2023

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 2

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 2: Experimental Design — 12 points

(a)(i) For indicating two quantities that, when graphed together, produce a straight line whose slope can be used to determine the acceleration a — **1 point**

Example Response

Vertical Axis : *Position* Horizontal Axis : *Time squared*

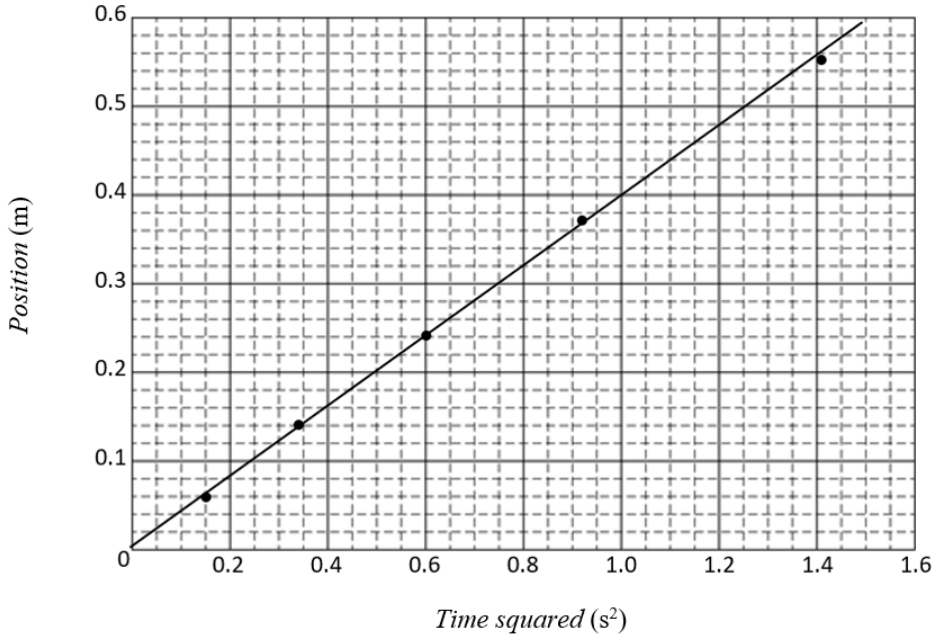
Position x (m)	Time t (s)	Time squared t^2 (s^2)
0.06	0.39	0.15
0.14	0.59	0.35
0.24	0.77	0.59
0.37	0.96	0.92
0.55	1.20	1.44

(a)(ii) The axes have a linear scale and are identified (labels **OR** units) so that when graphed correctly, the data will span more than half of the horizontal and vertical axes — **1 point**

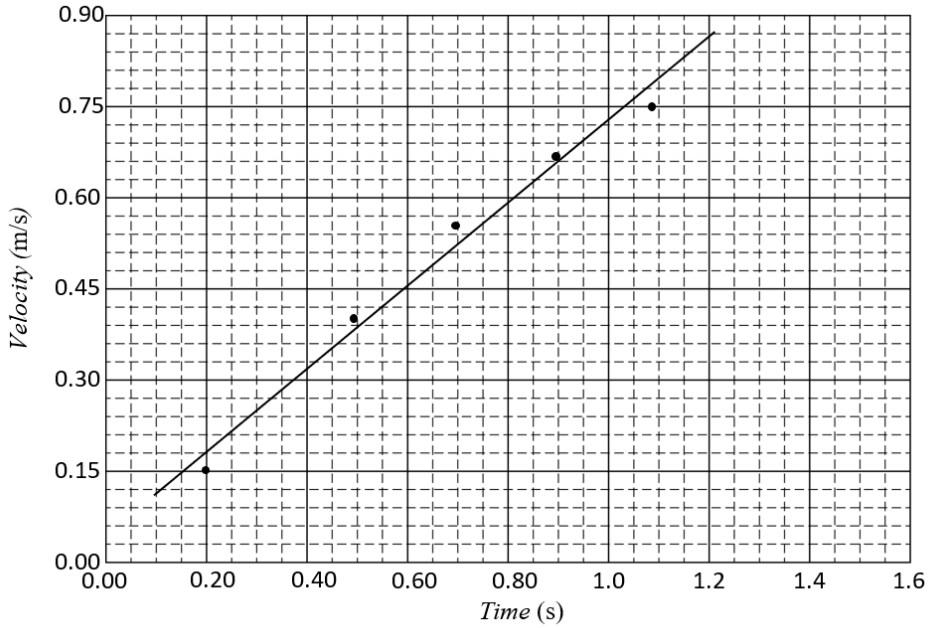
For plotting at least 4 of the data points correctly — **1 point**

For drawing a best-fit line that approximates the trend of the data — **1 point**

Example Response



Alternate Example Response



Scoring Note: The following tables represent the most common linearized graphs with the data that were used to determine the acceleration.

Graph: v vs. t	
$v\ \left(\frac{\text{m}}{\text{s}}\right)$	t (s)
0.15	0.20
0.40	0.49
0.56	0.68
0.68	0.87
0.75	1.08

Graph: $2x$ vs. t^2	
$2x$ (m)	$t^2\ \left(\text{s}^2\right)$
0.12	0.15
0.28	0.35
0.48	0.59
0.74	0.92
1.10	1.44

Graph: $2v_{\text{avg}}$ vs. t	
$2v_{\text{avg}}\ \left(\frac{\text{m}}{\text{s}}\right)$	t (s)
0.31	0.39
0.47	0.59
0.62	0.77
0.77	0.96
0.92	1.20

Graph: x vs. $\frac{1}{2}t^2$	
x (m)	$\frac{1}{2}t^2\ \left(\text{s}^2\right)$
0.06	0.08
0.14	0.17
0.24	0.30
0.37	0.46
0.55	0.72

Graph: ${v_{\text{avg}}}^2$ vs. x	
${v_{\text{avg}}}^2\ \left(\frac{\text{m}^2}{\text{s}^2}\right)$	x (m)
0.02	0.06
0.06	0.14
0.10	0.24
0.15	0.37
0.21	0.55

Graph: $\sqrt{x}$ vs. t	
$\sqrt{x}\ \left(\sqrt{\text{m}}\right)$	t (s)
0.24	0.39
0.37	0.59
0.49	0.77
0.61	0.96
0.74	1.20

(a)(iii)

For attempting to find the slope, $\left(\frac{\text{rise}}{\text{run}}\right)$ or $\left(\frac{\Delta y}{\Delta x}\right)$, of the best-fit line drawn in part (a)(ii) **1 point**

Scoring Note: An indication that a calculator was used for linear regression to determine the value of the slope may earn this point.

For using the slope in a valid kinematic equation to calculate the acceleration **1 point**

Scoring Note: This point can be earned if evidence of a kinematic equation exists in graphed quantities (e.g., a graph of position as a function of $\frac{1}{2}t^2$).

Example Response

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta \text{ position}}{\Delta \text{ time}^2} = \frac{0.48 \text{ m} - 0.18 \text{ m}}{1.2 \text{ s}^2 - 0.4 \text{ s}^2} = 0.375 \ \frac{\text{m}}{\text{s}^2}$$

$$\Delta x = v_0 t + \frac{1}{2}at^2$$

$$\frac{\Delta x}{t^2} = \frac{1}{2}a$$

$$\text{slope} \times 2 = a$$

$$a = 0.75 \ \frac{\text{m}}{\text{s}^2}$$

Total for part (a) 6 points

(b)(i) For indicating a quantity to be measured **1 point**

Accept **one** of the following:

- The angle θ with the horizontal
- The height h and length L of the ramp

Scoring Note: Stating only the height needs to be measured can earn this point if an energy approach is used.

(b)(ii) For providing a correct expression relating the acceleration of gravity to the acceleration measured **1 point**

Scoring Note: If $\cos\theta$ is used, the response must specify that θ was measured from the vertical.

Example Response

$mg_{\text{exp}} \sin\theta = ma$

$g_{\text{exp}} = \dfrac{a}{\sin\theta}$

OR

$\sin\theta = \dfrac{h}{L}$

$g_{\text{exp}} = \left(\dfrac{L}{h}\right)a$

OR

$mg_{\text{exp}}h = \dfrac{1}{2}mv^2$

$g_{\text{exp}}h = \dfrac{1}{2}v^2$

$v = \sqrt{2g_{\text{exp}}h}$

$v = at$

$at = \sqrt{2g_{\text{exp}}h}$

$g_{\text{exp}} = \dfrac{a^2t^2}{2h}$

Total for part (b) 2 points

(c)(i) For identifying a physical factor that could have affected the result **1 point**

Accept **one** of the following:

- A physical factor in the materials used (e.g., the wheels have nonnegligible rotational inertia, the ramp was bumpy, the wheels were wobbly or not perfectly round, the base of the ramp was not level, the floor was not level.)
- A physical factor in the environment (e.g., the room was being accelerated, elevator, the experiment was performed at high elevation or on a different planet.)
- A physical error in measurement collection (e.g., time, position, or angle was measured incorrectly.)

Scoring Note: A statement of "Human error" does not earn this point.

(c)(ii) For correctly indicating the functional dependence between the reason listed in part (c)(i) and g_{exp} **1 point**

Accept **one** of the following:

- Correctly indicating the functional dependence between the physical factor in the materials used and g_{exp} (e.g., if the rotational inertia of the rotating wheels is nonnegligible, the cart will have a smaller acceleration and g_{exp} will be smaller.)
- Correctly indicating the functional dependence between the physical factor in the environment and g_{exp} (e.g., if the experiment was performed at a high elevation, the acceleration will be smaller and g_{exp} will be smaller.)
- Correctly indicating the functional dependence between the physical error in the measurement collection and g_{exp} (e.g., if the angle of the ramp is smaller than the measured value, the cart will have a smaller acceleration and g_{exp} will be smaller.)

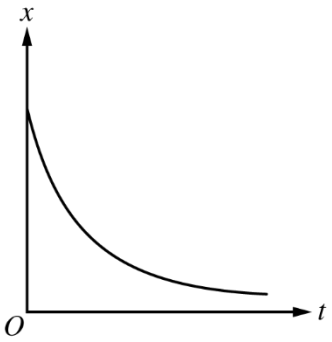
Example Response

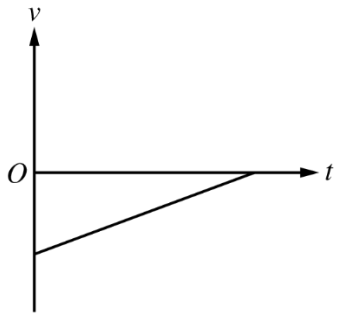
The expression I derived for the value for g_{exp} did not take into consideration that the wheels had any rotational inertia. If the wheels have rotational inertia and are rotating, the acceleration of the cart would be less than $g\sin\theta$, so the value of g_{exp} would be less than $9.8\ \frac{\text{m}}{\text{s}^2}$.

Total for part (c) 2 points

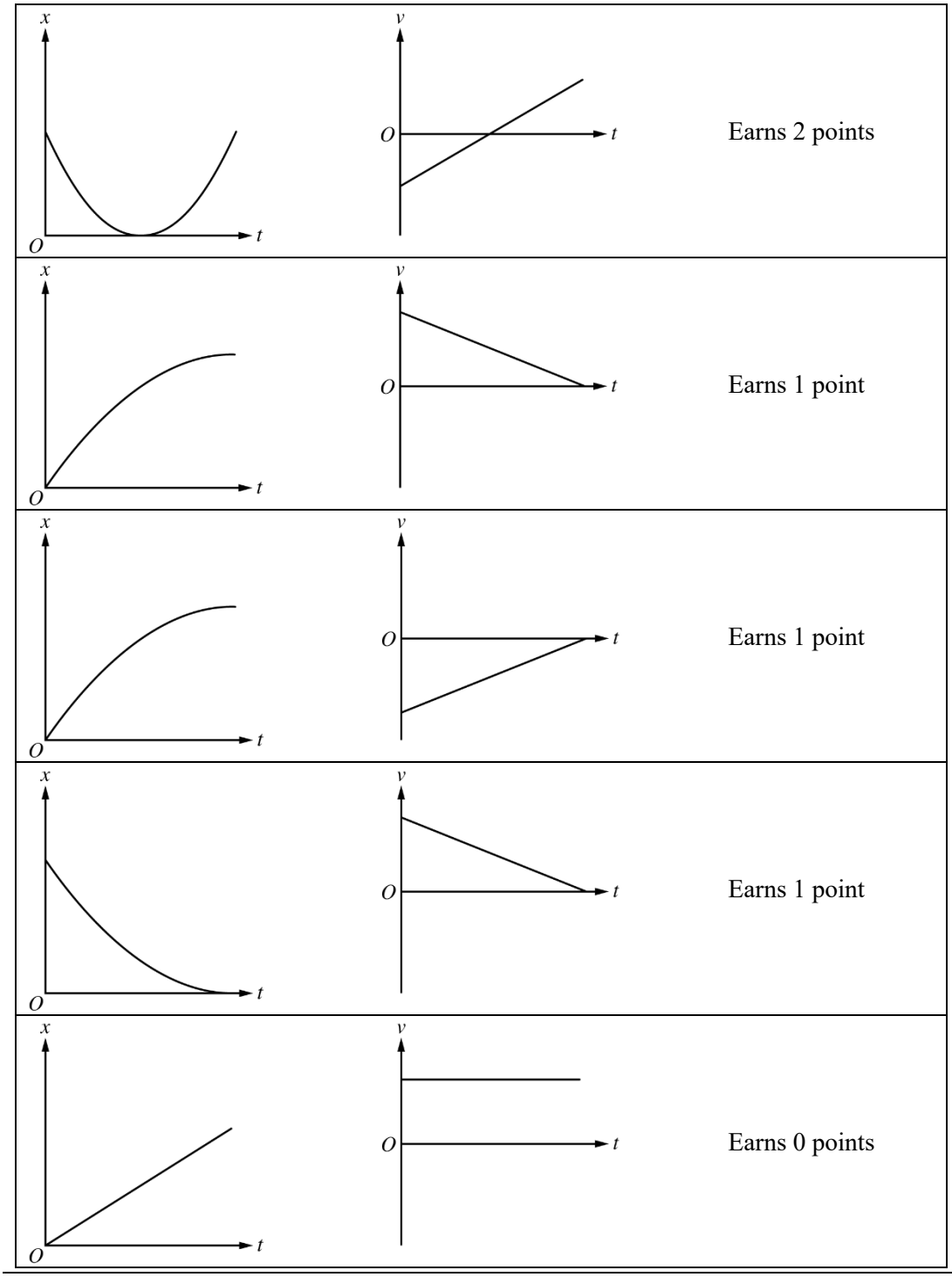
(d)	For sketching a concave up curve with an initially negative slope for the graph of position as a function of time	**1 point**
	For **one** of the following: • Drawing a line with a positive slope and a negative vertical intercept for the v vs. t graph • Drawing a v vs. t graph that is consistent with the x vs. t graph that shows acceleration	**1 point**

Example Response





Scoring Note: The following are alternate example graphs with the points the response would earn.



Total for part (d) 2 points

Total for question 2 12 points

Question 2

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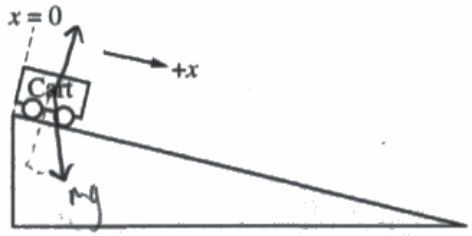

2. (12 points, suggested time 25 minutes)

(a) Students conduct an experiment to determine the acceleration a of a cart. The cart is released from rest at the top of the ramp at time $t = 0$ and moves down the ramp. The x-axis is defined to be parallel to the ramp with its origin at the top, as shown in the figure. The students collect the data shown in the following table.

	Position x (m)	Time t (s)	time t^2 (s^2)
	0.06	0.39	0.15
	0.14	0.59	0.35
	0.24	0.77	0.59
	0.37	0.96	0.92
	0.55	1.20	1.44

i. Indicate which quantities could be graphed to yield a straight line whose slope could be used to determine the acceleration a of the cart. You may use the remaining columns in the table, as needed, to record any quantities (including units) that are not already in the table.

Vertical axis: time t^2 (s^2) Horizontal axis: position x (m)

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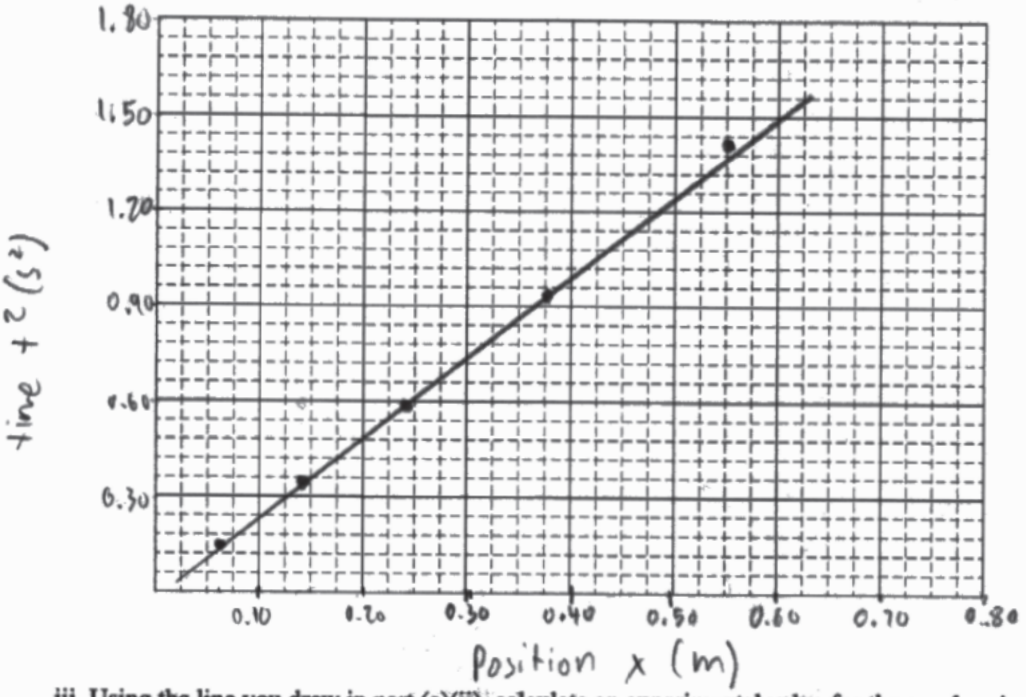
Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 2

Continue your response to **QUESTION 2** on this page.

ii. On the following grid, plot the appropriate quantities to create a graph that can be used to determine the acceleration a of the cart as it rolls down the ramp. Clearly scale and label all axes (including units), as appropriate. Draw a straight line that best represents the data.



iii. Using the line you drew in part (a)(ii), calculate an experimental value for the acceleration a of the cart as it rolls down the ramp.

$\text{slope} = \frac{0.59 - 0.35}{0.24 - 0.14} = 2.4$ | $a = \frac{1}{\text{slope}} = \frac{1}{2.4} = 0.42\ m/s^2$

(b) The students are asked to determine an experimental value for the acceleration due to gravity g_{exp} using their data.

i. What additional quantities do the students need to measure in order to calculate g_{exp} from a ?

$\Sigma F = ma$
$mg\sin\theta = ma$ | Students need to measure angle of ramp

ii. Write an expression for the value of g_{exp} in terms of a.

$\Sigma F = ma$

$mg\sin\theta = ma$

$g_{exp} = \frac{a}{\sin\theta}$

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Question 2

Continue your response to **QUESTION 2** on this page.

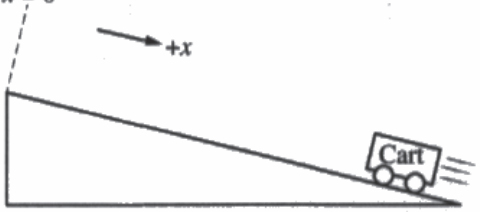
(c) The students calculate the value of g_{exp} to be significantly lower than the accepted value of 9.8 m/s^2.

(i) What is a physical reason, other than friction or air resistance, that could lead to a significant difference in the experimentally determined value of g_{exp} ?

The students may have measured the angle of the ramp to be too large.

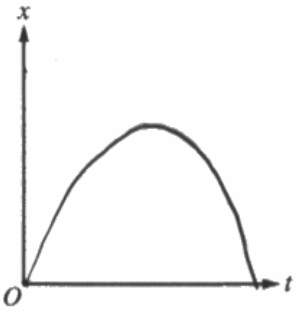
ii. Briefly explain how the physical reason you identified in part (c)(i) would lead to the decrease in the experimentally determined value of g_{exp} .

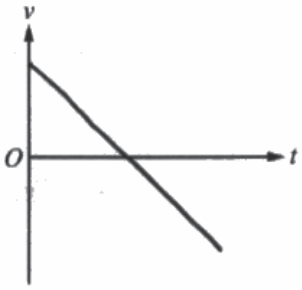
since $g_{exp} = \frac{a}{\sin\theta}$, if θ is too large $\sin\theta$ becomes large and since g is inversly proportional to g_{exp} the large θ leads to smaller g_{exp}.



The students want to confirm that the acceleration is the same whether the cart rolls up or down the ramp. The students start the cart at the bottom and give the cart a quick push so that it rolls up the ramp and momentarily comes to rest. The x-axis is still defined to be parallel to the ramp with the origin at the top.

(d) On the following graphs, sketch the position x and velocity v as functions of time t that correspond to the scenario shown while the cart moves up the ramp.





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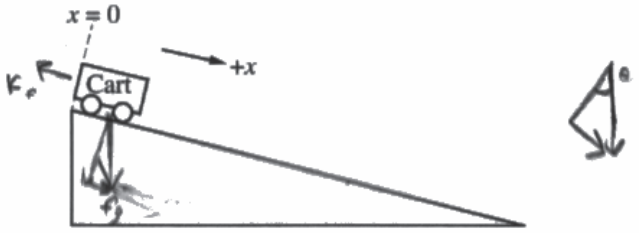


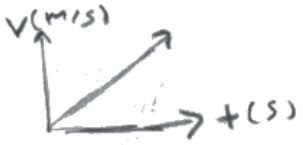
2. (12 points, suggested time 25 minutes)

(a) Students conduct an experiment to determine the acceleration a of a cart. The cart is released from rest at the top of the ramp at time $t = 0$ and moves down the ramp. The x-axis is defined to be parallel to the ramp with its origin at the top, as shown in the figure. The students collect the data shown in the following table.

Velocity v (m/s)	Position x (m)	Time t (s)	
≈0.15	0.06	0.39	
≈0.27	0.14	0.59	
≈0.31	0.24	0.77	
≈0.39	0.37	0.96	
≈0.46	0.55	1.20	

i. Indicate which quantities could be graphed to yield a straight line whose slope could be used to determine the acceleration a of the cart. You may use the remaining columns in the table, as needed, to record any quantities (including units) that are not already in the table.

Vertical axis: Velocity (m/s) Horizontal axis: Time (s)



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Question 2

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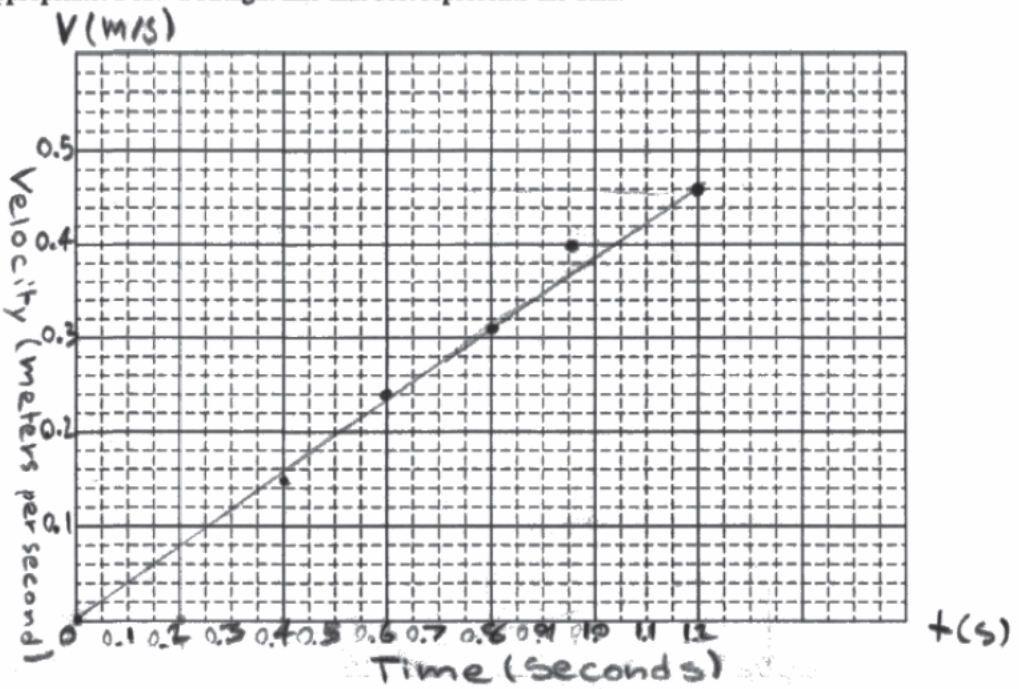
ii. On the following grid, plot the appropriate quantities to create a graph that can be used to determine the acceleration a of the cart as it rolls down the ramp. Clearly scale and label all axes (including units), as appropriate. Draw a straight line that best represents the data.



iii. Using the line you drew in part (a)(ii), calculate an experimental value for the acceleration a of the cart as it rolls down the ramp.

$$a = \frac{.46\left(\frac{m}{s}\right)}{1.2(s)} = 0.383\overline{3} \approx \boxed{0.383\ m/s^2} = a$$

(b) The students are asked to determine an experimental value for the acceleration due to gravity g_{exp} using their data.

i. What additional quantities do the students need to measure in order to calculate g_{exp} from a ?

none, as provided friction is negligible, a and g_{exp} are the same value as it is the only force acting on the system that isn't canceled out

ii. Write an expression for the value of g_{exp} in terms of a.

$a = F_g \sin\theta = g_{exp}$

$\Rightarrow \boxed{a = g_{exp}}$

or

$a + \vec{F}_f = g_{exp}$

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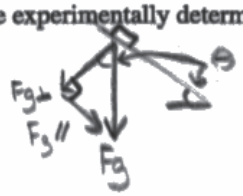
Question 2

Continue your response to **QUESTION 2** on this page.

(c) The students calculate the value of g_{exp} to be significantly lower than the accepted value of 9.8 m/s^2.

i. What is a physical reason, other than friction or air resistance, that could lead to a significant difference in the experimentally determined value of g_{exp} ?

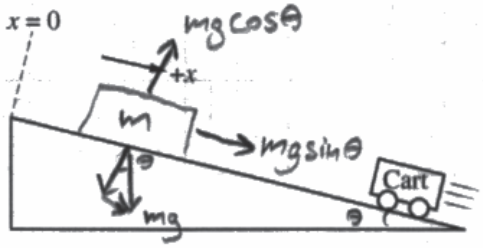


g_{exp} is lower than 9.8 m/s^2 because $F_g \sin\theta$ is the force causing the acceleration of the cart, which is not equal to the entire force of gravity.

ii. Briefly explain how the physical reason you identified in part (c)(i) would lead to the decrease in the experimentally determined value of g_{exp} .

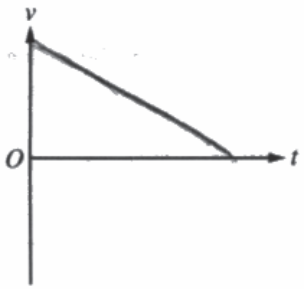
$\sqrt{(mg\sin\theta)^2 + (mg\cos\theta)^2} = mg$

$mg\sin(\theta) < mg$



The students want to confirm that the acceleration is the same whether the cart rolls up or down the ramp. The students start the cart at the bottom and give the cart a quick push so that it rolls up the ramp and momentarily comes to rest. The x-axis is still defined to be parallel to the ramp with the origin at the top.

(d) On the following graphs, sketch the position x and velocity v as functions of time t that correspond to the scenario shown while the cart moves up the ramp.



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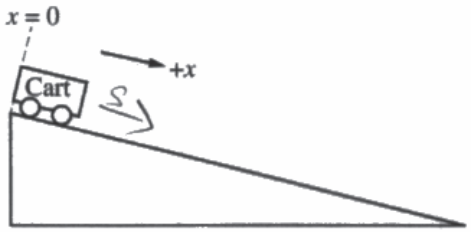

2. (12 points, suggested time 25 minutes)

(a) Students conduct an experiment to determine the acceleration a of a cart. The cart is released from rest at the top of the ramp at time $t = 0$ and moves down the ramp. The x-axis is defined to be parallel to the ramp with its origin at the top, as shown in the figure. The students collect the data shown in the following table.

Velocity (m/s)	Position x (m)	Time t (s)	
0.153	0.06	0.39	
.237	0.14	0.59	
.311	0.24	0.77	
.385	0.37	0.96	
.458	0.55	1.20	

i. Indicate which quantities could be graphed to yield a straight line whose slope could be used to determine the acceleration a of the cart. You may use the remaining columns in the table, as needed, to record any quantities (including units) that are not already in the table.

Vertical axis: Velocity (m/s) Horizontal axis: time.

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Question 2

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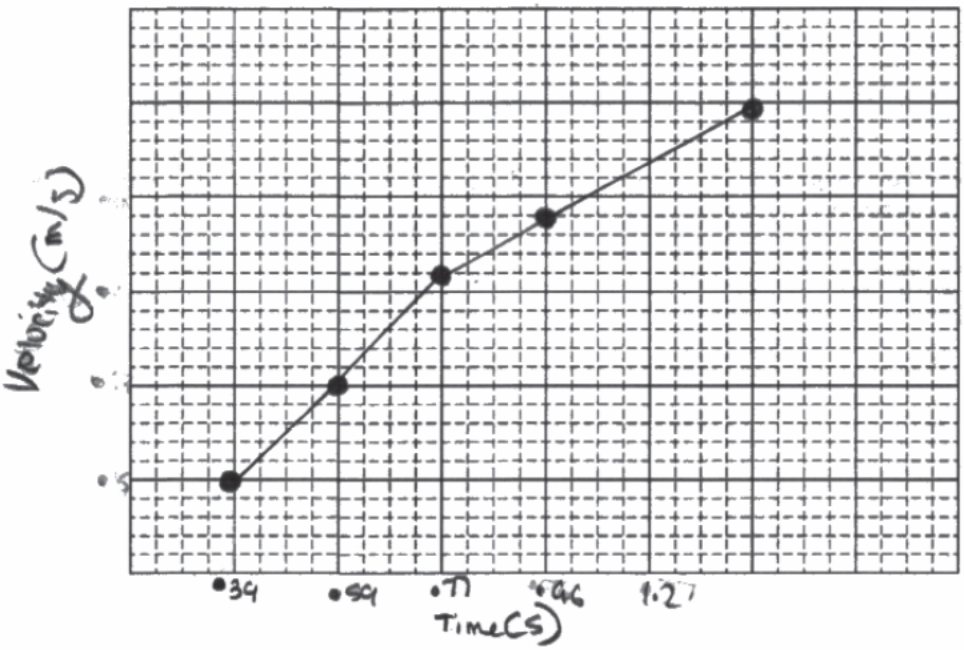

iii. Using the line you drew in part (a)(ii), calculate an experimental value for the acceleration a of the cart as it rolls down the ramp.

An experimental value would be $\frac{.237}{.59} = a$

$a = .40\ m/s^2$

(b) The students are asked to determine an experimental value for the acceleration due to gravity g_{exp} using their data.

i. What additional quantities do the students need to measure in order to calculate g_{exp} from a ?

The student would need to measure the net force.

ii. Write an expression for the value of g_{exp} in terms of a.

$g_{exp} = f_{net}(m)$

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Question 2

Continue your response to **QUESTION 2** on this page.

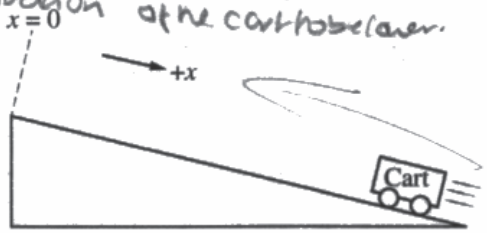
(c) The students calculate the value of g_{exp} to be significantly lower than the accepted value of 9.8 m/s^2.

i. What is a physical reason, other than friction or air resistance, that could lead to a significant difference in the experimentally determined value of g_{exp} ?

The significance reason needs to be the total mass of the system that is greater than earth. Higher the mass > the gravity pull causing the acceleration to be higher.

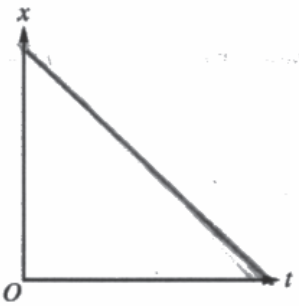
ii. Briefly explain how the physical reason you identified in part (c)(i) would lead to the decrease in the experimentally determined value of g_{exp}.

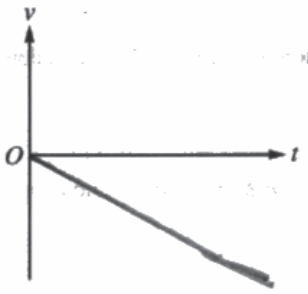
Since the gravity acceleration or gxp is lower in this system. A physical reason would be since the mass of cart is similar to the earths the gravitational pull would be lower making the acceleration of the cart to be lower.



The students want to confirm that the acceleration is the same whether the cart rolls up or down the ramp. The students start the cart at the bottom and give the cart a quick push so that it rolls up the ramp and momentarily comes to rest. The x-axis is still defined to be parallel to the ramp with the origin at the top.

(d) On the following graphs, sketch the position x and velocity v as functions of time t that correspond to the scenario shown while the cart moves up the ramp.





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Question 2

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Identify a pair of variables (i.e., x vs. t^2) whose slope can be used with kinematics equations to determine the acceleration of the cart moving down a ramp.
- Apply an appropriate linear scale to the graph.
- Draw a reasonable best-fit line that follows the trend of the data points in the graph and that is not forced to go through data points or the origin.
- Use the slope of the best-fit line to calculate the acceleration of the cart down the ramp.
- Identify additional information needed to determine a relationship between g_{exp} and acceleration.
- Derive an equation to determine g_{exp} from acceleration.
- Identify a physical reason beyond friction and air resistance that would reduce g_{exp}.
- Develop arguments to justify a correct functional dependence between the physical reason and g_{exp}.
- Graph the position versus time and the velocity versus time for a cart going up a ramp.

Sample: 2A
Score: 10

Part (a)(i) earned 1 point for correctly identifying two variables that will yield a straight line that could be used to determine a value for acceleration. If there are multiple conflicting labels, of which at least one is correct, look at the data table for clarification. If the data in the data table does not help clarify, use the following priority, if present: quantity, variable, and lastly units. The response initially is unclear if time or t squared was graphed, but the values in the data table confirm that the response is graphing time squared. Part (a)(ii) earned 3 points. One point was earned for scaling the axes so that the data spans more than half the horizontal and vertical axes. Both axes are appropriately identified. The second point was earned for plotting at least four points correctly. The third point was earned for showing a best-fit line that approximates the trend of the data. Part (a)(iii) earned 1 point for using two points from the best-fit line to calculate the slope of the line. The second point was not earned because the response does not use the slope in a valid kinematic equation to calculate the acceleration. Part (b)(i) earned 1 point for correctly identifying a quantity that is needed to calculate g_{exp} from a. Part (b)(ii) earned 1 point for providing a correct expression relating the acceleration of gravity to the acceleration measured. Part (c)(i) earned 1 point for identifying a physical factor that might have affected the experimentally determined value of g_{exp}. Part (c)(ii) earned 1 point for correctly indicating the functional dependence between the reason listed in part (c)(i) and g_{exp}. Part (d) earned 1 point for showing a v versus t line with a positive slope and a negative intercept. The second half of this graph does not affect this point. The other point was not earned because the response does not show an x versus t curve that is concave up and has an initially negative slope.

Question 2 (continued)

Sample: 2B
Score: 5

Part (a)(i) earned 1 point for correctly identifying two variables that will yield a straight line that could be used to determine a value for acceleration. Part (a)(ii) earned 3 points. One point was earned for scaling the axes so that the data spans more than half the horizontal and vertical axes. Both axes are appropriately identified. The second point was earned for plotting at least four points correctly. The third point was earned for showing a best-fit line that approximates the trend of the data. Part (a)(iii) earned 1 point for using the origin and another point from the best-fit line to calculate the slope of the line. The second point was not earned because the response does not use the slope in a valid kinematic equation to calculate the acceleration. Part (b)(i) earned no points because the response does not correctly identify a quantity that is needed to calculate g_{exp} from a. Part (b)(ii) earned no points because the response does not provide a correct expression relating the acceleration of gravity to the acceleration measured. Part (c)(i) earned no points because the response does not identify a physical factor that might have affected the experimentally determined value of g_{exp}. Part (c)(ii) earned no points because the response does not correctly indicate the functional dependence between the reason listed in part (c)(i) and g_{exp}. Part (d) earned no points because the response does not show an x versus t curve that is concave up and has an initially negative slope. The second point was not earned because the response shows a v versus t graph that is neither a line with a positive slope and a negative intercept nor a line consistent with the x versus t graph.

Sample: 2C
Score: 1

Part (a)(i) earned 1 point for correctly identifying two variables that will yield a straight line that could be used to determine a value for acceleration. Part (a)(ii) earned no points. The first point was not earned because the response uses a nonlinear scaling, and one axis is unscaled. The second point was not earned because the response does not plot at least four points correctly. The third point was not earned because the response does not have a best-fit line that approximates the trend of the data. Part (a)(iii) earned no points. The first point was not earned because the response does not use correct y values from the best-fit line. The second point was not earned because the response does not use the slope in a valid kinematic equation to calculate the acceleration. Part (b)(i) earned no points because the response does not correctly identify a quantity that is needed to calculate g_{exp} from a. Part (b)(ii) earned no points because the response does not provide a correct expression relating the acceleration of gravity to the acceleration measured. Part (c)(i) earned no points because the response does not identify a physical factor that might have affected the experimentally determined value of g_{exp}. Part (c)(ii) earned no points because the response does not correctly indicate the functional dependence between the reason listed in part (c)(i) and g_{exp}. Part (d) earned no points because the response does not show an x versus t curve that is concave up and has an initially negative slope. The second point was not earned because the response shows a v versus t graph that is neither a line with a positive slope and a negative intercept nor a line consistent with the x versus t graph.