2025

AP

AP® Physics C: Electricity and Magnetism

Scoring Guidelines

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Question 1: Mathematical Routines (MR) — 10 points

A (i) For a multistep derivation that includes the equation $\oint \vec{E} \cdot d\vec{A} = \dfrac{q_{\text{enc}}}{\varepsilon_0}$ — **Point A1**

Scoring Note: Vector notation is not required for this point to be earned.

For a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$ (e.g., $2\pi r\ell$) — **Point A2**

For a correct expression for the enclosed charge (e.g., $\sigma_1(2\pi R_1 \ell)$) — **Point A3**

Example Response

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}$$

$$E(2\pi r\ell) = \frac{\sigma_1(2\pi R_1\ell)}{\varepsilon_0}$$

$$E = \frac{\sigma_1 R_1}{\varepsilon_0 r}$$

(ii) For substituting the expression for E from part A (i) into $\Delta V = -\int_a^b \vec{E} \cdot d\vec{r}$ — **Point A4**

Scoring Notes:
- Vector notation is not required for this point to be earned.
- The sign of ΔV is not considered for this point to be earned.

For an attempt to solve the integral for $|\Delta V|$ that includes correct limits (e.g., $|\Delta V| = \dfrac{\sigma_1 R_1}{\varepsilon_0}\int_{R_1}^{R_2} \dfrac{1}{r} dr$) — **Point A5**

Scoring Note: This point may be earned regardless of the order of the limits of integration; for example, $\dfrac{\sigma_1 R_1}{\varepsilon_0}\int_{R_2}^{R_1} \dfrac{1}{r} dr$.

Example Response

$$|\Delta V| = \left| -\int_a^b \vec{E} \cdot d\vec{r} \right|$$

$$|\Delta V| = \int_{R_1}^{R_2} \frac{\sigma_1 R_1}{r\varepsilon_0} dr = \frac{\sigma_1 R_1}{\varepsilon_0}\int_{R_1}^{R_2} \frac{1}{r} dr$$

$$|\Delta V| = \frac{\sigma_1 R_1}{\varepsilon_0} \ln(r)\Big|_{R_1}^{R_2} = \frac{\sigma_1 R_1}{\varepsilon_0} \ln\left(\frac{R_2}{R_1}\right)$$

(iii) For sketching a graph that is zero for both $0 < r < R_1$ and $r > R_2$ — **Point A6**

For sketching a graph that is decreasing and concave up for $R_1 < r < R_2$ — **Point A7**

Scoring Note: The curve does not have to intersect the vertical dashed lines for this point to be earned.

Example Response

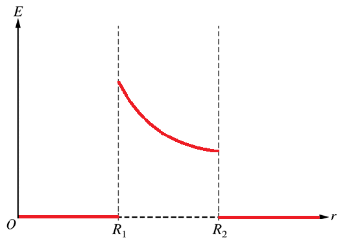

Figure 2

B	For a multistep derivation that includes the equation $C = \dfrac{Q}{\Delta V}$	**Point B1**
	For indicating that C with the dielectric material inserted is C without the dielectric material inserted multiplied by κ (e.g., $C = \kappa \dfrac{Q}{\Delta V}$)	**Point B2**
	For substitutions of both the total charge Q and the potential difference ΔV that are consistent with part A	**Point B3**

Example Response

Without the dielectric material

$$C = \frac{Q}{\Delta V}$$

$$C = \frac{\sigma_1 (2\pi L R_1)}{\left(\dfrac{\sigma_1 R_1}{\varepsilon_0} \ln\left(\dfrac{R_2}{R_1}\right)\right)}$$

$$C = \frac{2\pi L \varepsilon_0}{\ln\left(\dfrac{R_2}{R_1}\right)}$$

With the dielectric material

$$C = \kappa \frac{Q}{\Delta V}$$

$$C = \frac{2\pi L \kappa \varepsilon_0}{\ln\left(\dfrac{R_2}{R_1}\right)}$$

Question 2: Translation Between Representations (TBR) — 12 points

A	For drawing a bar at $\frac{1}{4}T$	**Point A1**
	For drawing a bar at $\frac{1}{4}T$ that has a height of 3 units	**Point A2**
	For indicating that $\lvert\mathcal{E}\rvert$ is zero at times $t = 0$ and $\frac{1}{2}T$	**Point A3**

Example Response

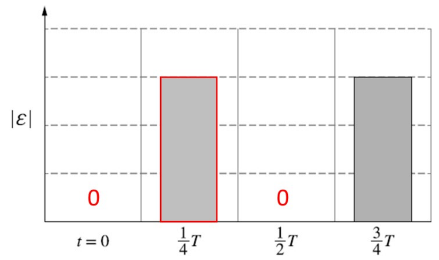

Figure 2

B	For a multistep derivation that includes the equation $\mathcal{E} = -\dfrac{d\Phi_B}{dt}$ **Scoring Note:** The negative sign does not have to be present in the expression for this point to be earned.	**Point B1**
	For a correct expression for the induced emf (e.g., $\mathcal{E} = BA\omega \sin(\omega t)$)	**Point B2**
	For using Ohm's law to relate current and emf (e.g., $I = \dfrac{\mathcal{E}}{R}$)	**Point B3**
	For a correct expression for the absolute value of the maximum induced current (e.g., $I = \dfrac{BA\omega}{R}$)	**Point B4**

Example Response

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

$$\mathcal{E} = -\frac{d}{dt}\left[BA\cos(\omega t)\right] = BA\omega\sin(\omega t)$$

$$\mathcal{E}_{max} = BA\omega$$

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

$$I_{max} = \frac{\mathcal{E}_{max}}{R} = \frac{BA\omega}{R}$$

C	For a curve that is approximately sinusoidal	**Point C1**
	For a curve that shows exactly two cycles	**Point C2**
	For a curve that starts at the origin and has equal maximum values and equal minimum values **Scoring Note:** A curve that starts and ends at $P = 0$ and has a single maximum can earn this point.	**Point C3**

Example Response

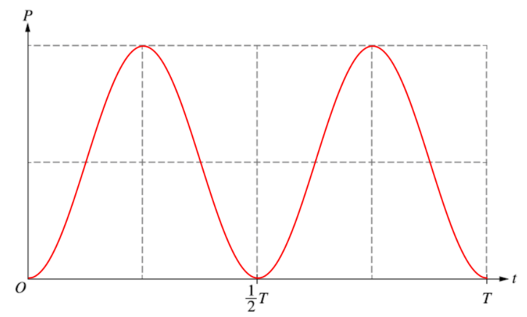

Figure 3

D	For correctly indicating whether the representations are consistent in parts A and C	**Point D1**
	For a correct justification that indicates that the maxima and/or minima of the graph in part C align with the bars drawn in part A because *P* is proportional to $\mathcal{E}^2$	**Point D2**

Example Response

Yes, part C is consistent with part A. P is proportional to $\mathcal{E}^2$. *When* $|\mathcal{E}|$ *is maximum, P is maximum.*

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Question 3: Experimental Design and Analysis (LAB) — 10 points

A		For a procedure in which the length of and the current in the circuit element are measured, and the cross-sectional area of the circuit element is determined	**Point A1**
		For a procedure that indicates a reasonable method of reducing experimental uncertainty Examples of acceptable responses may include the following: • Making different measurements of the current in the circuit element • Varying the potential difference of the power supply	**Point A2**

Example Response

Measure the length and diameter of the circuit element. Use the diameter to calculate the area of the circuit element. Measure the current in the circuit element. Repeat the procedure multiple times for different potential difference settings on the variable power supply.

B		For indicating quantities that can be graphed appropriately to determine ρ_1, consistent with the procedure from part A, such as potential difference as a function of current **Scoring Notes:** • Responses that include the reciprocals of the preceding example, in addition to other equivalent graphs, also earn this point. • This point may be earned independently of the response in part A.	**Point B1**
		For a correct analysis of the graph, consistent with the first point of part B	**Point B2**

Example Response

Graph the potential difference across the circuit element as a function of the current in the circuit element. Use the slope of the graph, which is $\frac{\rho_1 \ell}{\pi r^2}$, *where* ℓ *is the length of the circuit element and r is equal to the radius of the circuit element, to determine* ρ_1.

C	**(i)**	For indicating appropriate quantities that could be plotted on the graph to determine ρ_2, for example *R* as a function of *L* **Scoring Note:** This point may be earned: • if the vertical and horizontal variables are reversed. • for other equivalent graphs.	**Point C1**
	(ii)	For labeling the axes (including units) with a linear scale	**Point C2**
		For correctly plotting data points consistent with **one** of the following: • The quantities indicated in part C (i) • The quantities provided in the table • The axes indicated in the first point of part C (ii)	**Point C3**
	(iii)	For drawing a line or curve that approximates the trend of the plotted data	**Point C4**

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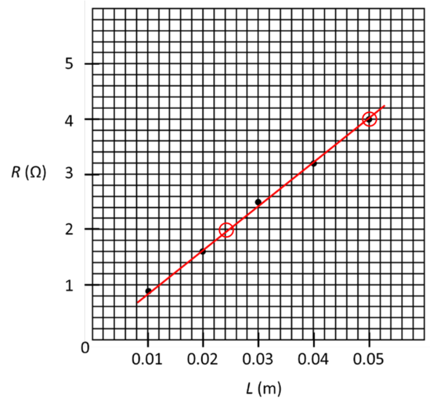
Example Response



D

For correctly relating the slope of the best-fit line to ρ_2 **Point D1**

(e.g., $\frac{\Delta R}{\Delta L} = \text{slope} = \frac{\rho_2}{A}$)

For a value for ρ_2 that is between $3.5\times10^{-4}\ \Omega\cdot\text{m}$ and $4.5\times10^{-4}\ \Omega\cdot\text{m}$ **Point D2**

Example Response

$$\text{slope} = \frac{\Delta R}{\Delta L}$$

$$\frac{\Delta R}{\Delta L} = \frac{4.0\ \Omega - 2.0\ \Omega}{0.050\ \text{m} - 0.024\ \text{m}}$$

$$\frac{\Delta R}{\Delta L} = 77\ \frac{\Omega}{\text{m}}$$

$$R = \frac{\rho L}{A}$$

$$R = \left(\frac{\rho_2}{A}\right)L$$

$$\text{slope} = \frac{\rho_2}{A}$$

$$\rho_2 = A(\text{slope})$$

$$\rho_2 = \left(5.0\times10^{-6}\ \text{m}^2\right)\left(77\ \frac{\Omega}{\text{m}}\right)$$

$$\rho_2 \approx 3.9\times10^{-4}\ \Omega\cdot\text{m}$$

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Question 4: Qualitative Quantitative Translation (QQT) — 8 points

A

For indicating that $F_2 > F_1$ **Point A1**

For correctly relating the magnitude of the magnetic force to the magnitude of the magnetic field **Point A2**

For indicating that the magnitude of the magnetic field at the location of Sphere 2 is greater than the magnitude of the magnetic field at the location of Sphere 1 by referring to either: **Point A3**

- The relative distance from the spheres to Wires S and T
- The direction of the magnetic fields from Wires S and T at the locations of the spheres

Example Response

The magnitude of the magnetic force exerted on a sphere is directly proportional to Q, v, and B. Because Q and v are the same for both spheres, the difference in the magnitudes of the magnetic forces is due to the difference in the magnitudes of the magnetic fields at the locations of the spheres. The magnitude of the magnetic field is greater at the location of Sphere 2 than at the location of Sphere 1 because the fields from the wires are in the same direction. Therefore, $F_2 > F_1$.

B

For a multistep derivation that includes the equation $\oint \vec{B}\cdot d\vec{\ell} = \mu_0 I_{\text{enc}}$ or **Point B1**

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\left(d\vec{\ell}\times\hat{r}\right)}{r^2}$$

Scoring Note: Vector notation is not required for this point to be earned. A multistep derivation that includes $B = \frac{\mu_0 I}{2\pi d}$ can earn this point.

For a correct expression for the magnitude of the magnetic field due to the current in one wire at the location of Sphere 2 **Point B2**

For indicating that the magnitude of the total field is twice that due to one wire **Point B3**

Example Response

Determine the magnitude B of the magnetic field due to one wire.

$$\oint \vec{B}\cdot d\vec{\ell} = \mu_0 I_{\text{enc}}$$

$$B(2\pi d) = \mu_0 I$$

$$B = \frac{\mu_0 I}{2\pi d}$$

Determine B_{tot}.

$$B_{\text{tot}} = \frac{\mu_0 I}{2\pi d} + \frac{\mu_0 I}{2\pi d}$$

$$B_{\text{tot}} = \frac{\mu_0 I}{\pi d}$$

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C	For indicating $F_{new} = F_2$	**Point C1**
	For indicating $B_{tot} = \frac{3\mu_0 I}{2\pi d} - \frac{\mu_0 I}{2\pi d}$ OR For indicating that the net magnitude of the magnetic field at the location of Sphere 2 will remain the same even though the field from Wire T will change	**Point C2**
	Example Response *The magnetic field at the location of Sphere 2 due to the current in Wire T is in the opposite direction to the magnetic field due to the current in Wire S. The current in Wire T is increased by a factor of 3. Therefore,* $B_{tot} = \frac{3\mu_0 I}{2\pi d} - \frac{\mu_0 I}{2\pi d} = \frac{\mu_0 I}{\pi d}$ *in this scenario. Thus,* $F_{new} = F_2$.	

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