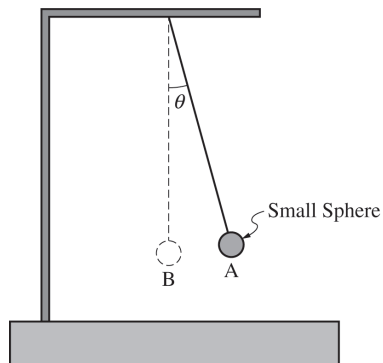


Begin your response to **QUESTION 4** on this page.

4. (7 points, suggested time 13 minutes)

A simple pendulum consists of a small sphere that hangs from a string with negligible mass. The top end of the string is fixed. The sphere is pulled to Point A so that the string makes a small angle θ with the vertical, as shown. The sphere is then released from rest and swings through its lowest point at Point B. The work done on the sphere by Earth between points A and B is W_E .

The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X .

(a) **Justify** why W_X is less than W_E .

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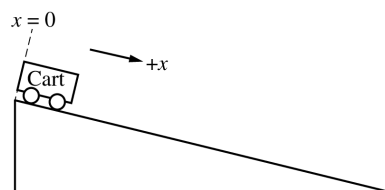
Continue your response to **QUESTION 4** on this page.

A new pendulum is made by hanging the same small sphere from a different string with negligible mass. The new string is slightly elastic, and the length of the string may increase or decrease depending on the tension applied to the string. On Earth, when the sphere is again displaced θ from the vertical and released from rest, the new pendulum oscillates with period T_E .

The new pendulum is then taken to a different planet, Planet Y. The radius of Planet Y is the same as the radius of Earth, but the mass of Planet Y is larger than the mass of Earth. On Planet Y, when the sphere is again displaced from the vertical and released from rest, the new pendulum oscillates with period T_Y .

(b) In a clear, coherent paragraph-length response that may also contain drawings, **explain** how T_Y could be larger than T_E but also could be smaller than T_E .

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(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)	
	0.06	0.39	
	0.14	0.59	
	0.24	0.77	
	0.37	0.96	
	0.55	1.20	

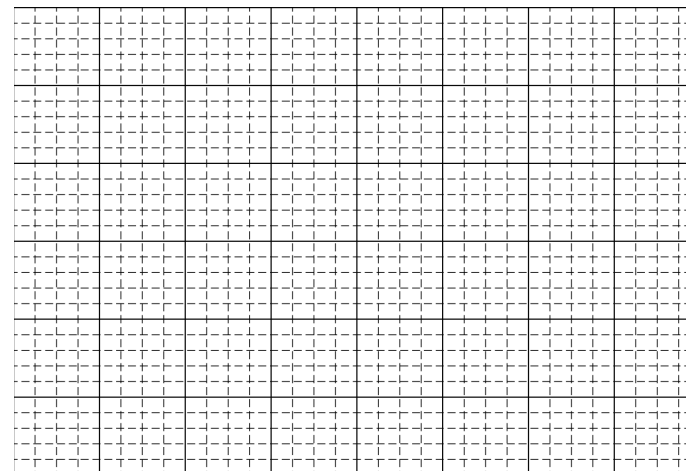
- i. Indicate which quantities could be graphed to yield a straight line whose slope could be used to determine the acceleration a of the cart. You may use the remaining columns in the table, as needed, to record any quantities (including units) that are not already in the table.

Vertical axis: _____ Horizontal axis: _____

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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.

- (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 ?

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

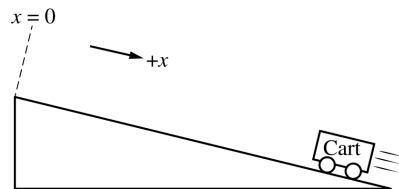
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Continue your response to QUESTION 2 on this page.

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

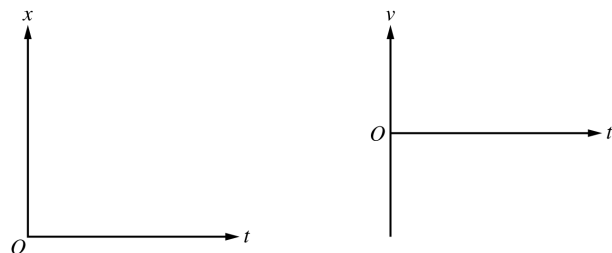
i. What is a physical reason, other than friction or air resistance, that could lead to a significant difference in the experimentally determined value of g_{exp} ?

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} .



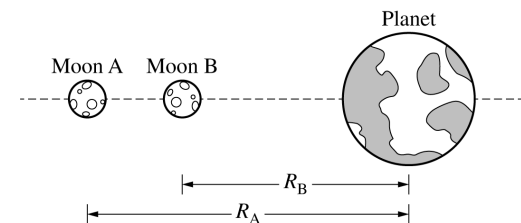
The students want to confirm that the acceleration is the same whether the cart rolls up or down the ramp. The students start the cart at the bottom and give the cart a quick push so that it rolls up the ramp and momentarily comes to rest. The x -axis is still defined to be parallel to the ramp with 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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Continue your response to QUESTION 2 on this page.

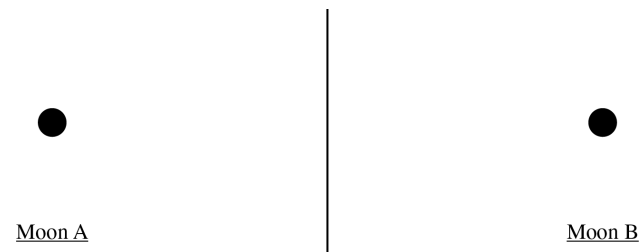


Note: Figure not drawn to scale.

(12 points, suggested time 25 minutes)

Two identical moons, Moon A and Moon B, orbit a planet. The mass m_0 of each moon is significant, but less than the mass m_p of the planet. At some point in their orbits, the planet and the two moons are aligned as shown in the figure.

(a) The following dots represent the two moons when they are at the locations shown in the previous figure. On each dot, draw and label the forces (not components) exerted on Moon A and on Moon B. Each force must be represented by a distinct arrow starting on, and pointing away from, the appropriate dot.



(b) Consider the net gravitational force exerted on each moon due to the planet and the other moon.

i. Justify why the magnitude of the net force exerted on Moon A could be larger than the magnitude of the net force exerted on Moon B.

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

ii. Justify why the magnitude of the net force exerted on Moon B could be larger than the magnitude of the net force exerted on Moon A.

(c) Derive expressions for both of the following quantities. Express your answers in terms of m_0 , m_p , R_A , R_B , and physical constants, as appropriate.

• The net force F_A exerted on Moon A

• The net force F_B exerted on Moon B

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

(d)

i. Could the expressions in part (c) support your reasoning in part (b)(i) ?

___ Yes ___ No

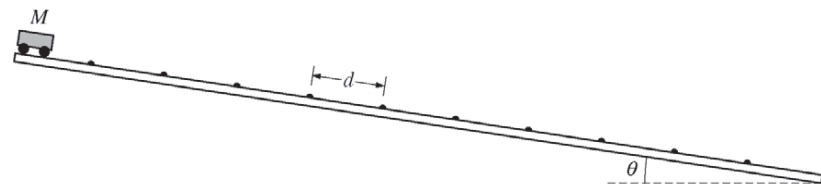
Explain your reasoning.

ii. Could the expressions in part (c) support your reasoning in part (b)(ii) ?

___ Yes ___ No

Explain your reasoning.

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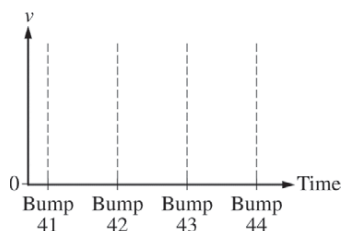
Note: Figure not drawn to scale.

3. (12 points, suggested time 25 minutes)

A long track, inclined at an angle θ to the horizontal, has small speed bumps on it. The bumps are evenly spaced a distance d apart, as shown in the figure above. The track is actually much longer than shown, with over 100 bumps. A cart of mass M is released from rest at the top of the track. A student notices that after reaching the 40th bump the cart's average speed between successive bumps no longer increases, reaching a maximum value v_{avg} . This means the time interval taken to move from one bump to the next bump becomes constant.

(a) Consider the cart's motion between bump 41 and bump 44.

- In the figure below, sketch a graph of the cart's velocity v as a function of time from the moment it reaches bump 41 until the moment it reaches bump 44.
- Over the same time interval, draw a dashed horizontal line at $v = v_{\text{avg}}$. Label this line " v_{avg} ".



(b) Suppose the distance between the bumps is increased but everything else stays the same.

Is the maximum speed of the cart now greater than, less than, or the same as it was with the bumps closer together?

____ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

(c) With the bumps returned to the original spacing, the track is tilted to a greater ramp angle θ . Is the maximum speed of the cart greater than, less than, or the same as it was when the ramp angle was smaller?

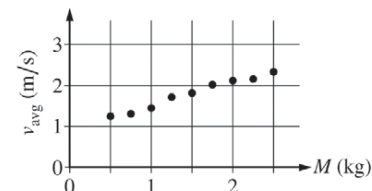
____ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

- (d) Before deriving an equation for a quantity such as v_{avg} , it can be useful to come up with an equation that is intuitively expected to be true. That way, the derivation can be checked later to see if it makes sense physically. A student comes up with the following equation for the cart's maximum average speed:

$$v_{\text{avg}} = C \frac{Mg \sin \theta}{d}, \text{ where } C \text{ is a positive constant.}$$

- To test the equation, the student rolls a cart down the long track with speed bumps many times in front of a motion detector. The student varies the mass M of the cart with each trial but keeps everything else the same. The graph shown below is the student's plot of the data for v_{avg} as a function of M .



Are these data consistent with the student's equation?

____ Yes ____ No

Briefly explain your reasoning.

- Another student suggests that whether or not the data above are consistent with the equation, the equation could be incorrect for other reasons. Does the equation make physical sense?

____ Yes ____ No

Briefly explain your reasoning.