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 $g = 9.8\ \mathrm{m/s^2}$, but use of $10\ \mathrm{m/s^2}$ 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

15 points total | **Distribution of points**

(a) 2 points

For checking "Positive" — 1 point

For a correct justification (point only awarded if "Positive" checked) — 1 point

Example: At point P, the electric field due to charge q_1 points to the right because electric fields point toward negative charges. The field from q_2 must point to the left, i.e., away from the charge, to cancel the field from q_1. So q_2 must be positive.

Point is not awarded if the justification is "*charges cancel each other out.*"

(b) 4 points

For a correct equation for electric field strength of a point charge — 1 point

$$E = \frac{1}{4\pi\epsilon_0}\frac{q_i}{r_i^2}$$

For showing that the sum of the electric fields at P is zero — 1 point

$$0 = \frac{1}{4\pi\epsilon_0}\frac{q_1}{d_1^2} + \frac{1}{4\pi\epsilon_0}\frac{q_2}{d_2^2}$$

$$\frac{1}{4\pi\epsilon_0}\frac{q_2}{d_2^2} = -\frac{1}{4\pi\epsilon_0}\frac{q_1}{d_1^2}$$

$$q_2 = -\frac{d_2^2}{d_1^2}q_1$$

For correct substitution of values — 1 point

$$q_2 = -\frac{(0.40\text{ m})^2}{(0.10\text{ m})^2}\left(-3.0\times10^{-9}\text{ C}\right)$$

For the correct answer — 1 point

$$q_2 = +4.8\times10^{-8}\text{ C}$$

(c) 3 points

For writing Coulomb's law — 1 point

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

For correct substitution of given values and the charge found in part (b) — 1 point

$$F_2 = \left(9.0\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\frac{\left(3.0\times10^{-9}\text{ C}\right)\left(48\times10^{-9}\text{ C}\right)}{(0.30\text{ m})^2}$$

$$F_2 = 1.4\times10^{-5}\text{ N}$$

For a direction consistent with the answer to part (a) — 1 point

The electric force on q_2 is to the left (or to the right if the answer to part (a) is "Negative")

Question 3 (continued)

Distribution of points

(d) 4 points

For showing that the sum of the potentials is zero — 1 point

$V_1 + V_2 = 0$

For using the point charge formula for electric potential — 1 point

$V = \dfrac{q}{4\pi\epsilon_0 r}$ OR $V = k\dfrac{q}{r}$

$\dfrac{1}{4\pi\epsilon_0}\dfrac{q_1}{r_1} + \dfrac{1}{4\pi\epsilon_0}\dfrac{q_2}{r_2} = 0$

For correctly substituting values into the equation above, including q_1, the value of q_2 from part (b), and distances in the denominators that sum to 0.3 m and include a valid distance variable — 1 point

Example:

$$\frac{1}{4\pi\epsilon_0}\frac{-3.0\times10^{-9}\text{ C}}{(0.30\text{ m}-d)} + \frac{1}{4\pi\epsilon_0}\frac{48\times10^{-9}\text{ C}}{d} = 0$$

$$d\left(-3.0\times10^{-9}\text{ C}\right) = -(0.30\text{ m}-d)\left(48\times10^{-9}\text{ C}\right)$$

$$d\left(3.0\times10^{-9}\text{ C}\right) = (0.30\text{ m}-d)\left(48\times10^{-9}\text{ C}\right)$$

$$\left(48\times10^{-9}\text{ C}+3.0\times10^{-9}\text{ C}\right)d = (0.30\text{ m})\left(48\times10^{-9}\text{ C}\right)$$

$$d = \frac{(0.30\text{ m})\left(48\times10^{-9}\text{ C}\right)}{\left(48\times10^{-9}\text{ C}+3.0\times10^{-9}\text{ C}\right)}$$

$d = 0.28$ m

For finding a value for x within the range $-0.1\text{ m} < x < 0.2\text{ m}$ — 1 point

Note: This point was only awarded if the substitution point was awarded

$x = 0.20\text{ m} - 0.28\text{ m} = -0.08$

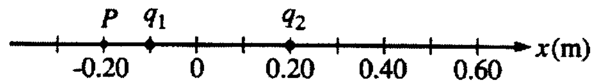
(e) 2 points

For stating that net work done is zero — 1 point

For a correct justification — 1 point

Example:

$W = \Delta U = q\,\Delta V$. Since the potential is zero at infinity and is also zero at the final position, $\Delta V = 0$. Therefore $W = 0$.



3. (15 points)

Two point charges, q_1 and q_2, are placed 0.30 m apart on the x-axis, as shown in the figure above. Charge q_1 has a value of -3.0×10^{-9} C. The net electric field at point P is zero.

(a) What is the sign of charge q_2?

X Positive ____ Negative

Justify your answer.

At point P, the net electric field is zero, which means that the field due to negatively charged q_1, a field whose direction is to the right at point P, must be cancelled by a positively charged q_2, whose field direction would be to the left at point P.

(b) Calculate the magnitude of charge q_2.

$$E_2 = \frac{F_2}{q} = \frac{1}{4\pi\epsilon_0}\frac{q_2}{r_2^2} = -E_1 = -\frac{F_1}{q} = -\frac{1}{4\pi\epsilon_0}\frac{q_1}{r_1^2}$$

$$\frac{q_2}{r_2^2} = -\frac{q_1}{r_1^2} \qquad q_2 = -\frac{q_1 r_2^2}{r_1^2} = -\frac{(-3.0\times10^{-9}\ C)(.40\ m)^2}{(.10\ m)^2}$$

$$q_2 = \boxed{4.8\times10^{-8}\ C}$$

(c) Calculate the magnitude of the electric force on q_2 and indicate its direction.

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\epsilon_0}\cdot\frac{(-3.0\times10^{-9}\ C)(4.8\times10^{-8}\ C)}{(.30\ m)^2}$$

$$\boxed{F = 1.4\times10^{-5}\ N \text{ (to the left, toward } q_1)}$$

(d) Determine the x-coordinate of the point on the line between the two charges at which the electric potential is zero.

$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$ $V_1 = -V_2$ $\frac{q_1}{r_1} = -\frac{q_2}{r_2}$

$\frac{q_1}{(x+.1)} = -\frac{q_2}{(.2-x)}$ $-.2q_1 + xq_1 = q_2x + .1q_2$

~~$xq_2 + xq_1 = .2q_1 - .1q_2 = x(q_1 + q_2)$~~

~~$x = \frac{.2q_1 - .1q_2}{(q_1 + q_2)}$~~ ~~$x = (.20\ m)($~~

$xq_1 - xq_2 = .2q_1 + .1q_2$

$x(q_1 - q_2) = .2q_1 + .1q_2$

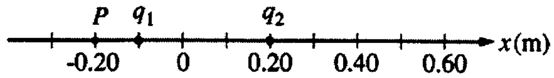
$x = \frac{.2q_1 + .1q_2}{q_1 - q_2}$

$$x = \frac{(.20\ m)(-3.0\times10^{-9}\ C) + (.10\ m)(4.8\times10^{-8}\ C)}{-3.0\times10^{-9}\ C - 4.8\times10^{-8}\ C}$$

$x = \boxed{-.08\ m}$

(e) How much work must be done by an external force to bring an electron from infinity to the point at which the electric potential is zero? Explain your reasoning.

Zero work is required. Since the electric potential here is zero, and the electric potential at infinity is zero, there is no change in potential, and thus no net work is done.



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Two point charges, q_1 and q_2, are placed 0.30 m apart on the x-axis, as shown in the figure above. Charge q_1 has a value of -3.0×10^{-9} C. The net electric field at point P is zero.

(a) What is the sign of charge q_2?

✓ Positive ____ Negative

Justify your answer.

The electric field due to q_1 at point P will be directed toward q_1. In order to create a net electric field of zero, the electric field from q_2 must point in the opposite direction to that of q_1. The electric field at q_1 is to the right, so the field from q_2 must point left, and only positive charges create fields directed away from themselves.

(b) Calculate the magnitude of charge q_2.

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

$E_{q_1} = -E_{q_2}$

$E_{q_1} = \frac{(9 \times 10^9) q_1}{r^2}$

$-2700 = \frac{(9 \times 10^9)(-3 \times 10^{-9})}{(.10)^2}$

$-2700 = \frac{(9 \times 10^9) q_2}{(.4)^2}$

$-432 = (9 \times 10^9) q_2$

$\boxed{q_2 = 4.8 \times 10^{-8}\ C}$

(c) Calculate the magnitude of the electric force on q_2 and indicate its direction.

$F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}$

$= \frac{(9 \times 10^9)(-3.0 \times 10^{-9})(4.8 \times 10^{-8})}{(.3)^2}$

$= -1.44 \times 10^{-5}$

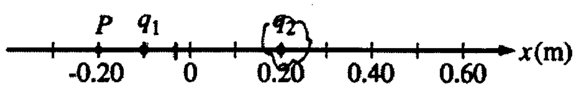
$\boxed{1.44 \times 10^{-5}\ \text{nt to the left}}$

(d) Determine the x-coordinate of the point on the line <u>between</u> the two charges at which the electric potential is zero.

There is no point between the charges where the electric potential is zero.

(e) How much work must be done by an external force to bring an electron from infinity to the point at which the electric potential is zero? Explain your reasoning.

No work would have to be performed, because the electron would naturally move toward the point at which the electric potential is zero.



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(a) What is the sign of charge q_2?

✓ Positive ____ Negative

Justify your answer.

If q_1 has a negative charge and the net electric field at point P is zero, their must be some charge countering q_1's negative charge and this charge must be positive.

(b) Calculate the magnitude of charge q_2.

$q_1 = -3.0E-9$

$k = 9E9$

$Q_2 = K \frac{q_1}{R}$

$Q_2 = 9E9 \left(\frac{-3.0E-9}{.3}\right)$

$Q_2 = 90 \text{ C}$

$F_p = 0$

$F =$

(c) Calculate the magnitude of the electric force on q_2 and indicate its direction.

$F = K \frac{Q_1 Q_2}{R^2}$

$F = (9E9) \frac{(-3.0E-9)(90)}{(.3)^2}$

$F = -27000 \text{ N}$

(d) Determine the *x*-coordinate of the point on the line between the two charges at which the electric potential is zero.

$V = k\frac{q}{R}$

~~$\frac{(9E9)(-3E-9)}{R} = \frac{(9E9)(90)}{R}$~~

~~$8.1E11R = -27R$~~

$\frac{90}{3E-9} = 3E10$ $\frac{3m}{3E10} = 1E-10$

$q_1 + 1E-10$

$-.1 + .1E-10 = -.100$

(e) How much work must be done by an external force to bring an electron from infinity to the point at which the electric potential is zero? Explain your reasoning.

No Work. $V_\infty = 0$ and at this point the electric potential is still zero, so $\Delta V = 0$, so $W = q\Delta V$, no work has been done.

Question 3

Overview

This 15-point question asked students to demonstrate their understanding of electric fields of point charges. Two charges, one known and the other unknown, exist on a line. Students were told that the total field strength at a place on the line is zero; they were asked to determine the magnitude and sign of the unknown charge from this information and to justify their answer. The question went on to ask for the force of the two charges upon one another, then for determination of the place between the charges where the potential is zero, and finally for the amount of work needed to bring a third charge from infinity to this place of zero potential.

Sample: B3A
Score: 15

This student correctly sets up the calculation in part (c), so no translation to the x coordinate is necessary.

Sample: B3B
Score: 10

The first three parts earned full credit. Part (d) earned nothing, and part (e) earned 1 point for indicating that no work needs to be done.

Sample: B3C
Score: 6

Part (a) earned only 1 point since the justification says the charges, not the fields, cancel. Part (b) earned nothing. Part (c) earned 2 points since the magnitude of the force is correctly calculated using the incorrect answer from part (b). However, a negative sign on the answer is not a definitive indication that the student knows the direction of the force. Part (d) earned only the equation point, and part (e) earned full credit.