AP® Physics C: Electricity and Magnetism
2001 Sample Student Responses

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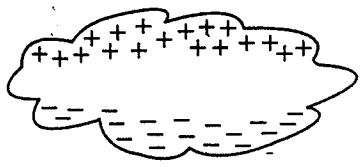
PHYSICS C

Section II, ELECTRICITY AND MAGNETISM

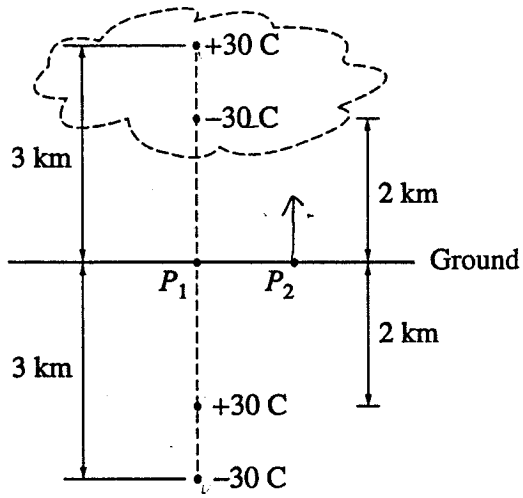
Time—45 minutes

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 this booklet in the spaces provided after each part, NOT in the green insert.



Ground



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 C at a height of 2 km above ground and a positive charge of +30 C at a height of 3 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 C at a depth of 2 km below ground and a charge of −30 C at a depth of 3 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 km horizontally away from P_1.

(a) Determine the direction and magnitude of the electric field at point P_1.

4 components of $\vec{E}$ at P_1

$\frac{1}{4\pi\varepsilon_0}\frac{(30\text{ C})}{(3\text{ km})^2}$ [down] $\quad\frac{1}{4\pi\varepsilon_0}\frac{(30\text{ C})}{(2\text{ km})^2}$ [up]

$\frac{1}{4\pi\varepsilon_0}\frac{(-30\text{ C})}{(2\text{ km})^2}$ [up] $\quad\frac{1}{4\pi\varepsilon_0}\frac{(-30\text{ C})}{(3\text{ km})^2}$ [down]

magnitude of components pointing up is greater than that of those pointing down

Electric field at point P_1 : 7.5×10^4 N/C up

GO ON TO THE NEXT PAGE.

(b) i. On the diagram on the previous page, 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

point P_2 is further away from the charges than point P_1 is. Electrical field varies according to $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

(c) Letting the zero of potential be at infinity, determine the potential at these points.

i. Point P_1

$$V = \frac{1}{4\pi\varepsilon_0}\sum_i \frac{q_i}{r_i}$$

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{30\,C}{3\,km} + \frac{-30\,C}{2\,km} + \frac{30\,C}{2\,km} + \frac{-30\,C}{3\,km}\right)$$

$$V = 0$$

ii. Point P_2

$$V = \frac{1}{4\pi\varepsilon_0}\sum_i \frac{q_i}{r_i}$$

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{30\,C}{\sqrt{3^2+1^2}\,km} + \frac{-30\,C}{\sqrt{2^2+1^2}\,km} + \frac{30\,C}{\sqrt{2^2+1^2}\,km} + \frac{-30\,C}{\sqrt{3^2+1^2}\,km}\right)$$

$$V = 0$$

GO ON TO THE NEXT PAGE.

(d) Determine the electric potential at an altitude of 1 km directly above point P_1.

$$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$$

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{30\,C}{2\,km} + \frac{-30\,C}{1\,km} + \frac{30\,C}{3\,km} + \frac{-30\,C}{4\,km}\right)$$

$$V = -1.12 \times 10^8 \quad V$$

(e) Determine the total electric potential energy of this arrangement of charges.

$$U_E = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

$$U_E = \frac{1}{4\pi\varepsilon_0}\left[\frac{(30\,C)(-30\,C)}{1\,km} + \frac{(30\,C)(30\,C)}{5\,km} + \frac{(30\,C)(-30\,C)}{6\,km} + \cdots\right.$$

$$\left. \frac{(-30\,C)(30\,C)}{4\,km} + \frac{(-30\,C)(-30\,C)}{5\,km} + \frac{(30\,C)(-30\,C)}{1\,km}\right]$$

$$U_E = -1.63 \times 10^{10} \quad J$$

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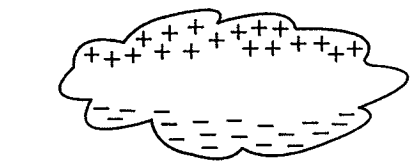
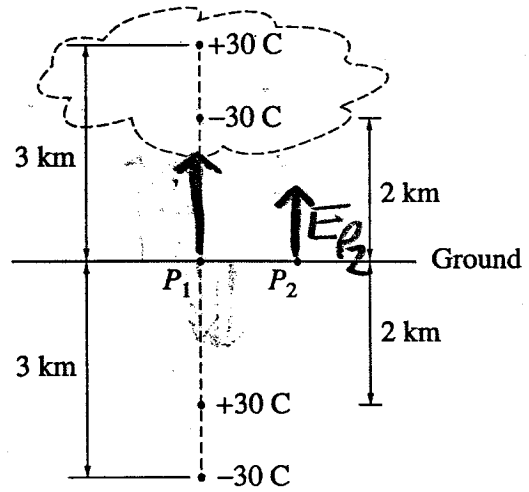


Ground



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E&M 1.

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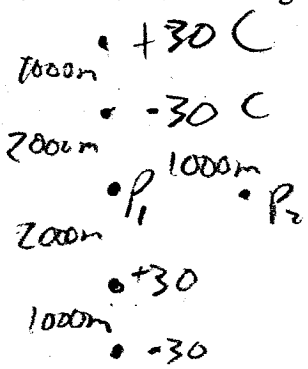
(a) Determine the direction and magnitude of the electric field at point P_1.



$$E = \sum_{i=1} \frac{kQ_i}{4\pi\varepsilon_0 r_i^2}$$

$$E = \frac{-30}{4\pi\varepsilon_0(3000^2)} + \frac{+30}{4\pi\varepsilon_0(3000^2)}$$

$$+\frac{30}{4\pi\varepsilon_0(2000^2)} + \frac{+30}{4\pi\varepsilon_0(2000^2)}$$

$E = 75{,}000$ N/C

straight up as shown above

GO ON TO THE NEXT PAGE.

E E E E E E E E E E E E E E E E

(b) i. On the diagram on the previous page, 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

It must have a smaller magnitude because the distances from the charges are greater

(c) Letting the zero of potential be at infinity, determine the potential at these points.

i. Point P_1

$$V = \sum_{i=0}^{n} \frac{Q}{4\pi\varepsilon_0 r}$$

$$V = -\frac{30}{4\pi\varepsilon_0(2000)} + \frac{30}{4\pi\varepsilon_0(2000)} - \frac{30}{4\pi\varepsilon_0(3000)} + \frac{30}{4\pi\varepsilon_0(3000)}$$

$$V = 0\ V$$

ii. Point P_2

$$V = \frac{30}{4\pi\varepsilon_0(\sqrt{5000})} - \frac{30}{4\pi\varepsilon_0(\sqrt{5000})} + \frac{30}{4\pi\varepsilon_0(\sqrt{10000})} - \frac{30}{4\pi\varepsilon_0(\sqrt{10000})}$$

$$V = 0\ V$$

GO ON TO THE NEXT PAGE.

(d) Determine the electric potential at an altitude of 1 km directly above point P_1.

$$V = \frac{30}{4\pi\varepsilon_0(2000)} + \frac{30}{4\pi\varepsilon_0(3000)} - \frac{30}{4\pi\varepsilon_0(4000)} - \frac{30}{4\pi\varepsilon_0(1000)}$$

$$V = -1.12E^{8}\,V$$

(e) Determine the total electric potential energy of this arrangement of charges.

$$E = -\frac{30\cdot30}{4\pi\varepsilon_0(1000)} + \frac{30\cdot30}{4\pi\varepsilon_0(5000)} - \frac{30\cdot30}{4\pi\varepsilon_0(6000)}$$

$$E = -7.8E^{9}\,J$$