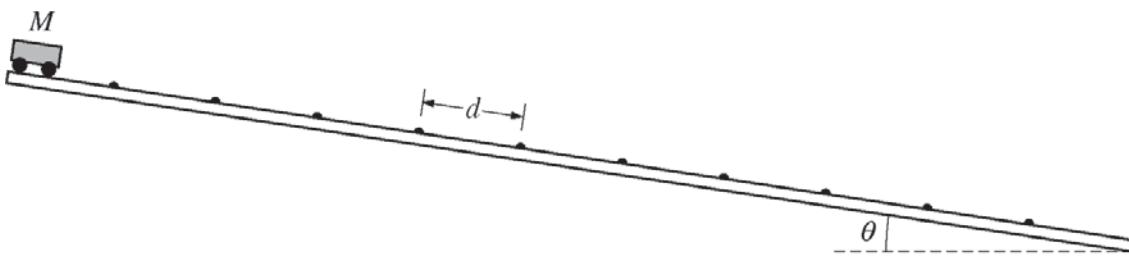


2016 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS



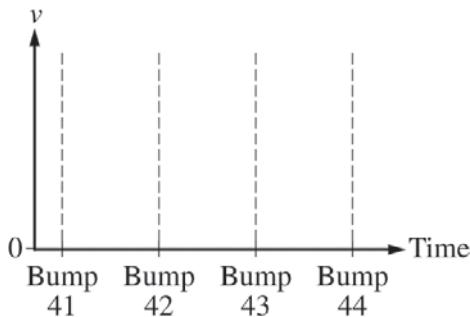
Note: Figure not drawn to scale.

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

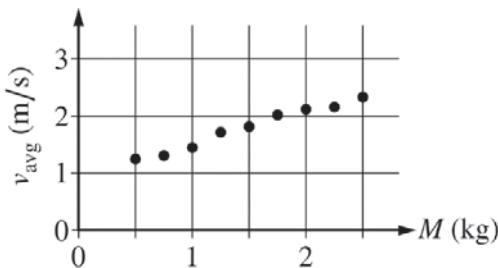
Briefly explain your reasoning.

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- (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:

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

- i. 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.

- ii. 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.

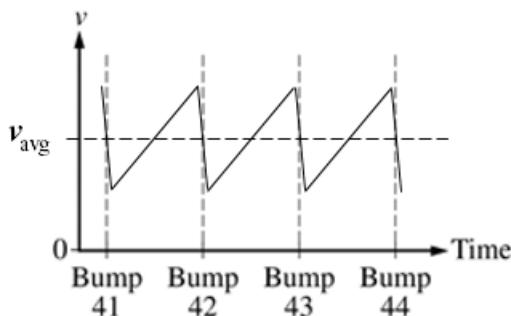
AP® PHYSICS 1
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Question 3

12 points total

**Distribution
of points**

(a)



- i. 3 points

For having a constant upward slope in each segment between bumps

1 point

For having the velocity “reset” abruptly at each bump (i.e., as a sawtooth function, not a sinusoidal curve) to a minimum positive value that is the same for each bump

1 point

For having the same maximum value in each cycle that occurs near the bump times (This point can be earned for a sinusoidal curve with peaks at the bump times.)

1 point

- ii. 1 point

For drawing a v_{avg} line that is horizontal and consistent with the graph drawn, even if that graph is wrong

1 point

(b) 2 points

Correct answer: Greater than

No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.

1 point

No points are earned if the wrong answer is selected.

For indicating that there is more time between bumps

1 point

For connecting that the cart has more time or more distance to accelerate between bumps

1 point

Example: The maximum speed is greater because the cart has more space (or time) to accelerate (build up speed) between bumps.

Alternate solution in terms of energy

Alternate points

For indicating that the potential energy difference increases due to increased height between successive bumps

1 point

For relating the increase in potential energy to an increase in kinetic energy

1 point

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Question 3 (continued)

**Distribution
of points**

(c) 2 points

Correct answer: Greater than

No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.

No points are earned if the wrong answer is selected.

For indicating that the acceleration is greater

1 point

For indicating that the component of the gravitational force increases

1 point

Alternate solution in terms of energy

Alternate points

For indicating that the potential energy difference increases due to increased height between successive bumps

1 point

For relating the increase in potential energy to an increase in kinetic energy

1 point

(d) i. 2 points

Correct answer: No

No points are earned if the correct answer is selected, but the explanation is completely incorrect or there is no explanation.

For indicating that v_{avg} is not proportional to M

1 point

For connecting the equation to the data

1 point

Examples:

The y-intercept of the graph is not zero, but the equation indicates that it should be zero.

Doubling the mass from the graph does not double v_{avg} , but the equation indicates that it should double.

If "yes" is selected, one point may be earned for explaining that v_{avg} increases

with M or that v_{avg} looks (approximately) proportional to M for a limited portion of the data (e.g., the points at $M = 1.0$ kg and $M = 2.0$ kg).

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Question 3 (continued)

**Distribution
of points**

(d)

ii. 2 points

Correct answer: No

For indicating that the distance dependency is incorrect

1 point

For indicating that, according to the equation, greater d leads to a smaller v_{avg} , OR

1 point

for stating or implying the contradiction between this inverse relation and the reasoning of part (b)

Credit is earned for any answer that is consistent with reasoning in part (b).

Example: According to the equation, a larger d corresponds to a smaller v_{avg} ,

because they are inversely proportional. But according to the reasoning of part (b), a bigger distance d between the bumps leads to a larger maximum average speed, showing that the equation is implausible.

If “yes” is selected, one point can be earned for indicating that an increase in the angle increases v_{avg} .