2025

AP® Physics C: Electricity and Magnetism

Sample Student Responses and Scoring Commentary

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Question 1: Mathematical Routines (MR) — 10 points

A (i) For a multistep derivation that includes the equation $\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}$ — **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., $\sigma_1\left(2\pi R_1\ell\right)$) — **Point A3**

Example Response

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

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

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

(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 $\left|\Delta V\right|$ that includes correct limits (e.g., $\left|\Delta V\right| = \frac{\sigma_1 R_1}{\varepsilon_0}\int_{R_1}^{R_2} \frac{1}{r}dr$) — **Point A5**

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

Example Response

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

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

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

(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

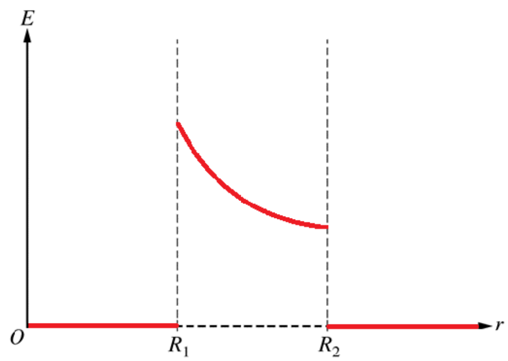

Figure 2

B	For a multistep derivation that includes the equation $C = \frac{Q}{\Delta V}$	**Point B1**
	For indicating that C with the dielectric material inserted is C without the dielectric material inserted multiplied by κ (e.g., $C = \kappa \frac{Q}{\Delta V}$)	**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

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

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

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

With the dielectric material

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

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

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 1: Version J

PART A

i. $\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$

$q_{enc} = \sigma_1 V$

$q_{enc} = \sigma_1 \pi R_1^2 L$

$E \cdot 2\pi r L = \frac{q_{enc}}{\varepsilon_0}$

$E = \frac{q_{enc}}{\varepsilon_0 2\pi r L}$

$E = \frac{\sigma_1 \pi R_1^2 L}{\varepsilon_0 2\pi r L}$

$\boxed{E = \frac{\sigma_1 R_1^2}{2\varepsilon_0 r}}$

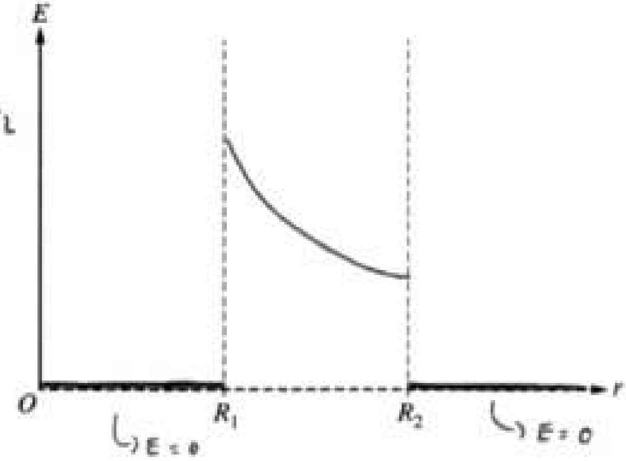

Figure 2

ii. $|\Delta V| = \int_{R_1}^{R_2} E\, dr$

$= \int_{R_1}^{R_2} \frac{\sigma_1 R_1^2}{2\varepsilon_0 r} dr$

$= \frac{\sigma_1 R_1^2}{2\varepsilon_0} \cdot \int_{R_1}^{R_2} \frac{1}{r} dr$

$= \frac{\sigma_1 R_1^2}{2\varepsilon_0} \cdot \ln \frac{R_2}{R_1}$

$\boxed{|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \ln \frac{R_2}{R_1}}$

PART B

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

$Q = \sigma_1 \pi R_1^2 L$

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

$C = \frac{K \cdot \sigma_1 \pi R_1^2 L}{\frac{\sigma_1 R_1^2}{2\varepsilon_0} \ln \frac{R_2}{R_1}} = \frac{K \sigma_1 \pi R_1^2 L}{\ln \frac{R_2}{R_1}} \cdot \frac{2\varepsilon_0}{\sigma_1 R_1^2}$

$C = \frac{K\, 2\pi L \varepsilon_0}{\ln \frac{R_2}{R_1}}$

Go to Question 2 in Bluebook when you're done with this question.

0019723

Q5824/03

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 1: Version J

PART A

i.) $\oint E \cdot dA = \frac{Q_{en}}{\varepsilon_0}$

$E \oint dA = \frac{Q_{en}}{\varepsilon_0}$

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

$E = \frac{\sigma_1 \pi R_1^2 L}{2\pi r L \varepsilon_0} = \boxed{\frac{\sigma_1 R_1^2}{2 r \varepsilon_0}}$

$\sigma_1 = \frac{Q_{en}}{A}$

$\sigma_1 = \frac{Q_{en}}{\pi R_1^2 L}$

$Q_{en} = \sigma_1 (\pi R_1^2 L)$

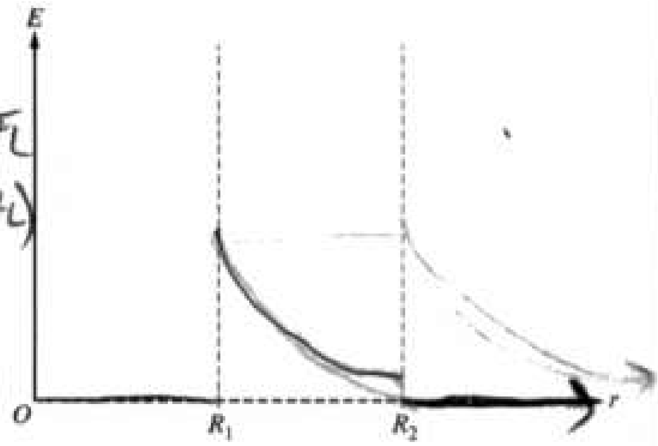

Figure 2

ii.) $\Delta V = -\int E \cdot dr$

$|\Delta V| = \int_{R_1}^{R_2} \frac{\sigma_1 R_1^2}{2 r \varepsilon_0} dr$

$|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \int \frac{1}{r} dr$

$|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \left[\ln(r)\right]_{R_1}^{R_2}$

$|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} (\ln(R_2) - \ln(R_1))$

$\boxed{|\Delta V| = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \ln\left(\frac{R_2}{R_1}\right)}$

PART B

$d = R_2 - R_1$

$C = \frac{K \varepsilon_0 A}{d}$

$C = \frac{K \varepsilon_0 A}{R_2 - R_1}$

$\boxed{C = \frac{K \varepsilon_0 \pi L (R_2^2 + R_1^2)}{R_2 - R_1}}$

$A_+ = \pi R_1^2 L$

$A_- = \pi R_2^2 L$

$A_{total} = \pi R_2^2 L + \pi R_1^2 L$

$A_{total} = \pi L (R_2^2 + R_1^2)$

Go to Question 2 in Bluebook when you're done with this question.

0019979

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 1: Version J

PART A

$\sigma = \frac{Q}{A}$ $Q = \sigma A$

i) $\oint E\,dA = \frac{q_{enc}}{\varepsilon_0}$ $A = \pi(R_1^2)$

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

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

ii) $|\Delta V| = \left| -\int_{R_1}^{R_2} E\,dr \right|$

$|\Delta V| = +\int_{R_1}^{R_2} \frac{\sigma R_1^2}{2 r \varepsilon_0} dr$

$= \frac{\sigma_1 R_1^2}{2\varepsilon_0} \int_{R_1}^{R_2} \frac{1}{r} dr$

$= \frac{\sigma_1 R_1^2}{2\varepsilon_0} \left[\ln|r| \right]_{R_1}^{R_2}$

$= \frac{\sigma_1 R_1^2}{2\varepsilon_0} (\ln(R_2) - \ln(R_1)) = \frac{\sigma_1 R_1^2}{2\varepsilon_0} \ln\left(\frac{R_2}{R_1}\right)$

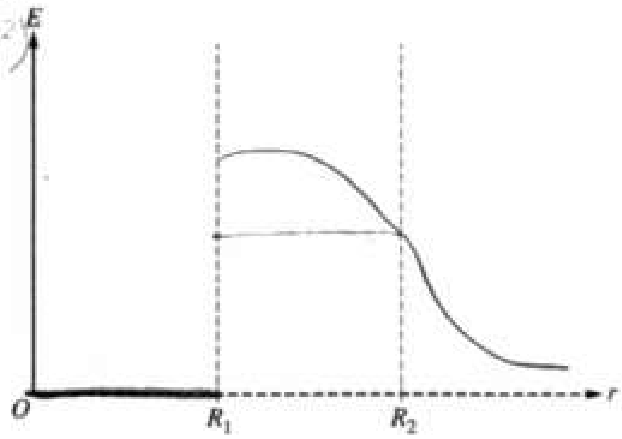

Figure 2

PART B $C = \frac{\kappa \varepsilon_0 A}{d}$ $A = 2\pi(R_2^2 - R_1^2) l$

$C = \frac{\kappa \varepsilon_0 \pi (R_2^2 - R_1^2) l}{R_2 - R_1}$

Go to Question 2 in Bluebook when you're done with this question.

0006592

Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

NEW for 2025: The question overviews can be found in the *Chief Reader Report on Student Responses* on AP Central.

Sample: 1A
Score: 9

Part A (i) earned two out of three points. The first point (A1) was earned for including a multistep derivation that includes Gauss's law. The second point (A2) was earned for including a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$. The third point (A3) was not earned because the response uses the volume of the inner cylinder as opposed to its surface area to determine the enclosed charge. Part A (ii) earned both points. The first point (A4) was earned for including a substitution of the expression for E from part A (i) into an equation that correctly relates ΔV and E. The second point (A5) was earned for including an attempt to solve an integral for ΔV that includes correct limits. Part A (iii) earned both points. The first point (A6) was earned for including a sketch of a graph that is zero for both $0 < r < R_1$ and $r > R_2$. The second point (A7) was earned for including a sketch of a graph that is decreasing and concave up for $R_1 < r < R_2$.

Part B earned all three points. The first point (B1) was earned for including a multistep derivation that includes the equation $C = Q/\Delta V$. The second point (B2) was earned for indicating that the capacitance with the dielectric material inserted is multiplied by a factor of κ. The third point (B3) was earned for including substitutions of both the total charge Q and the potential difference ΔV that are consistent with part A.

Sample: 1B
Score: 6

Part A (i) earned two out of three points. The first point (A1) was earned for including a multistep derivation that includes Gauss's law. The second point (A2) was earned for including a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$. The third point (A3) was not earned because the response uses the volume of the inner cylinder, as opposed to its surface area, to determine the enclosed charge. Part A (ii) earned both points. The first point (A4) was earned for including a substitution of the expression for E from part A (i) into an equation that correctly relates ΔV and E. The second point (A5) was earned for including an attempt to solve an integral for ΔV that includes correct limits. Part A (iii) earned both points. The first point (A6) was earned for including a sketch of a graph that is zero for both $0 < r < R_1$ and $r > R_2$. The second point (A7) was earned for including a sketch of a graph that is decreasing and concave up for $R_1 < r < R_2$.

Part B did not earn any of the three points. The first point (B1) was not earned because the response does not include a multistep derivation that includes the equation $C = Q/\Delta V$. The second point (B2) was not earned because the response does not indicate that the capacitance with the dielectric material inserted is multiplied by a factor of κ. Instead, the response states the equation for the capacitance of a parallel plate capacitor, as given on the reference sheet. The third point (B3) was not earned because the response does not include substitutions of both the total charge Q and the potential difference ΔV. Instead, it includes substitutions of the area of a parallel plate capacitor and the distance between the plates.

Question 1 (continued)

Sample: 1C
Score: 3

Part A (i) earned one out of three points. The first point (A1) was earned for including a multistep derivation that includes Gauss's law. The second point (A2) was not earned because the response does not include a correct substitution of the area of an appropriate Gaussian surface with nonzero flux for the region $R_1 < r < R_2$. The third point (A3) was not earned because the response does not include a correct expression for the enclosed charge. Part A (ii) earned both points. The first point (A4) was earned for including a substitution of the expression for E from part A (i) into an equation that correctly relates ΔV and E. The second point (A5) was earned for including an attempt to solve an integral for ΔV that includes correct limits. Part A (iii) did not earn either point. The first point (A6) was not earned because the response does not include a sketch of a graph that is zero for both $0 < r < R_1$ and $r > R_2$. The second point (A7) was not earned because the response does not include a sketch of a graph that is decreasing and concave up for $R_1 < r < R_2$.

Part B did not any of the three points. The first point (B1) was not earned because the response does not include a multistep derivation that includes the equation $C = Q/\Delta V$. The second point (B2) was not earned because the response does not indicate that the capacitance with the dielectric material inserted is multiplied by a factor of κ. Instead, the response states the equation for the capacitance of a parallel plate capacitor, as given on the reference sheet. The third point (B3) was not earned because the response does not include substitutions of both the total charge Q and the potential difference ΔV. Instead, it includes substitutions of the area of a parallel plate capacitor and the distance between the plates.