AP® Physics B
2001 Sample Student Responses

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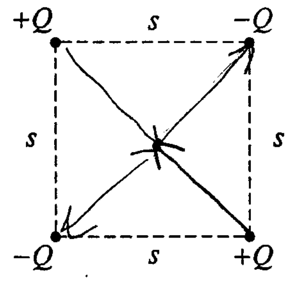


Arrangement 1

3. (15 points)

Four charged particles are held fixed at the corners of a square of side s. All the charges have the same magnitude Q, but two are positive and two are negative. In Arrangement 1, shown above, charges of the same sign are at opposite corners. Express your answers to parts (a) and (b) in terms of the given quantities and fundamental constants.

(a) For Arrangement 1, determine the following.

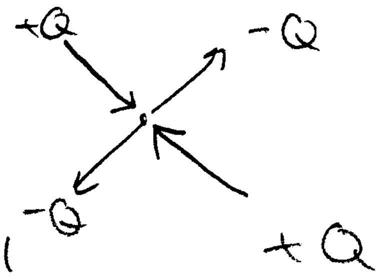
i. The electrostatic potential at the center of the square

$$V = \sum \frac{1}{4\pi\epsilon_0}\frac{q}{r} \Rightarrow r = \frac{s\sqrt{2}}{2}$$

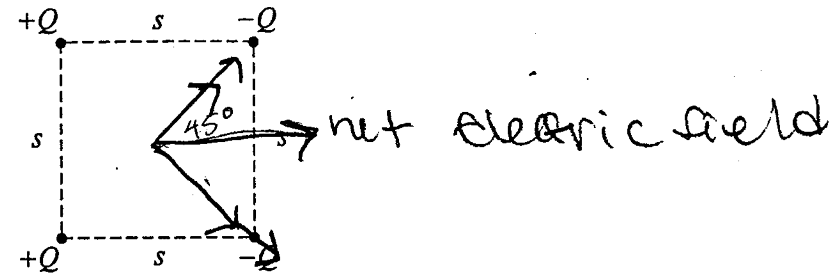
$$= \sum \frac{1}{4\pi\epsilon_0}\cdot\left[\left(\frac{-Q}{\frac{s\sqrt{2}}{2}}\right)\cdot 2 + \left(\frac{Q}{\frac{s\sqrt{2}}{2}}\right)2\right]$$

$$= 0$$

ii. The magnitude of the electric field at the center of the square



0. Since the electric field due to +Q and +Q cancel, and the electric field due to −Q and −Q cancel, the electric field is $\boxed{\text{zero}}$



Arrangement 2

The bottom two charged particles are now switched to form Arrangement 2, shown above, in which the positively charged particles are on the left and the negatively charged particles are on the right.

(b) For Arrangement 2, determine the following.

i. The electrostatic potential at the center of the square

$$V = \sum \frac{kQ}{r} \quad \Rightarrow r = \frac{s\sqrt{2}}{2}$$

$$= \sum k \cdot \left(\frac{+2Q}{r} + \frac{-2Q}{r}\right)$$

$$= 0$$

ii. The magnitude of the electric field at the center of the square

$$E = \frac{F}{q} = \left(2\frac{kQ}{r^2}\cos\theta\right)2 \qquad r = \frac{s\sqrt{2}}{2} \qquad \theta = 45°$$

$$= \frac{\cancel{4}^{2} kQ}{\left(\frac{s\sqrt{2}}{2}\right)^2} \cdot \frac{\sqrt{2}}{\cancel{2}} = \frac{\cancel{2}\sqrt{2}\, kQ}{s^2} \cdot \frac{4}{\cancel{2}}$$

$$= \boxed{4\sqrt{2}\, kQ / s^2}$$

(c) In which of the two arrangements would more work be required to remove the particle at the upper right corner from its present position to a distance a long way away from the arrangement?

✓ Arrangement 1 ___ Arrangement 2

Justify your answer.

Since the positive Q charges are closer to the −Q at the right corner for arrangement #1, they attract more. Also, −Q is farther too. These forces are more significant, so the external work to separate them is greater

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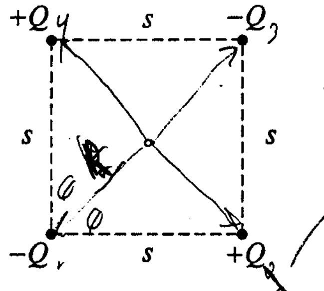

Arrangement 1

$$s^2 + s^2 = d^2$$
$$d^2 = 2s^2$$
$$d = \sqrt{2}\,s$$
$$R = \frac{\sqrt{2}\,s}{2}$$
$$\frac{d}{2} = R$$

3. (15 points)

Four charged particles are held fixed at the corners of a square of side s. All the charges have the same magnitude Q, but two are positive and two are negative. In Arrangement 1, shown above, charges of the same sign are at opposite corners. Express your answers to parts (a) and (b) in terms of the given quantities and fundamental constants.

(a) For Arrangement 1, determine the following.

i. The electrostatic potential at the center of the square

$$V = \frac{KQ_1}{R} + \frac{KQ_2}{R} + \frac{KQ_3}{R} + \frac{KQ_4}{R} = -\frac{KQ_1}{\frac{\sqrt{2}s}{2}} + \frac{KQ_2}{\frac{\sqrt{2}s}{2}} - \frac{KQ_3}{\frac{\sqrt{2}s}{2}} + \frac{KQ_4}{\frac{\sqrt{2}s}{2}} =$$

no vectors

$$-\frac{2KQ_1}{\sqrt{2}s} + \frac{2KQ_2}{\sqrt{2}s} - \frac{2KQ_3}{\sqrt{2}s} + \frac{2KQ_4}{\sqrt{2}s} = 0$$

ii. The magnitude of the electric field at the center of the square

vectors

$$E = \frac{KQ_1}{R^2} - \frac{KQ_2}{R^2} + \frac{KQ_3}{R^2} - \frac{KQ_4}{R^2} = 0$$

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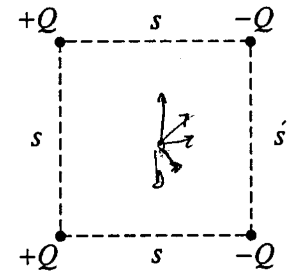

Arrangement 2

The bottom two charged particles are now switched to form Arrangement 2, shown above, in which the positively charged particles are on the left and the negatively charged particles are on the right.

(b) For Arrangement 2, determine the following.

same as a ii)

i. The electrostatic potential at the center of the square

$V = \frac{-2KQ}{\sqrt{2}s} + \frac{2KQ}{\sqrt{2}s} - \frac{2KQ}{\sqrt{2}s} + \frac{2KQ}{\sqrt{2}s} = 0$

ii. The magnitude of the electric field at the center of the square

$E = \frac{KQ}{r^2} = \frac{KQ}{\left(\frac{\sqrt{2}s}{2}\right)^2} + \frac{KQ}{\left(\frac{\sqrt{2}s}{2}\right)^2} + \frac{KQ}{\left(\frac{\sqrt{2}s}{2}\right)^2} + \frac{KQ}{\left(\frac{\sqrt{2}s}{2}\right)^2} = \frac{2KQ}{s^2} + \frac{2KQ}{s^2} + \frac{2KQ}{s^2} + \frac{2KQ}{s^2} = \frac{8KQ}{s^2}$ V

$r = \frac{\sqrt{2}s}{2}$

(c) In which of the two arrangements would more work be required to remove the particle at the upper right corner from its present position to a distance a long way away from the arrangement?

X Arrangement 1 ___ Arrangement 2

Justify your answer.

$W = U = \frac{KQ}{r}$

arr 1 $W = \frac{KQ}{s} + \frac{KQ}{s} - \frac{KQ}{\sqrt{2}s} = \frac{\sqrt{2}KQ}{\sqrt{2}s} + \frac{\sqrt{2}KQ}{\sqrt{2}s} - \frac{KQ}{\sqrt{2}s} = \frac{1.83KQ}{\sqrt{2}s}$ ← bigger U

arr 2 $W = \frac{KQ}{s} - \frac{KQ}{s} + \frac{KQ}{\sqrt{2}s} = \frac{\sqrt{2}KQ}{\sqrt{2}s} - \frac{\sqrt{2}KQ}{\sqrt{2}s} + \frac{KQ}{\sqrt{2}s} = \frac{KQ}{\sqrt{2}s}$

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