2021

AP CollegeBoard

# AP® Physics C: Mechanics

## Sample Student Responses and Scoring Commentary Set 1

**Inside:**

**Free Response Question 1**

- ☑ **Scoring Guideline**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

## Question 1: Free-Response Question — 15 points

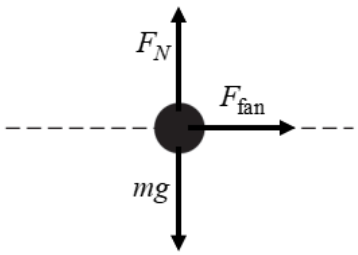
**(a)**

| | |
|---|---|
| For correctly drawing and labeling all the forces on the cart on the flat surface | **1 point** |
| For correctly drawing and labeling the weight of the cart on the incline | **1 point** |
| For correctly drawing and labeling the normal force on the cart on the incline | **1 point** |
| For correctly drawing and labeling the force of the fan on the cart on the incline | **1 point** |

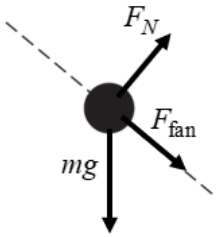
**Scoring note:** A maximum of three points can be earned if there are any extraneous vectors.

**Example responses for part (a)**

Cart on Horizontal Track




Cart on Incline




**Scoring note**: Examples of appropriate labels for the force due to gravity include: $F_{\text{G}}$, $F_{\text{g}}$, $F_{\text{grav}}$, $W$, $mg$, $Mg$, "grav force," "F Earth on cart," "F on cart by Earth," $F_{\text{Earth on cart}}$, $F_{\text{E,Cart}}$, $F_{\text{Cart,E}}$. The labels G or g are not appropriate labels for the force due to gravity. $F_n$, $F_N$, $N$, "normal force," "ground force," or similar labels may be used for the normal force.

**Total for part (a) 4 points**

**(b)**

| | |
|---|---|
| For correctly applying Newton's second law for the cart on the flat surface<br>$F_{\text{fan}} = m_{\text{cart}} a_1$ | **1 point** |
| For the correct answer with units<br>$F_{\text{fan}} = (0.50\ \text{kg})\left(0.8\ \text{m/s}^2\right) = 0.40\ \text{N}$ | **1 point** |

**Total for part (b) 2 points**

**(c)** For including the correct component of weight in a Newton's second law equation for the cart **1 point**

$F_{\text{fan}} + mg\sin\theta = ma_2$

For a correct Newton's second law equation **1 point**

$F_{\text{fan}} + mg\sin\theta = ma_2$

For correct substitutions consistent with part (b) into the above equation **1 point**

$mg\sin\theta = ma_2 - F_{\text{fan}}$

$\theta = \sin^{-1}\left(\dfrac{ma_2 - F_{\text{fan}}}{mg}\right)$

$\theta = \sin^{-1}\left(\dfrac{(0.50\text{ kg})\left(2.4\text{ m/s}^2\right) - (0.50\text{ kg})\left(0.8\text{ m/s}^2\right)}{(0.50\text{ kg})\left(9.8\text{ m/s}^2\right)}\right)$

$\theta = 9.4°$

**Total for part (c) 3 points**

**(d)** For selecting "No" and an attempted justification **1 point**

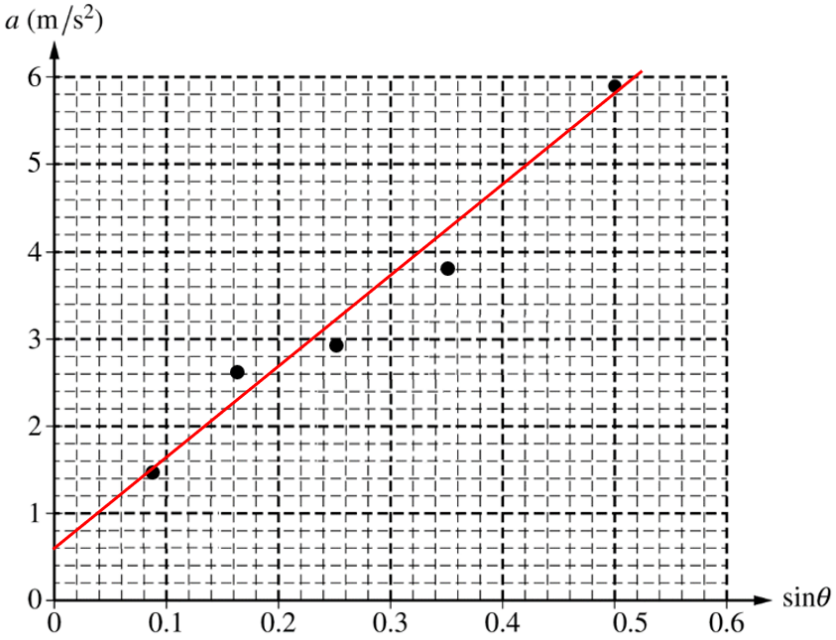
For a correct justification **1 point**

**Example response for part (d)**

*The mass of the cart cancels out in the equation used to find the angle of the incline.*

**Total for part (d) 2 points**

**(e)** **i.** For drawing an appropriate best-fit line **1 point**




**ii.** For correctly calculating slope using two points from the best-fit line **1 point**

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{(5-1)\left(\text{m/s}^2\right)}{(0.42-0.04)} = 10.52\ \text{m/s}^2$$

For correctly using an expression that relates the slope to the acceleration due to gravity **1 point**

$$F_{\text{net}} = F_{\text{fan}} + mg\sin\theta = ma$$
$$\therefore a = g\sin\theta + \frac{F_{\text{fan}}}{m}$$

$$\text{from } y = mx + b$$
$$a = (\text{slope})\sin\theta + (y\text{-intercept})$$
$$\therefore \text{slope} = g = 10.52\ \text{m/s}^2$$

**Total for part (e)** **3 points**

**(f)** For a correct explanation **1 point**

**Example response for part (f)**

*The mass of the cart is in the denominator of the y-intercept, so increasing the mass decreases the y-intercept without changing the rest of the graph. So the new line of data is predicted to be parallel to and below the original line.*

**Total for question 1** **15 points**

Begin your response to **QUESTION 1** on this page.

**PHYSICS C: MECHANICS**

**SECTION II**

**Time—45 minutes**

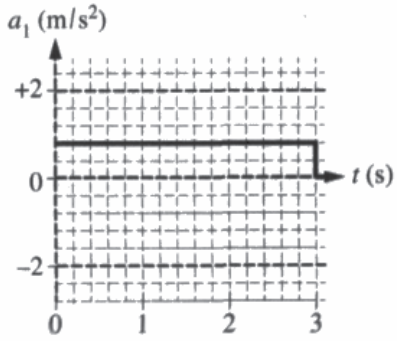
**3 Questions**

**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.

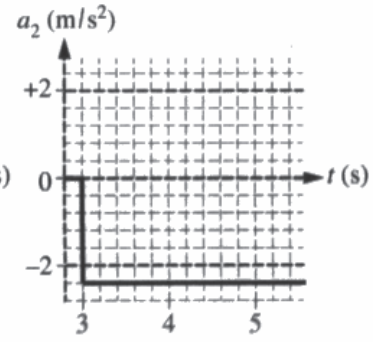

Note: Figure not drawn to scale.

1. A 0.50 kg fan cart is placed on a level, horizontal track of negligible friction, as shown. The fan is turned on, and the fan cart is released from rest and moves to the right. The cart travels along the horizontal track and then down an incline. Motion detector 1 measures the acceleration $a$ of the cart from time $t = 0$ to $t = 3$ s. At $t = 3$ s, the cart makes a smooth transition to the incline, and motion detector 2 measures the acceleration of the cart after $t = 3$ s. The fan exerts the same magnitude of force on the cart during the entire motion. The graphs below show $a$ as functions of $t$. For each motion detector, the positive direction is away from the detector.

MOTION DETECTOR 1




MOTION DETECTOR 2





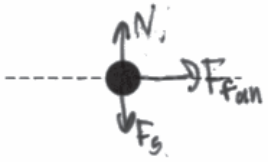



GO ON TO THE NEXT PAGE.

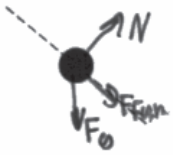
Continue your response to **QUESTION 1** on this page.

(a) On the dots below that represent the cart at two different locations, draw and label the forces (not components) that act on the cart at each location. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

Cart on Horizontal Track




Cart on Incline




(b) Calculate the magnitude of the net force exerted on the fan cart when it is on the horizontal track.

$F = m \cdot a = 0.5\,kg \cdot \frac{4}{5}\,m/s^2 = \boxed{\frac{2}{5}\,N}$

(c) Calculate the angle $\theta$ of the incline.

$\frac{12}{5} = \frac{4}{5} + g\sin\theta \quad \frac{8}{5} = 10\sin\theta \quad \sin^{-1}\left(\frac{8}{50}\right) = \boxed{9.2^\circ}$

(d) Suppose careful measurement determines the angle of the incline to be 3° larger than that calculated in part (c). Consider the following explanation.

"The scale used to measure the mass of the fan cart was not calibrated properly before the measurement, and this could account for the observed difference in the angle."

Does the explanation sufficiently account for the observed discrepancy?

____ Yes __X__ No

Justify your answer.

m does not appear in the calculations for acceleration and so has no effect on the measured angle

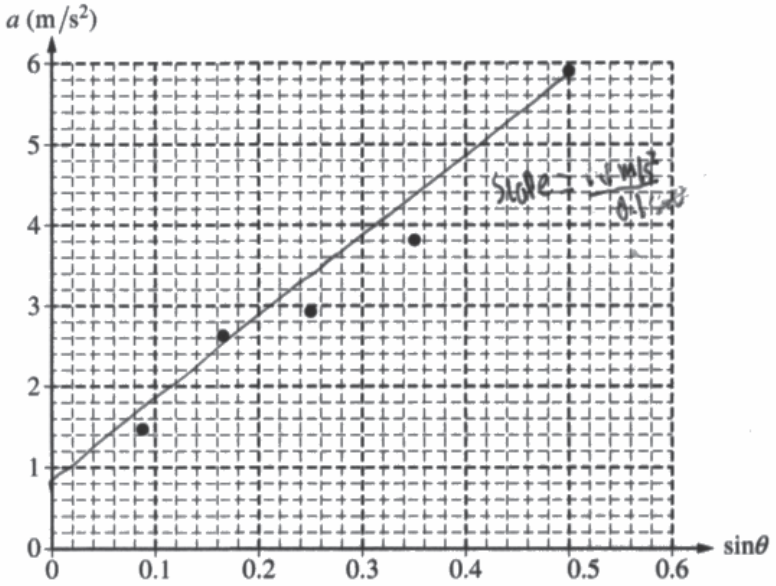




GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

The experiment is repeated for several trials, each with a different angle for the incline. The acceleration of the cart down the incline is measured for each angle. The graph below shows the plot of the acceleration $a$ of the cart as a function of the sine of the angle $\sin\theta$.




(e)

i. Draw a best-fit line for the data.

ii. Using the straight line, calculate an experimental value for the acceleration due to gravity $g$.

$a = c + g\sin\theta$. $\frac{da}{d\sin\theta} = g$ $\Rightarrow \frac{da}{d\sin\theta} = g$. $\Rightarrow g = 10\ m/s^2$

(f) If the cart were replaced with a second cart of mass 1.0 kg that has a fan that exerts the same magnitude of force as the original fan, explain how the graph given in part (e) would change.

The slope would remain constant, but the x-intercept would halve.



GO ON TO THE NEXT PAGE.

Begin your response to **QUESTION 1** on this page.

**PHYSICS C: MECHANICS**

**SECTION II**

**Time—45 minutes**

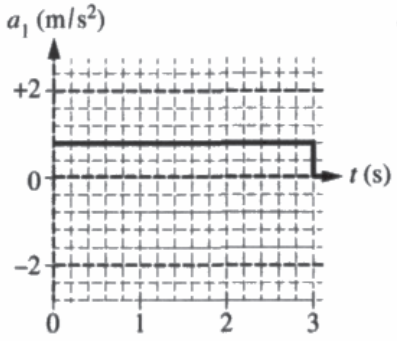
**3 Questions**

**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.

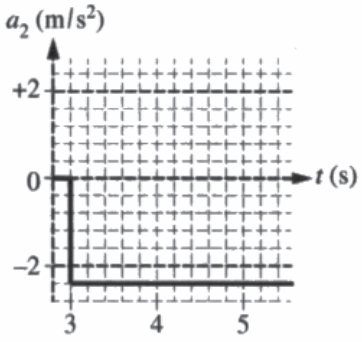

Note: Figure not drawn to scale.

1. A 0.50 kg fan cart is placed on a level, horizontal track of negligible friction, as shown. The fan is turned on, and the fan cart is released from rest and moves to the right. The cart travels along the horizontal track and then down an incline. Motion detector 1 measures the acceleration $a$ of the cart from time $t = 0$ to $t = 3$ s. At $t = 3$ s, the cart makes a smooth transition to the incline, and motion detector 2 measures the acceleration of the cart after $t = 3$ s. The fan exerts the same magnitude of force on the cart during the entire motion. The graphs below show $a$ as functions of $t$. For each motion detector, the positive direction is away from the detector.

MOTION DETECTOR 1




MOTION DETECTOR 2





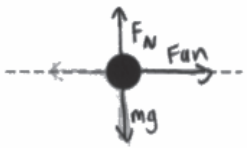



GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

(a) On the dots below that represent the cart at two different locations, draw and label the forces (not components) that act on the cart at each location. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

Cart on Horizontal Track




Cart on Incline


(b) Calculate the magnitude of the net force exerted on the fan cart when it is on the horizontal track.

$\Sigma F = ma$

$F = (.5)(.8)$

$F = .4$

$\Sigma F = ma$

$mg - F_N = ma^{\,0}$

$mg - F_N = 0$

(c) Calculate the angle $\theta$ of the incline.

$\Sigma F = ma$

$F + mg\sin\theta = ma$

$-(.4) - (.5)g\sin\theta = (.5)(-2.4)$

$.4 + .5g\sin\theta = 9.6$

$.5g\sin\theta = 9.2$

$\sin\theta = \frac{18.4}{9}$

$\theta = \sin^{-1}\left(\frac{18.4}{9.8}\right)$

$\theta = 28°$

(d) Suppose careful measurement determines the angle of the incline to be 3° larger than that calculated in part (c). Consider the following explanation.

"The scale used to measure the mass of the fan cart was not calibrated properly before the measurement, and this could account for the observed difference in the angle."

Does the explanation sufficiently account for the observed discrepancy?

✓ Yes _____ No

Justify your answer.

The mass does not cancel out so it plays a role in determining the angle

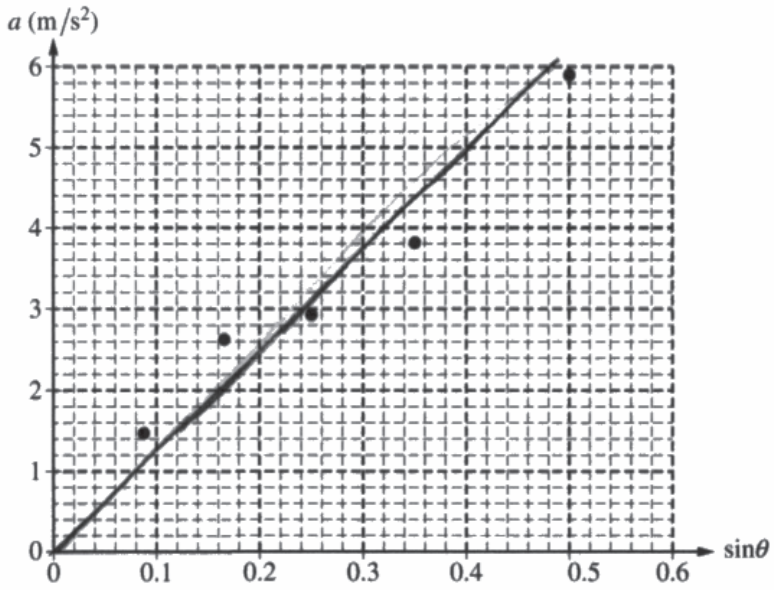




GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

The experiment is repeated for several trials, each with a different angle for the incline. The acceleration of the cart down the incline is measured for each angle. The graph below shows the plot of the acceleration $a$ of the cart as a function of the sine of the angle $\sin\theta$.




(e)

i. Draw a best-fit line for the data.

ii. Using the straight line, calculate an experimental value for the acceleration due to gravity $g$.

(f) If the cart were replaced with a second cart of mass 1.0 kg that has a fan that exerts the same magnitude of force as the original fan, explain how the graph given in part (e) would change.





GO ON TO THE NEXT PAGE.

Begin your response to **QUESTION 1** on this page.

**PHYSICS C: MECHANICS**

**SECTION II**

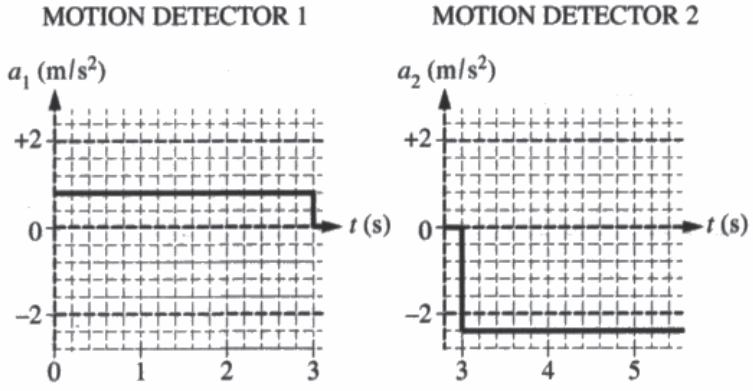
**Time—45 minutes**

**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.


Note: Figure not drawn to scale.

1. A 0.50 kg fan cart is placed on a level, horizontal track of negligible friction, as shown. The fan is turned on, and the fan cart is released from rest and moves to the right. The cart travels along the horizontal track and then down an incline. Motion detector 1 measures the acceleration $a$ of the cart from time $t = 0$ to $t = 3$ s. At $t = 3$ s, the cart makes a smooth transition to the incline, and motion detector 2 measures the acceleration of the cart after $t = 3$ s. The fan exerts the same magnitude of force on the cart during the entire motion. The graphs below show $a$ as functions of $t$. For each motion detector, the positive direction is away from the detector.





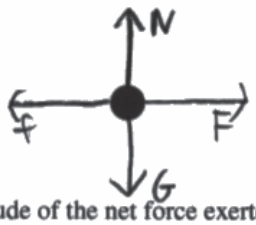



GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

(a) On the dots below that represent the cart at two different locations, draw and label the forces (not components) that act on the cart at each location. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

Cart on Horizontal Track




Cart on Incline


(b) Calculate the magnitude of the net force exerted on the fan cart when it is on the horizontal track.

Weight .50 kg
$t_i = 0$
$t_2 = 3$
$a_1 = 1$
$a_2 = -1$
$F = 3$

(c) Calculate the angle $\theta$ of the incline.

$x = 0 + 2(3) + \frac{1}{2}(2)(3)^2$
$x = 6 + 1(9) = 15$
$15^0$

(d) Suppose careful measurement determines the angle of the incline to be 3° larger than that calculated in part (c). Consider the following explanation.

"The scale used to measure the mass of the fan cart was not calibrated properly before the measurement, and this could account for the observed difference in the angle."

Does the explanation sufficiently account for the observed discrepancy?

____ Yes ✓ No

Justify your answer.

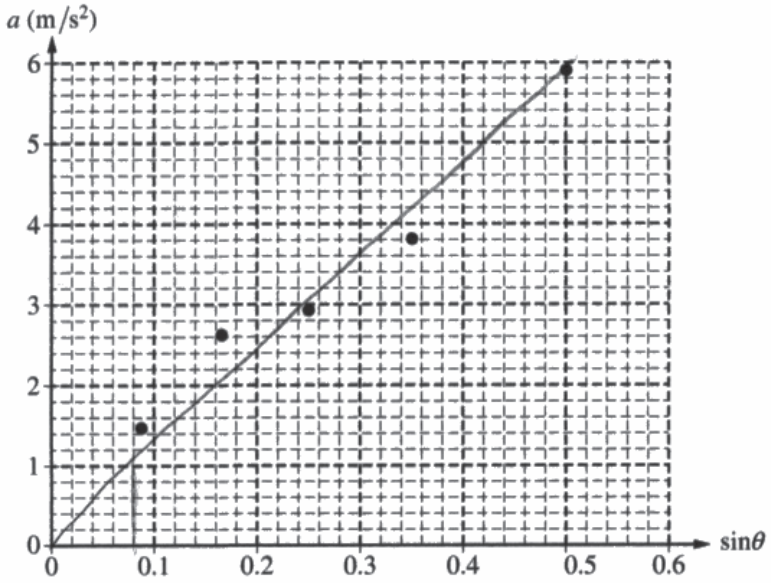
The test was not performed enough times to determine correct value. The device could have been calibrated correctly, but was affected by other external factors



GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

The experiment is repeated for several trials, each with a different angle for the incline. The acceleration of the cart down the incline is measured for each angle. The graph below shows the plot of the acceleration $a$ of the cart as a function of the sine of the angle $\sin\theta$.




(e)

i. Draw a best-fit line for the data.

ii. Using the straight line, calculate an experimental value for the acceleration due to gravity $g$.

$a = \frac{1.5}{.5} = \frac{3}{.5}$ $\frac{.5}{1.5}$ 1.5 m/s

(f) If the cart were replaced with a second cart of mass 1.0 kg that has a fan that exerts the same magnitude of force as the original fan, explain how the graph given in part (e) would change.

The trials for each angle will be larger than they are now. The points would shift up due to the increase in mass.





GO ON TO THE NEXT PAGE.

# Question 1

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

**Overview**

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

- The use of problem-solving strategies to translate written and graphical information into a mathematical description using Newton's second law.
- The use of force vectors and their components to predict the acceleration of an object.
- The ability to draw a best-fit line.
- The use of the mathematical description to find an unknown quantity.
- The ability to predict and explain changes to a linear graph if one of the variables in the mathematical description changed.

**Sample: M Q1 A**
**Score: 14**

Part (a) earned a total of 4 points. One point was earned for correctly drawing and labeling the normal, fan, and weight forces on the horizontal track. Three points were earned for correctly drawing and labeling the weight force, the normal force, and the fan force on the inclined track. Part (b) earned a total of 2 points where 1 point was earned for correctly applying Newton's second law for the cart on the horizontal surface, and 1 point was earned for the correct answer, 0.4 N, including units. Part (c) earned a total of 3 points. One point was earned for implicitly including the correct component of weight, $mg\ sin\theta$, in a Newton's second law equation for the cart. Another point was earned for having an implicitly correct Newton's second law equation, $F_{fan} + mg\ sin\theta = ma_2$., while the third point was earned for using implicitly correct substitutions that are consistent with part (b) in the above equation. Part (d) earned 1 point for selecting "No" with an attempt to justify that selection, and 1 point for a correct justification. Part (e)(i) earned 1 point for drawing an appropriate best-fit line, and part (e)(ii) earned 1 point for correctly using an expression that relates the slope to the acceleration due to gravity. No point was earned for incorrectly calculating the slope using 2 points from the best-fit line: the calculation can be found in the graph, but there is no indication of which 2 points were used. Part (f) earned 1 point for a correct explanation.

**Sample: M Q1 B**
**Score: 8**

Part a) earned a total of 4 points. One point was earned for correctly drawing and labeling the normal, fan, and weight forces on the horizontal track, as well as 3 points for correctly drawing and labeling the normal, fan, and weight forces on the inclined track. Part (b) earned 1 point for correctly applying Newton's second law for the cart on the horizontal surface. No point was earned because while the magnitude is correct, no units are included in the answer. Part (c) earned two points. One point was earned for including the correct component of weight, $mg\ sin\theta$, in a Newton's second law equation for the cart, and another point was earned for a correct Newton's second law equation, $F_{fan} + mg\ sin\theta = ma_2$. No point was earned for incorrect substitutions that are consistent with part (b) in the above equation. Part (d) earned no points for incorrectly selecting "Yes" and for an incorrect justification. Part (e)(i) earned 1 point for drawing an appropriate best-fit line, but no points were earned for (e)(ii) for not correctly calculating the slope using two points from the best-fit line and for not correctly using an expression that relates the slope to the acceleration due to gravity. No points were earned for part (f) because there is no explanation.

## Question 1 (continued)

**Sample: M Q1 C**
**Score: 3**

Part (a) earned only 1 point. Although the normal and fan forces on the horizontal track are correctly drawn, there is an incorrect label for the downward force, and there is an additional incorrect force. One point was earned for correctly labeling the normal force on the inclined track, but no points were earned for the drawing and labeling of the weight and fan force. From the forces drawn on the cart on the horizontal surface, $F_{fan}$ is referred to as being $F$ rather than $f$. Part (b) earned no points because of the absence of Newton's second law for the cart on the horizontal surface and because of an incorrect answer. Part (c) earned no points. The correct component of weight, $mg\ sin\theta$, is not included in a Newton's second law equation for the cart, there is no Newton's second law equation, $F_{fan} + mg\ sin\theta = ma_2$, and there are no correct substitutions that are consistent with part (b) in the above equation. Part (d) earned 1 point for selecting "No" with an attempt to justify that selection, but no point was earned for the incorrect justification. Part (e)(i) earned 1 point for drawing an appropriate best-fit line, but part (e)(ii) earned no points for not calculating the slope using two points from the best-fit line, and for not using an expression that relates the slope to the acceleration due to gravity. Part (f) earned no points for an incorrect explanation.