2017

AP® CollegeBoard

AP Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

- ☑ Free Response Question 4
- ☑ Scoring Guideline
- ☑ Student Samples
- ☑ Scoring Commentary

General Notes About 2017 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. The requirements that have been established for the paragraph length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. 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.

4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution embeds the application of that equation to the problem in other work, 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 exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.

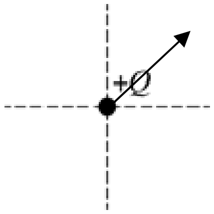
5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m}/\text{s}^2$, but use of $10 \text{ m}/\text{s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. 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 4

10 points total **Distribution of points**

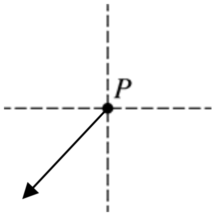
(a) 1 point



For an arrow pointing outward from the object, along a diagonal of the square and away from the object with charge $-2Q$, with no other arrows — 1 point

(b)

i. 3 points



For correctly determining magnitudes of the field from individual objects — 1 point

The fields from the $+2Q$ objects cancel. This can be implicit or explicit in the calculations.

For the $-2Q$ object, $E = 2kQ/d^2$

For the $+Q$ object, $E = kQ/d^2$

For correctly adding the individual fields — 1 point

$E = 3kQ/d^2$

For showing the correct direction on the diagram, along a diagonal of the square and toward the object with charge $-2Q$ — 1 point

ii. 1 point

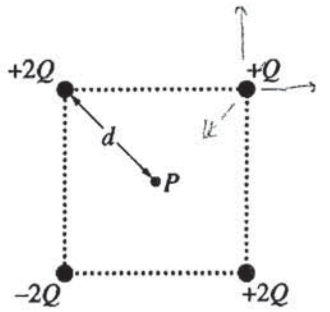
For showing a correct scalar potential summation — 1 point

A final answer is not required; however, no credit is given if an incorrect final answer is included.

$V = (k/d)(+2Q + Q + 2Q - 2Q) = 3kQ/d$

(c) 5 points

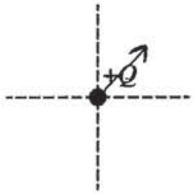
	Distribution of points
For indicating that electric potential energy is the energy stored in a configuration of charged objects	1 point
For indicating that the change in potential energy is equal to the work done by an external force to create a particular configuration	1 point
For indicating that moving the object with $+2Q$ charge results in an increase in energy and indicating that moving the object with $+Q$ charge results in a decrease in energy (i.e., for showing understanding that moving charges of the same sign closer together increases the energy and/or moving charges of opposite sign closer together decreases the energy, with some support such as $U = kqQ/r$ or a description of doing work against forces)	1 point
For indicating that the net result is an increase in the energy with some explanation	1 point
For a logical, relevant, and internally consistent response that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response	1 point



4. (10 points, suggested time 20 minutes)

The figure above represents four objects, with charges as shown, that are held in place at the corners of a square. Point *P* is at the center of the square, a distance *d* from each of the objects. Express all algebraic answers to the following in terms of *Q*, *d*, and physical constants.

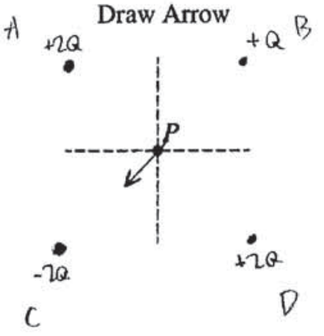
(a) On the dot below, draw an arrow that represents the direction of the net electric force exerted on the object with charge +*Q* by the other three objects.



(b)

i. Calculate the magnitude of the electric field at point *P* due to all four objects. On the dot below, draw an arrow to indicate the direction of the net field at point *P*.

Draw Arrow



Calculate Electric Field

$E = \frac{kQ}{d^2} + \frac{k(2Q)}{d^2}$

A and D are equal magnitude and opposite direction

$E = \frac{k3Q}{d^2}$

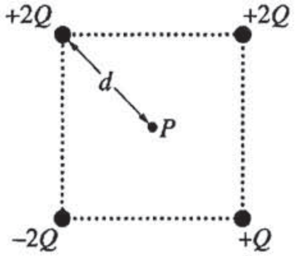
ii. Calculate the electric potential at point *P* due to all four objects.

$V = \frac{kQ}{d} + \frac{k(2Q)}{d} + \cancel{\frac{k(2Q)}{d}} + \cancel{\frac{k(-2Q)}{d}}$

$V = \frac{k3Q}{d}$

GO ON TO THE NEXT PAGE.

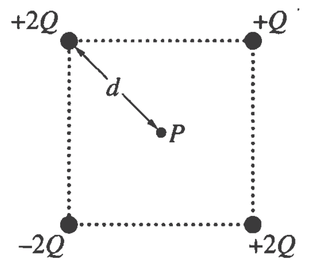
(c) In a coherent, paragraph-length response, briefly describe the meaning of electric potential energy and explain qualitatively how electric potential energy can be related to work. Also explain qualitatively how the electric potential energy of the four-object system would change if the $+Q$ and $+2Q$ objects on the right side of the square now switch positions as shown in the figure below. Support your explanation using appropriate physics principles.



Electric potential energy is the energy stored when charges are held stationery near each other. The charges can be released to attract or repel each other, thus doing work. If the +Q and +2Q charges on the right side were switched, the potential energy of the system would increased because both the +2Q charges would be opposite to each other. They could have stronger attraction to the −2Q charge and stronger repulsion to the −Q charge. If the weren't switched, only the repulsion between the +2Q charges would be stronger.

GO ON TO THE NEXT PAGE.

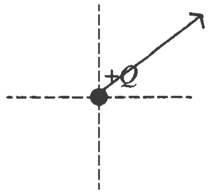
P2 Q4 B1



4. (10 points, suggested time 20 minutes)

The figure above represents four objects, with charges as shown, that are held in place at the corners of a square. Point *P* is at the center of the square, a distance *d* from each of the objects. Express all algebraic answers to the following in terms of *Q*, *d*, and physical constants.

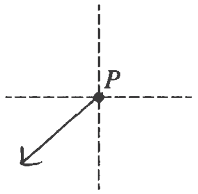
(a) On the dot below, draw an arrow that represents the direction of the net electric force exerted on the object with charge +*Q* by the other three objects.



(b)

i. Calculate the magnitude of the electric field at point *P* due to all four objects. On the dot below, draw an arrow to indicate the direction of the net field at point *P*.

Draw Arrow



Calculate Electric Field

$E = \frac{kq}{r^2}$

$E_P = \frac{KQ}{d^2} + 2\left(\frac{K2Q}{d^2}\right) + \frac{-K2Q}{d^2}$

$E_P = \frac{KQ}{d^2} + 4 \cdot \frac{KQ}{d^2} - 2 \cdot \frac{KQ}{d^2}$

$\boxed{E_P = \frac{3KQ}{d^2}}$

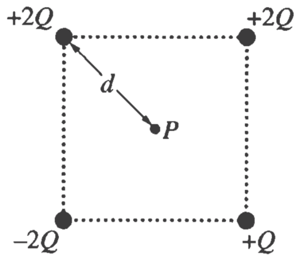
ii. Calculate the electric potential at point *P* due to all four objects.

$E = \frac{V}{d}$

$V = E \cdot d = \frac{3KQ}{d^2} \cdot d$

$\boxed{V = \frac{3KQ}{d}}$

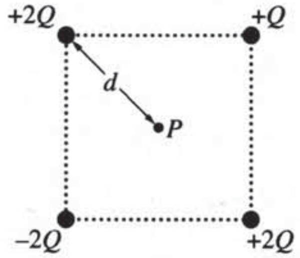
(c) In a coherent, paragraph-length response, briefly describe the meaning of electric potential energy and explain qualitatively how electric potential energy can be related to work. Also explain qualitatively how the electric potential energy of the four-object system would change if the $+Q$ and $+2Q$ objects on the right side of the square now switch positions as shown in the figure below. Support your explanation using appropriate physics principles.



Electric potential energy is the energy required to move a charge from the point where the potential is zero to a different point. This is explained by the Formula $U_E = qV$. This can be related to work in that the electric potential energy is the required amount of work needed to be done on the object to move it from its original position to the new point.

The electric potential energy would change if charges switched positions as shown because the net field would point differently at Point P.

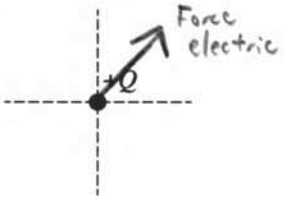
P2 Q4 C1



4. (10 points, suggested time 20 minutes)

The figure above represents four objects, with charges as shown, that are held in place at the corners of a square. Point *P* is at the center of the square, a distance *d* from each of the objects. Express all algebraic answers to the following in terms of *Q*, *d*, and physical constants.

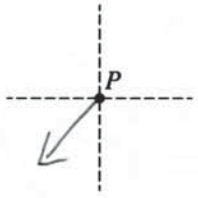
(a) On the dot below, draw an arrow that represents the direction of the net electric force exerted on the object with charge +*Q* by the other three objects.



(b)

i. Calculate the magnitude of the electric field at point *P* due to all four objects. On the dot below, draw an arrow to indicate the direction of the net field at point *P*.

Draw Arrow



Calculate Electric Field

$$|\vec{E}| = \frac{k|q|}{r^2}$$

$$\boxed{\vec{E} = \frac{9\times10^9\ N\cdot m^2/c^2}{d^2}}$$

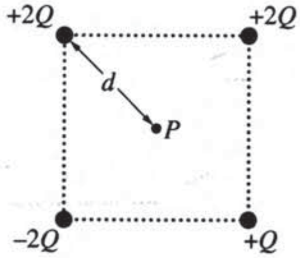
ii. Calculate the electric potential at point *P* due to all four objects.

$$V = \frac{kq}{r}$$

$$V = k\left(\frac{2}{d} + \frac{2}{d} + \frac{1}{d} - \frac{2}{d}\right) = \boxed{\frac{3k}{d}}$$

P2 Q4 C2

(c) In a coherent, paragraph-length response, briefly describe the meaning of electric potential energy and explain qualitatively how electric potential energy can be related to work. Also explain qualitatively how the electric potential energy of the four-object system would change if the $+Q$ and $+2Q$ objects on the right side of the square now switch positions as shown in the figure below. Support your explanation using appropriate physics principles.



The valve of the electric potential of the system would become more positive due to the two +2Q charges no longer being able to cancel each other out. Electric potential energy is the total sum of electric charge forces exerted on a particular point. This force is directly related to work if the value of the charges /electric potential result in anytype of work being done, such as motion or decelleration.

AP® PHYSICS 2
2017 SCORING COMMENTARY

Question 4

Overview

This question assessed learning objectives 2.C.4.2, 3.C.2.3, 5.B.2.1, 5.B.4.1, and 5.B.4.2.
The responses to this question were expected to demonstrate the following:

- Demonstrate the ability to correctly sum vectors in the form of multiple electrostatic forces.
- Understanding how the fields from individual charges contribute to an overall electric field (through calculation).
- Understanding how to properly combine vector quantities in two dimensions (for the electric field) and scalar quantities (for the potential difference).
- Understanding that forces are applied to objects (in this case, charged particles), while potentials and fields are evaluated at specific locations (with or without objects there).
- Understanding that electric potential energy cannot simply be stored in a single charge, or just in an electric field by itself, but instead that the energy is stored within a system, due to multiple charges, or due to a charge moved through a potential difference.
- Understanding that in order to change the internal energy of a system, work must be done by an external force, so external forces were used to place the charges in their current arrangement, giving the system that amount of electric potential energy.
- Understanding the difference between electric potential at a certain point within a system, and the electric potential *energy* of the system as a whole, and recognizing that rearranging the charges requires work.

Sample: P2 Q4 A
Score: 9

Parts (a) and (b) earned full credit of 5 points. Part (b) has an explicit indication of the cancellation of fields from the $+2Q$ charges. The response also clearly shows the summation of the potentials. Part (c) earned 4 out of 5 points because the effect of the switch of charges is explained with forces and not with electric potential energy.

Sample: P2 Q4 B
Score: 6

Part (a) earned 1 point for a correctly drawn net electric force arrow. In part (b)(i) the electric field arrow and the magnitudes of the individual fields are correct, but the individual fields are added as scalars instead of vectors, so 2 points were earned. The response in part (b)(ii) treats the electric field as a uniform field in the method used to calculate the potential difference at a distance d away and earned no points. Part (c) earned 3 points for a good description of electric potential energy, for the relationship between electric potential energy and work, and for writing a coherent paragraph.

Sample: P2 Q4 C
Score: 3

Part (a) earned 1 point for a correctly drawn net electric force arrow. Part (b) also has a correctly drawn electric field arrow and earned 1 point. There is no attempt to add the fields of the particles, and the electric potential calculation is missing the charge variable. In part (c) 1 point was earned for writing a paragraph response related to the situation. The response indicates that the electric potential, not potential energy, increases, and it does not include any other correct statement.