AP® Physics C: Electricity and Magnetism
2012 Scoring Guidelines

The College Board

General Notes About 2012 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 in part (b). One exception to this practice may occur in cases where the numerical answer to a later part should easily be recognized as wrong, for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if the use of an 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 sheets. 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 $g = 9.8\ \text{m/s}^2$, 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.

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 owing 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 eliminate the level of 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

For an expression of Gauss's Law — 1 point

$$\frac{Q_i}{\epsilon_0} = \oint \mathbf{E} \cdot d\mathbf{A}$$

For a correct intermediate step indicating that the area of the Gaussian surface is $4\pi r^2$ — 1 point

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

For a correct final expression, specifically using Q_i — 1 point

$$E(r) = \frac{1}{4\pi\epsilon_0}\frac{Q_i}{r^2} \quad \text{or} \quad E(r) = \frac{kQ_i}{r^2}$$

(b) 2 points

For indicating that the enclosed charge is the sum of the inner and outer charges — 1 point

$$\frac{Q_i + Q_o}{\epsilon_0} = \oint \mathbf{E} \cdot d\mathbf{A}$$

For a correct expression for the electric field — 1 point

$$E(r) = \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r^2}$$

Note: The correct expression by itself earns both points.

(c) 2 points

For using the integral definition of potential in terms of electric field — 1 point

$$V(r) - V_\infty = -\int_\infty^r \mathbf{E} \cdot d\mathbf{r}$$

$$V(r) = -\int_\infty^r \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r^2}\,dr$$

$$V(r) = -\frac{(Q_i + Q_o)}{4\pi\epsilon_0}\left[-\frac{1}{r}\right]_\infty^r$$

For the correct expression — 1 point

$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r}$$

Note: The correct expression by itself earns both points.

Question 1 (continued)

Distribution of points

(c) continued

Alternate solution — *Alternate points*

Outside the shells, the charges on each can be treated as point charges at their centers.

For using the concept of summation of point charge potentials — *1 point*

$$V(r) = \frac{1}{4\pi\epsilon_0}\sum_j \frac{q_j}{r_j}$$

$$V(r) = \frac{1}{4\pi\epsilon_0}\left(\frac{Q_i}{r} + \frac{Q_o}{r}\right)$$

For the correct expression (the correct expression by itself earns both points) — *1 point*

$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r}$$

(d) 1 point

The answer from part (c), with $Q_T = Q_i + Q_o$, can be solved for Q_T. Values at the outer shell are then used to determine a numerical value.

For correct work resulting in the correct value, with units — 1 point

$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{Q_T}{r},\ r \geq 0.20\,\text{m}$$

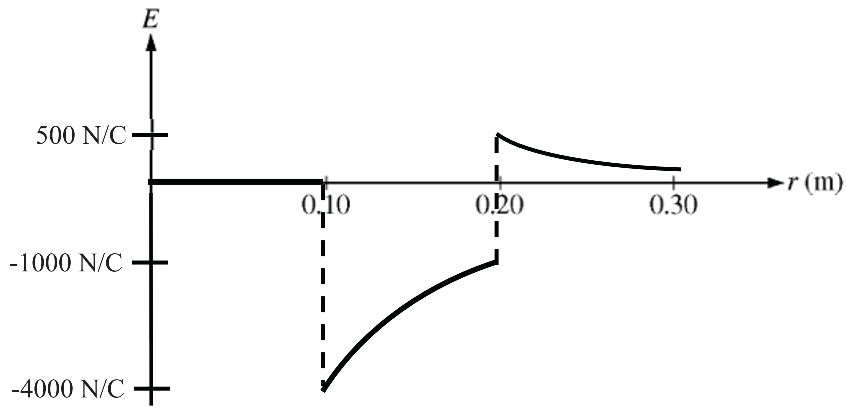
$$Q_T = 4\pi\epsilon_0 r V(r) = \left(\frac{(0.20\text{ m})(100\text{ V})}{\left(9.0\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)}\right)$$

$$Q_T = 2.2\times10^{-9}\ \text{C}$$

Question 1 (continued)

Distribution of points

(e) 3 points



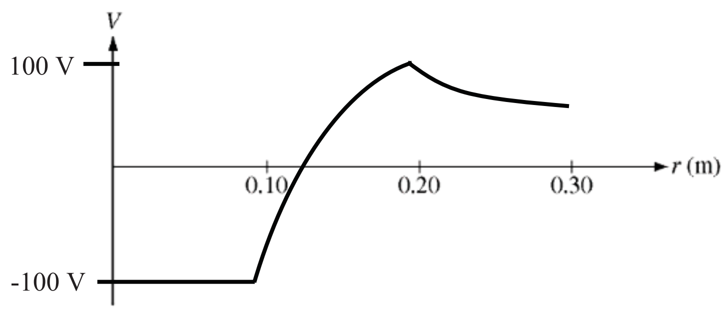
For a segment indicating an E-field of 0 for $r < 0.10$ m, explicitly drawn — 1 point

For a segment that is concave down and negative for 0.10 m $< r <$ 0.20 m — 1 point

For a segment that is concave up and positive for $r > 0.20$ m. The line must not touch or cross the horizontal axis. — 1 point

Note: The labels on the vertical axis are not to scale and are not required to receive full credit.

(f) 4 points



For a continuous set of segments that have slope discontinuities at $r = 0.10$ m and at $r = 0.20$ m — 1 point

For a segment indicating a constant negative potential for $r < 0.10$ m — 1 point

For a segment that is increasing, concave down, and crosses the r axis, for 0.10 m $< r <$ 0.20 m — 1 point

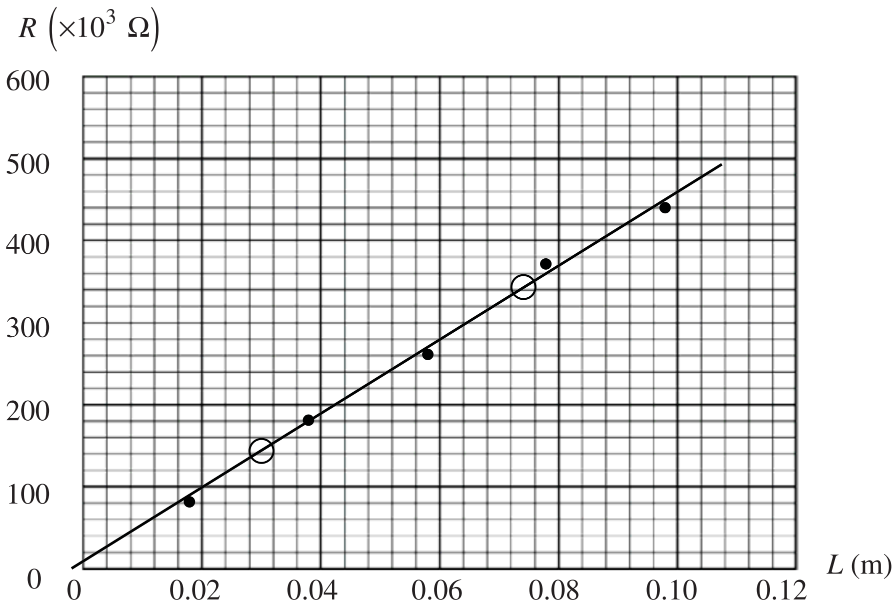
For a segment that is concave up and positive for $r > 0.20$ m. The line must not touch or cross the horizontal axis. — 1 point

Note: The labels on the vertical axis are not scored and are not required to receive full credit.

Question 2

15 points total | **Distribution of points**

(a) 4 points



For a correct label on each axis (one including resistance, one including length), that leads to a linear graph — 1 point

For two linear scales, one for each axis, corresponding to the labels and occupying at least three-quarters of each axis — 1 point

For reasonably correctly plotted points according to the scale — 1 point

For a reasonable best-fit straight line — 1 point

<u>Note</u>: Circles on the graph are to indicate points chosen to calculate slope in part (b). They are not necessary to receive credit.

Question 2 (continued)

Distribution of points

(b) 3 points

For correctly using the equation $R = \rho L/A$ to solve for the resistivity — 1 point

$\rho = (R/L)A$

For calculating the slope m from two points that lie on the indicated best-fit line — 1 point

Example (using the two points indicated on the graph)

$$m = \Delta R/\Delta L = \left(340 \times 10^3\ \Omega - 140 \times 10^3\ \Omega\right)/(0.076\text{ m - }0.032\text{ m})$$

$$m = 4.55 \times 10^6\ \Omega/\text{m}$$

Note: The slope point can also be earned for indicating that a linear regression function on a calculator was used (exact answer required): $m = 4.5 \times 10^6\ \Omega/\text{m}$ (to two significant figures).

$\rho = mA = mtw$

$\rho = \left(4.5 \times 10^6\ \Omega/\text{m}\right)\left(1.0 \times 10^{-4}\text{ m}\right)(0.02\text{ m})$

For a correct answer, with supporting work — 1 point

$\rho = 9.0\ \Omega\text{•m}$ ($\pm 0.2\ \Omega\text{•m}$ is acceptable)

(c) 3 points

For correctly stating the RC circuit time constant equation — 1 point

$\tau = RC$

For the correct value of the equivalent resistance — 1 point

$$\frac{1}{R_P} = \frac{1}{R4} + \frac{1}{R5} = \frac{1}{(370\text{ k}\Omega)} + \frac{1}{(440\text{ k}\Omega)}$$

$R_P = 201\text{ k}\Omega$

For the correct value of the time constant (units not evaluated here) — 1 point

$\tau = R_P C = (201\text{ k}\Omega)(10\ \mu\text{F})$

$\tau = 2.01\text{ s}$

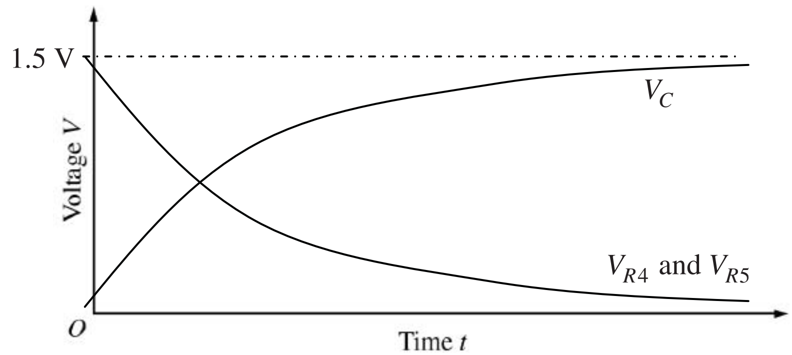
Units 1 point

For correct units for the answers in both parts (b) and (c) — 1 point

Question 2 (continued)

Distribution of points

(d) 4 points



For correctly indicating the battery voltage as an asymptote for the V_C curve (or in the absence of a correct V_C curve, as the maximum of the resistor curves) — 1 point

For a capacitor voltage curve starting at the origin, increasing, concave down, and appropriately labeled — 1 point

For a resistor voltage curve starting at the intersection of the asymptotic voltage with the voltage axis, decreasing and concave up (asymptotic with the time axis), and appropriately labeled — 1 point

For any indication that $V_{R4} = V_{R5}$ — 1 point

Question 3

15 points total	**Distribution of points**

(a) 1 point

$$\phi_m = \int \mathbf{B} \bullet d\mathbf{A}$$

For a correct answer	1 point

$\phi_m = B_0 L h_0$

(b) 2 points

For a correct direction arrow	1 point
For a valid justification using Lenz's Law or the right-hand rule, if the direction is also correct	1 point

Examples

The flux is decreasing as the area is decreasing, and a current to the right would cause an inward magnetic field that would increase flux.

The force on the falling positive charge carriers is to the right, which causes a conventional current to the right.

(c) 3 points

For a correct relationship between current, voltage, and resistance	1 point

$$I = \frac{\mathcal{E}}{R}$$

For a correct relationship between the induced emf and the magnetic field	1 point

$$|\mathcal{E}| = \frac{d\phi_m}{dt}$$

$$|\mathcal{E}| = B_0 L \frac{dh}{dt}$$

$$|\mathcal{E}| = B_0 L v$$

For a correct answer#	1 point

$I = B_0 L v / R$

Note: If only the correct answer is given, with no accompanying work, only 1 point can be awarded.

Question 3 (continued)

Distribution of points

(d) 4 points

For a correct net force equation showing opposite directions for the gravitational and magnetic forces, F_g and F_M — 1 point

$$\sum F = ma = F_g - F_M = mg - F_M$$

$$a = g - \frac{F_M}{m}$$

For using an appropriate equation to find F_M — 1 point

$$F_M = \int I \, |d\ell \times \mathbf{B}| = ILB_0$$

For substituting the current from part (c) — 1 point

$$F_M = \left(\frac{B_0 L \upsilon}{R}\right) LB_0 = \frac{B_0^2 L^2 \upsilon}{R}$$

For expressing acceleration a as $d\upsilon/dt$ — 1 point

$$\frac{d\upsilon}{dt} = g - \frac{B_0^2 L^2 \upsilon}{mR}$$

(e) 2 points

For setting the gravitational force equal to the magnetic force — 1 point

$a = 0$; therefore $F_M = F_g$

For correct substitution of expressions for the forces — 1 point

$$mg = ILB_0 = B_0^2 L^2 \upsilon_T / R$$

$$\upsilon_T = \frac{mgR}{B_0^2 L^2}$$

Note: If the correct expression for υ_T is stated without support, 2 points are awarded.

Question 3 (continued)

Distribution of points

(f) 3 points

For correctly checking “Increases” — 1 point

Note: If an incorrect choice is made for the change in terminal speed, the justification points cannot be earned.

For indicating the inverse relationship between resistance and current — 1 point

For indicating that a smaller current produces a smaller magnetic force on the bar, leading to the conclusion that to achieve a magnetic force equal to the bar’s weight, the bar must be moving faster to produce the necessary current in the bar. — 1 point

Note: If the only justification is stating that $v_T \propto R$ from the equation for v_T in part (e), only 1 justification point is awarded, because the question specifically asks for the answer in terms of forces on the crossbar.