AP® PHYSICS
2011 SCORING GUIDELINES

General Notes About 2011 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 earned. 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 earn 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 earned. 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 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 earn 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 5

15 points total | **Distribution of points**

(a) 4 points

$\Sigma F_y = F_E - F_g = ma_y$

The sphere is in equilibrium, so $a_y = 0$.

For setting the electrical force equal to the gravitational force — 1 point

$F_E = F_g$

For correct substitutions for F_E and F_g — 1 point

$qE = mg$

Note: If the solution starts with the equation above, the first 2 points are earned.

For substituting into the equation above the relationship $E = V/L$ — 1 point

$q\dfrac{V}{L} = mg$

For the correct final expression for q — 1 point

$q = mgL/V$

Note: The points for substitution of expressions for F_E, F_g, and E are earned only if the solution starts with an indication that the electric and gravitational forces are equal in magnitude.

Alternate solution: — *Alternate points*

For setting the amount of gravitational potential energy lost equal to the amount of electrical potential energy gained — *1 point*

$|\Delta U_g| = |\Delta U_E|$

For substituting mgL for $|\Delta U_g|$ — *1 point*

Substituting qV for $|\Delta U_E|$ — *1 point*

$mgL = qV$

For the correct final expression for q — *1 point*

$q = mgL/V$

Note: The points for the substitution of expressions for $|\Delta U_g|$ *and* $|\Delta U_E|$ *are earned only if the solution starts with an indication of conservation of energy between gravitational and electric potential energy.*

(b) 1 point

For an appropriate physical explanation — 1 point

Example: The gap can be explained by the quantization of electric charge. There are no spheres with charges between the values of 3.2×10^{-19} C and 1.6×10^{-19} C , the difference being the electron charge, the smallest charge that can exist.

Note: Answers that refer to the fact that charge is quantized earn this point.

Question 5 (continued)

Distribution of points

(c) 3 points

From part (a), $q = mgL/V$

$$m = \frac{qV}{gL}$$

For selecting a correct data point (V, q) from the graph, such as $\left(500\ \text{V},\ 9.6 \times 10^{-19}\ \text{C}\right)$ — 1 point

Note: This point is earned for the use of any correct data point from the graph. Many students used the point $\left(500\ \text{V},\ 1.0 \times 10^{-18}\ \text{C}\right)$, which is acceptable.

For substituting the data point value into a correct expression for m — 1 point

$$m = \frac{\left(9.6 \times 10^{-19}\ \text{C}\right)(500\ \text{V})}{\left(9.8\ \text{m/s}^2\right)(0.050\ \text{m})}$$

For the correct value of m with correct units — 1 point

$m = 9.8 \times 10^{-16}\ \text{kg}$ (or an equivalent correct value using a different data point or using $g = 10\ \text{m/s}^2$)

(d)

When the sphere enters the magnetic field, the upward electric force and the downward gravitational force do not change in magnitude or direction, so they still cancel each other. The resultant force on the sphere is then due to the magnetic force only.

i. 1 point

For an indication that the sphere moves in a circular arc or a curved path — 1 point

ii. 2 points

For stating that if q is positive, then when the sphere enters the magnetic field it will move toward the right (or counterclockwise); however, if q is negative, it will move toward the left (or clockwise). — 2 points

Notes:

One point only is earned if the description mentions that the sphere would move either left or right depending on its charge but does not link a positive charge to moving right and a negative charge to moving left.

One point only is also earned if the description mentions either that if q is positive the sphere would move to the right or that if q is negative the sphere would move to the left but does not mention both.

Question 5 (continued)

Distribution of points

(e) 4 points

$\Sigma F = F_B = ma_c$

For an indication that it is the magnetic force F_B that provides the centripetal force — 1 point

For a correct substitution for the magnetic force $F_B = qvB$ — 1 point

For a correct substitution for the centripetal force $ma_c = mv^2/r$ — 1 point

Note: The two substitution points are earned only if the solution starts with an indication that the centripetal force is due to the magnetic force.

$$qvB = m\frac{v^2}{r}$$

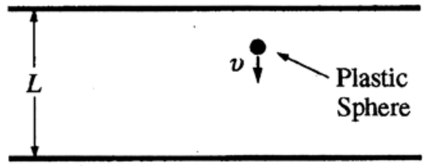
Note: If a response starts with the equation above, 3 points are earned.

$$B = \frac{mv}{qr}$$

For an indication that the radius r must be smaller than $L/2$ to prevent the sphere from reaching the bottom of the plate, so $r_{max} = L/2$ — 1 point

Because B is inversely proportional to r, the value r_{max} corresponds to the minimum value of B needed.

$$B_{min} = \frac{2mv}{qL}$$



Note: Figure not drawn to scale.

5. (15 points)

In the experimental setup represented above, a very small plastic sphere of mass m with charge q is allowed to fall under the influence of gravity between two parallel metal plates separated by a fixed distance L. A variable potential difference may be applied between the two plates. The experiment is conducted inside a vacuum chamber.

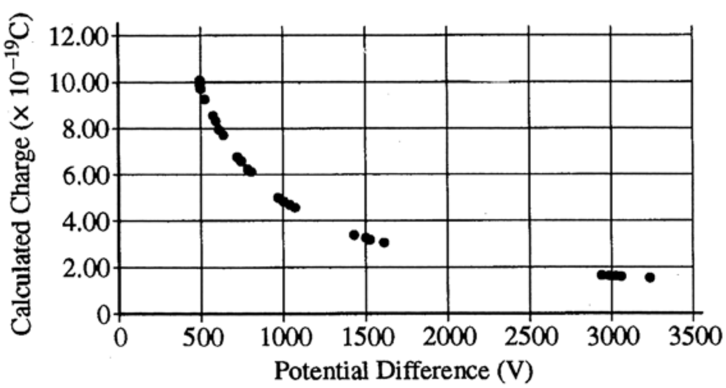
(a) A potential difference of magnitude V is applied between the top and bottom plates such that the sphere falls at constant speed v. Derive an expression for the magnitude of the charge q on the sphere. Express your answer in terms of m, L, V, and fundamental constants, as appropriate.

$F_E = F_g$ $\quad E = \frac{V}{d}$

$qE = mg$

$q = \frac{mg}{E} = \frac{mg}{\frac{V}{L}} = \boxed{\frac{mgL}{V}}$

The experiment is performed many times with spheres of identical known mass but different unknown charges, each time adjusting the potential difference V to the value needed so that the sphere falls at constant speed v. The magnitudes of the charges are calculated from the measured values of the potential difference. The data is plotted below as a function of the magnitude of V.



(b) Provide a physical explanation for the gap observed in the data between potential differences of 1700 V and 2800 V.

spheres with charges between 1.9×10^{-19} C and 3×10^{-19} C were not in the testing group and therefore would not appear in the gap in the data

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(c) If the value of L is 0.050 m, calculate the mass m of the spheres.

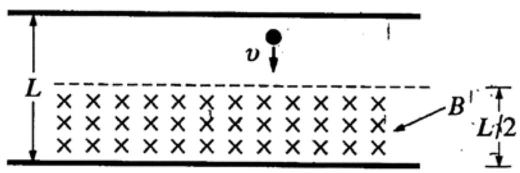
$q = 10\times10^{-19}C$ $\quad q = \frac{mgL}{V}$ $\quad m = \frac{qV}{gL} = \frac{(10\times10^{-19}C)(500V)}{(10m/s^2)(.05m)} \approx \boxed{1\times10^{-15}kg}$

$g = 10\ m/s^2$

$V = 500V$

$L = .05\ m$

A uniform magnetic field of magnitude B, directed into the page, is now applied in the bottom half of the region between the plates, as shown in the figure below. The experiment is repeated, with the potential difference adjusted again so that the charged sphere falls with constant speed prior to entering the magnetic field.



Note: Figure not drawn to scale.

(d)

i. Describe the motion of the sphere as it travels through the magnetic field.

The sphere curves to one side or the other on a circular path.

ii. Describe how the motion could be used to determine the sign of the charge.

Using the right-hand-rule, if the sphere is positively charged then it curves to the right and if it is negative it curves to the left.

(e) Derive an expression for the minimum value of B needed to prevent the sphere from reaching the bottom plate. Express your answer in terms of m, q, v, L, and fundamental constants, as appropriate.

~~$x = x_0 + v_0 t$~~

~~$\frac{L}{2}$~~

~~v~~

$qvB = m\frac{v^2}{L}$

$B = \boxed{\frac{mv}{qL}}$

$v_f = v^2 + 2a\frac{L}{2}$

$a = \frac{v^2}{L}$

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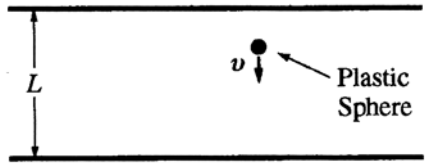


Note: Figure not drawn to scale.

5. (15 points)

In the experimental setup represented above, a very small plastic sphere of mass m with charge q is allowed to fall under the influence of gravity between two parallel metal plates separated by a fixed distance L. A variable potential difference may be applied between the two plates. The experiment is conducted inside a vacuum chamber.

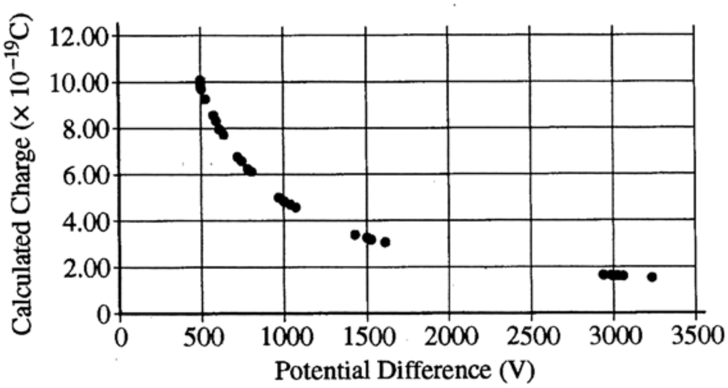
(a) A potential difference of magnitude V is applied between the top and bottom plates such that the sphere falls at constant speed v. Derive an expression for the magnitude of the charge q on the sphere. Express your answer in terms of m, L, V, and fundamental constants, as appropriate.

$E = V/d \qquad E = F/q \qquad \boxed{q = \frac{mgL}{V}}$

$V/d = F/q$

$V/L = mg/q$

The experiment is performed many times with spheres of identical known mass but different unknown charges, each time adjusting the potential difference V to the value needed so that the sphere falls at constant speed v. The magnitudes of the charges are calculated from the measured values of the potential difference. The data is plotted below as a function of the magnitude of V.



(b) Provide a physical explanation for the gap observed in the data between potential differences of 1700 V and 2800 V.

K q/r:

$V = 9\times10^9$

$500\,V = 9\times10^9\ N\cdot m^2/C^2\ \frac{10\times10^{-19}C}{r}$

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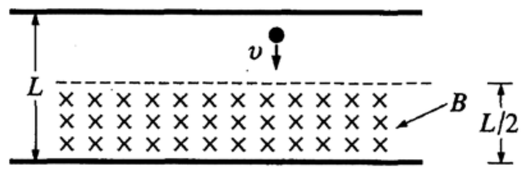
(c) If the value of L is 0.050 m, calculate the mass m of the spheres.

$$10\times10^{-19}C = \frac{m\,(10\,\tfrac{m}{s^2})\,(0.05m)}{500^V}$$

$$5\times10^{-16}\,\tfrac{C}{V} = m\,(0.5\,\tfrac{m^2}{s^2})$$

$$\boxed{m = 1\times10^{-15}\,Kg}$$

A uniform magnetic field of magnitude B, directed into the page, is now applied in the bottom half of the region between the plates, as shown in the figure below. The experiment is repeated, with the potential difference adjusted again so that the charged sphere falls with constant speed prior to entering the magnetic field.



Note: Figure not drawn to scale.

(d)

i. Describe the motion of the sphere as it travels through the magnetic field.

The ball will slowly curve to the left when first entering and then continue in a straight path after fully entering the magnetic field

ii. Describe how the motion could be used to determine the sign of the charge.

If the motion goes left, it is an electron, and if the motion goes right when entering, it is a proton.

(e) Derive an expression for the minimum value of B needed to prevent the sphere from reaching the bottom plate. Express your answer in terms of m, q, v, L, and fundamental constants, as appropriate.

$F_B = qvB$ $\qquad$ $F_g = mg$

$$\Downarrow$$

$$F_B = F_g$$

$$qvB = mg$$

$$\boxed{B = \frac{mg}{qv}}$$

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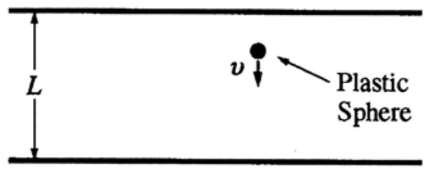

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5. (15 points)

In the experimental setup represented above, a very small plastic sphere of mass m with charge q is allowed to fall under the influence of gravity between two parallel metal plates separated by a fixed distance L. A variable potential difference may be applied between the two plates. The experiment is conducted inside a vacuum chamber.

(a) A potential difference of magnitude V is applied between the top and bottom plates such that the sphere falls at constant speed v. Derive an expression for the magnitude of the charge q on the sphere. Express your answer in terms of m, L, V, and fundamental constants, as appropriate.

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

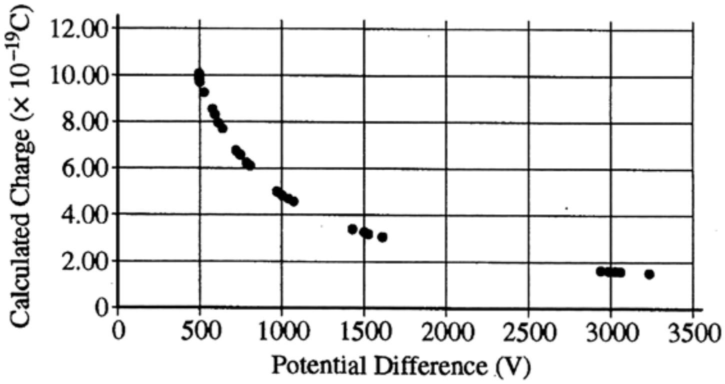
$E = \frac{V}{L}$

$\frac{F}{q} = \frac{V}{L}$

$\frac{qV}{V} = \frac{F \cdot L}{V}$

$q = \frac{F \cdot L}{V}$

The experiment is performed many times with spheres of identical known mass but different unknown charges, each time adjusting the potential difference V to the value needed so that the sphere falls at constant speed v. The magnitudes of the charges are calculated from the measured values of the potential difference. The data is plotted below as a function of the magnitude of V.



(b) Provide a physical explanation for the gap observed in the data between potential differences of 1700 V and 2800 V.

The charge versus voltage plot is an inverse function and the differences varies inversley so inorder to maintain a constant speed there are large gaps in the voltage.

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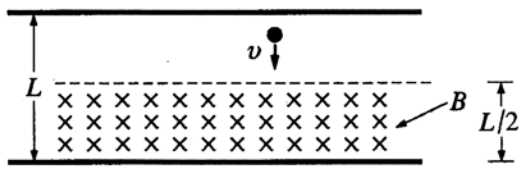
(c) If the value of L is 0.050 m, calculate the mass m of the spheres.

$$q \quad \frac{10 \times 10^{-19} C = F \cdot 0.05 m}{500 V}$$

$$1 \times 10^{-14} = F = ma$$

A uniform magnetic field of magnitude B, directed into the page, is now applied in the bottom half of the region between the plates, as shown in the figure below. The experiment is repeated, with the potential difference adjusted again so that the charged sphere falls with constant speed prior to entering the magnetic field.



Note: Figure not drawn to scale.

(d)

i. Describe the motion of the sphere as it travels through the magnetic field.

The motion of the sphere is down as it first enter and then starts to move in a circular motion.

ii. Describe how the motion could be used to determine the sign of the charge.

$$qvB = \frac{mv^2}{r}$$

The velocity is ~~to~~wards the bottom and the magnetic field ~~is~~ perpendicular to the right which can help you find the charge because its motion depends on its charge.

(e) Derive an expression for the minimum value of B needed to prevent the sphere from reaching the bottom plate. Express your answer in terms of m, q, v, L, and fundamental constants, as appropriate.

$$qvB = \frac{mv^2}{r}$$

$$\frac{qvB}{qv} = \frac{mv^2}{L}$$

$$B > \frac{mv^2 qv}{L}$$

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Question 5

Overview

This question assessed students' understanding of the behavior of an electrically charged object traveling at constant speed, in both electric and magnetic uniform fields.

Sample: B5A
Score: 13

The response earned full credit for part (a). No points were earned for part (b) because the student does not reference charge quantization. Parts (c) and (d) earned full credit. In part (e) 1 point was lost for substituting L instead of $L/2$ for the radius.

Sample: B5B
Score: 9

The response earned full credit in part (a). No credit was earned in part (b). Full credit was earned in part (c). No credit was earned for part (d) i because of the reference to straight-line motion. Full credit was earned for part (d) ii. No points were earned in part (e), which incorrectly equates the magnetic and gravitational forces.

Sample: B5C
Score: 5

The response earned no points in part (a) because the solution does not start with equating the electrostatic and gravitational forces. No points were earned in part (b) because the student does not reference charge quantization. Part (c) earned 1 point for the use of a data point from the graph. Part (d) i earned full credit. Part (d) ii did not earn any points because the response does not indicate how to determine the sign of the charge. Part (e) lost 1 point for substituting L instead of $L/2$ for the radius.