2018

AP CollegeBoard

AP Physics C: Mechanics

Sample Student Responses and Scoring Commentary

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Free Response Question 1

- ☑ **Scoring Guideline**
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AP® PHYSICS
2018 SCORING GUIDELINES

General Notes About 2018 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. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. 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.

4. 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 embeds the application of that equation to the problem in other work, 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 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

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

6. 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.

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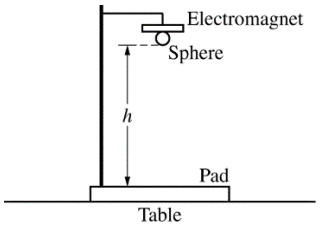
AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**



A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

(a) 2 points

While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

For selecting "Less than" with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Because the measured time to fall the same distance will be larger, the acceleration must be less.		
Example: Because the time is larger and $a \propto 1/t^2$ *, then g must decrease.*		

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Question 1 (continued)

Distribution of points

The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

(b) 1 point

Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

Vertical axis: _____

Horizontal axis: _____

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

For correctly indicating two variables that will yield a straight line that could be used to determine a value for g		1 point
Example: Vertical Axis: h *Horizontal Axis:* $(\Delta t)^2$		
Note: Student earns full credit if axes are reversed or if they use another acceptable combination.		

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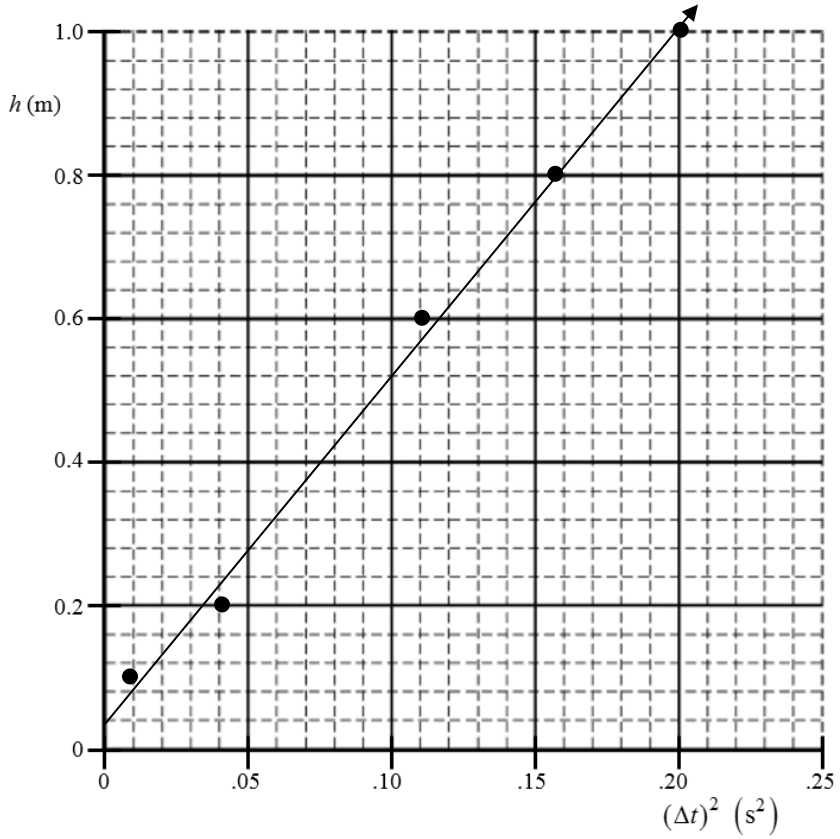
Question 1 (continued)

Distribution of points

(c) 4 points

Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



For a correct scale that uses more than half the grid		1 point
For correctly labeling the axis with variables and units consistent with part (b)		1 point
For correctly plotting data consistent with part (b)		1 point
For drawing a straight line consistent with the plotted data		1 point

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Question 1 (continued)

Distribution of points

(d) 2 points

Using the straight line, calculate an experimental value for *g*.

For using points on the line rather than the data to calculate the slope		1 point
$\text{slope} = \dfrac{\Delta h}{\Delta(\Delta t)^2} = \dfrac{(0.80 - 0.20)\ \text{m}}{(0.160 - 0.039)\ \text{s}^2} = 4.96\ \text{m/s}^2$ (Linear regression = $4.83\ \text{m/s}^2$)		
For correctly relating the slope to the acceleration due to gravity		1 point
$\text{slope} = \dfrac{1}{2}g\ \therefore\ g = 2 \times \text{slope} = 2 \times \left(4.96\ \text{m/s}^2\right)$		
$g = 9.92\ \text{m/s}^2$ (Linear regression = $9.66\ \text{m/s}^2$)		

Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen *y* as a function of time *t* is $y = At^2 + Bt + C$, where $A = 5.75\ \text{m/s}^2$, $B = -0.524\ \text{m/s}$, and $C = +0.080\ \text{m}$. Vertically down is the positive direction.

(e) Using the student's equation above, do the following.

i. 1 point

Derive an expression for the velocity of the sphere as a function of time.

For correctly taking the time derivative of the given equation		1 point
$y = y_0 + v_1 t + \dfrac{1}{2}at^2 = At^2 + Bt + C$		
$v(t) = \dfrac{dy}{dt} = 2At + B$		
Note: Credit is earned for substituting numbers: $v(t) = \left(11.5\ \text{m/s}^2\right)t - 0.524\ \text{m/s}$.		

ii. 2 points

Calculate the new experimental value for g.

For correctly relating the given equation to a correct kinematic equation		1 point
$\Delta y = y - y_0 = v_1 t + \dfrac{1}{2}at^2$		
$y = y_0 + v_1 t + \dfrac{1}{2}at^2 = At^2 + Bt + C$		
For correctly relating the equation to the value of g		1 point
$A = \dfrac{1}{2}a = \dfrac{1}{2}g$		
$g = 2A = (2)\left(5.75\ \text{m/s}^2\right) = 11.5\ \text{m/s}^2$		

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Question 1 (continued)

Distribution of points

iii. 1 point

Using $9.81\ \text{m/s}^2$ as the accepted value for *g* at this location, calculate the percent error for the value found in part (e)(ii).

For correctly calculating the percent error		1 point
$\%\text{error} = \frac{\lvert\text{acc} - \text{exp}\rvert}{\text{acc}} \times 100\% = \frac{\left\lvert\left(11.5\ \text{m/s}^2\right) - \left(9.81\ \text{m/s}^2\right)\right\rvert}{\left(9.81\ \text{m/s}^2\right)} \times 100\%$		
$\%\text{error} = 17.2\%$		
Note: Credit is earned if percent error is expressed as positive or negative.		

iv. 2 points

Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

For relating the coefficients of the equation to the kinematic variables		1 point
$y = At^2 + Bt + C \ \therefore v_1 = B = -0.524\ \text{m/s}$		
$a = 2A = 2 \times \left(5.75\ \text{m/s}^2\right) = 11.5\ \text{m/s}^2$		
$y_0 = C = 0.080\ \text{m}$		
For correctly using an appropriate kinematics equation to determine the velocity of the sphere		1 point
$v_2^2 = v_1^2 + 2a\Delta y$		
$v = \sqrt{v_1^2 + 2a\Delta y} = \sqrt{(-0.524\ \text{m/s})^2 + (2)\left(11.5\ \text{m/s}^2\right)(1.40\ \text{m} - 0.080\ \text{m})}$		
$v = 5.54\ \text{m/s}$		
Alternate solution:		*Alternate Points*
For correctly determining the time of fall for the sphere		*1 point*
$y = At^2 + Bt + C$		
$1.40 = \left(5.75\ \text{m/s}^2\right)t^2 + (-0.524\ \text{m/s})t + (0.080\ \text{m})$		
$5.75t^2 - 0.524t - 1.32 = 0$		
$t = 0.53\ \text{s}$ or $-0.44\ \text{s} \ \therefore t = 0.53\ \text{s}$		
For correctly using the equation from part (e)(i)		*1 point*
$v(t) = \left(11.5\ \text{m/s}^2\right)(0.53\ \text{s}) - 0.524\ \text{m/s}$		
$v = 5.54\ \text{m/s}$		

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Question 1 (continued)

Distribution of points

(e)

iv. (continued)

Alternate Solution — Conservation of Energy		
For relating the coefficients of the equation to the initial height and speed		1 point
$y = At^2 + Bt + C \ \therefore v_1 = B = -0.524$ m/s		
$y_0 = C = 0.080$ m		
For correctly using conservation of energy to determine the velocity of the sphere		1 point
$U_i + K_i = U_f + K_f$		
$mgh + \frac{1}{2}mv_1^2 = \frac{1}{2}mv^2$		
$v = \sqrt{2(11.5)(1.40 - 0.080) + (-0.524)^2} = 5.54$ m/s		

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M Q1 A p1

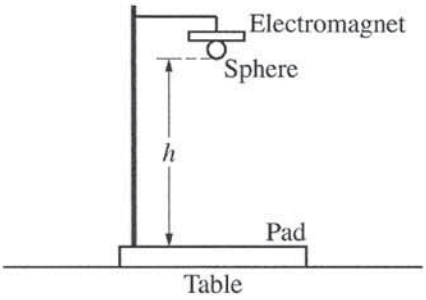
PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



$\Delta y = v_0 t + \frac{1}{2} g t^2$

$\Delta y = \frac{1}{2} g t^2$

1. A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

   (a) While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

   ____ Greater than ___X___ Less than ____ Equal to

   Justify your answer.

To calculate for the accleration due to gravity, one must use the equation $\Delta y = \frac{1}{2} g t^2$ or $h = \frac{1}{2} g t^2$. g is, therefore inversely proportional to t^2 so if t^2 is greater t^2 is greater meaning g would be calculated as less than the actual value of g.

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The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451
t^2 (s^2)	.011025	.045369	.116964	.160801	.203401

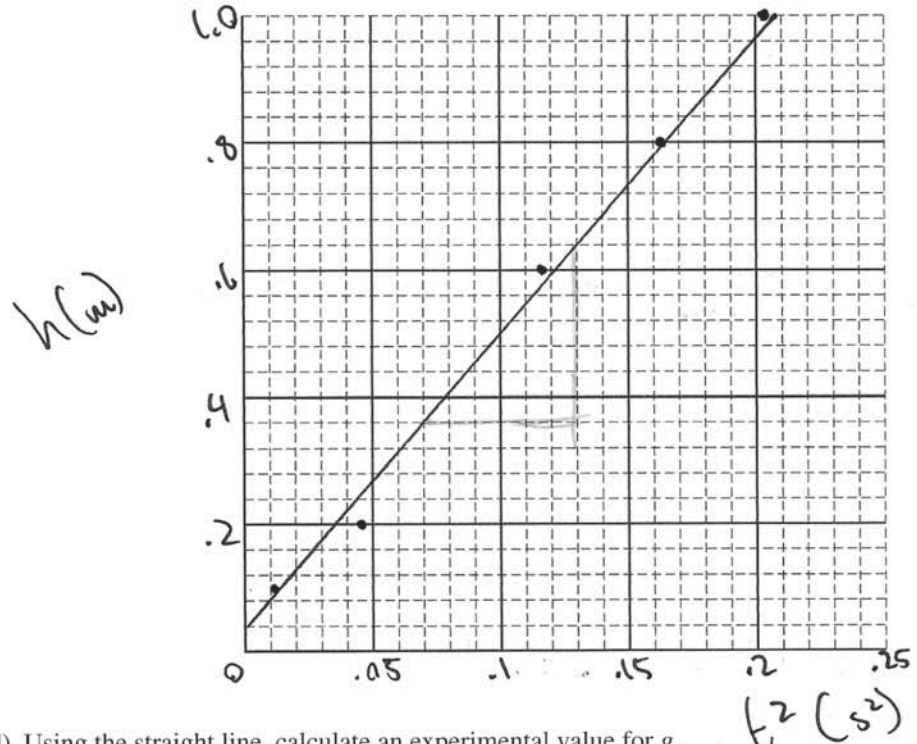
(b) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

Vertical axis: h (m)

Horizontal axis: t^2 (s^2)

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

(c) Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(d) Using the straight line, calculate an experimental value for g.

$m = \frac{\Delta y}{\Delta x} = \frac{.64 - .36}{.13 - .07} = 4.667 = \frac{dh}{dt^2}$

$\Delta y = h = \frac{1}{2} g t^2 \qquad g = \frac{2h}{t^2} \qquad g = 2(4.667) = 9.333\ m/s^2$

Question 1 continues on the next page.

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Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where $A = 5.75\ \text{m/s}^2$, $B = -0.524\ \text{m/s}$, and $C = +0.080\ \text{m}$. Vertically down is the positive direction.

(e) Using the student's equation above, do the following.

i. Derive an expression for the velocity of the sphere as a function of time.

$v(t) = y'(t) = 2At + B$

$v(t) = 11.5t - .524$

ii. Calculate the new experimental value for g.

$g = a(t) = v'(t) = y''(t) = 11.5$

$g = 11.5\ \text{m/s}^2$

iii. Using $9.81\ \text{m/s}^2$ as the accepted value for g at this location, calculate the percent error for the value found in part (e)ii.

$\%\ \text{error} = \frac{\text{final} - \text{intial}}{\text{initial}} \times 100 = 17.23\%$

iv. Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

$1.4 = 5.75t^2 - .524t + .08$

$t = .527\ \text{s}$

$v(t) = y'(t) = 11.5t - .524$

$v(.527) = 11.5 \cdot .527 - .524 = 5.5365\ \text{m/s}$

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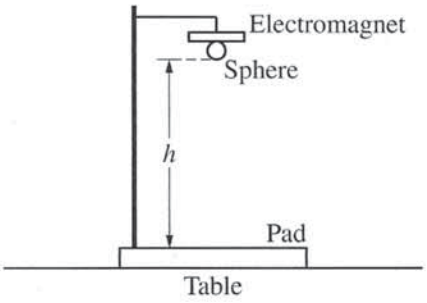
M Q1 B p1

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

   (a) While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

   ____ Greater than ✓ Less than ____ Equal to

   Justify your answer.

   Since the sphere is released after the timer begins, the timer will count longer than it actually takes the ball, reflecting a perceived lower average acceleration

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The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

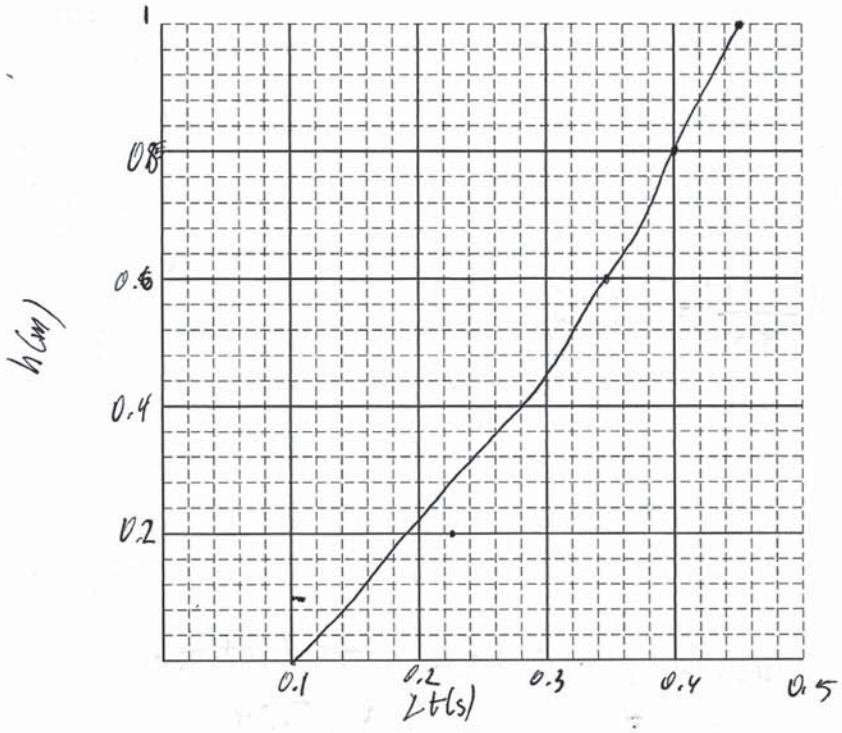
(b) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

Vertical axis: h(m)

Horizontal axis: Δt(s)

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

(c) Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(d) Using the straight line, calculate an experimental value for g.

$\frac{0.451-0}{1-0} = 0.45$ m/s

Question 1 continues on the next page.

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Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where $A = 5.75\ \text{m/s}^2$, $B = -0.524\ \text{m/s}$, and $C = +0.080\ \text{m}$. Vertically down is the positive direction.

(e) Using the student's equation above, do the following.

i. Derive an expression for the velocity of the sphere as a function of time.

$\frac{dy}{dt} = v = 11.5t - 0.524$

ii. Calculate the new experimental value for g.

$\frac{dv}{dt} = a = 11.5\ \text{m/s}^2$

iii. Using $9.81\ \text{m/s}^2$ as the accepted value for g at this location, calculate the percent error for the value found in part (e)ii.

$\frac{11.5 - 9.81}{9.81} = 17\%$

iv. Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

$\frac{1}{2}at^2 * vt = x$ $\quad 4.4t^2 = 1.4$ $\quad t = 0.58$ $\quad v = at + v_0$ $\quad$ ~~$v = 5.61\ \text{m/s}$~~ $\quad v = 5.24$

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M Q1 C p1

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

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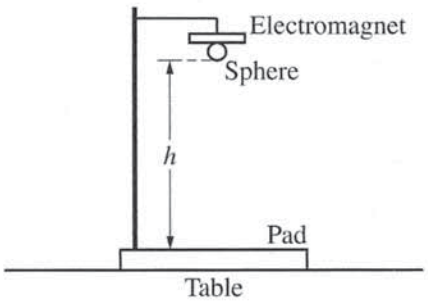

1. A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

   (a) While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

   ✓ Greater than ___ Less than ___ Equal to

   Justify your answer.

$a = \frac{\Delta v}{\Delta t}$ → actual

∴ less time means greater "a"

$a = \frac{\Delta v}{\text{smaller } \Delta t}$ → experiment

$a = g$

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The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451
v (m/s)	.952	[illegible]	[illegible]	[illegible]	[illegible]
		.939	1.754	2.000	2.217

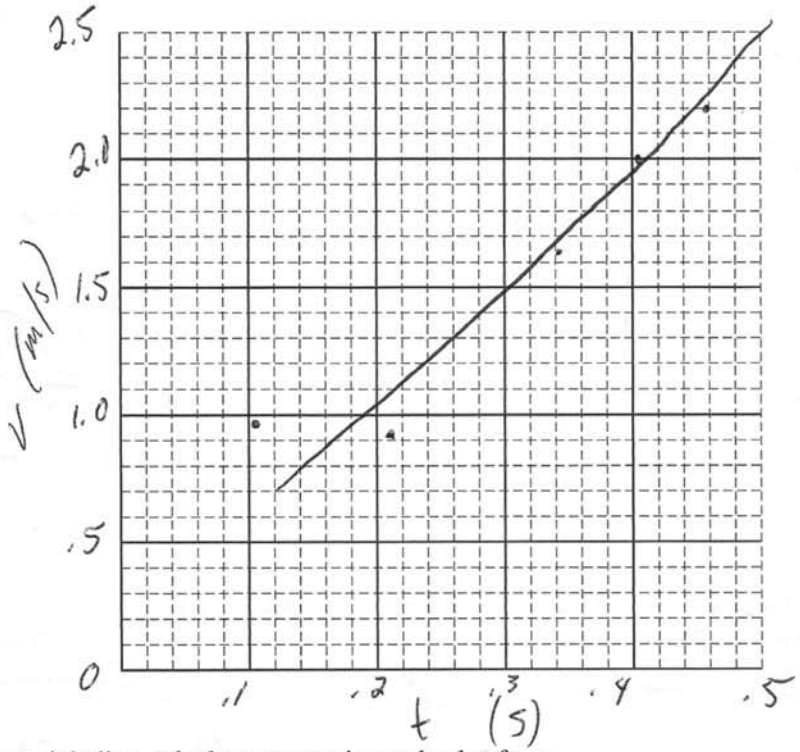
(b) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

Vertical axis: [illegible] v

Horizontal axis: Δt

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

(c) Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(d) Using the straight line, calculate an experimental value for g.

$\frac{1}{.2}$ $5 = g$ m/s^2

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Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where $A = 5.75\ \text{m/s}^2$, $B = -0.524\ \text{m/s}$, and $C = +0.080\ \text{m}$. Vertically down is the positive direction.

(e) Using the student's equation above, do the following.

i. Derive an expression for the velocity of the sphere as a function of time.

$y = 5.75t^2 - .524t + .08$

$v(t) = 11.5t - .524$

ii. Calculate the new experimental value for g.

$v'(t) = 11.5$

iii. Using $9.81\ \text{m/s}^2$ as the accepted value for g at this location, calculate the percent error for the value found in part (e)ii.

$$\frac{|9.81 - 11.5|}{11.5} \cdot 100 = 14.696\%\ \text{error}$$

iv. Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

$\frac{1}{2}mv^2 = mgh$

$v = \sqrt{2gh}$

$v = \sqrt{2(9.81\ \text{m/s}^2)(1.4\ \text{m})}$

$v = 5.241\ \text{m/s}$

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2018 SCORING COMMENTARY

Question 1

Overview

The responses to this question were expected to demonstrate the following:

- A basic understanding of kinematics and students' ability to linearize experimental data using kinematic relationships.
- Graphing skills and students' ability to analyze both graphed and modeled data.

Sample: M Q1 A
Score: 15

All parts earned full credit. In part (a) "Less than" is selected, and the justification indicates that an increase in time would decrease the value of acceleration due to gravity g, so 2 points were earned. In part (b) 1 point was earned because the indicated variables will result in a straight line graph. In part (c) the graph has an appropriate scale, the axes are properly labeled, the data points are plotted correctly, and an appropriate best-fit line is drawn, so all 4 points were earned. In part (d) the slope is correctly calculated and related to the acceleration due to gravity g, so 2 points were earned. In part (e)(i) 1 point was earned for correctly taking the derivative. In part (e)(ii) an appropriate kinematics equation is used and correctly related to the acceleration due to gravity, which earned 2 points. In part (e)(iii) the percent is calculated correctly, so 1 point was earned. In part (e)(iv) a correct kinematics equation is used, and the equation from (e)(i) is used to calculate the velocity, so 2 points were earned.

Sample: M Q1 B
Score: 9

Part (a) earned full credit, 2 points. Part (b) indicates variables that will not create a straight line, so no points were earned. In part (c) the graph has an appropriate scale, the axes are properly labeled, the data points are plotted correctly, but the best-fit line is not properly drawn, so 3 points were earned. In part (d) the slope is calculated from data points and not the line drawn, and the slope is not related to g, so no points were earned. In part (e)(i) 1 point was earned for correctly taking the derivative. In part (e)(ii) the derivative of velocity is indicated and correctly related to the acceleration due to gravity, which earned 2 points. In part (e)(iii) the percent is calculated correctly, so 1 point was earned. In part (e)(iv) a correct kinematics equation is used, but 9.8 is used for acceleration instead of the value from part (e)(ii), so no points were earned.

Sample: M Q1 C
Score: 5

In part (a) an incorrect selection is made, and the justification is incorrect, so no points were earned. In part (b) because there is not a valid way to calculate the speed, no points were earned. In part (c) the graph has an appropriate scale, the axes are labeled consistent with (b), but the third data point is not correct, and the best-fit line is not properly drawn, so 2 points were earned. In part (d) the slope is not calculated correctly, and the relation to g is not correct, so no points were earned. In part (e)(i) there is no indication that the derivative was taken (for "derive," this must be explicitly shown), so no points were earned. Part (e)(ii) earned full credit, totaling 2 points. In part (e)(iii) the correct equation is used, and the accepted value is used in the denominator, so 1 point was earned. In part (e)(iv) the coefficients from the given quadratic fit are not correctly related to the initial conditions, and 9.8 is used for acceleration due to gravity instead of the value from part (e)(ii), so no points were earned.

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