2021

AP CollegeBoard

AP® Physics C: Mechanics

Sample Student Responses and Scoring Commentary Set 2

Inside:

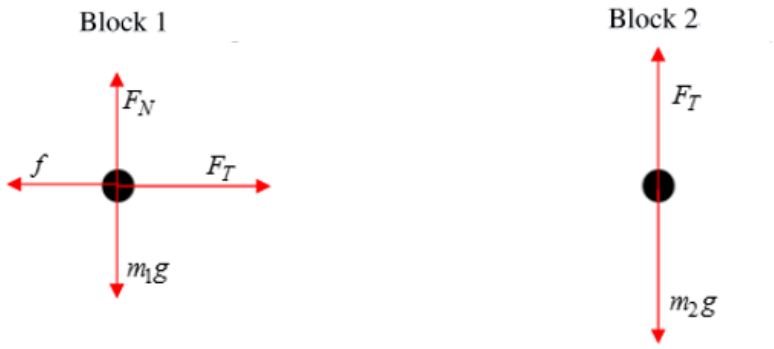
Free Response Question 1

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

Question 1: Free-Response Question — 15 points

(a)	For correctly evaluating Newton's second law equations for the system at rest $m_2 g - f = (m_1 + m_2)a = 0 \therefore m_2 g = f$	**1 point**
	For correctly substituting for static friction into above equation: $m_2 g = f = \mu_s F_N = \mu_s m_1 g$ $\mu_s = \frac{m_2}{m_1} = \frac{(0.20\ \text{kg})}{(0.44\ \text{kg})} = 0.45$	**1 point**
	Total for part (a)	**2 points**
(b)	For correctly drawing and labeling the horizontal forces of friction and tension on block of mass m_1	**1 point**
	For correctly drawing and labeling the vertical forces of weight and normal force on block of mass m_1	**1 point**
	For correctly drawing and labeling forces of weight and tension on block of mass m_2	**1 point**
	For indicating that the gravitational forces on each block are different	**1 point**

Example responses for part (b)

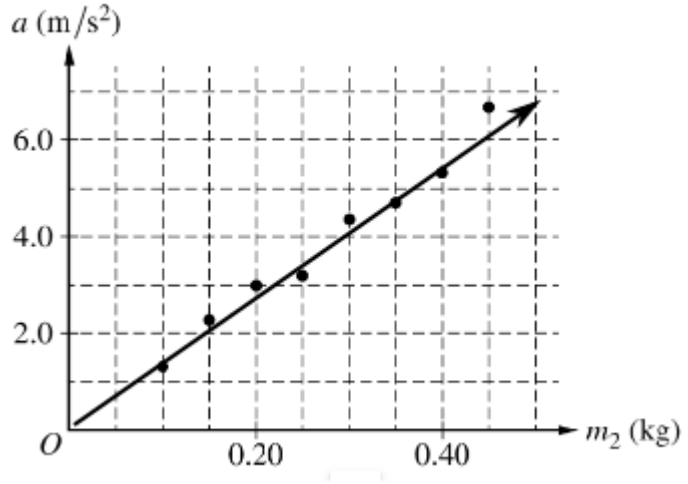


Scoring note: Examples of appropriate labels for the force due to gravity include: F_G, F_g, F_{grav}, W, mg, Mg, "grav force," "F Earth on block," "F on block by Earth," $F_{\text{Earth on block}}$, $F_{E,\text{Block}}$, $F_{\text{Block},E}$. The labels G or g are not appropriate labels for the force 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 (b)	**4 points**

(c)	For correctly evaluating Newton's second law equation for block 1: $T - f = m_1 a$	**1 point**
	For correctly evaluating Newton's second law equation for block 2: $m_2 g - T = m_2 a$ Combining the two equations $m_2 g - f = (m_1 + m_2)a \therefore f = m_2 g - (m_1 + m_2)a$ **Scoring note:** Both points are earned for a single correct Newton's second law equation for the two-block system.	**1 point**
	For correctly substituting for kinetic friction into above equation $f = \mu_k F_N = \mu_k m_1 g = m_2 g - (m_1 + m_2)a \therefore \mu_k = \frac{m_2 g - (m_1 + m_2)a}{m_1 g}$ $\mu_k = \frac{(0.20\text{ kg})\left(9.8\text{ m/s}^2\right) - (0.44\text{ kg} + 0.20\text{ kg})\left(2.3\text{ m/s}^2\right)}{(0.44\text{ kg})\left(9.8\text{ m/s}^2\right)} = 0.11$	**1 point**
		Total for part (c) 3 points
(d)	For selecting "Yes" and attempting a relevant justification	**1 point**
	For a correct justification	**1 point**
	Example response for part (d) *If the track is not level, the angle of the track must be incorporated into the equation for acceleration, and this could account for the larger coefficient of kinetic friction.*	
		Total for part (d) 2 points

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



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

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{(6-2)\left(\text{m}/\text{s}^2\right)}{(0.45-0.15)(\text{kg})} = 13.3\ \text{m}/\text{kg}\cdot\text{s}^2$$

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

From $y = mx + b$

$a =$ (slope)m_2 + (y-intercept)

$$a = \frac{m_2 g}{(m_1 + m_2)} \therefore \text{slope} = \frac{g}{(m_1 + m_2)}$$

$$g = \text{slope} \times (m_1 + m_2) = \left(13.3\ \text{m}/\text{kg}\cdot\text{s}^2\right)(0.44\ \text{kg} + 0.20\ \text{kg}) = 8.5\ \text{m}/\text{s}^2$$

Total for part (e) 3 points

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

Example response for part (f)

The acceleration would be greater because there would be a component of the gravitational force on block 1 along the surface, which would be in the same direction as the tension force.

Total for question 1 15 points

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

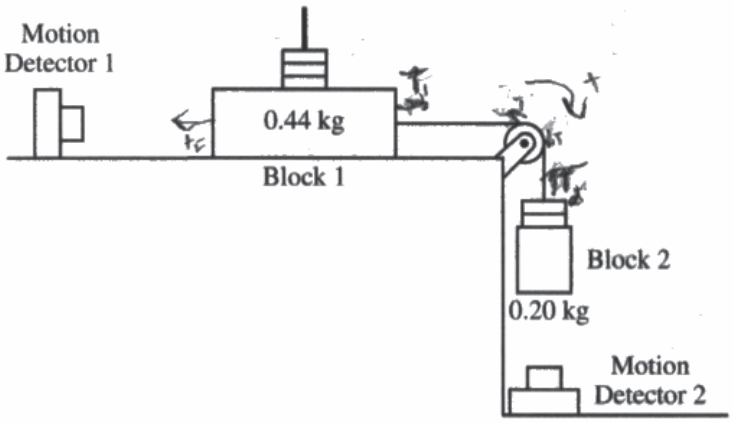
PHYSICS C: MECHANICS

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.



1. Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

   (a) Calculate the minimum value of the coefficient of static friction μ_s that would keep the two-block system at rest.

$\sum F_{net} = ma = 0$

$m_2 g - T_2 + T_1 - F_f = 0$

$m_{2g} = T_2$

$T_1 = F_f$

$m_{1g} = \mu F_N$

$m_{1g} = \mu_s m_1 g$

$\mu_s = \frac{m_{2g}}{m_{1g}}$

$\mu_s = \frac{2}{.44}$

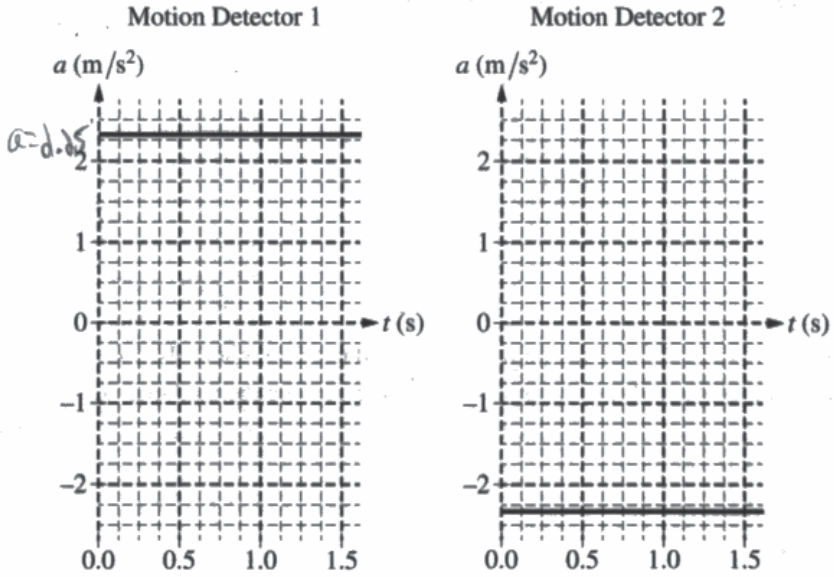
$\mu_s \geq .455$

Down to right is positive

Tensions between block and pulleys cancel out.

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

The coefficient of friction is such that when block 2 is released from rest, block 1 travels across the surface. The acceleration a of each block is recorded with motion detectors 1 and 2, as shown in the figure. The data for the motion detectors as functions of time t are shown on the graphs. For each motion detector, the positive direction is away from the detector.



(b) On the dots below, which represent the blocks, draw and label the forces (not components) that act on each block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

Block 1 Block 2

(c) Calculate the coefficient of kinetic friction μ_k between block 1 and the table.

$\sum F_{net} = ma$

$m_2 g - T_2 + T_1 - F_F = (m_1 + m_2)a$

$m_2 g - F_F = (m_1 + m_2)a$

$m_2 g - \mu_k F_N = (m_1 + m_2)a$

$m_2 g - \mu_k m_1 g = (m_1 + m_2)a$

$m_2 g - (m_1 + m_2)a = \mu_k m_1 g$

$\mu_k = \frac{m_2 g - (m_1 + m_2)a}{m_1 g}$

$\mu_k = \frac{.02(9.8) - (.44 + .02)(0.05)}{(.44)(9.8)}$

$\mu_k = .044$

GO ON TO THE NEXT PAGE.

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

(d) Careful measurements determine that the coefficient of kinetic friction is larger than the value calculated in part (c). Does the following explanation sufficiently account for the observed discrepancy?

"The horizontal table was not perfectly level before the experiment was conducted. The observed difference in the angle accounts for the difference in the expected and calculated values of μ_k."

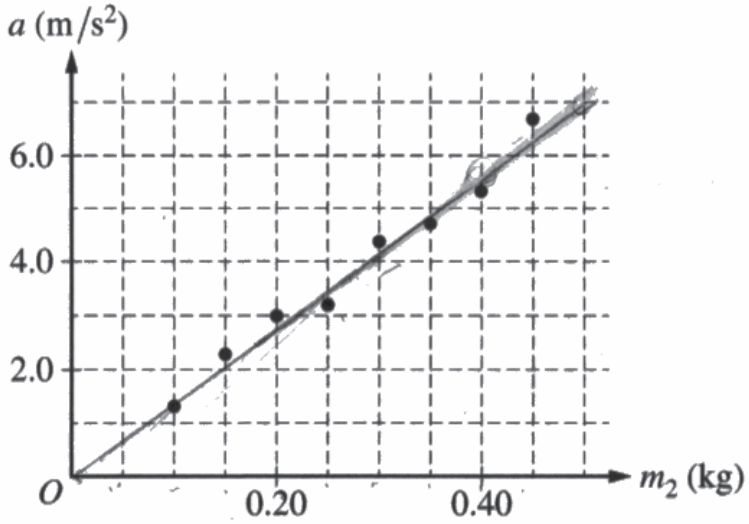
X Yes _____ No

Justify your answer.

An angle or increased angle θ will result in a lesser $m_1 g_\perp$, and thus a smaller $F_\perp$ value. Thus, the μ_k value would be lower than expected.

experimental

The experiment is moved to a surface with negligible friction and run for eight trials. In each trial, the students vary the masses m_1 and m_2 of blocks 1 and 2, respectively, while keeping the total mass $(m_1 + m_2) = 0.64\,\text{kg}$ constant. The data for the acceleration a of block 1 as a function of m_2 are shown on the graph below.



(e)

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

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

$a(.5) = 7$

$a(.4) = 5.5$

$g = \frac{a(.5) - a(.4)}{.5 - .4}$

$g = \frac{7 - 5.5}{.1}$

$g = 15\ \text{m/s}^2$

GO ON TO THE NEXT PAGE.

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

(f) The students lift the left end of the surface so that the surface is inclined at an angle to the horizontal, and the experiment for $m_2 = 0.20\,\text{kg}$ is repeated. Would the acceleration of the system be greater than, less than, or equal to the acceleration of the system in the original experiment?

X Greater than ___ Less than ___ Equal to

Justify your claim.

$\Sigma F = ma$

$m_2 g - T_2 + T_1 - F_F = (m_1 + m_2) a$

$m_2 g \sin\theta - F_F = (m_1 + m_2) a$

$a = \frac{m_2 g \sin\theta - F_F}{(m_1 + m_2)}$

$a = \frac{m_2 g \sin\theta - \mu_k m_1 g \cos\theta}{(m_1 + m_2)}$

If the board is lifted and there's an angle θ, then there's a perpendicular force that reduces F_F, and thus accel. increases

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

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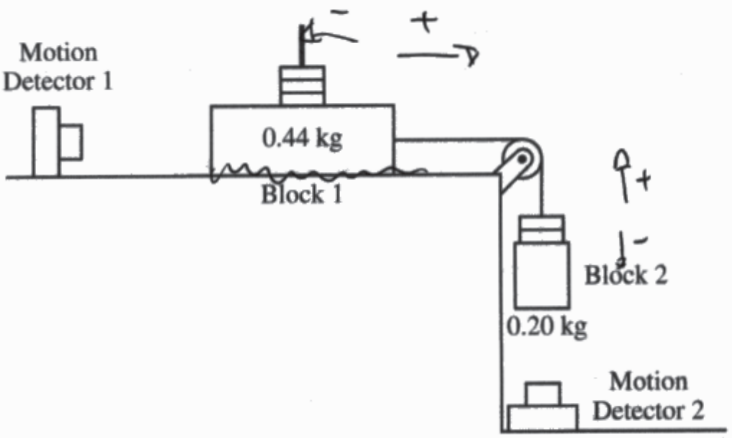


1. Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

   (a) Calculate the minimum value of the coefficient of static friction μ_s that would keep the two-block system at rest.

$F = ma$

$F = 0$

$F_{fs} - m_2 g = 0$

$\mu_s F_{n_1} = m_2 g$

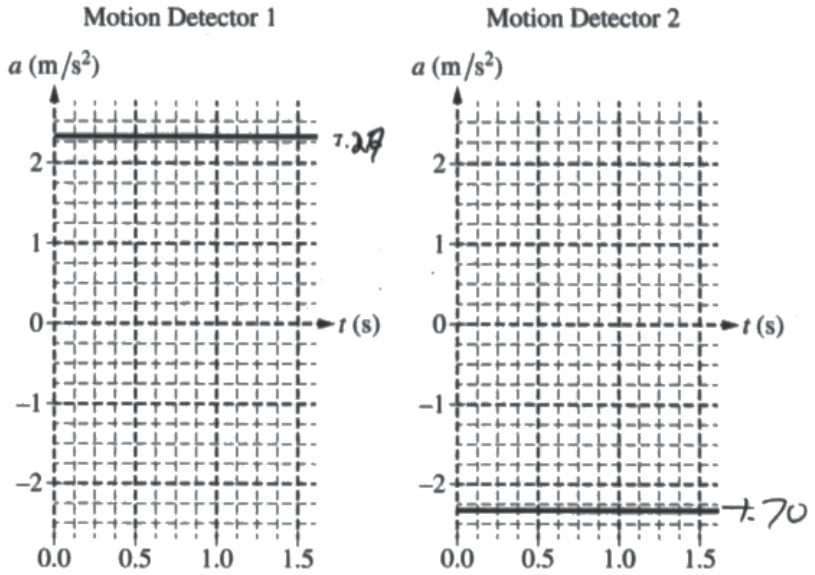
$\mu_s (.44)(9.8) = (.2)(9.8)$

$\mu_s = .45$

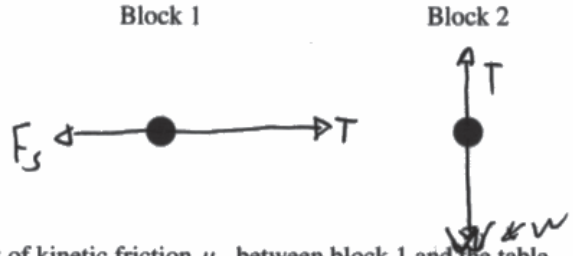
GO ON TO THE NEXT PAGE.

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

The coefficient of friction is such that when block 2 is released from rest, block 1 travels across the surface. The acceleration a of each block is recorded with motion detectors 1 and 2, as shown in the figure. The data for the motion detectors as functions of time t are shown on the graphs. For each motion detector, the positive direction is away from the detector.



(b) On the dots below, which represent the blocks, draw and label the forces (not components) that act on each block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(c) Calculate the coefficient of kinetic friction μ_k between block 1 and the table.

$F = ma$

$F = (.44)(3.27)$

$\mu_k F_{n_1} - m_2 g = .44 \cdot 3.27$

$\mu_k = \dfrac{(44 \cdot 3.27) + (.2)(9.8)}{(.44)(9.8)} = .788$

GO ON TO THE NEXT PAGE.

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

(d) Careful measurements determine that the coefficient of kinetic friction is larger than the value calculated in part (c). Does the following explanation sufficiently account for the observed discrepancy?

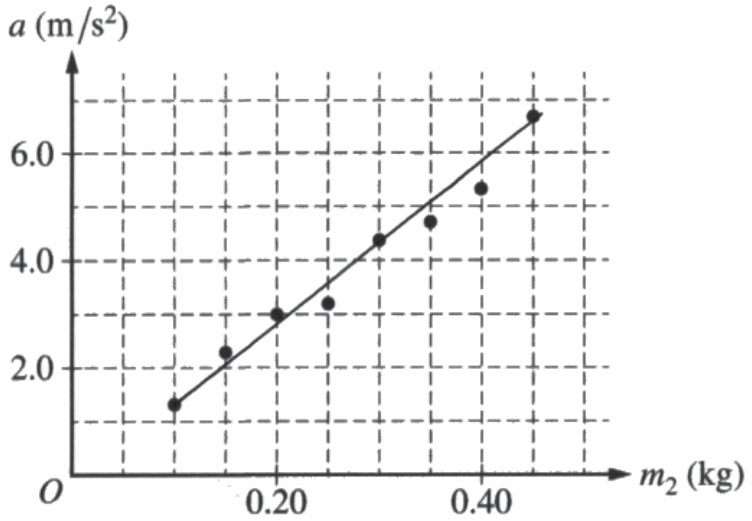
"The horizontal table was not perfectly level before the experiment was conducted. The observed difference in the angle accounts for the difference in the expected and calculated values of μ_k."

✓ Yes No

Justify your answer.

If the horizontal table was not perfectly level, the normal force on block 1 would have been a bit less than than the normal force if the surface had been perfectly horizontal. Since μ_k is inversely proportional to the F_N of block 1, it would increase as F_N decreases.

The experiment is moved to a surface with negligible friction and run for eight trials. In each trial, the students vary the masses m_1 and m_2 of blocks 1 and 2, respectively, while keeping the total mass $(m_1 + m_2) = 0.64\,\text{kg}$ constant. The data for the acceleration a of block 1 as a function of m_2 are shown on the graph below.



(e)

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

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

$g = 9.8\,\text{m/s}^2$

GO ON TO THE NEXT PAGE.

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

(f) The students lift the left end of the surface so that the surface is inclined at an angle to the horizontal, and the experiment for $m_2 = 0.20\,\text{kg}$ is repeated. Would the acceleration of the system be greater than, less than, or equal to the acceleration of the system in the original experiment?

____ Greater than X Less than ____ Equal to

Justify your claim.

F_n on an inclined plane would be lower than on a horizontal surface and since both the static coefficient of friction & and the kinetic coefficient of friction are inversely proportional to the normal force of block B, μ_s and μ_k will be higher. Higher μ_s and μ_k would mean stronger frictional forces acting on the system and thus the acceleration of the system would be less than the original experiment.

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

PHYSICS C: MECHANICS

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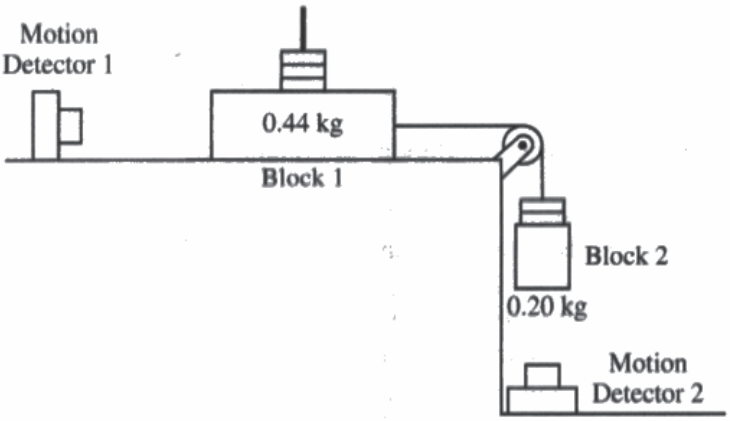


1. Students design an experiment using blocks of adjustable mass to investigate friction using the setup shown. Block 1 of initial mass 0.44 kg is placed on a rough horizontal surface and connected by a string to block 2 of initial mass 0.20 kg. The string extends over a pulley that has negligible mass and friction.

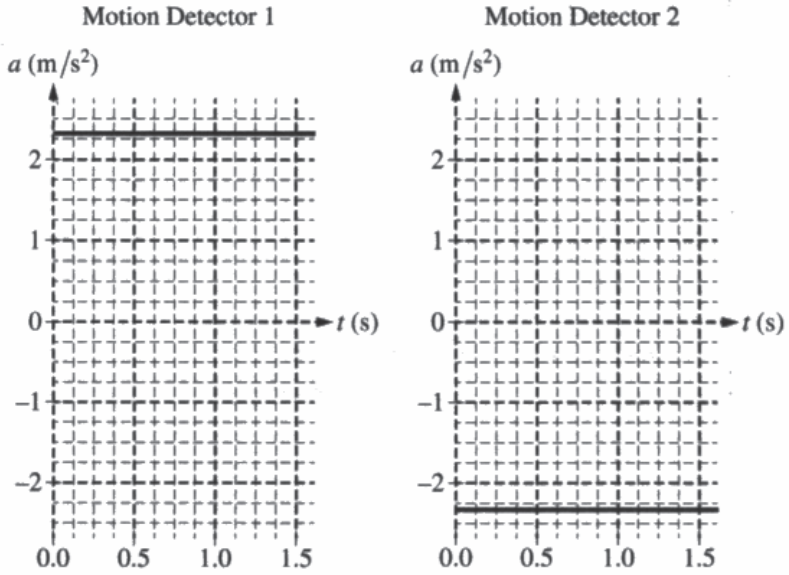
   (a) Calculate the minimum value of the coefficient of static friction μ_s that would keep the two-block system at rest.

$F = ma$

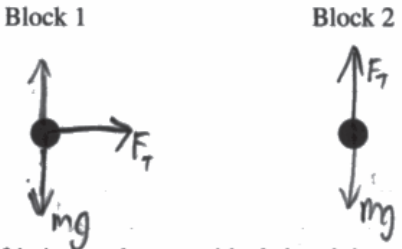
GO ON TO THE NEXT PAGE.

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

The coefficient of friction is such that when block 2 is released from rest, block 1 travels across the surface. The acceleration a of each block is recorded with motion detectors 1 and 2, as shown in the figure. The data for the motion detectors as functions of time t are shown on the graphs. For each motion detector, the positive direction is away from the detector.



(b) On the dots below, which represent the blocks, draw and label the forces (not components) that act on each block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(c) Calculate the coefficient of kinetic friction μ_k between block 1 and the table.

$F = ma$

$K = \frac{1}{2}mv^2$

GO ON TO THE NEXT PAGE.

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

(d) Careful measurements determine that the coefficient of kinetic friction is larger than the value calculated in part (c). Does the following explanation sufficiently account for the observed discrepancy?

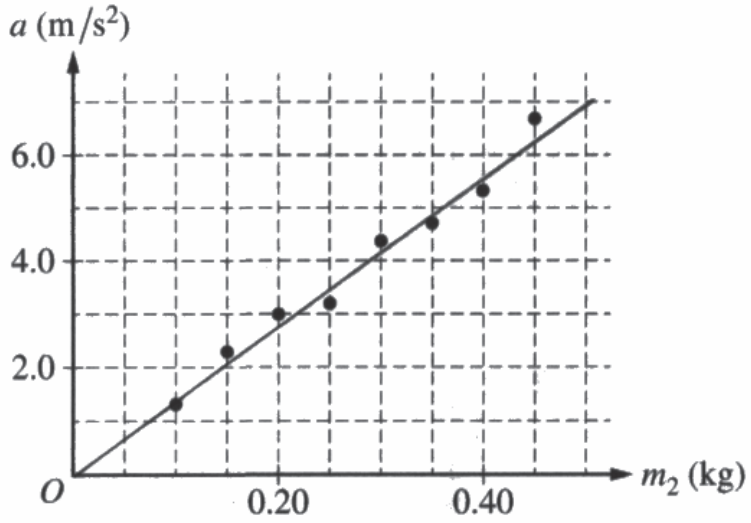
"The horizontal table was not perfectly level before the experiment was conducted. The observed difference in the angle accounts for the difference in the expected and calculated values of μ_k."

____Yes ✓ No

Justify your answer.

F=mg

The experiment is moved to a surface with negligible friction and run for eight trials. In each trial, the students vary the masses m_1 and m_2 of blocks 1 and 2, respectively, while keeping the total mass $(m_1 + m_2) = 0.64\,\text{kg}$ constant. The data for the acceleration a of block 1 as a function of m_2 are shown on the graph below.



(e)

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

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

$\frac{0.55 - 0.28}{0.4 - 0.2} = \frac{0.27}{0.2} = 1.35\ m/s^2$

GO ON TO THE NEXT PAGE.

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

(f) The students lift the left end of the surface so that the surface is inclined at an angle to the horizontal, and the experiment for $m_2 = 0.20\,\text{kg}$ is repeated. Would the acceleration of the system be greater than, less than, or equal to the acceleration of the system in the original experiment?

✓ Greater than _____ Less than _____ Equal to

Justify your claim.

The increase in the angle results in a greater acceleration

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 knowledge and skills:

- Derive a complete set of equations for a modified Atwood's machine both with and without friction.
- Describe an object's motion and the forces on the object both in equilibrium and while accelerating. Derive an expression for the net force in a system for these cases.
- Identify relationships within a system of connected objects.
- Determine the coefficient of friction between surfaces.
- Read and interpret data on a graph.
- Correctly draw and use a free body diagram.
- Defend or refute a student's contention.
- Calculate the slope of a best-fit line and use an appropriate equation to determine the acceleration due to gravity.

Sample: M Q1 A
Score: 14

Part (a) earned 2 points. The first point was earned for evaluating Newton's second law for system at rest, and the second point was earned for correct substitution of static friction. Part (b) earned 4 points. These points were earned for correct horizontal forces on m_1, for correct vertical forces on m_1, for correct vertical forces on m_2, and for indicating gravitational forces on blocks are different. Part (c) earned 3 points. The first 2 points were earned for correctly applying Newton's second law to the two-block system. The third point was earned for a correct substitution of kinetic friction. Part (d) earned 2 points. The first point was earned for choosing "Yes" and attempting relevant justification, and the second point was earned for a correct justification. Part (e) earned 2 points for drawing an appropriate best-fit line, and one point was earned for calculating slope using two points from the best-fit line. The relationship of slope to gravity is incorrect. Part (f) earned 1 point for choosing "Greater than" and providing correct justification.

Sample: M Q1 B
Score: 8

Part (a) earned 2 points for evaluating Newton's second law for system at rest and for correct substitution of static friction. Part (b) earned 2 points. One point was earned for having correct horizontal forces on m_1, but there are no vertical forces indicated on m_1. One point was earned for having correct vertical forces on m_2, but there is no weight force on m_1 to make distinction between gravitational forces on each block. Part (c) earned 1 point. No points were earned for the application of Newton's second law on the two-block system because it is incorrect, but 1 point was earned for correct substitution of kinetic friction. Part (d) earned 2 points for choosing "Yes" and attempting relevant justification and for correct justification. Part (e) earned 1 point for drawing a best-fit line. Slope is not calculated, and the relationship of slope to gravity is not provided. Part (f) earned no points for an incorrect justification.

Question 1 (continued)

Sample: M Q1 C
Score: 2

Part (a) earned no points because Newton's second law is not evaluated for a system at rest, and there is no substitution of static friction. Part (b) earned 1 point for correct vertical forces on m_2. The horizontal and vertical forces on m_1 are incomplete, and no distinction is made between the gravitational forces on each block. Part (c) earned no points because the application of Newton's second law on the blocks is incorrect, and the kinetic friction is not substituted. Part (d) earned no points because the wrong checkbox is selected, and the justification is incorrect. Part (e) earned 1 point for drawing a best-fit line. The slope is not calculated, and the relationship of slope to gravity is incorrect. Part (f) earned no points because the justification is incorrect.