General Notes About 2006 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

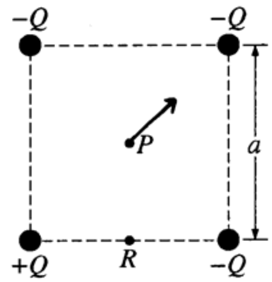
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m}/\text{s}^2$, but use of $10 \text{ m}/\text{s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 1

15 points total **Distribution of points**

(a) 1 point



For a single arrow pointing toward the upper-right negative charge — 1 point

(b)

(i) 3 points

The fields at point P due to the upper left and lower right negative charges are equal in magnitude and opposite in direction so they sum to zero.

The fields at point P due to the other two charges are equal in magnitude and in the same direction so they add.

For determining the distance between each charge and point P — 1 point

$r = \dfrac{a}{\sqrt{2}}$ OR $r^2 = \dfrac{1}{2}a^2$

For correctly summing the fields of the two contributing point charges — 1 point

$$E = 2\left(\frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}\right) = 2\frac{kQ}{r^2}$$

For substituting the distance relationship into an electric field relationship — 1 point

$$E = 2\left(\frac{1}{4\pi\epsilon_0}\frac{Q}{\left(a/\sqrt{2}\right)^2}\right) = 2\frac{kQ}{\left(a/\sqrt{2}\right)^2}$$

Note: Use of the equation above with all substitutions overtly included earned full credit.

$$E = \frac{Q}{\pi\epsilon_0 a^2} = \frac{4kQ}{a^2}$$

Note: Because of the use of the word "derive" in the question stem, no credit was awarded for a final answer equation with no supporting work.

Question 1 (continued)

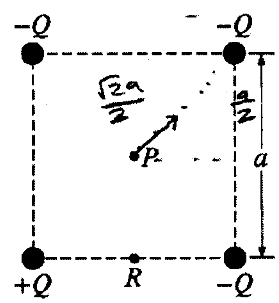
	Distribution of points
(b) (continued)	
(ii) 3 points	
For a correct expression for the potential of a point charge or charges which is subsequently applied	1 point
$V = \dfrac{1}{4\pi\epsilon_0}\sum_i \dfrac{q_i}{r_i} = k\sum_i \dfrac{q_i}{r_i}$	
For indicating the scalar sum of the four charges or potentials	1 point
$V = \dfrac{1}{4\pi\epsilon_0 r}(-Q - Q - Q + Q) = -\dfrac{2Q}{4\pi\epsilon_0 r} = -\dfrac{2kQ}{r}$	
For substituting the correct distance relationship into an electric potential relationship	1 point
$V = \dfrac{-2Q}{4\pi\epsilon_0\left(a/\sqrt{2}\right)} = \dfrac{-2kQ}{\left(a/\sqrt{2}\right)}$	
$V = -\dfrac{Q}{\sqrt{2}\pi\epsilon_0 a} = -\dfrac{2\sqrt{2}kQ}{a}$	
<u>Note</u>: *Because of use of the word "derive" in the question stem, 2 points were awarded for the final expression with no supporting work.*	
(c) 3 points	
For checking "Negative"	1 point
For relating the motion of the charge to either a field direction or the potential difference	2 points
Examples:	
The field is directed generally from R to P and the charge moves in the opposite direction. Thus, the field does negative work on the charge.	
The potential difference between P and R is positive and the charge moves through the positive potential difference. Thus, the field does negative work on the charge.	
<u>Notes</u>:	
Only indicating the direction of the field or sign of the potential difference without relating that to the charge motion earned 1 point.	
Any obviously incorrect statement within an otherwise correct answer resulted in a 1 point deduction. Examples: "The charges cancelled," or "The field is a scalar," or "The voltage is a vector."	

Question 1 (continued)

	Distribution of points
(d)	
(i) 2 points	
For replacing the top right negative charge with a positive charge OR replacing the bottom left positive charge with a negative charge	1 point
For an appropriate justification	1 point
Example:	
The vector fields/forces all cancel from oppositely located same charge pairs.	
<u>Note</u>: *Any obviously incorrect statement resulted in a 1 point deduction.*	
Examples: "The charges cancelled," or "The field is a scalar," or "The voltage is a vector."	
(ii) 3 points	
For replacing the top left negative charge with a positive charge OR replacing the bottom right negative charge with a positive charge	1 point
For an appropriate justification for zero electric potential	1 point
Example:	
The scalar potentials all cancel from equidistant located opposite charge pairs.	
For indicating the direction of the resultant nonzero field using words or diagram	1 point
<u>Note</u>: *Any obviously incorrect statement resulted in a 1 point deduction.*	
Examples: "The charges cancelled," or "The field is a scalar," or "The voltage is a vector."	

PHYSICS C: ELECTRICITY AND MAGNETISM
SECTION II
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.



E&M 1.

The square of side a above contains a positive point charge $+Q$ fixed at the lower left corner and negative point charges $-Q$ fixed at the other three corners of the square. Point P is located at the center of the square.

(a) On the diagram, indicate with an arrow the direction of the net electric field at point P.

(b) Derive expressions for each of the following in terms of the given quantities and fundamental constants.

i. The magnitude of the electric field at point P

$$E = \frac{kq}{r^2} \rightarrow E = \frac{2kQ}{\left(\frac{\sqrt{2}a}{2}\right)^2} = \frac{8kQ}{2a^2} = \frac{4kQ}{a^2}$$

upper left charge cancels lower right charge

ii. The electric potential at point P

$$V = \frac{kq}{r} \rightarrow V = 3\left(\frac{-kQ}{\frac{\sqrt{2}a}{2}}\right) + \frac{kQ}{\frac{\sqrt{2}a}{2}}$$

$$V = -\frac{6kQ}{\sqrt{2}a} + \frac{2kQ}{\sqrt{2}a}$$

$$= \frac{-4kQ}{\sqrt{2}a}$$

(c) A positive charge is placed at point P. It is then moved from point P to point R, which is at the midpoint of the bottom side of the square. As the charge is moved, is the work done on it by the electric field positive, negative, or zero?

____ Positive ✓ Negative ____ Zero

Explain your reasoning.

It will take work by an external foce to move the charge against the electric field so the field does negative work.

(d)

i. Describe one way to replace a single charge in this configuration that would make the electric field at the center of the square equal to zero. Justify your answer.

if the positive charge in the lower left were replared by a $-Q$ then the E field at the center would be zero since all the E vectors would cancel

ii. Describe one way to replace a single charge in this configuration such that the electric potential at the center of the square is zero but the electric field is not zero. Justify your answer.

replacing the charge in the upper left with a $+Q$ since V is the $\Sigma \frac{kq}{r}$, V would be zero but since E is a vector quantity the net E field would be to the right at point P

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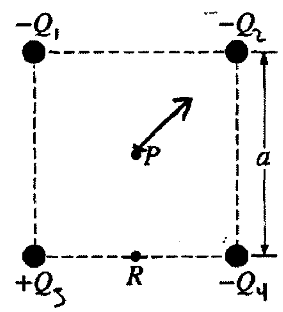

E&M 1.

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(a) On the diagram, indicate with an arrow the direction of the net electric field at point P.

(b) Derive expressions for each of the following in terms of the given quantities and fundamental constants.

i. The magnitude of the electric field at point P

$$E = \frac{KQ}{R^2}$$

$$E_p = \frac{K}{\left(\frac{\sqrt{2}\cdot a}{2}\right)^2}(Q+Q)$$

$$E_p = \frac{4K_eQ}{a^2}$$

ii. The electric potential at point P

$$V = \frac{KQ}{R}$$

$$V = K_e\frac{2Q}{\frac{\sqrt{2}\cdot a}{2}}$$

$$V = \frac{4K_eQ}{\sqrt{2}\cdot a}$$

(c) A positive charge is placed at point P. It is then moved from point P to point R, which is at the midpoint of the bottom side of the square. As the charge is moved, is the work done on it by the electric field positive, negative, or zero?

X Positive ____ Negative ____ Zero

Explain your reasoning.

Because the field is producing a force in the direction of the motion the work is positive.

(d)

i. Describe one way to replace a single charge in this configuration that would make the electric field at the center of the square equal to zero. Justify your answer.

Replace the top right charge with +Q b/c it would balance the +Q directly diagonal to it.

ii. Describe one way to replace a single charge in this configuration such that the electric potential at the center of the square is zero but the electric field is not zero. Justify your answer.

Replace the lower left with -Q b/c they are all negative there would be no potential difference between them.

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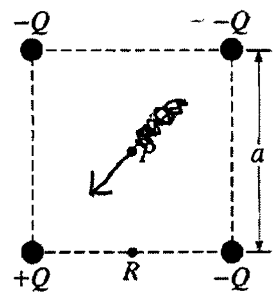

E&M 1.

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(a) On the diagram, indicate with an arrow the direction of the net electric field at point P.

(b) Derive expressions for each of the following in terms of the given quantities and fundamental constants.

i. The magnitude of the electric field at point P

$E = \frac{F}{q} = \frac{F}{1.60 \times 10^{-19}}$

ii. The electric potential at point P

$V = IR$

(c) A positive charge is placed at point P. It is then moved from point P to point R, which is at the midpoint of the bottom side of the square. As the charge is moved, is the work done on it by the electric field positive, negative, or zero?

____ Positive X Negative ____ Zero

Explain your reasoning.

$k = \frac{1}{4\pi\varepsilon_0}$

$W = \int F \cdot dr$

$\int k \frac{q_1 q_2}{r^2} \cos 180 \, dr$

$\int k \frac{-1.60 \times 10^{-19} \cdot 1.60 \times 10^{-19}}{r^2} (-1) \, dr$

cos 180 is negative • I

(d)

i. Describe one way to replace a single charge in this configuration that would make the electric field at the center of the square equal to zero. Justify your answer.

Replace the negative charge in the top right hand corner with a positive charge thus canceling all charge values.

ii. Describe one way to replace a single charge in this configuration such that the electric potential at the center of the square is zero but the electric field is not zero. Justify your answer.

Replace the positive charge with a negative charge and the electric field would still exist outside the box.

Question 1

Overview

This question explored student understanding of electric fields and electric potentials due to point charges, superposition of field vectors, and the scalar addition of potentials. Students were given four point charges (three negative and one positive) at the corners of a square. In part (a) students were asked to draw the direction of the net electric field at the center of the square. In part (b) they were asked to derive the magnitude of the electric field and the electric potential at the center of the square. For part (c) a positive charge was placed in the center of the four existing charges and then moved to the midpoint of the bottom side of the square. Students had to identify the work done on the moving charge by the field as positive, negative, or zero and explain their reasoning. In part (d)(i) students were asked to replace one of the existing charges in order to make the electric field at the center equal to zero. They had to describe the replacement and justify their answer. In part (d)(ii) students were asked to replace one of the existing charges in order to make the electric potential at the center equal to zero, yet have a nonzero electric field at that same point. They had to describe the replacement and justify their answer.

Sample: E1A
Score: 15

This clearly written response earned full credit on all the parts.

Sample: E1B
Score: 7

This response earned the 1 point for part (a) and 3 points for part (b)(i). In part (b)(ii) the student correctly determines the distance to be used and substitutes it into an expression for potential and thus earned 2 points. But the sign of the answer is incorrect, and it is not clear from the supporting work that all four charges were considered in the calculation, so the third point was not given. The remaining point was earned for the correct replacement of a charge in part (d)(i), but the justification point was not awarded for balancing charges instead of forces or vectors. No credit was given for the incorrect answers in parts (c) and (d)(ii).

Sample: E1C
Score: 3

No credit was given for part (a) because the field is in the wrong direction, and no credit was given in part (b) for the irrelevant work shown. Part (c) earned a point for indicating that the work was negative, but the justification was awarded 1 point only. Although the justification recognizes that the force is opposite to the displacement, 1 point was lost for the incorrect expression for the force in the integral and for the incorrect assumption that the magnitudes of the charges are equal to that of an electron. The remaining point was earned in part (d)(i) for the correct replacement of a charge, but the justification point was not awarded for canceling charge values instead of forces or vectors. No credit was given for the incorrect answer in part (d)(ii).