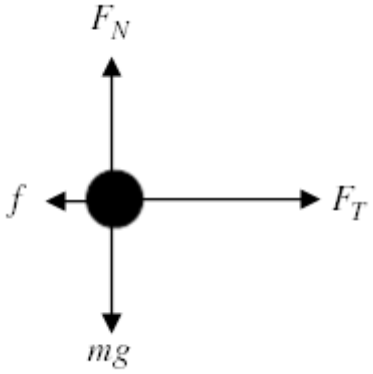
AP® PHYSICS C: MECHANICS
2016 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

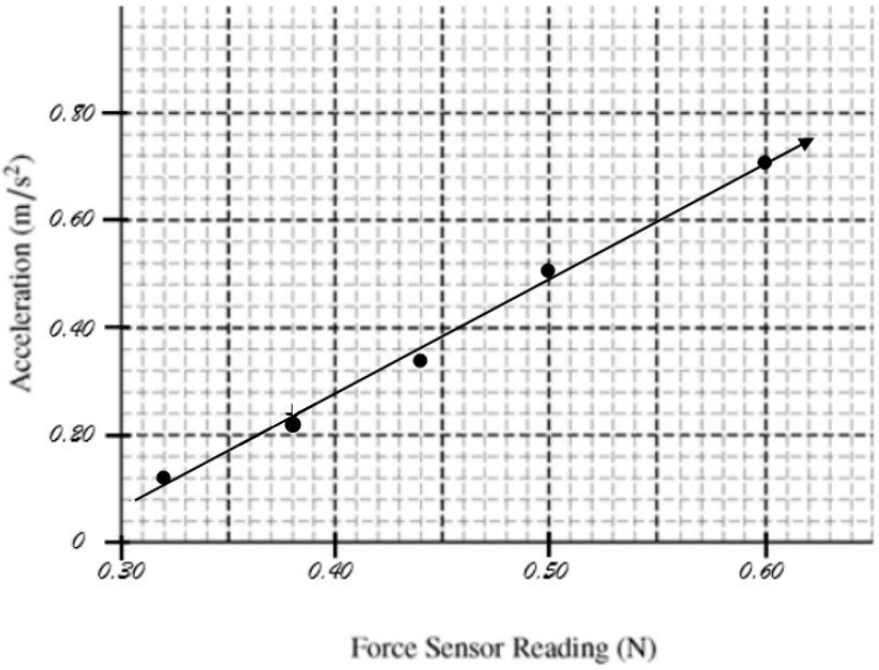
(a) 3 points



For correctly drawing and labeling the force of tension 1 point
For correctly drawing and labeling the force of friction 1 point
For correctly drawing and labeling both forces in the vertical direction 1 point
Note: A maximum of two points may be earned if there are any extraneous vectors.

(b)

i. 3 points



For a correct scale that uses more than half the grid 1 point
For correctly plotting the given data 1 point
For drawing a straight line consistent with the given data 1 point
Note: Full credit can be earned if the axes are switched.

Question 1 (continued)

Distribution of points

(b)

ii. 2 points

For correctly calculating slope using the best-fit straight line and not data points — 1 point

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(0.70 - 0.16)}{(0.60 - 0.35)}\text{kg}^{-1} = 2.16\ \text{kg}^{-1}$$

Note: Linear regression gives slope $= 2.12\ \text{kg}^{-1}$.

For correctly calculating the mass of the cart using the slope — 1 point

$$m = \frac{1}{\text{slope}} = \frac{1}{\left(2.16\ \text{kg}^{-1}\right)}$$

Correct answer:

$m = 0.463\ \text{kg}$ (Note: linear regression gives $m = 0.472\ \text{kg}$)

iii. 1 point

For an answer with correct units consistent with the x-intercept of the graph from (b) i. — 1 point

$f = 0.272\ \text{N}$

(c)

i. 1 point

Applying Newton's second law and substituting the values from part (b)

$$\sum F = ma = F_a - f$$

$$a = \frac{F_a - f}{m} = \frac{0.45\ \text{N} - 0.272\ \text{N}}{0.463\ \text{kg}}$$

For an answer with correct units consistent with part (b), either from the graph or calculated using the mass and frictional force. — 1 point

$a = 0.376\ \text{m/s}^2$

Question 1 (continued)

Distribution of points

(c)

ii. 3 points

For using a correct equation to solve for the speed of the cart when the string breaks, with an acceleration consistent with part (c) i. — 1 point

$v_2 = v_1 + at$

$v_2 = 0 + \left(0.376 \text{ m/s}^2\right)(2.0 \text{ s})$

$v_2 = 0.752 \text{ m/s}$

For recognizing that the acceleration of the cart after the string breaks is due to the frictional force determined in part (b) — 1 point

Use a correct equation to solve for the time for the cart to stop after the string breaks

$v_2 = v_1 + at$

$0 = v_1 - \frac{f}{m}t$

For using the final velocity before the string breaks as the initial velocity for the cart stopping in the correct equation for time — 1 point

$t = \frac{mv_1}{f}$

$t = \frac{(0.463 \text{ kg})(0.752 \text{ m/s})}{(0.272 \text{ N})}$

Correct answer

$t = 1.28 \text{ s}$

Alternate solution — *Alternate points*

For setting the magnitude of the impulse before the string breaks equal to the magnitude of the impulse after the string breaks — *1 point*

$F_1 t_1 = F_2 t_2$

For correctly using the proper force (e.g., the tension force minus the friction force) for F_1 — *1 point*

For correctly using the proper force (e.g., the friction force) for F_2 — *1 point*

Correct answer

$t = 1.28 \text{ s}$

(d)

i. 1 point

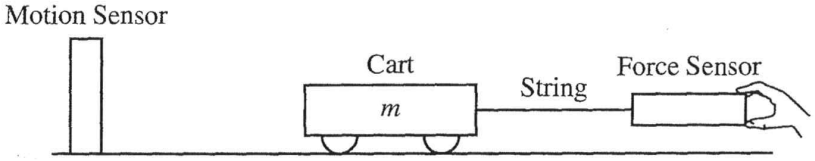
For selecting "Equal to" — 1 point

ii. 1 point

For selecting "Greater than" — 1 point

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

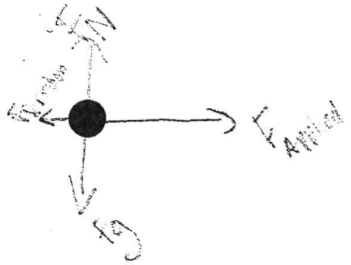
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Mech.1.

A cart of mass m is pulled along a level dynamics track as shown above. A force sensor is attached to the cart with a string and used to measure the horizontal force exerted on the cart to the right. A motion sensor is used to measure the acceleration of the cart with the positive direction toward the right. Friction is not negligible.

(a) On the dot below, which represents the cart, draw and label the forces (not components) that act on the cart. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



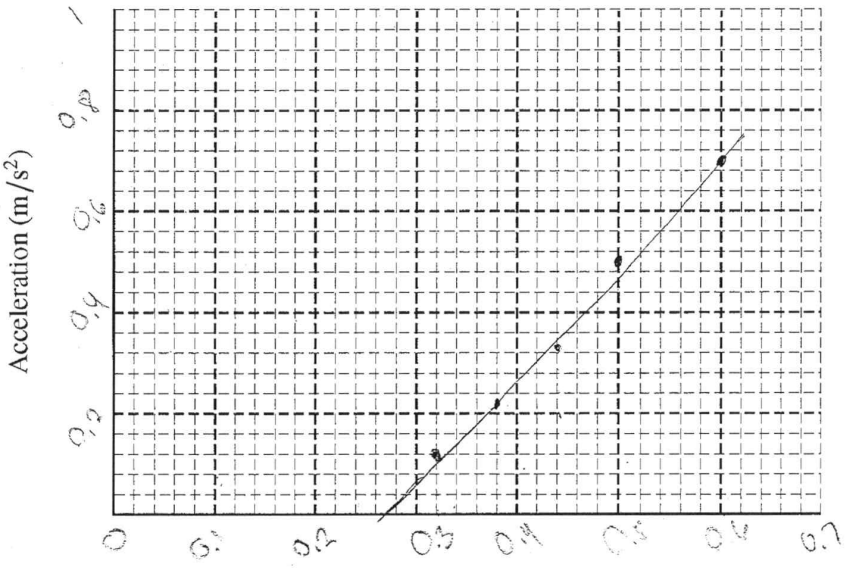
A student pulls the force sensor with a constant force, and the cart accelerates. This is repeated for several trials, with a different constant force used for each trial. The data are recorded in the table below.

Trial	1	2	3	4	5
Force sensor reading (N)	0.32	0.38	0.44	0.50	0.60
Acceleration $\left(\mathrm{m/s^2}\right)$	0.12	0.22	0.33	0.50	0.70

GO ON TO THE NEXT PAGE.

(b)

i. On the grid below, plot data points for the acceleration of the cart as a function of the force sensor reading. Clearly scale all axes. Draw a straight line that best represents the data.



ii. Using the straight line from the graph, calculate the mass of the cart.

$F_{net} = F_A$ $\quad ma = F_A$ $\quad m = \frac{F_A}{a} = \frac{0.6N - 0.38N}{0.7 m/s^2 - 0.22 m/s^2} = \frac{0.22N}{0.48 m/s^2} = 0.4583 kg$

iii. Using the straight line from the graph, determine the magnitude of the force of friction.

the magnitude of the force of friction is 0.27N, because this is the minimum force need to accelerate the cart

The above experiment is repeated by using a constant force sensor reading of 0.45 N. The cart starts from rest at time $t = 0$ s and is pulled for a time of 2.0 s along the dynamics track.

(c)

i. Determine the acceleration of the cart.

$a = 0.36 m/s^2$ (from graph)

ii. The string breaks at time $t = 2.0$ s. Calculate the time it takes for the cart to stop after the string breaks.

after break: $F_{net} = F_F = ma$ $\quad a = \frac{-0.27N}{0.4583kg} = -0.59 m/s^2$

before break: $v_f = v_i + 0.36 m/s (2)$ $\quad v_i = 0 + a$ $\quad v_f = 0.72 m/s$

$v_f =$

$t = 1.22s$

after break: $v_i = 0.72 m/s$ $\quad v_f = 0$ $\quad a = -0.59 m/s^2$ $\quad 0 = 0.72 m/s - 0.59 m/s^2 t$ $\quad t = 1.22s$

Question 1 continues on next page.

The experiment and analysis in parts (a) and (b) are repeated with a cart that has the same mass but a greater force of friction.

(d)

i. Will the slope of your new line be greater than, less than, or equal to the slope of your line in part (b)i?

____ Greater than ____ Less than ✓ Equal to

ii. Will the horizontal intercept of your new line be greater than, less than, or equal to the horizontal intercept of your line in part (b)i?

✓ Greater than ____ Less than ____ Equal to

PHYSICS C: MECHANICS
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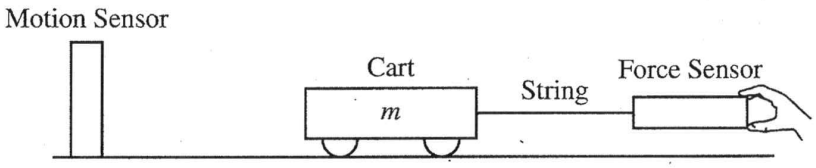

Mech.1.

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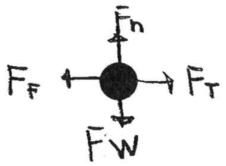
(a) On the dot below, which represents the cart, draw and label the forces (not components) that act on the cart. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



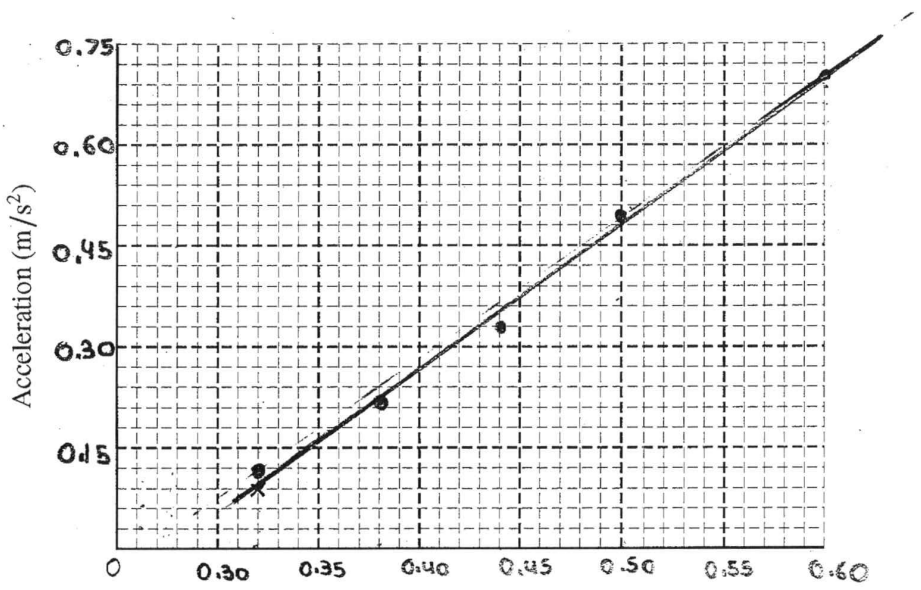
A student pulls the force sensor with a constant force, and the cart accelerates. This is repeated for several trials, with a different constant force used for each trial. The data are recorded in the table below.

Trial	1	2	3	4	5
Force sensor reading (N)	0.32	0.38	0.44	0.50	0.60
Acceleration $\left(\mathrm{m/s^2}\right)$	0.12	0.22	0.33	0.50	0.70

GO ON TO THE NEXT PAGE.

(b)

i. On the grid below, plot data points for the acceleration of the cart as a function of the force sensor reading. Clearly scale all axes. Draw a straight line that best represents the data.



ii. Using the straight line from the graph, calculate the mass of the cart.

$F = ma$

$\therefore m = \frac{F}{a}$

Slope of Straight Line:

Points: (0.60, 0.70), (0.32, 0.09)

$\text{Slope} = \frac{0.70 - 0.09}{0.60 - 0.32} = 2.178 \frac{m/s^2}{kg\,m/s^2} = \frac{1}{kg}$ $\therefore 2.178^{-1} = 0.459\ kg$

iii. Using the straight line from the graph, determine the magnitude of the force of friction.

$F_f = \mu F_N$

The above experiment is repeated by using a constant force sensor reading of 0.45 N. The cart starts from rest at time $t = 0$ s and is pulled for a time of 2.0 s along the dynamics track.

(c) $V_0 = 0$ $F = ma = 0.45$

$t = 2$

i. Determine the acceleration of the cart.

$F = ma$

$a = F/m = 0.45/0.459 = 0.980\ m/s^2$

ii. The string breaks at time $t = 2.0$ s. Calculate the time it takes for the cart to stop after the string breaks.

Question 1 continues on next page.

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(d)

i. Will the slope of your new line be greater than, less than, or equal to the slope of your line in part (b)i?

____ Greater than ___X___ Less than ____ Equal to

ii. Will the horizontal intercept of your new line be greater than, less than, or equal to the horizontal intercept of your line in part (b)i?

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M Q1 C1

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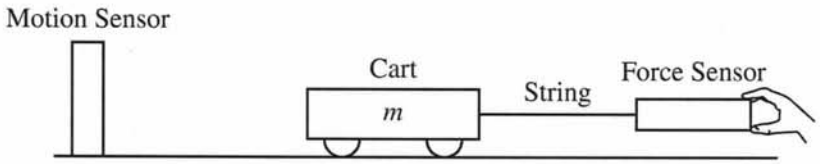

Mech.1.

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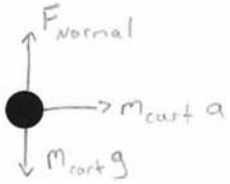

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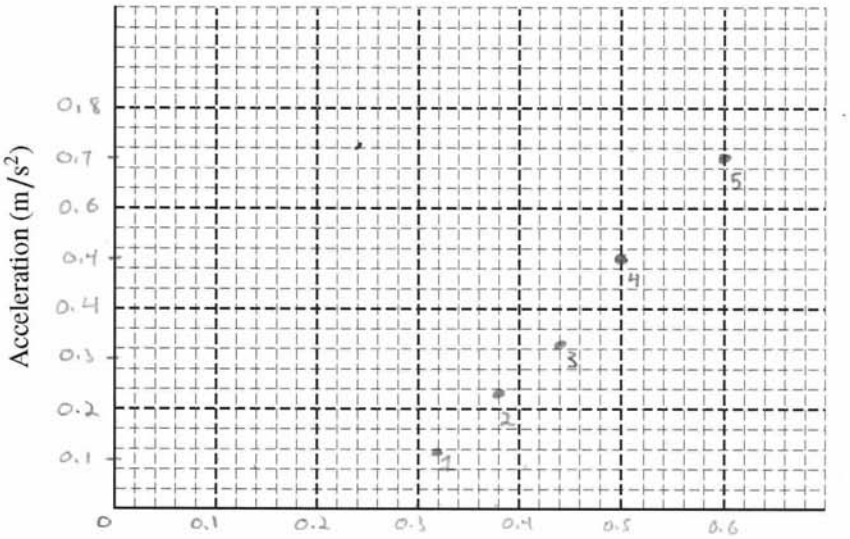
(b)

i. On the grid below, plot data points for the acceleration of the cart as a function of the force sensor reading. Clearly scale all axes. Draw a straight line that best represents the data.



Force Sensor Reading (N)

ii. Using the straight line from the graph, calculate the mass of the cart.

$F = m \cdot a$

$\frac{F}{a} = m$

$\frac{0.70\,N - 0.12\,N}{0.60\,N - 0.32\,N} = 2.07\ kg = 2.1\ kg$

iii. Using the straight line from the graph, determine the magnitude of the force of friction.

$a = \frac{F}{m}$. $a_1 = .15\,m/s^2$ $a_2 = 0.18\,m/s^2$ $a_3 = .21\,m/s^2$ $a_4 = .24\,m/s^2$ $a_5 = .29\,m/s^2$

$F_F = (0.03\,m/s^2)(2.1\,kg) = 0.063\,N$

The above experiment is repeated by using a constant force sensor reading of 0.45 N. The cart starts from rest at time $t = 0$ s and is pulled for a time of 2.0 s along the dynamics track.

(c)

i. Determine the acceleration of the cart.

$F_{net} = F_{constant} - F_{friction} = ma$ $\qquad a = 0.18\,m/s^2$

$0.45N - 0.063N = 2.1kg(a)$

ii. The string breaks at time $t = 2.0$ s. Calculate the time it takes for the cart to stop after the string breaks.

Question 1 continues on next page.

The experiment and analysis in parts (a) and (b) are repeated with a cart that has the same mass but a greater force of friction.

(d)

i. Will the slope of your new line be greater than, less than, or equal to the slope of your line in part (b)i?

____ Greater than ✓ Less than ____ Equal to

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AP® PHYSICS C: MECHANICS
2016 SCORING COMMENTARY

Question 1

Overview

Students were expected to demonstrate an understanding of Newton's second law and kinematics in a motion that consisted of two distinct parts: a cart being pulled by a string and then slowed by friction. The main intent of this question was to assess the students' mastery of graphical analysis. Students were asked to properly build a graph from a given data table, with the expectation that they would correctly label and scale the axes, draw a best-fit straight line, and determine the slope. Students were expected to interpret the graph to obtain relationships between physical quantities and find numerical values of dynamic and kinematic quantities.

Sample: M Q1 A
Score: 14

Part (a) earned all 3 points for a proper free-body diagram. The tension, friction, and both vertical forces are correctly drawn and labeled. Part (b)(i) earned all 3 points for using a correct scale that utilizes more than half of the grid, correctly plotting the data, and drawing an appropriate best-fit straight line. Part (b)(ii) earned 1 point for calculating the mass from the slope. However, the slope is calculated using actual data points to compute the slope, instead of the best-fit line. Part (b)(iii) earned 1 point for using the graph to determine the magnitude of the force of friction. Part (c) earned all 4 points for determining the acceleration of the cart for a 0.45 N applied force, and using the correct equations with the correct velocity to calculate the time for the cart to stop after the string breaks. Part (d) earned 2 points for selecting the correct answers.

Sample: M Q1 B
Score: 7

Part (a) earned all 3 points. Part (b)(i) earned 2 points for correctly plotting the data and drawing an appropriate best-fit straight line, but the x-axis was scaled by 0.3 in the first grid, then by 0.05 in the remaining grids. Part (b)(ii) earned 2 points for evidence of attempting to calculate the slope of the actual line and computing a reasonable mass value. Part (c)(i) earned no credit as the frictional force is ignored and, therefore, an incorrect value for the acceleration of the cart is calculated. Parts (b)(iii) and (c)(ii) earned no credit as there was not any evidence of relevant physics. Part (d) earned no credit for incorrect answers.

Sample: M Q1 C
Score: 4

Part (a) earned 1 point for the proper vertical forces. Part (b)(i) earned 2 points as it does not have a best-fit line drawn. Part (b)(ii) earned no credit because the slope is calculated from data points, and the slope is not correctly related to the mass. Part (b)(iii) earned no credit for incorrectly calculating the force of friction. Part (c)(i) earned 1 point for an answer consistent with (b)(iii). No credit was earned in parts (c)(ii) and (d).