

**2001 AP<sup>®</sup> PHYSICS C: ELECTRICITY AND MAGNETISM  
FREE-RESPONSE QUESTIONS**

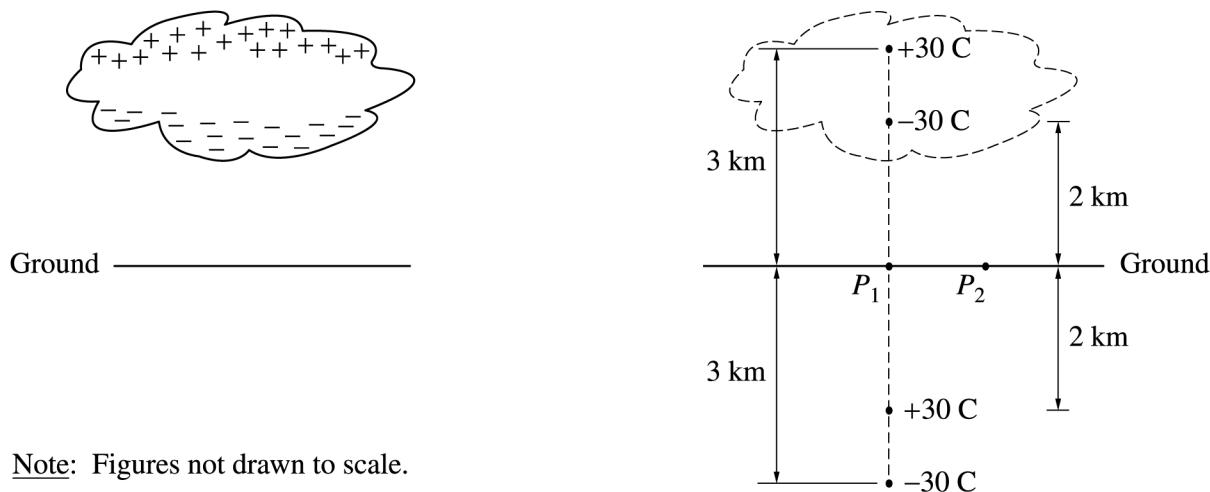
**PHYSICS C**

**Section II, ELECTRICITY AND MAGNETISM**

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



Note: Figures not drawn to scale.

E&M 1.

A thundercloud has the charge distribution illustrated above left. Treat this distribution as two point charges, a negative charge of  $-30\text{ C}$  at a height of  $2\text{ km}$  above ground and a positive charge of  $+30\text{ C}$  at a height of  $3\text{ km}$ . The presence of these charges induces charges on the ground. Assuming the ground is a conductor, it can be shown that the induced charges can be treated as a charge of  $+30\text{ C}$  at a depth of  $2\text{ km}$  below ground and a charge of  $-30\text{ C}$  at a depth of  $3\text{ km}$ , as shown above right. Consider point  $P_1$ , which is just above the ground directly below the thundercloud, and point  $P_2$ , which is  $1\text{ km}$  horizontally away from  $P_1$ .

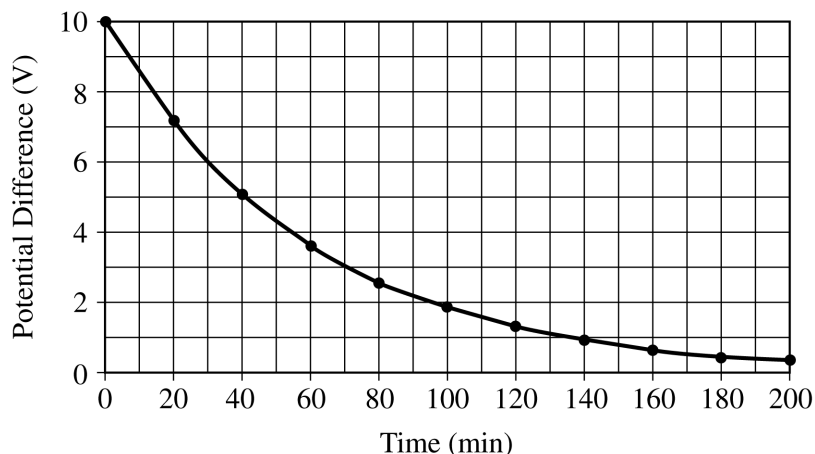
- (a) Determine the direction and magnitude of the electric field at point  $P_1$ .
- (b) i. On the diagram above, clearly indicate the direction of the electric field at point  $P_2$ .
- ii. How does the magnitude of the field at this point compare with the magnitude at point  $P_1$ ?

\_\_\_ Greater      \_\_\_ Equal      \_\_\_ Less

Justify your answer

- (c) Letting the zero of potential be at infinity, determine the potential at these points.
- i. Point  $P_1$
- ii. Point  $P_2$
- (d) Determine the electric potential at an altitude of  $1\text{ km}$  directly above point  $P_1$ .
- (e) Determine the total electric potential energy of this arrangement of charges.

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E & M 2.

You have been hired to determine the internal resistance of  $8.0\ \mu\text{F}$  capacitors for an electronic component manufacturer. (Ideal capacitors have an infinite internal resistance—that is, the material between their plates is a perfect insulator. In practice, however, the material has a very small, but nonzero, conductivity.) You cannot simply connect the capacitors to an ohmmeter, because their resistance is too large for an ohmmeter to measure. Therefore you charge the capacitor to a potential difference of 10 V with a battery, disconnect it from the battery and measure the potential difference across the capacitor every 20 minutes with an ideal voltmeter, obtaining the graph shown above.

(a) Determine the internal resistance of the capacitor.

The capacitor can be approximated as a parallel-plate capacitor separated by a 0.10 mm thick dielectric with  $\kappa = 5.6$ .

(b) Determine the approximate surface area of one of the capacitor “plates.”

(c) Determine the resistivity of the dielectric.

(d) Determine the magnitude of the charge leaving the positive plate of the capacitor in the first 100 min.

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**2001 SCORING GUIDELINES**

**Question 1**

**15 points total**

1. (a) **4 points**

**Distribution  
of Points**

For a correct formula for determining the electric field

**1 point**

$$\mathbf{E} = \sum \frac{kQ}{r^2} \hat{\mathbf{r}} \quad \text{or} \quad \mathbf{E} = \frac{kQ}{r^2} \hat{\mathbf{r}}$$

Summing the contributions to the field from the four charges, letting fields directed upward be positive and fields directed downward be negative (full credit also given for using opposite convention as long as answers were consistent):

$$E = - \frac{(9 \times 10^9)(30)}{(3 \times 10^3)^2} + \frac{(9 \times 10^9)(30)}{(2 \times 10^3)^2} + \frac{(9 \times 10^9)(30)}{(2 \times 10^3)^2} - \frac{(9 \times 10^9)(30)}{(3 \times 10^3)^2}$$

For correct substitutions shown in the above equation

**1 point**

$$E = -30,000 \text{ N/C} + 67,500 \text{ N/C} + 67,500 \text{ N/C} - 30,000 \text{ N/C}$$

$$E = 75,000 \text{ N/C, directed upward}$$

**1 point**

For correct magnitude ( $E = \frac{8 \times 10^{-6}}{4\pi\epsilon_0}$  or  $k(8 \times 10^{-6})$  also accepted)

For correct direction, either stated or shown by an upward directed arrow

**1 point**

Notes: If wrong signs were used in the substitution, the point for correct magnitude was not awarded. If calculation was done using only the two real charges, a maximum of **3 points** was awarded as follows: **1 point** for the formula, **1 point** for the calculation, **1 point** for direction.

1. (b) i. **1 point**

For correctly indicating direction, such as by an upward directed arrow at  $P_2$ ,

**1 point**

1. (b) ii. **2 points**

For correctly checking the space in front of “Less”

**1 point**

For correct justification, such as “ $P_2$  is farther from all the charges than  $P_1$ , so the net field is less.” If student chose to work out the actual magnitude of the field at  $P_2$  (which is about 45,000 N/C), the justification point was awarded for any calculated numerical value less than 75,000 N/C.

**1 point**

Note: **No points** were awarded for (b) ii. if the wrong space was checked.