2023

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 4

- ☑ Scoring Guidelines
- ☑ Student Samples
- ☑ Scoring Commentary

Question 4: Short Answer Paragraph Argument — 10 points

(a)	For an evaluation of Student Y 's statement that correctly includes the vector nature of electric field	**1 point**
	For indicating that Student Y should have stated that the third particle must have charge $+Q$ for the electric field at Point P to be zero **OR** For a statement indicating what the resultant magnitude of the electric field at Point P would be for a particle with charge $+2Q$	**1 point**
	For an evaluation of Student Z 's statement that correctly includes the scalar nature of electric potential	**1 point**
	For indicating that zero electric potential at Point P would require the third particle having charge $-2Q$	**1 point**
	For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response	**1 point**

Example Response

Student Y is incorrect. Before the third particle is placed at the bottom-right vertex, the electric field from particles A and B at Point P is down and to the right. The electric field from a positively charged particle placed at the bottom-right vertex is up and to the left. The third particle needs to have charge $+Q$, rather than $+2Q$, in order to have the correct magnitude to make the resultant field zero at Point P.

Student Z is incorrect. Before the third particle is placed at the bottom-right vertex, the value of the electric potential at Point P is positive. Because Point P is equidistant from all three particles, the electric potential at Point P is proportional to the total charge of the system. If the total charge of the system is zero, the electric potential at Point P will be zero. This requires the third particle to have charge $-2Q$.

OR

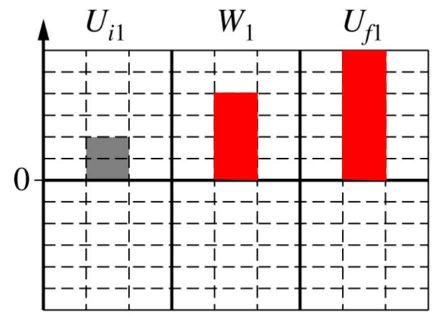
Student Y is incorrect that a particle with charge $+2Q$ placed at the bottom-right vertex will result in no electric field at Point P. The horizontal component of the electric field from Particle A is less than the horizontal component of the electric field from the particle with charge $+2Q$. The sum of the vertical components of the fields from particles A and B is less than the vertical component of the field from the particle with charge $+2Q$. Therefore, the resulting electric field at Point P is nonzero and points in a direction between particles A and B.

Student Z is incorrect. Before the third particle is placed at the bottom-right vertex, the value of the electric potential at Point P is positive. Electric potential is a scalar quantity, so if the third particle has charge $-2Q$ rather than $-Q$, the electric potential at Point P will be zero.

Total for part (a) — 5 points

(b)(i)	For drawing a bar on the grid that shows a positive value for W_1	**1 point**
	For drawing a bar on the grid that shows $U_{f1} = 3U_{i1}$	**1 point**
	For drawing bars on the grid so that the work done on the system is equal to the change in energy, $U_{i1} + W_1 = U_{f1}$	**1 point**

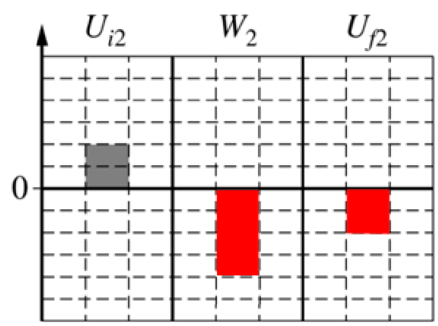
Example Response



Scenario 1

(b)(ii)	For drawing a bar on the grid that shows $U_{f2} = -U_{i2}$	**1 point**
	For drawing a bar on the grid that shows a negative value of W_2 so that the work done on the system is equal to the change in energy $U_{i2} + W_2 = U_{f2}$	**1 point**

Example Response



Scenario 2

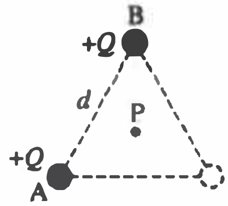
Total for part (b) 5 points

Total for question 4 10 points

Question 4

Begin your response to QUESTION 4 on this page.

$\frac{\sqrt{3}}{2}$



4. (10 points, suggested time 20 minutes)

Particles A and B each have positive charge $+Q$ and are held fixed at two vertices of an equilateral triangle of side length d, as shown. Point P is located equidistant from each vertex of the triangle.

Students Y and Z discuss the electric field and the electric potential at Point P after a third charged particle is placed at the bottom-right vertex. The students make the following statements.

Student Y: "If a particle with positive charge $+2Q$ is placed at the bottom-right vertex, the magnitude of the electric field will be zero at Point P."

Student Z: "To make the value of the electric potential zero at Point P, a particle with negative charge $-Q$ should be placed at the bottom-right vertex."

(a) In a coherent, paragraph-length response, evaluate the accuracy of each student's statement. If any aspect of either student's statement is inaccurate, explain how to correct the student's statement. Support your evaluations using appropriate physics principles.

Student Y's statement is incorrect, to make the electric field at P 0, we should instead place a particle w/ +Q charge. Because w/ a particle w/ +Q charge at the third vertexe, a particle @ P would experice 3 electric force in such configuration, which would cancel ~~e~~/o out and give P an electric field of 0.

Student Z's stantment is incorrect, to make the electric potential at P 0, we should instead place a particle w/ −2Q charge. Because the current V at P is $2 \cdot \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q}{\frac{2}{\sqrt{3}}d}$, The only way to negotive this V is by placing a charge of −2Q, which changes the V by $\frac{1}{4\pi\varepsilon_0} \cdot \frac{-2Q}{\frac{2}{\sqrt{3}}d}$. giving a ΣV of 0.

Question 4

Continue your response to **QUESTION 4** on this page.

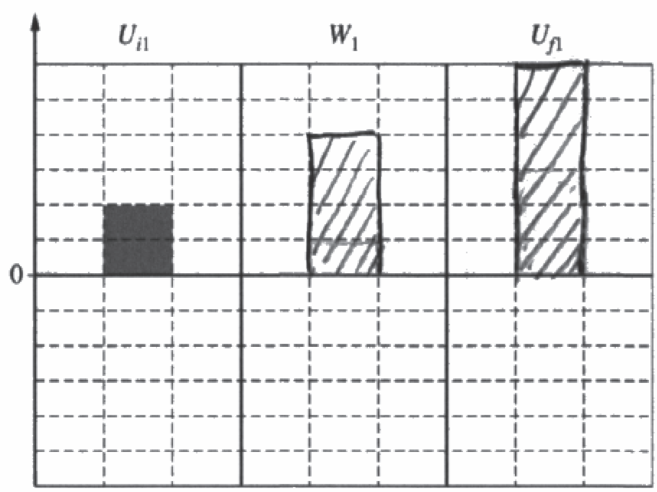
(b) Particles A and B are once again held in place at two vertices of the equilateral triangle. The students want to represent the electric potential energy of a system of particles when a third charged particle is brought from very far away to the bottom-right vertex. Scenarios 1 and 2 are considered.

i. In Scenario 1, a third particle with positive charge $+Q$ is moved from very far away to the bottom-right vertex and then held in place. A bar is shown on the following chart that represents the electric potential energy U_{i1} of the system consisting of all three particles when the third particle with positive charge is very far away from the other particles.

In the grid provided, complete the bar chart.

- Draw a bar to represent the work W_1 required to move the third particle with positive charge from very far away to the bottom-right vertex.
- Draw another bar to represent the electric potential energy U_{f1} of the system consisting of all three particles when the third particle with positive charge is held in place at the bottom-right vertex.

The height of each bar should be proportional to the energy represented. If the quantity is zero, write a "0" in that column.



Scenario 1

Question 4

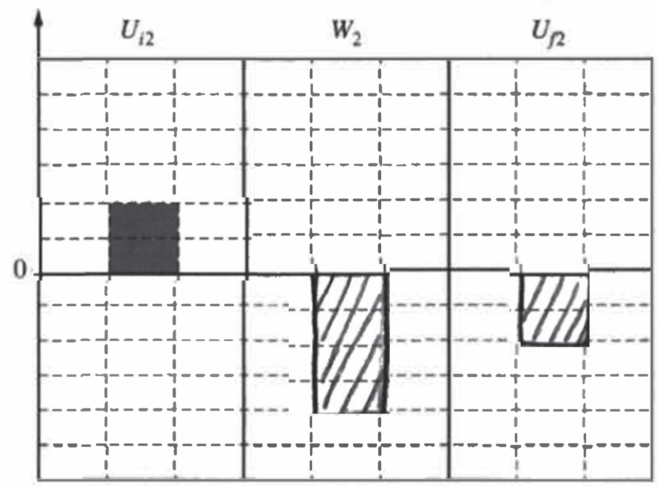
Continue your response to QUESTION 4 on this page.

ii. In Scenario 2, a particle with negative charge $-Q$ is moved from very far away to the bottom-right vertex and then held in place. A bar is shown on the following chart that represents the electric potential energy U_{i2} of the system consisting of all three particles when the particle with negative charge is very far away from the other particles.

In the grid provided, complete the bar chart.

- Draw a bar to represent the work W_2 required to move the particle with negative charge from very far away to the bottom-right vertex.
- Draw another bar to represent the electric potential energy U_{f2} of the system consisting of all three particles when the particle with negative charge is held in place at the bottom-right vertex.

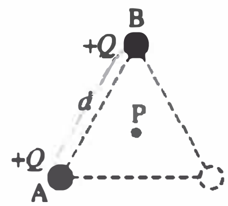
The height of each bar should be proportional to the energy represented. If the quantity is zero, write a "0" in that column.



Scenario 2

Question 4

Begin your response to QUESTION 4 on this page.



4. (10 points, suggested time 20 minutes)

Particles A and B each have positive charge $+Q$ and are held fixed at two vertices of an equilateral triangle of side length d, as shown. Point P is located equidistant from each vertex of the triangle.

Students Y and Z discuss the electric field and the electric potential at Point P after a third charged particle is placed at the bottom-right vertex. The students make the following statements.

Student Y: "If a particle with positive charge $+2Q$ is placed at the bottom-right vertex, the magnitude of the electric field will be zero at Point P."

Student Z: "To make the value of the electric potential zero at Point P, a particle with negative charge $-Q$ should be placed at the bottom-right vertex."

(a) In a coherent, paragraph-length response, evaluate the accuracy of each student's statement. If any aspect of either student's statement is inaccurate, explain how to correct the student's statement. Support your evaluations using appropriate physics principles.

The charge would have to be $-2Q$. Student Y was correct about the charge being $2Q$ but it would have to be negative. Student Z understood it was a negative charge but not the magnitude of $2Q$. The goal is to get the charges to sum up to 0 because the charges would have to sum up to 0 to have an electric potential and field of 0 so the charge would have to be $-2Q$ because $E = \frac{F_e}{q}$ and $\Delta V = \frac{\Delta U_e}{q}$

Electric Field $= \frac{F_e}{q}$

GO ON TO THE NEXT PAGE.

Question 4

Continue your response to QUESTION 4 on this page.

(b) Particles A and B are once again held in place at two vertices of the equilateral triangle. The students want to represent the electric potential energy of a system of particles when a third charged particle is brought from very far away to the bottom-right vertex. Scenarios 1 and 2 are considered.

i. In Scenario 1, a third particle with positive charge $+Q$ is moved from very far away to the bottom-right vertex and then held in place. A bar is shown on the following chart that represents the electric potential energy U_{i1} of the system consisting of all three particles when the third particle with positive charge is very far away from the other particles.

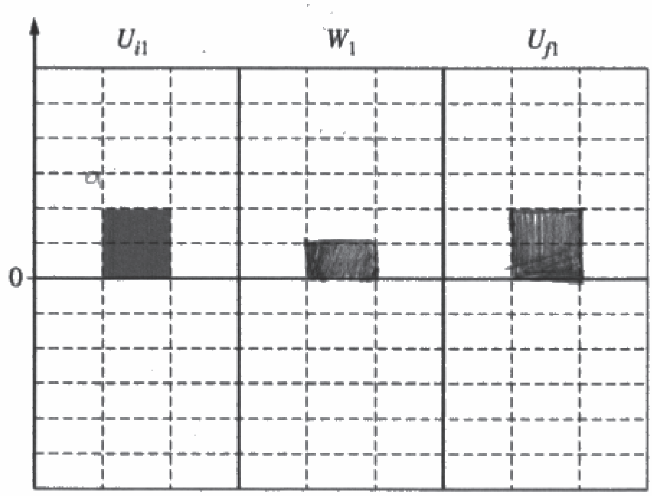
In the grid provided, complete the bar chart.

- Draw a bar to represent the work W_1 required to move the third particle with positive charge from very far away to the bottom-right vertex.
- Draw another bar to represent the electric potential energy U_{f1} of the system consisting of all three particles when the third particle with positive charge is held in place at the bottom-right vertex.

The height of each bar should be proportional to the energy represented. If the quantity is zero, write a "0" in that column.

$W = F \cdot d = Eqd$

$\frac{1}{2} q \epsilon$



Scenario 1

$U = qV$

Question 4

Continue your response to **QUESTION 4** on this page.

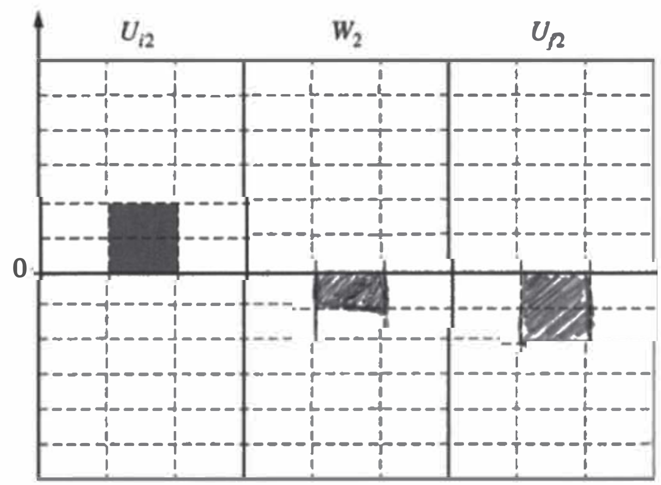
ii. In Scenario 2, a particle with negative charge $-Q$ is moved from very far away to the bottom-right vertex and then held in place. A bar is shown on the following chart that represents the electric potential energy U_{i2} of the system consisting of all three particles when the particle with negative charge is very far away from the other particles.

In the grid provided, complete the bar chart.

- Draw a bar to represent the work W_2 required to move the particle with negative charge from very far away to the bottom-right vertex.
- Draw another bar to represent the electric potential energy U_{f2} of the system consisting of all three particles when the particle with negative charge is held in place at the bottom-right vertex.

The height of each bar should be proportional to the energy represented. If the quantity is zero, write a "0" in that column.

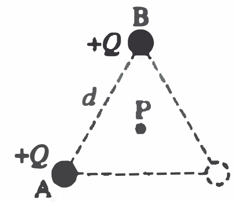
$U = W + Q$



Scenario 2

Question 4

Begin your response to QUESTION 4 on this page.



4. (10 points, suggested time 20 minutes)

Particles A and B each have positive charge $+Q$ and are held fixed at two vertices of an equilateral triangle of side length d, as shown. Point P is located equidistant from each vertex of the triangle.

Students Y and Z discuss the electric field and the electric potential at Point P after a third charged particle is placed at the bottom-right vertex. The students make the following statements.

Student Y: "If a particle with positive charge $+2Q$ is placed at the bottom-right vertex, the magnitude of the electric field will be zero at Point P."

Student Z: "To make the value of the electric potential zero at Point P, a particle with negative charge $-Q$ should be placed at the bottom-right vertex."

(a) In a coherent, paragraph-length response, evaluate the accuracy of each student's statement. If any aspect of either student's statement is inaccurate, explain how to correct the student's statement. Support your evaluations using appropriate physics principles.

Y: If the charge at the bottom right vertex was negative, point P would be zero

Z: the charge at the bottom needs to be a stronger negative charge to make point P zero

Question 4

Continue your response to **QUESTION 4** on this page.

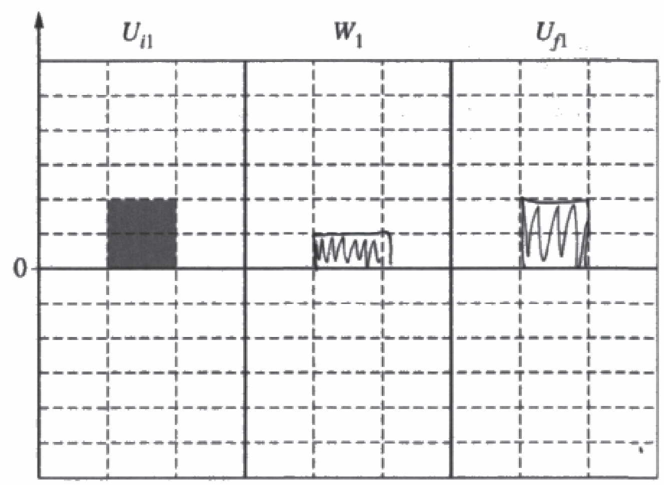
(b) Particles A and B are once again held in place at two vertices of the equilateral triangle. The students want to represent the electric potential energy of a system of particles when a third charged particle is brought from very far away to the bottom-right vertex. Scenarios 1 and 2 are considered.

i. In Scenario 1, a third particle with positive charge $+Q$ is moved from very far away to the bottom-right vertex and then held in place. A bar is shown on the following chart that represents the electric potential energy U_{i1} of the system consisting of all three particles when the third particle with positive charge is very far away from the other particles.

In the grid provided, complete the bar chart.

- Draw a bar to represent the work W_1 required to move the third particle with positive charge from very far away to the bottom-right vertex.
- Draw another bar to represent the electric potential energy U_{f1} of the system consisting of all three particles when the third particle with positive charge is held in place at the bottom-right vertex.

The height of each bar should be proportional to the energy represented. If the quantity is zero, write a "0" in that column.



Scenario 1

Question 4

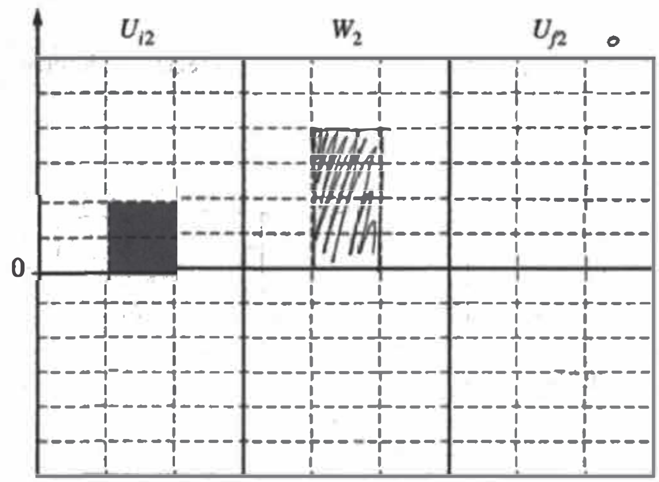
Continue your response to QUESTION 4 on this page.

ii. In Scenario 2, a particle with negative charge $-Q$ is moved from very far away to the bottom-right vertex and then held in place. A bar is shown on the following chart that represents the electric potential energy U_{i2} of the system consisting of all three particles when the particle with negative charge is very far away from the other particles.

In the grid provided, complete the bar chart.

- Draw a bar to represent the work W_2 required to move the particle with negative charge from very far away to the bottom-right vertex.
- Draw another bar to represent the electric potential energy U_{f2} of the system consisting of all three particles when the particle with negative charge is held in place at the bottom-right vertex.

The height of each bar should be proportional to the energy represented. If the quantity is zero, write a "0" in that column.



Scenario 2

Question 4

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses to this question were expected to demonstrate the ability to:

- Identify the relationship between a symmetrical distribution of charged particles and the types of charged particles to find the resulting electric field at the center of that particle distribution.
- Identify the relationship between the types of charged particles and their arrangement to find the electrical potential at the center of that particle distribution.
- Evaluate and critique the accuracy of a given statement through a concise, logical argument, using correct and appropriate physics.
- Represent the work required to move particles with positive and negative charges from very far away to the center of a particle distribution using bar charts.
- Represent the potential energy of a system of positively and negatively charged particles using a bar chart.

Sample: 4A
Score: 10

Part (a) earned 5 points. The first point was earned for correctly indicating the vector nature of the electric field. The second point was earned for correcting Student Y 's statement. The response correctly identifies that a particle of charge $+Q$ placed at the bottom-right vertex will create an electric field contribution at Point P that cancels the contributions to the field from the particles at points A and B and, thus, the electric field at Point P will be zero. Although the response shows force cancellation, the response relates the force on a particle placed at Point P with the electric field at P. The third point was earned for correctly referring to the scalar nature of electric potential shown by the use of the equation for the electric potential at Point P due to the two particles at points A and B. The fourth point was earned for correctly stating that placing a particle of charge $-2Q$ at the vertex would create an electric potential of zero at Point P. The fifth point was earned for a logical, relevant, and internally consistent paragraph-length response. Part (b) earned 5 points. The first point was earned for showing a bar in the positive region of the grid indicating that W_1 is a positive quantity. The second point was earned for showing a bar indicating U_{f1} is three times the size of U_{i1}, such that $U_{f1} = 3U_{i1}$. The third point was earned for showing a bar indicating that U_{f1} is the sum of W_1 and U_{i1}, so that $U_{i1} + W_1 = U_{f1}$. The fourth point was earned for showing a bar indicating that U_{f2} is equal but opposite in sign to U_{i2}, such that $U_{f2} = -U_{i2}$. The fifth point was earned for showing a bar in the negative region of the grid indicating that W_2 is a negative quantity AND the bar drawn for U_{f2} is the sum of U_{i2}, so that $U_{i2} + W_2 = U_{f2}$.

Question 4 (continued)

Sample: 4B
Score: 5

Part (a) earned 3 points. The first point was not earned because the response does not correctly indicate the vector nature of the electric field. The second point was not earned because the response makes no statement about changing the charge of the particle to $+Q$ in order for the electric field at Point P to be zero. Additionally, the response does not describe that adding a particle of charge $+2Q$ at the bottom-right vertex would have created an electric field at Point P that is directed toward the top left of the page. The third point was earned for indicating the scalar nature of electric potential by discussing the proportionality between the sum of charges and the net electric potential. The fourth point was earned for correctly stating that placing a particle of charge $-2Q$ at the vertex would create an electric potential of zero at Point P. The fifth point was earned for a logical, relevant, and internally consistent paragraph-length response. Part (b) earned 2 points. The first point was earned for correctly showing a bar drawn on the grid that represents positive W_1. The second point was not earned because the response shows an incorrectly sized bar for U_{f1}. The third point was not earned because the response shows a bar for W_1 and for U_{f1}, such that $U_{i1} + W_1 \neq U_{f1}$. The fourth point was earned for correctly showing a bar drawn on the grid that represents $U_{f2} = -U_{i2}$. The fifth point was not earned because the response does show a negative bar drawn on the grid for W_2, but the response does not show bars that correctly represent $U_{i2} + W_2 = U_{f2}$. For the point to be earned, both parts of the response must be correct.

Sample: 4C
Score: 1

Part (a) earned no points. The first point was not earned because the response does not correctly indicate the vector nature of the electric field. The second point was not earned because the response incorrectly states that the charge of the particle would need to be negative in order for the electric field at Point P to be zero. The third point was not earned because the response makes no reference to electric potential. The fourth point was not earned because, although the response states that a “stronger negative charge” is needed to make the electric potential zero, the response does not say that the value would need to be $-2Q$. The fifth point was not earned because there is not a logical, relevant, or internally consistent paragraph-length response. Part (b) earned 1 point for correctly showing a bar drawn on the grid that represents a positive W_1. The second point was not earned because the response incorrectly shows that $U_{f1} = U_{i1}$. The third point was not earned because the response shows a bar for work W_1 and a bar for U_{f1}, such that $U_{i1} + W_1 = U_{f1}$. The fourth point was not earned because the response shows a value of zero for U_{f2}. The fifth point was not earned because the response incorrectly shows a positive value drawn on the grid for W_2.