



AP[®] Physics C: Electricity and Magnetism 2016 Scoring Guidelines

© 2016 The College Board. College Board, Advanced Placement Program, AP, AP Central, and the acorn logo are registered trademarks of the College Board.
Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.

2016 SCORING GUIDELINES

Question 1

15 points total

Distribution
of points

(a) 3 points

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

1 point

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

For correctly substituting into the above equation (signs are ignored at this step)

1 point

$$-V_1 = V_2$$

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

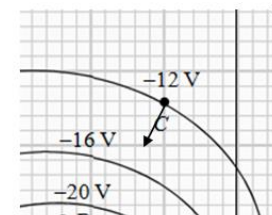
$$-\frac{q_1}{(5 \times 0.5 \text{ m})} = \frac{(2.0 \text{ nC})}{(2 \times 0.5 \text{ m})}$$

For a correct answer with correct sign and units

1 point

$$q_1 = -5.0 \text{ nC}$$

(b) 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

(c) 2 points

For using the equation relating the electric field to potential difference

1 point

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

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

For substituting values from the figure

1 point

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

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

2016 SCORING GUIDELINES

Question 1 (continued)

Distribution
of points

(d) 2 points

For using a correct equation for the electric flux

$$\Phi_E = \frac{q_{enc}}{\epsilon_0}$$

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

For a correct answer with units

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

1 point

1 point

(e)

i. 2 points

For using an equation that relates the work done to the change in potential energy

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

For a correct answer including sign and units

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

1 point

1 point

ii. 2 points

For indicating that the kinetic energy of the proton at E will be equal to the work done

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

For correctly substituting the answer from part (e) i. into the above equation

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

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

1 point

1 point

(f) 2 points

For correctly selecting Left

For a correct justification

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.

1 point

1 point

2016 SCORING GUIDELINES

Question 2

15 points total

Distribution
of points

(a) 2 points

For selecting "It is the same through both."

For a correct justification

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.

1 point

1 point

(b) 2 points

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

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

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

1 point

(c) 1 point

For indicating the correct quantities for each axis

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

Note: Credit is received if the axes are reversed.

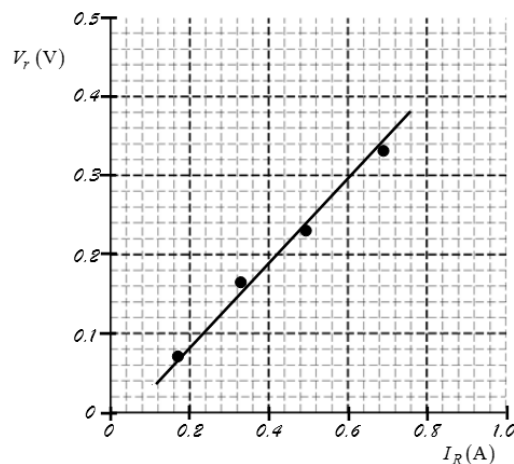
1 point

2016 SCORING GUIDELINES

Question 2 (continued)

Distribution
of points

(d) 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

(e) 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 slope = 0.485 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

$$V_r = I_R r, \text{ therefore the slope equals } r$$

$$r = 0.526 \, \Omega$$

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

2016 SCORING GUIDELINES

Question 2 (continued)

Distribution
of points

(f) 1 point

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

1 point

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

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

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

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

(g)

i. 2 points

For selecting "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.

No points are earned if the wrong answer is selected.

ii. 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.

2016 SCORING GUIDELINES

Question 3

15 points total

Distribution
of points

(a) 1 point

For selecting “Left”

1 point

(b)

i. 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.

ii. 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.

(c) 4 points

For correctly applying Newton’s second law to the motion of the bar

1 point

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

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

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

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

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

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

For writing the acceleration as dv/dt

1 point

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

2016 SCORING GUIDELINES

Question 3 (continued)

Distribution
of points

(d) 2 points

For setting the net force at terminal velocity equal to zero

1 point

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

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

For an answer consistent with part (c)

1 point

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

(e) 1 point

For a correct or consistent substitution in an appropriate power equation

1 point

$$P = I^2 R \quad \text{or} \quad V = IR$$

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

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

Alternate Solution

Alternate points

For a correct or consistent substitution in an appropriate power equation

1 point

$$P = I^2 R$$

$$Mg = BIL$$

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

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

2016 SCORING GUIDELINES

Question 3 (continued)

Distribution
of points

(f) 3 points

Using the equation from part (c)

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

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

For attempting separation of variables

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

1 point

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

1 point

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

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

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

For a correct answer

1 point

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

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