

2025



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# **AP<sup>®</sup> Physics C: Electricity and Magnetism**

## **Free-Response Questions**

**PHYSICS C: ELECTRICITY AND MAGNETISM****SECTION II****TIME – 1 HOUR AND 40 MINUTES****Directions:**

Section II has 4 questions and lasts 1 hour and 40 minutes.

You may use the available paper for scratch work and planning, but you must write your answers in the free-response booklet. Label parts (e.g., A, B, C) and sub-parts (e.g., i, ii, iii) as needed. Use a pencil or a pen with black or dark blue ink to write your responses.

A calculator is allowed in this section, as well as a ruler and straightedge. You may use a handheld four-function, scientific, or graphing calculator, or the calculator available in this application. Reference information, including lists of equations, can also be accessed in this application and is available throughout the exam.

All final numerical answers should include appropriate units when applicable. Credit for your work depends on demonstrating that you know which physical principles to apply in a particular situation. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations. Therefore, you should show your work for each part in the space provided for that part. If you need more space, be sure to clearly indicate where you continue your work. When constructing a graph or diagram, use only one color of ink or pencil.

You may pace yourself as you answer the questions in this section, or you may use these optional timing recommendations:

It is suggested that you spend about 25 minutes each on Questions 1 and 3, about 30 minutes on Question 2, and about 20 minutes on Question 4.

You can go back and forth between questions in this section until time expires. The clock will turn red when 5 minutes remain—**the proctor will not give you any time updates or warnings.**

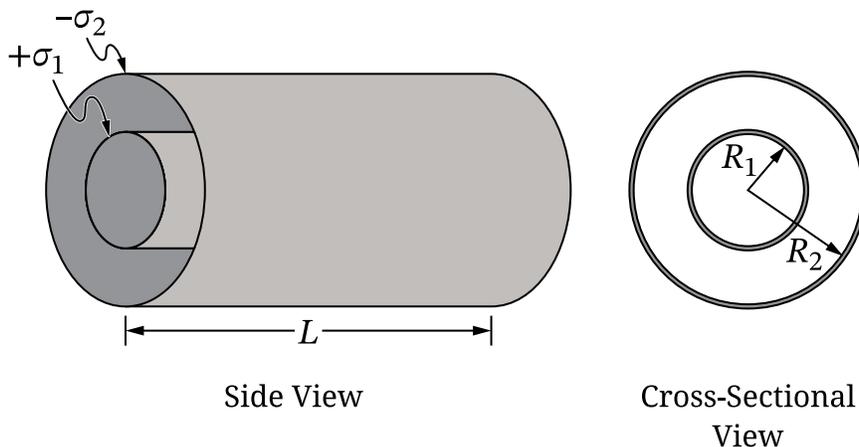
Note: This exam was originally administered digitally. It is presented here in a format optimized for teacher and student use in the classroom.

During the AP Exam administration, students have access to reference information. To see the reference information for this course, please visit AP Central:

<https://apcentral.collegeboard.org/courses/ap-physics-c-electricity-and-magnetism/exam>

**Question 1: Version J**

1. An isolated, air-filled, charged capacitor consists of two conducting, coaxial, cylindrical shells that each have length  $L$ . The inner shell has radius  $R_1$  and the outer shell has radius  $R_2$ , as shown in Figure 1, where  $R_1 < R_2 \ll L$ . The surface charge densities (amounts of charge per unit area) of the inner and outer shells are  $+\sigma_1$  and  $-\sigma_2$ , respectively. The absolute values of the total charges on the shells are equal.



Note: Figures not drawn to scale.

Figure 1

A.

- i. Using Gauss's law, **derive** an expression for the magnitude  $E$  of the electric field as a function of the radial distance  $r$  from the center of the capacitor for the region  $R_1 < r < R_2$ . Express your answer in terms of  $R_1$ ,  $\sigma_1$ ,  $r$ , and physical constants, as appropriate.
- ii. **Derive** an expression for the absolute value  $|\Delta V|$  of the potential difference between the outer and inner shells in terms of  $R_1$ ,  $R_2$ ,  $\sigma_1$ , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

iii. On the axes shown in Figure 2, **sketch** a graph of  $E$  as a function of  $r$  from  $r = 0$  to a position that is outside the outer shell.

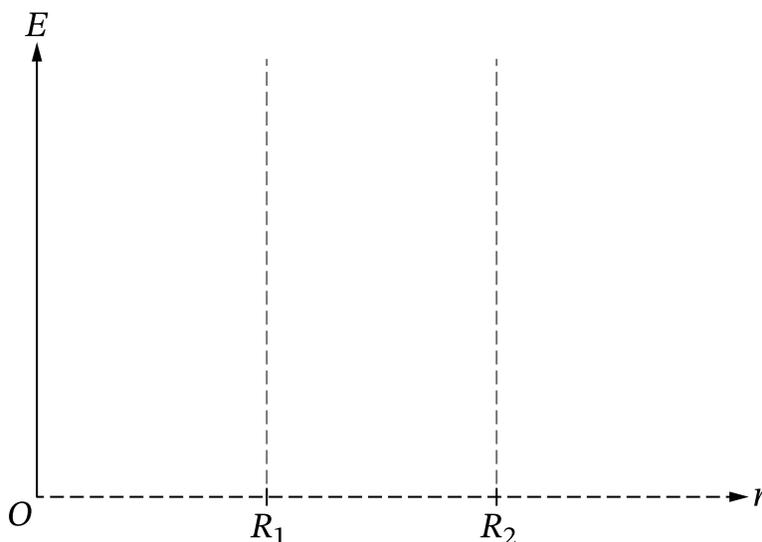
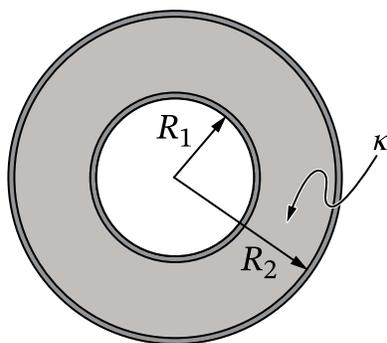


Figure 2

B. A material of dielectric constant  $\kappa$  is inserted into the isolated, charged capacitor such that the material fills the region  $R_1 < r < R_2$ , as shown in Figure 3.



Cross-Sectional View

Figure 3

**Derive** an expression for the capacitance  $C$  of the capacitor with the material inserted in terms of  $L$ ,  $R_1$ ,  $R_2$ ,  $\kappa$ , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

**Question 2: Version J**

2. A rotating, circular, conducting loop of area  $A$  and resistance  $R$  is in an external uniform magnetic field of magnitude  $B$  that is directed in the  $-z$ -direction. At time  $t = 0$ , the magnetic field is perpendicular to the plane of the loop, as shown in Figure 1. The loop is rotating with constant angular speed  $\omega$  and period  $T$  about the dashed line that is along the diameter of the loop. The value of the magnetic flux through the loop as a function of time  $t$  is  $\Phi = BA \cos(\omega t)$ .

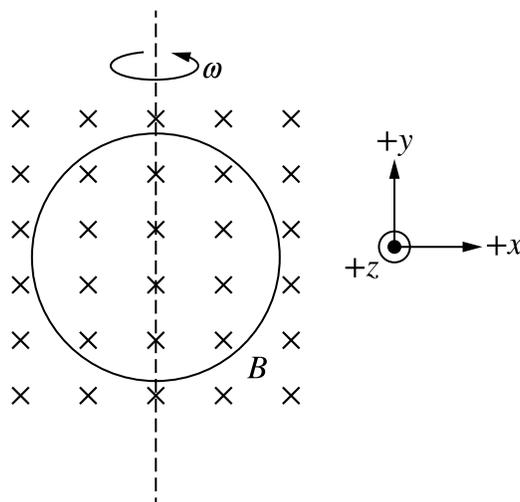


Figure 1

A. The absolute value of the induced emf in the loop is  $|\mathcal{E}|$ . The partially completed bar chart in Figure 2 shows a bar that represents  $|\mathcal{E}|$  at  $t = \frac{3}{4}T$ . In Figure 2, **draw** bars to represent  $|\mathcal{E}|$  at times  $t = 0$ ,  $\frac{1}{4}T$ , and  $\frac{1}{2}T$  relative to  $|\mathcal{E}|$  shown at  $\frac{3}{4}T$ . If  $|\mathcal{E}| = 0$ , **write** a “0” in that column.

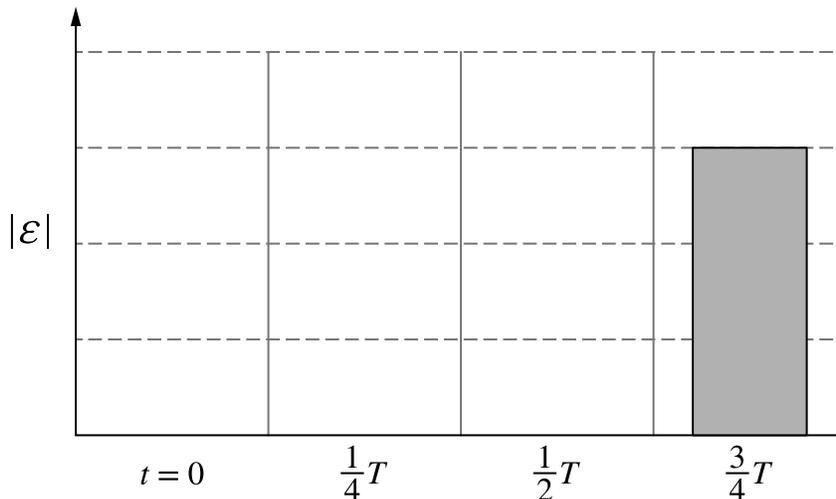


Figure 2

- B. Derive** an expression for the maximum induced current in the loop in terms of  $A$ ,  $R$ ,  $B$ ,  $\omega$ , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.
- C.** On the axes shown in Figure 3, **sketch** a graph of the instantaneous power  $P$  dissipated by the loop as a function of  $t$  during the time interval  $0 \leq t \leq T$ .

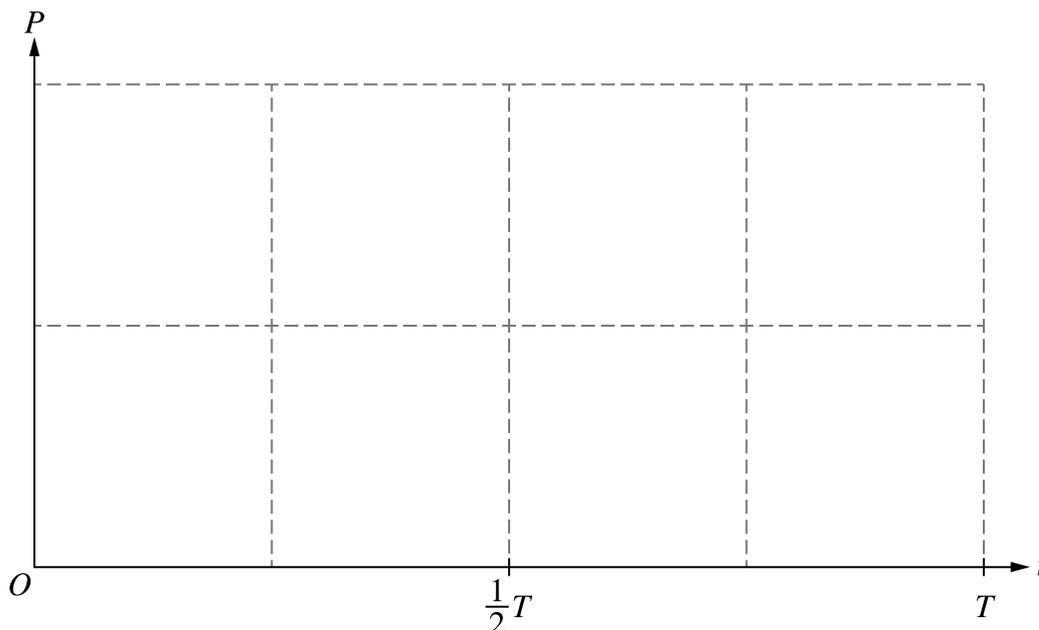


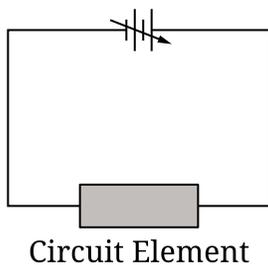
Figure 3

- D. Indicate** whether the sketch you drew in part C is or is not consistent with the bars that you drew in part A. Briefly **justify** your answer by referencing the functional dependence between  $P$  and  $|\mathcal{E}|$ .

**Question 3**

3. In Experiment 1, students are asked to use a graph to determine the resistivity  $\rho_1$  of a circuit element that is connected to a variable power supply, as shown in Figure 1. The circuit element is cylindrical and has uniform resistivity. The students have access to a voltmeter, an ammeter, and a ruler.

**Figure 1**



- A. **Describe** a procedure for collecting data that would allow the students to use a graph to determine  $\rho_1$ , including any steps necessary to reduce experimental uncertainty.
- B. **Describe** how the collected data could be graphed and how that graph would be analyzed to determine  $\rho_1$ .

In Experiment 2, the students are asked to use a graph to determine the resistivity  $\rho_2$  of solid, cylindrical resistors made of the same material but of different lengths  $L$ . The cross-sectional area of each resistor is  $5.0 \times 10^{-6} \text{ m}^2$ . The students directly measure the resistance  $R$  between the ends of each resistor. Table 1 provides  $L$  and  $R$  for each resistor.

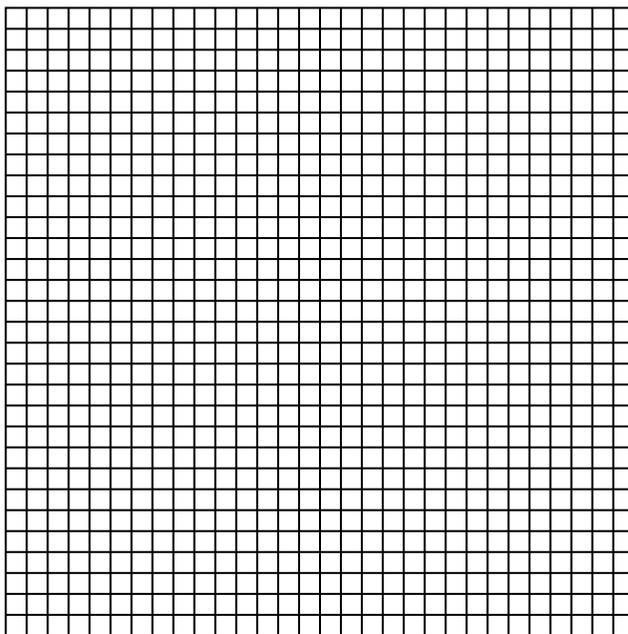
Table 1

$L$ (m)	$R$ ( $\Omega$ )
0.010	0.90
0.020	1.6
0.030	2.5
0.040	3.2
0.050	4.0

- C.
  - i. **Indicate** two quantities, either measured quantities from Table 1 or additional calculated quantities, that could be graphed to produce a straight line that could be used to determine  $\rho_2$ .

Vertical axis: \_\_\_\_\_ Horizontal axis: \_\_\_\_\_

- ii. On the grid provided, create a graph of the quantities indicated in part C (i).
  - Use Table 2 to record the measured or calculated quantities that you will plot.
  - Clearly **label** the axes, including units as appropriate.
  - **Plot** the points you recorded in Table 2.

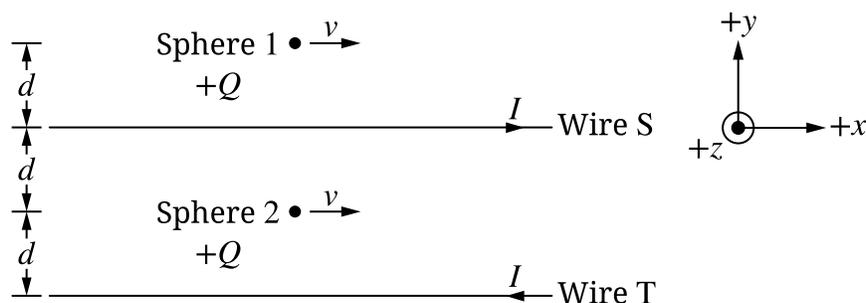


- iii. **Draw** a best-fit line for the data graphed in part C (ii).
- D.** Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for  $\rho_2$ .

**Question 4**

4. Long, parallel wires S and T are a distance  $2d$  apart. Both wires carry equal currents  $I$ , but the currents are in opposite directions. Both wires are parallel to the  $x$ -axis. At the instant shown in Figure 1, Sphere 1 is a distance  $d$  above Wire S, Sphere 2 is a distance  $d$  below Wire S, and both spheres are moving with speed  $v$  in the  $+x$ -direction. Each sphere has positive charge  $+Q$ . Gravitational effects are negligible.

**Figure 1**



A.  $F_1$  is the magnitude of the magnetic force exerted on Sphere 1 due to the currents in wires S and T.  $F_2$  is the magnitude of the magnetic force exerted on Sphere 2 due to the currents in wires S and T.

**Indicate** whether  $F_2$  is greater than, less than, or equal to  $F_1$  by writing one of the following.

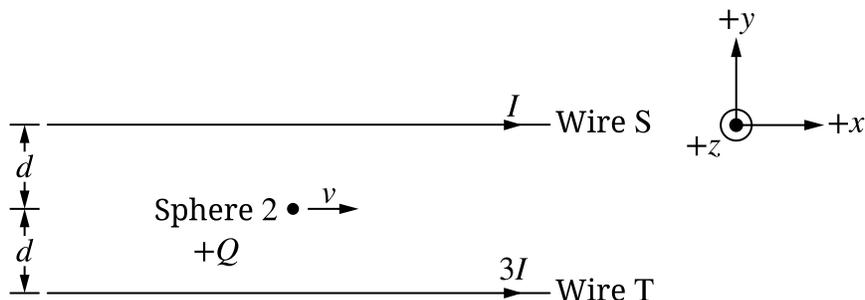
- $F_2 > F_1$
- $F_2 < F_1$
- $F_2 = F_1$

**Justify** your answer.

B. **Derive** an expression for the magnitude  $B_{\text{tot}}$  of the magnetic field at the location of Sphere 2 due to the currents in wires S and T in terms of  $d$ ,  $I$ , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. Later, Wire T carries current  $3I$  in the  $+x$ -direction. At the instant shown in Figure 2, Sphere 2 is a distance  $d$  below Wire S and is moving with speed  $v$  in the  $+x$ -direction.  $F_{\text{new}}$  is the new magnitude of the magnetic force exerted on Sphere 2 due to the currents in wires S and T.

Figure 2



Indicate whether  $F_{\text{new}}$  is greater than, less than, or equal to  $F_2$  by writing one of the following.

- $F_{\text{new}} > F_2$
- $F_{\text{new}} < F_2$
- $F_{\text{new}} = F_2$

Briefly justify your answer by referencing your derivation in part B.

**STOP**  
**END OF EXAM**