AP® PHYSICS B
2010 SCORING GUIDELINES

General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the 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 — for example, 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 Exams 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 Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\text{ m/s}^2$, but use of 10 m/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.

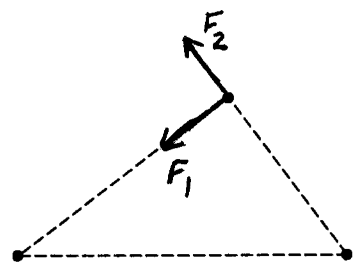
Question 3

10 points total | **Distribution of points**

(a) 1 point

For an indication that q_1 is negative and q_2 is positive — 1 point

(b) 2 points



For force $\mathbf{F}_1$ drawn and labeled correctly — 1 point

For force $\mathbf{F}_2$ drawn and labeled correctly — 1 point

Notes: The force vectors must either originate or terminate on q_3.
Forces on other particles are ignored.

(c) 3 points

For a correct statement or use of Coulomb's law — 1 point

Applying Coulomb's law to determine the magnitude of the forces $\mathbf{F}_1$ and $\mathbf{F}_2$:

$$F_1 = \frac{kq_1q_3}{r_{13}^{\ 2}} = \frac{\left(9\times10^9\ \mathrm{N\bullet m^2/C^2}\right)\left(4.0\times10^{-6}\ \mathrm{C}\right)\left(1.0\times10^{-6}\ \mathrm{C}\right)}{(4.0\ \mathrm{m})^2} = 2.25\times10^{-3}\ \mathrm{N}$$

$$F_2 = \frac{kq_2q_3}{r_{23}^{\ 2}} = \frac{\left(9\times10^9\ \mathrm{N\bullet m^2/C^2}\right)\left(1.7\times10^{-6}\ \mathrm{C}\right)\left(1.0\times10^{-6}\ \mathrm{C}\right)}{(3.0\ \mathrm{m})^2} = 1.70\times10^{-3}\ \mathrm{N}$$

For any indication that $\mathbf{F}$ is the vector sum of the two forces: $\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2$ — 1 point

Since $\mathbf{F}_1$ and $\mathbf{F}_2$ are at right angles to each other, the magnitude can be found using the Pythagorean theorem.

$$F = \sqrt{F_1^{\ 2} + F_2^{\ 2}} = \sqrt{\left(2.25\times10^{-3}\ \mathrm{N}\right)^2 + \left(1.70\times10^{-3}\ \mathrm{N}\right)^2}$$

Alternate solution: The y components cancel, so the magnitude of **F** *is the sum of the x components.*

$$F = F_{1x} + F_{2x} = F_1\cos37^\circ + F_2\cos53^\circ$$

$$F = \left(2.25\times10^{-3}\ \mathrm{N}\right)\cos37^\circ + \left(1.70\times10^{-3}\ \mathrm{N}\right)\cos53^\circ$$

$$F = 1.8\times10^{-3}\ \mathrm{N} + 1.0\times10^{-3}\ \mathrm{N}$$

For the correct answer with units — 1 point

$$F = 2.8\times10^{-3}\ \mathrm{N}$$

Question 3 (continued)

Distribution of points

(d) 2 points

For substituting the value of F from part (c) and using the correct value for q_3 — 1 point

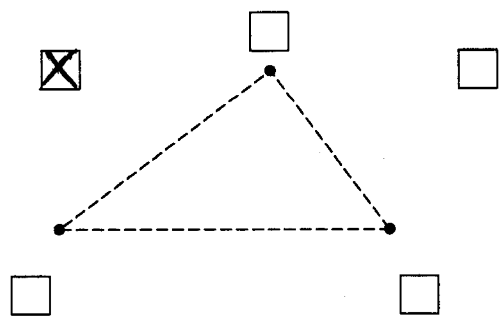
$$E = \frac{F}{q_3} = \frac{2.8 \times 10^{-3}\ \text{N}}{1.0 \times 10^{-6}\ \text{C}}$$

This point could also be earned for substituting F_1 and F_2 from part (c) into $E = F/q_3$ and then calculating the magnitude of the vector sum, or calculating E_1 and E_2 from $E = kq/r^2$ with correct q's and r's and then calculating the magnitude of the vector sum.

For a calculated answer with correct units — 1 point

$E = 2.8 \times 10^3\ \text{N/C}$

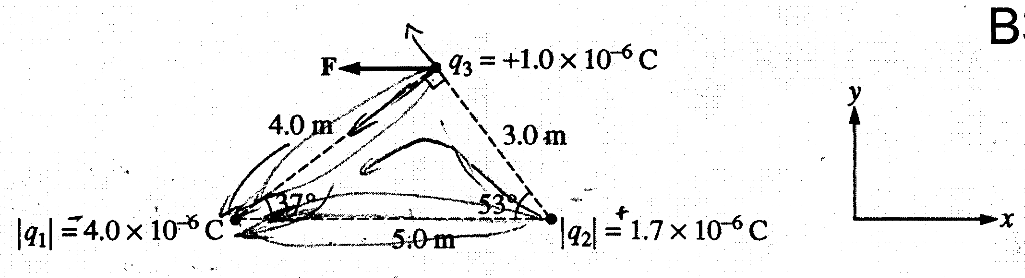
(e) 2 points



For an $\times$ in the correct position as shown above — 1 point

For a correct justification that refers to forces — 1 point

For example: Positive charges repel and a force to the right would cancel force **F** .



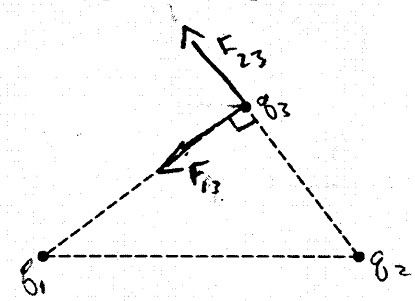
3. (10 points)

Three particles are fixed in place in a horizontal plane, as shown in the figure above. Particle 3 at the top of the triangle has charge q_3 of $+1.0 \times 10^{-6}$ C, and the electrostatic force **F** on it due to the charge on the two other particles is measured to be entirely in the negative x-direction. The magnitude of the charge q_1 on particle 1 is known to be 4.0×10^{-6} C, and the magnitude of the charge q_2 on particle 2 is known to be 1.7×10^{-6} C, but their signs are not known.

(a) Determine the signs of the charges q_1 and q_2 and indicate the correct signs below.

q_1	X Negative	q_2	____ Negative
	____ Positive		X Positive

(b) On the diagram below, draw and label arrows to indicate the direction of the force F_1 exerted by particle 1 on particle 3 and the force F_2 exerted by particle 2 on particle 3.



(c) Calculate the magnitude of **F**, the electrostatic force on particle 3.

$$F_{13} = \frac{k_c q_1 q_3}{r^2} = \frac{8.99e9(-4e{-6})(1e{-6})}{4^2}$$
$$= -.0022475$$
$$= -2.2475e{-3}\ N$$

$$F_{23} = \frac{k_c q_2 q_3}{r^2} = \frac{8.99e9(1.7e{-6})(1e{-6})}{3^2}$$
$$= 1.6981e{-3}\ N$$

$$F_{q3} = \sqrt{F_{13}^2 + F_{23}^2}$$
$$= \sqrt{(1.6981e{-3})^2 + (2.2475e{-3})^2}$$
$$= 2.8168e{-3}\ N$$

(d) Calculate the magnitude of the electric field at the position of particle 3 due to the other two particles.

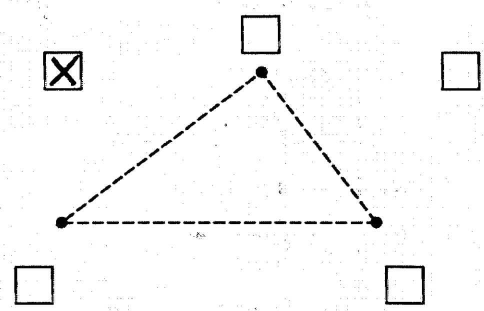
$E = \frac{k_e q}{r^2}$

$E_{@3} = E_{13} + E_{23}$

$= \frac{F_{13}}{q_3} + \frac{F_{23}}{q_3} = \frac{-2.2475e^{-3}}{1e^{-6}} + \frac{1.6981e^{-3}}{1e^{-6}}$

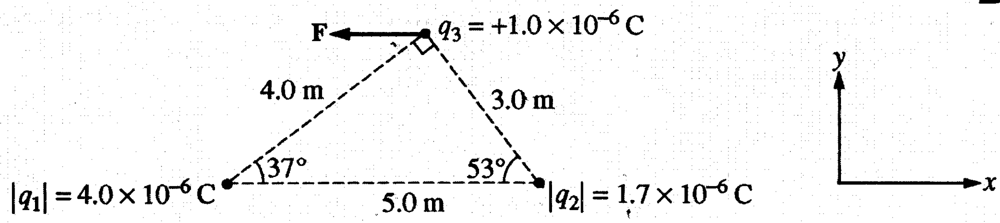
$= -549.4 \, \frac{N}{C}$

(e) On the figure below, draw a small × in the box that is at a position where another positively charged particle could be fixed in place so that the electrostatic force on particle 3 is zero.



Justify your answer.

The current resoltant force of the two vectors F_{13} and F_{23} is pointing directly toward the left. Placing a positive charge would repel this attractive force, and (given the proper quantity of charge) bring the force to zero.



3. (10 points)

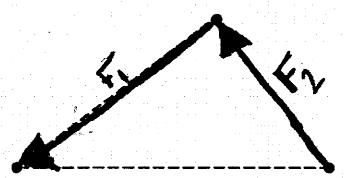
Three particles are fixed in place in a horizontal plane, as shown in the figure above. Particle 3 at the top of the triangle has charge q_3 of $+1.0 \times 10^{-6}$ C, and the electrostatic force **F** on it due to the charge on the two other particles is measured to be entirely in the negative x-direction. The magnitude of the charge q_1 on particle 1 is known to be 4.0×10^{-6} C, and the magnitude of the charge q_2 on particle 2 is known to be 1.7×10^{-6} C, but their signs are not known.

(a) Determine the signs of the charges q_1 and q_2 and indicate the correct signs below.

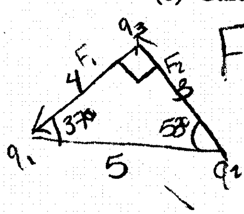
q_1 ✓ Negative
____ Positive

q_2 ____ Negative
✓ Positive

(b) On the diagram below, draw and label arrows to indicate the direction of the force F_1 exerted by particle 1 on particle 3 and the force F_2 exerted by particle 2 on particle 3.



(c) Calculate the magnitude of **F**, the electrostatic force on particle 3.



$F = F_1 + F_2$

$F_1 = k\frac{q_1 q_3}{r^2}$

$F_1 = 9\times10^9\left(\frac{4\times10^{-6}\times1\times10^{-6}}{4^2}\right)$

$F_1 = -2.25e{-3}$

$F_2 = k\frac{q_2 q_3}{r^2}$

$F_2 = 9\times10^9\left(\frac{1.7\times10^{-6}\times1\times10^{-6}}{3^2}\right)$

$F_2 = 1.7e{-3}$

$F = -2.25\times10^{-3} + 1.7\times10^{-3}$

$F = -5.25\times10^{-4}$ N

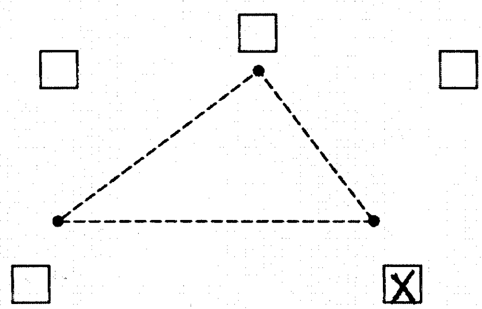
(d) Calculate the magnitude of the electric field at the position of particle 3 due to the other two particles.

$$E = \frac{F}{q}$$

$$E = \frac{-5.25 \times 10^{-4}}{1 \times 10^{-6}}$$

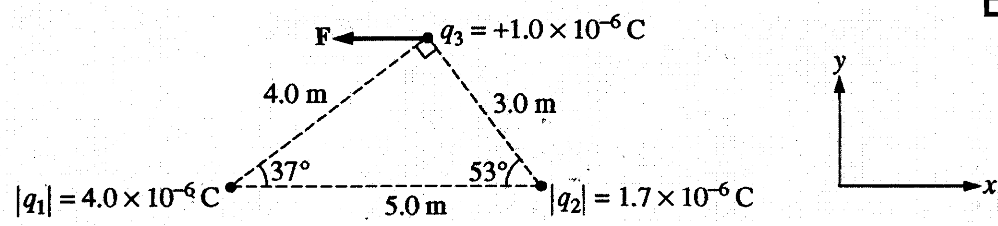
$$E = -525 \ N/C$$

(e) On the figure below, draw a small × in the box that is at a position where another positively charged particle could be fixed in place so that the electrostatic force on particle 3 is zero.



Justify your answer.

A positive charge could be placed at this location and make the Force equal zero because this charge would apply a force similar to the charge q_2 already in place and over power the force of q_1. If $q_1 = q_2 +$ new charge, the charges would be equal and the distance between q_3 and the new charge would be very close to that between q_3 and q_1. This would make the forces equal but opposite.



3. (10 points)

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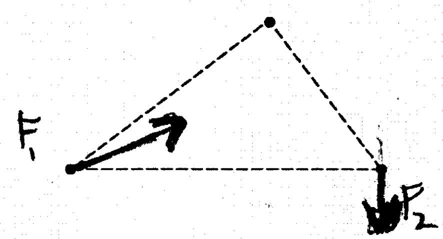
(a) Determine the signs of the charges q_1 and q_2 and indicate the correct signs below.

q_1 ✓ Negative
____ Positive

q_2 ____ Negative
✓ Positive

(b) On the diagram below, draw and label arrows to indicate the direction of the force F_1 exerted by particle 1 on particle 3 and the force F_2 exerted by particle 2 on particle 3.



(c) Calculate the magnitude of **F**, the electrostatic force on particle 3.

$$E = \frac{F}{q}$$

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

$$V = \frac{1}{4\pi\varepsilon_0} \sum \frac{q_i}{r_i}$$

$$V = 9E9 \sum \left(\frac{4.0\times10^{-6}}{4}\right) + \left(\frac{1.7\times10^{-6}}{3}\right)$$

$$E = -780$$

$$-780 = \frac{F}{(1.0 \times 10^{-6})}$$

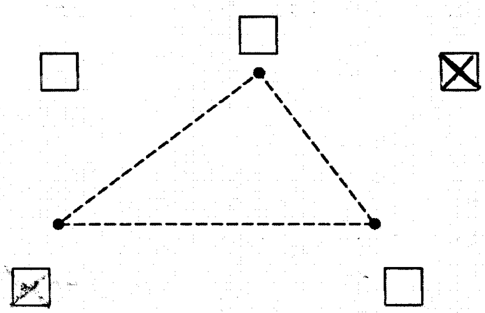
$$F = -.0078 \text{ N}$$

(d) Calculate the magnitude of the electric field at the position of particle 3 due to the other two particles.

$E = -\frac{V}{d}$ $V = \frac{1}{4\pi\varepsilon_0}\sum\frac{q_i}{r_i}$

$$-\frac{V = (9e9)\left[\frac{4.0\times10^{-6}}{4} + \frac{1.7\times10^{-4}}{3}\right]}{5} = -780 \text{ Tesla}$$

(e) On the figure below, draw a small × in the box that is at a position where another positively charged particle could be fixed in place so that the electrostatic force on particle 3 is zero.



Justify your answer.

By putting it next to the other ~~positive~~ particles the net electrostatic force would end up being zero. If you add up the magnitude forces of each particle on q_1 it would prove to be zero.

Question 3

Overview

The intent of this question was to determine students' understanding of various electrical concepts pertaining to point charges, as well as fundamental mechanics concepts involving the vector nature of force. Part (a) asked students to determine the signs of two point charges that together would produce a given direction of net electric force on a third point charge in a triangle formation, as seen in the given diagram. Part (b) asked students to draw the force vectors acting on this third point charge from the first and second point charges. Part (c) then asked students to calculate the magnitude of the net electric force acting on the third point charge, while part (d) had the students calculate the net electric field experienced by the third point charge. Finally, part (e) asked the students to determine a suitable location for a fourth point charge that could result in there being zero net electric force on the third point charge, and to justify their choice.

Sample: B3-A
Score: 9

Parts (a) and (b) earned full credit. Note the correct use of two indices on each vector in part (b). Part (c) also earned full credit. The student uses the Pythagorean theorem to find the magnitude of the vector sum. In part (d) the student does not add the electric fields as vectors and so lost the substitution point, but the response earned the point for a calculated answer with the correct units. Part (e) has the proper box checked and has a satisfactory justification in terms of forces.

Sample: B3-B
Score: 6

Parts (a) and (b) earned full credit. Note that in part (b) one vector starts on q_3 and the other terminates on q_3. Part (c) earned 1 point for using Coulomb's law correctly, but then the forces are added as scalars, resulting in a wrong answer. Part (d) earned full credit because the student correctly uses the answer obtained in part (c). Part (e) earned no credit.

Sample: B3-C
Score: 1

Although this response has a significant amount of work in all parts, it earned only 1 point, in part (a). Parts (c) and (d) both incorrectly use the potential in arriving at values for force and field.