\left(v - \frac{MRg}{B^2L^2}\right)$$

For attempting separation of variables — 1 point

$$\frac{dv}{v - \frac{MRg}{B^2L^2}} = \frac{-B^2L^2}{MR}dt$$

For attempting to integrate with the correct limits or the correct constant of integration — 1 point

$$\int_{v'=0}^{v'=v(t)} \frac{1}{\left(v' - \frac{MRg}{B^2L^2}\right)}\,dv' = \int_{t'=0}^{t'=t} \frac{-B^2L^2}{MR}dt'$$

$$\ln\left[v' - \frac{MRg}{B^2L^2}\right]_{v'=0}^{v'=v(t)} = \frac{-B^2L^2}{MR}t$$

$$\ln\left(\frac{v(t) - \frac{MRg}{B^2L^2}}{\frac{MRg}{B^2L^2}}\right) = \frac{-B^2L^2}{MR}t$$

For a correct answer — 1 point

$$v(t) = \frac{MRg}{B^2L^2}\left(1 - e^{-\frac{B^2L^2}{MR}t}\right)$$

ng a trial solution in the differential equation and verifying its correctness is also acceptable.