General Notes About 2009 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 one 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. 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*.

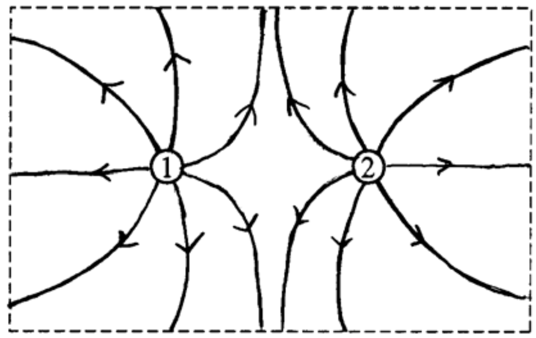
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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 2

10 points total **Distribution of points**

(a) 3 points



For the direction of all field lines away from the source charges — 1 point
For the correct shape, symmetry, and curvature of the field lines — 1 point
For a clear indication that the net field about point *A*, the point midway between the two charges, is zero; example: an absence of field lines in the area around point *A* — 1 point

(b) 2 points

For clearly showing the addition of both contributions to the potential at point *A* — 1 point

$V = \frac{kq_1}{r_1} + \frac{kq_2}{r_2}$ OR $V = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{d} + \frac{Q}{d}\right)$ OR equivalent

For a correct expression in terms of the given quantities — 1 point

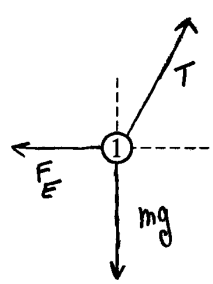
$V = \frac{2kQ}{L\sin\theta}$ OR $\frac{2Q}{4\pi\epsilon_0 L\sin\theta}$ OR $\frac{Q}{2\pi\epsilon_0 L\sin\theta}$ OR equivalent

Notes:

- The answer with no work shown earned 1 point.
- The following expression or its equivalents, with no other work shown, earned both points:

$$V = \frac{kQ}{L\sin\theta} + \frac{kQ}{L\sin\theta}$$

(c) 2 points



For all three vectors correctly drawn, with arrowheads, and no extraneous vectors — 1 point
For appropriate labeling of vectors (only if first point was awarded) — 1 point

Question 2 (continued)

Distribution of points

(d) 3 points

For an expression indicating that the *x*-component of tension is equal to F_E — 1 point

$T_x - F_E = 0$ OR $T\sin\theta = F_E$ OR equivalent

For an expression indicating that the *y*-component of tension is equal to *mg* — 1 point

$T_y - mg = 0$ OR $T\cos\theta = mg$ OR equivalent

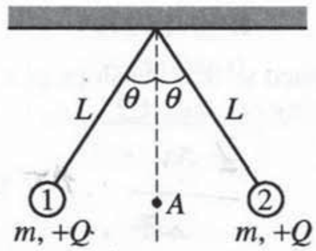
For stating the two equations in terms of the given quantities — 1 point

$T\sin\theta = \dfrac{kQ^2}{4L^2\sin^2\theta}$ OR $\dfrac{Q^2}{16\pi\epsilon_0 L^2\sin^2\theta}$ OR $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q^2}{4L^2\sin^2\theta}$ OR equivalent

$T\cos\theta = mg$

Notes:

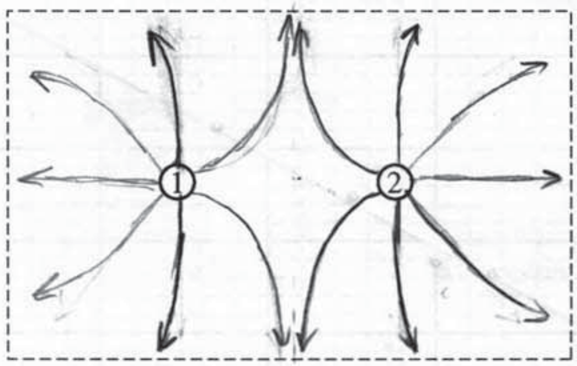
- Correct statement of both of the final two equations, in the absence of any other expressions, earned full credit.
- One point was deducted if sine and cosine were interchanged at any point.



2. (10 points)

Two small objects, labeled 1 and 2 in the diagram above, are suspended in equilibrium from strings of length L. Each object has mass m and charge $+Q$. Assume that the strings have negligible mass and are insulating and electrically neutral. Express all algebraic answers in terms of m, L, Q, θ, and fundamental constants.

(a) On the following diagram, sketch lines to illustrate a 2-dimensional view of the net electric field due to the two objects in the region enclosed by the dashed lines.



(b) Derive an expression for the electric potential at point A, shown in the diagram at the top of the page, which is midway between the charged objects.

elect potential = V is scalar

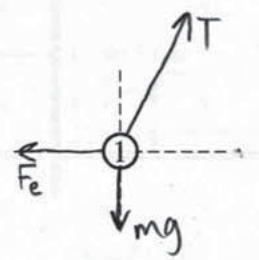
$V = \frac{kq}{r}$ $q = Q$, $r = L\sin\theta$

so electric potential at A will $= V_1 + V_2$

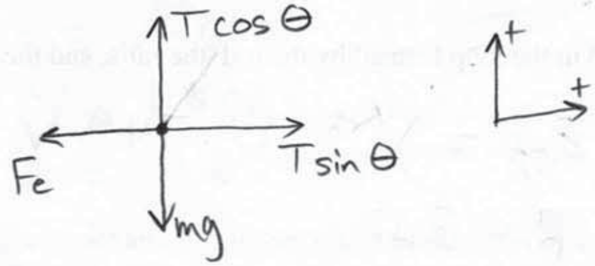
$V = \frac{kQ}{L\sin\theta} + \frac{kQ}{L\sin Q}$

$\boxed{V = \frac{2kQ}{L\sin\theta}}$

(c) On the following diagram of object 1, draw and label vectors to represent the forces on the object.



(d) Using the conditions of equilibrium, write—but do not solve—two equations that could, together, be solved for θ and the tension T in the left-hand string.



$\Sigma F = ma$

$T\cos\theta - mg = 0$

$T\sin\theta - F_e = 0$

$F_e = \frac{kq_1q_2}{r^2}$

$T\cos\theta = mg$

eqn 2 $\boxed{T = \frac{mg}{\cos\theta}}$

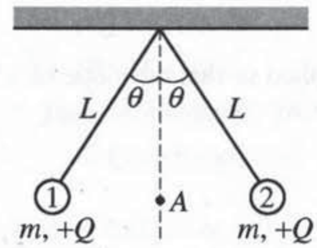
$r = L\sin\theta$

$q_1 = Q = q_2$

$F_e = \frac{kQ^2}{L^2\sin^2\theta}$

$T\sin\theta = \frac{kQ^2}{L^2\sin^2\theta}$

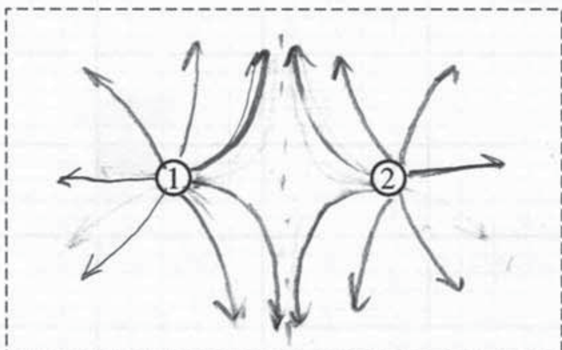
$\boxed{T = \frac{kQ^2}{L^2\sin^3\theta}}$ eqn 1



2. (10 points)

Two small objects, labeled 1 and 2 in the diagram above, are suspended in equilibrium from strings of length L. Each object has mass m and charge $+Q$. Assume that the strings have negligible mass and are insulating and electrically neutral. Express all algebraic answers in terms of m, L, Q, θ, and fundamental constants.

(a) On the following diagram, sketch lines to illustrate a 2-dimensional view of the net electric field due to the two objects in the region enclosed by the dashed lines.



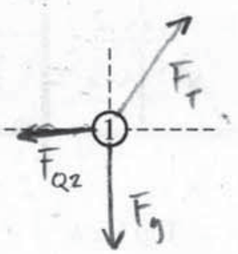
(b) Derive an expression for the electric potential at point A, shown in the diagram at the top of the page, which is midway between the charged objects.

$$V = k\sum \frac{q}{r}$$

$$V = k\frac{Q}{L\sin\theta} + k\frac{Q}{L\sin\theta}$$

$$= k\frac{2Q}{L\sin\theta}$$

(c) On the following diagram of object 1, draw and label vectors to represent the forces on the object.



(d) Using the conditions of equilibrium, write—but do <u>not</u> solve—two equations that could, together, be solved for θ and the tension T in the left-hand string.

$$F_{net} = 0$$

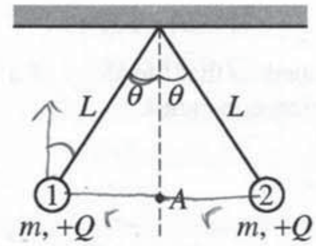
$$F_g = F_T + F_Q$$

$$mg = F_T + k\frac{q_1 q_2}{r^2}$$

$$\boxed{mg - k\frac{Q^2}{(2L\sin\theta)^2} = F_T}$$

$$mg - F_T = k\frac{Q^2}{(2L\sin\theta)^2}$$

$$\theta = \sin^{-1}\left(\frac{\sqrt{\dfrac{kQ^2}{mg - F_T}}}{2L}\right)$$



2. (10 points)

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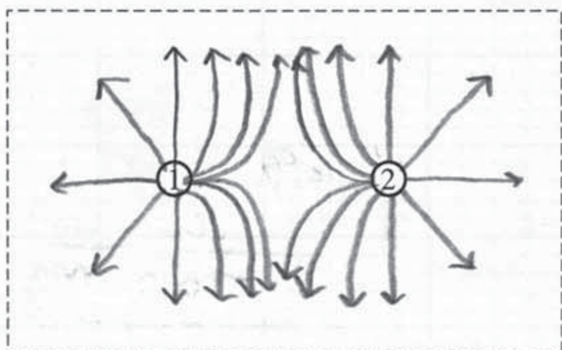
(a) On the following diagram, sketch lines to illustrate a 2-dimensional view of the net electric field due to the two objects in the region enclosed by the dashed lines.



(b) Derive an expression for the electric potential at point A, shown in the diagram at the top of the page, which is midway between the charged objects.

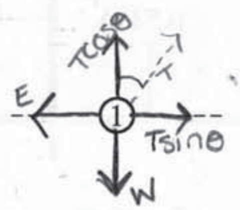
$E = \frac{F}{+Q}$ $\quad F = \frac{K q_1 q_2}{r^2}$

$\frac{\frac{K q_1 q_2}{r^2}}{q}$ $\quad \frac{K +Q^2}{r^2}\left(\frac{1}{+Q}\right)$

$\frac{K +Q}{r^2}$

$E = \frac{K+Q}{r^2}$

(c) On the following diagram of object 1, draw and label vectors to represent the forces on the object.



(d) Using the conditions of equilibrium, write—but do <u>not</u> solve—two equations that could, together, be solved for θ and the tension T in the left-hand string.

Horizontal

$E = T\sin\theta$

$\frac{KQ}{r^2} = T\sin\theta$

$\frac{KQ}{r^2\sin\theta} = T$

or

$\sin^{-1}\left(\frac{KQ}{T(r^2)}\right) = \theta$

Vertical

$T\cos\theta = W$

$T\cos\theta = mg$

$T = \frac{mg}{\cos\theta}$

or

$\theta = \cos^{-1}\left(\frac{mg}{T}\right)$

Question 2

Overview

The intent of this question was to determine students' understanding of electrical concepts as well as equilibrium situations. Part (a) asked students to draw the electric field lines in the region of two equally and positively charged spherical objects suspended in equilibrium from strings. Part (b) asked students to derive an algebraic expression for the electric potential halfway between the two charged objects. Part (c) then asked students to draw and label the forces on one of the charged objects (the one on the left). Finally, part (d) asked students to use the conditions of equilibrium to write (but not solve) two equations that could be used to determine both the tension in the string holding the left-most object and the angle that its string made with respect to vertical.

Parts (a) and (b) are typical electrostatics questions. Parts (c) and (d), though, required students to integrate knowledge from two different course topics: Newtonian mechanics and electrostatics. Part (d) especially provided an opportunity for students to show their ability to treat an electric force in combination with other, less abstract forces. Furthermore, because parts (b) through (d) required a response in variables only, this question differentiated between students who thoroughly understand the physical meaning of, say, "electric potential" and those who must rely on merely transferring equations from the equation sheet.

Sample: B-2A
Score: 9

Parts (a), (b), and (c) are correct and earned all 7 available points. In part (d) the expression for the distance between the two charges is missing a factor of "2" so the boxed answer labeled "eqn 1" is incorrect, for a loss of 1 point.

Sample: B-2B
Score: 7

Parts (a), (b), and (c) are correct. The work in part (d) adds the magnitudes of the forces and does not correctly equate components, so no points were earned.

Sample: B-2C
Score: 4

In part (a) several of the field lines that should be curved are straight, so 1 point was deducted. There are no expressions for potential in part (b), so no points were earned. In part (c) the directions are acceptable, but the labeling of the electric force as "E" resulted in the loss of the labeling point. Note that the tension force and its components are clearly represented in different ways (solid versus dashed lines). This is crucial to obtaining the maximum points because when the lines look the same, it is not clear if the student understands that they are not separate forces. In part (d) the equation for the vertical components is correct, but the horizontal analysis equates a force to an electric field. Therefore, only 1 point was earned.