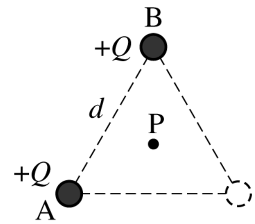
Begin your response to **QUESTION 4** on this page.



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.

GO ON TO THE NEXT PAGE.

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

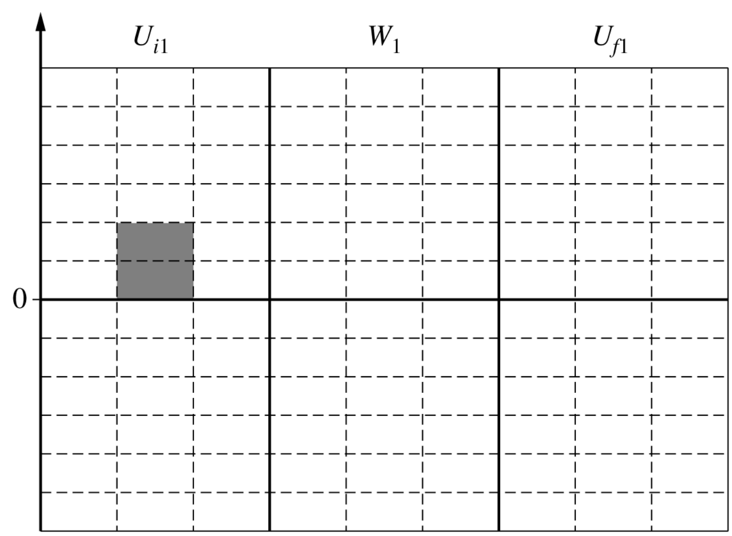
(b) Particles A and B are once again held in place at two vertices of the equilateral triangle. The students want to represent the electric potential energy of a system of particles when a third charged particle is brought from very far away to the bottom-right vertex. Scenarios 1 and 2 are considered.

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

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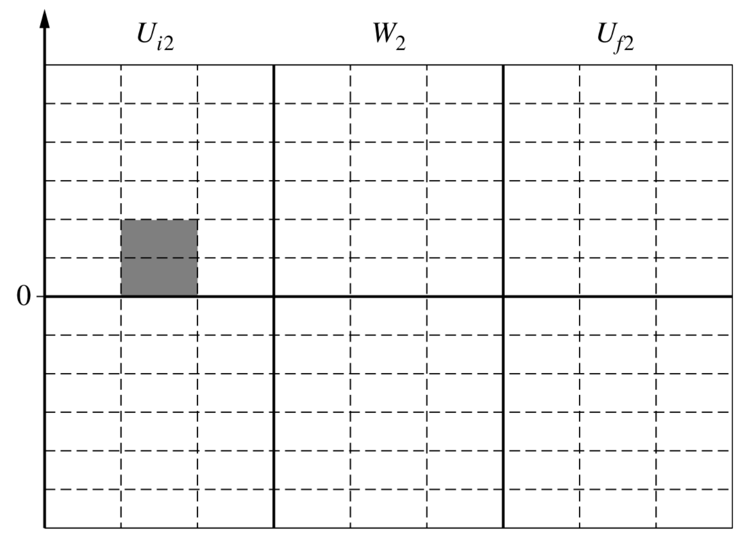
Continue your response to **QUESTION 4** on this page.

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

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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

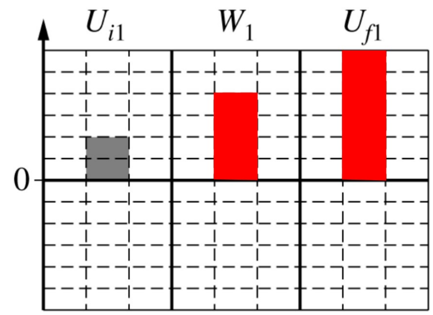
Student Y is incorrect that a particle with charge $+2Q$ placed at the bottom-right vertex will result in no electric field at Point P. The horizontal component of the electric field from Particle A is less than the horizontal component of the electric field from the particle with charge $+2Q$. The sum 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**

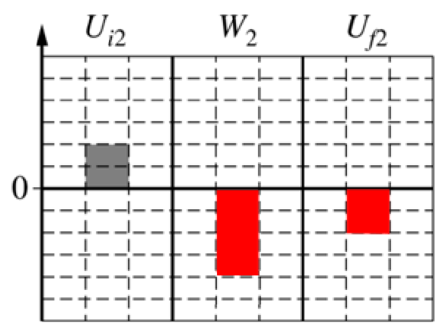
Example Response



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