2017

AP® CollegeBoard

AP Physics C: Mechanics

Sample Student Responses and Scoring Commentary

Inside:

- ☑ Free Response Question 1
- ☑ Scoring Guideline
- ☑ Student Samples
- ☑ Scoring Commentary

AP® PHYSICS
2017 SCORING GUIDELINES

General Notes About 2017 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.

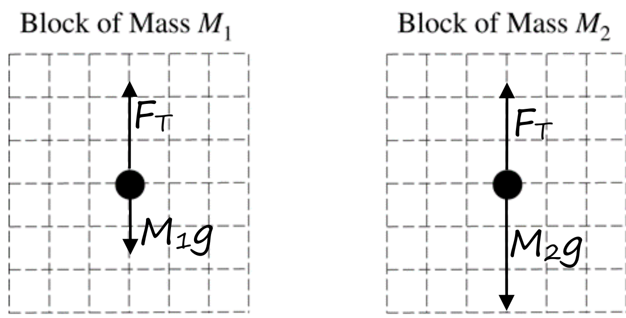
5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 1

15 points total | **Distribution of points**

(a) 3 points



For correctly drawing and labeling the vectors for the weight of the block and the tension for block M_1 with the tension larger than the weight — 1 point

For correctly drawing and labeling the vectors for the weight of the block and the tension for block M_2 with the weight larger than the tension — 1 point

For correctly drawing tension on the two blocks as equal in magnitude — 1 point

Note: If any extraneous vectors are drawn, only a maximum of two points may be earned.

(b) 3 points

For correctly applying Newton's second law to block 1 — 1 point

$F_T - M_1 g = M_1 a$

For correctly applying Newton's second law to block 2 — 1 point

$M_2 g - F_T = M_2 a$

For combining the two equations above in such a way that will lead to the correct equation — 1 point

$M_2 g - M_1 g = (M_1 + M_2) a$

$$a = \frac{(M_2 - M_1)}{(M_1 + M_2)} g$$

(c) 1 point

For indicating variables that will create a straight line whose slope can be used to determine g — 1 point

Example: Vertical axis: a

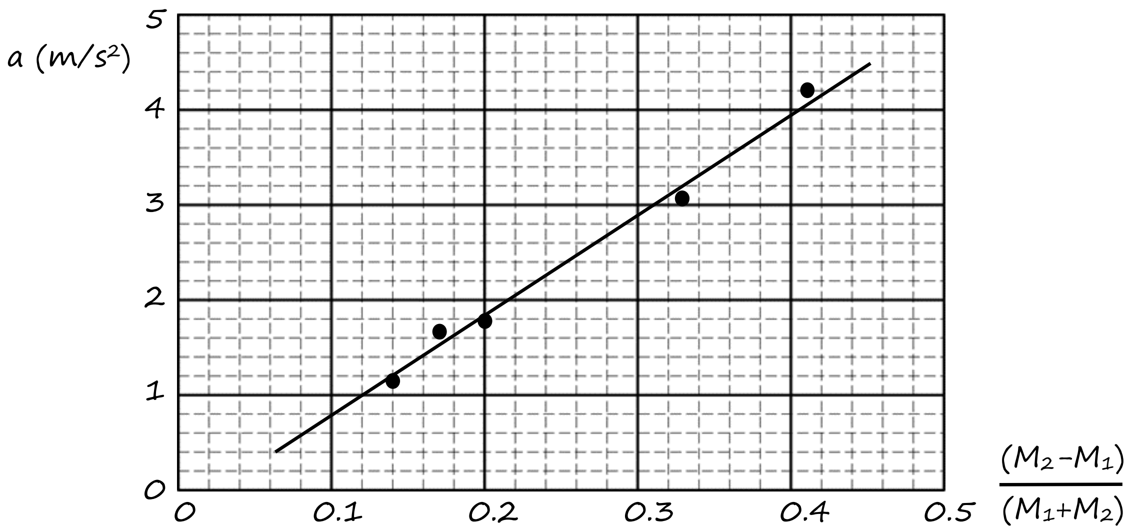
Horizontal axis: $\dfrac{(M_2 - M_1)}{(M_1 + M_2)}$

Note: Full credit is earned if axes are reversed, or if the student uses another acceptable combination.

Question 1 (continued)

Distribution of points

(d) 3 points



For using a correct scale that uses more than half the grid and for correctly labeling the axes, including units as appropriate — 1 point

For correctly plotting the data — 1 point

For drawing a straight best-fit line consistent with the plotted data — 1 point

(e) 2 points

For correctly calculating the slope using the best-fit line and not the data points, unless the points fall on the best-fit line — 1 point

(Note: Credit may be given for the linear regression only if the student states linear regression is used.)

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(3.0 - 1.0)\ \text{m/s}^2}{(0.31 - 0.12)} = 10.5\ \text{m/s}^2$$

For correctly relating the slope to g — 1 point

$g = \text{slope} = 10.5\ \text{m/s}^2$ (using linear regression yields $10.1\ \text{m/s}^2$)

Question 1 (continued)

	Distribution of points
(f) 2 points	
Correct answer: "Lower"	
For including a correct statement about the acceleration of the blocks	1 point
For including a correct statement about the forces on the blocks	1 point

Example: Because the block M_1 is on the table, the net force on the system increases, and therefore the acceleration increases. Because the acceleration of M_2 increases, the net force on M_2 must increase. Therefore, there must be a greater difference in the magnitude of the two forces on M_2. Because the weight of block M_2 stays the same, the retarding force — the tension in the string — must decrease.

(g) 1 point	
For a correct justification	1 point

Example: Block M_1 will experience friction with the table. The acceleration of the system will decrease and this will decrease the slope of the line; therefore, the value of g is determined by the experiment.

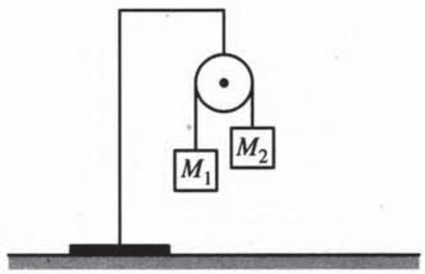
PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

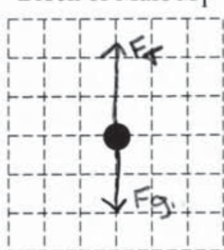
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



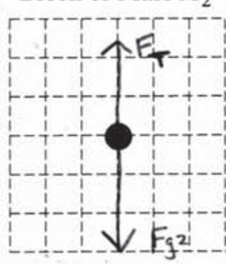
1. An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

   (a) On the dots below, which represent the blocks, draw and label the forces (not components) that act on the blocks. Each force must be represented by a distinct arrow starting on and pointing away from the appropriate dot. The relative lengths of the arrows should show the relative magnitudes of the forces.

Block of Mass M_1



Block of Mass M_2



   (b) Using the forces in your diagrams above, write an equation applying Newton's second law to each block and use these two equations to derive the magnitude of the acceleration of the blocks and show that it is given by the equation: $a = \frac{(M_2 - M_1)}{(M_1 + M_2)} g$

$\Sigma F = m_1 a$

$F_T - F_{g1} = M_1 a$

$F_T = M_1 a + F_{g1}$

$F_T = M_1 a + M_1 g$

$\Sigma F = M_2 a$

$F_{g2} - F_T = M_2 a$

$F_T = F_{g2} - M_2 a$

$F_T = M_2 g - M_2 a$

$F_T = F_T$

$M_1 a + M_1 g = M_2 g - M_2 a$

$M_1 a + M_2 a = M_2 g - M_1 g$

$a(M_1 + M_2) = g(M_2 - M_1)$

$$a = \frac{(M_2 - M_1)}{(M_1 + M_2)} g$$

GO ON TO THE NEXT PAGE.

The magnitude of the acceleration a was measured for different values of M_1 and M_2, and the data are shown below.

M_1 (kg)	1.0	2.0	5.0	6.0	10.0
M_2 (kg)	2.0	3.0	12.0	8.0	14.0
a (m/s^2)	3.02	1.82	4.21	1.15	1.71
$(M_2-M_1)/(M_1+M_2)$	0.333	0.2	0.412	0.143	0.167

(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity g.

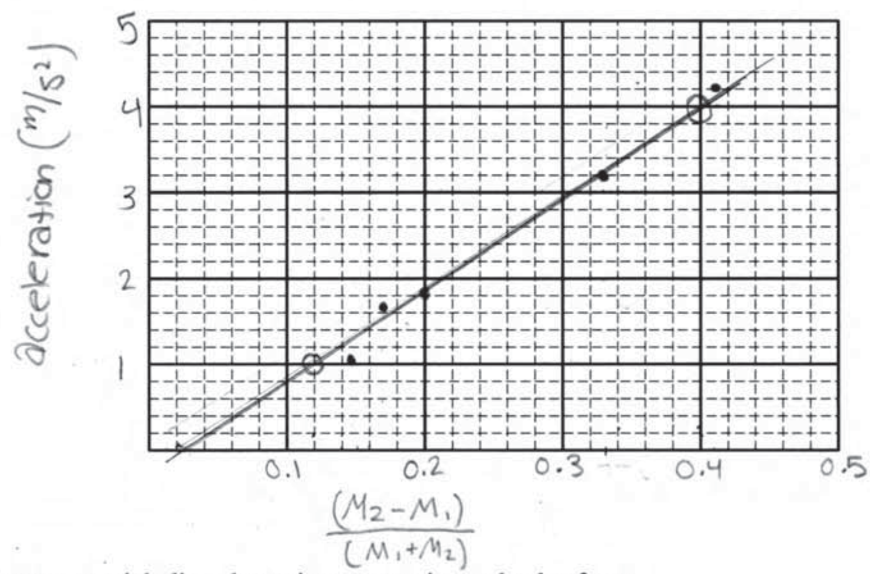
$g = \dfrac{a}{\left(\frac{M_2-M_1}{M_1+M_2}\right)}$

Vertical axis: acceleration

Horizontal axis: $\dfrac{M_2-M_1}{M_1+M_2}$

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

(d) Plot the data points for the quantities indicated in part (c) on the graph below. Clearly scale and label all axes including units, if appropriate. Draw a straight line that best represents the data.

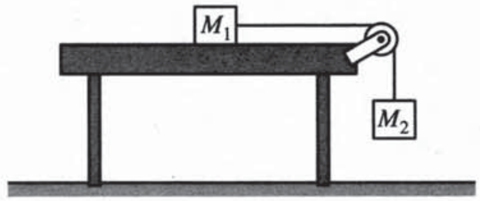


(e) Using your straight line, determine an experimental value for g.

$$g = \frac{y_2-y_1}{x_2-x_1} = \frac{4-1}{0.4-0.12} = \frac{3}{0.28} = 10.71\,m/s^2$$

Question 1 continues on the next page.

GO ON TO THE NEXT PAGE.



The experiment is now repeated with a modification. The Atwood's machine is now set up so that the block of mass M_1 is on a smooth, horizontal table and the block of mass M_2 is hanging over the side of the table, as shown in the figure above.

(f) For the same values of M_1 and M_2, is the magnitude of the tension in the string when the blocks are moving higher, lower, or equal to the magnitude of the tension in the string when the blocks are moving in the first experiment?

____ Higher   _✓_ Lower   ____ Equal to

Justify your answer.

The tension in the first block, M_1 is not opposing any forces like in the first experiment.

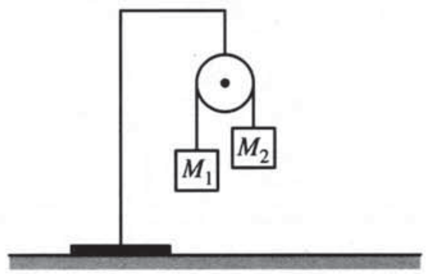
(g) The value determined for the acceleration due to gravity g is lower than in the first experiment. Give one physical factor that could account for this lower value and explain how this factor affected the experiment.

The table could have applied a force of friction so block M_2 would fall slower making it seem like g is lower than it actually is because the gravitational force was opposing a frictional force

GO ON TO THE NEXT PAGE.

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

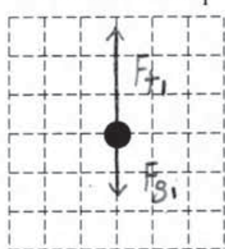
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



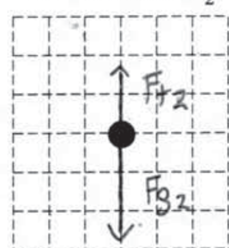
1. An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

(a) On the dots below, which represent the blocks, draw and label the forces (not components) that act on the blocks. Each force must be represented by a distinct arrow starting on and pointing away from the appropriate dot. The relative lengths of the arrows should show the relative magnitudes of the forces.

Block of Mass M_1



Block of Mass M_2



(b) Using the forces in your diagrams above, write an equation applying Newton's second law to <u>each</u> block and use these two equations to derive the magnitude of the acceleration of the blocks and show that it is given by the equation: $a = \frac{(M_2 - M_1)}{(M_1 + M_2)} g$

$\Sigma F_1 = M_1 a_1 = F_{t1} - F_{g1}$ | $\Sigma F_2 = M_2 a_2 = F_{g2} - F_{t2}$

$M_1 a_1 = M_2 g - M_1 g$ | $M_2 a_2 = M_2 g - M_1 g$

$a_1 = \frac{(M_2 - M_1) g}{M_1}$ | $a_2 = \frac{(M_2 - M_1) g}{M_2}$

GO ON TO THE NEXT PAGE.

The magnitude of the acceleration a was measured for different values of M_1 and M_2, and the data are shown below.

M_1 (kg)	1.0	2.0	5.0	6.0	10.0
M_2 (kg)	2.0	3.0	12.0	8.0	14.0
a (m/s^2)	3.02	1.82	4.21	1.15	1.71

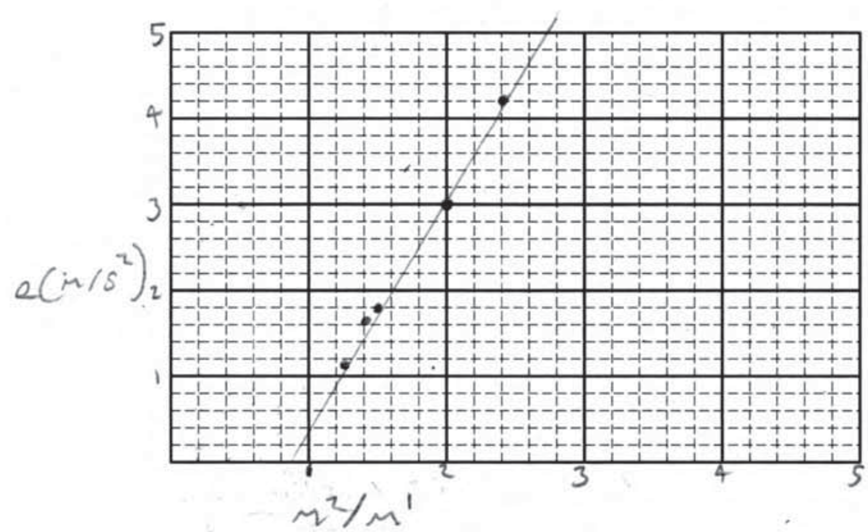
(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity g.

Vertical axis: a

Horizontal axis: $\frac{M^2}{M^1}$

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

(d) Plot the data points for the quantities indicated in part (c) on the graph below. Clearly scale and label all axes including units, if appropriate. Draw a straight line that best represents the data.



(e) Using your straight line, determine an experimental value for g.

(2.4, 4.21)

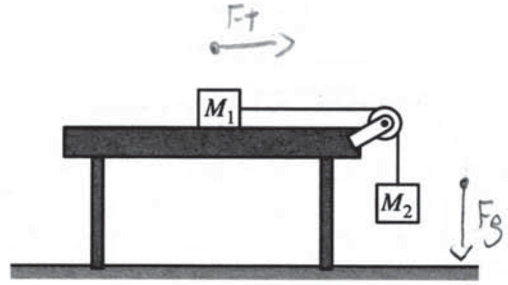
(2, 3.02)

$\frac{3.02 - 4.21}{2 - 2.4} = \boxed{2.975 \frac{m}{s^2}}$

Question 1 continues on the next page.

GO ON TO THE NEXT PAGE.

M Q1 B3



The experiment is now repeated with a modification. The Atwood's machine is now set up so that the block of mass M_1 is on a smooth, horizontal table and the block of mass M_2 is hanging over the side of the table, as shown in the figure above.

(f) For the same values of M_1 and M_2, is the magnitude of the tension in the string when the blocks are moving higher, lower, or equal to the magnitude of the tension in the string when the blocks are moving in the first experiment?

____ Higher __X__ Lower ____ Equal to

Justify your answer.

~~[illegible]~~

Because M_1 is not suspended in midair anymore, there is no gravitational force to cause tension in the string. Now the only tension in the string comes from block M_2. Thus the tension is lower.

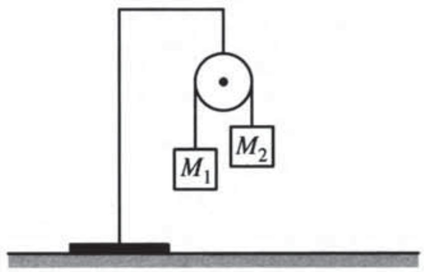
(g) The value determined for the acceleration due to gravity g is lower than in the first experiment. Give one physical factor that could account for this lower value and explain how this factor affected the experiment.

There is friction between the block of mass M_1 and the table. The friction force between on M_1 would make the F_{net} on the system smaller by opposing the gravitational force pulling on M_2. This smaller F_{net} either means that the mass of the system has decreased or the acceleration b/c $F_{net} = ma$. Since the mass of the system did not change the acceleration must have decreased.

GO ON TO THE NEXT PAGE.

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

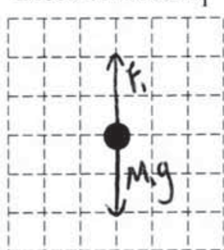
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



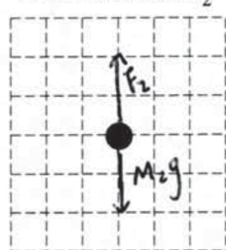
1. An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

(a) On the dots below, which represent the blocks, draw and label the forces (not components) that act on the blocks. Each force must be represented by a distinct arrow starting on and pointing away from the appropriate dot. The relative lengths of the arrows should show the relative magnitudes of the forces.

Block of Mass M_1



Block of Mass M_2



(b) Using the forces in your diagrams above, write an equation applying Newton's second law to <u>each</u> block and use these two equations to derive the magnitude of the acceleration of the blocks and show that it is given by the equation: $a = \frac{(M_2 - M_1)}{(M_1 + M_2)}g$

$\Sigma F = ma$

GO ON TO THE NEXT PAGE.

The magnitude of the acceleration a was measured for different values of M_1 and M_2, and the data are shown below.

M_1 (kg)	1.0	2.0	5.0	6.0	10.0
M_2 (kg)	2.0	3.0	12.0	8.0	14.0
a (m/s^2)	3.02	1.82	4.21	1.15	1.71

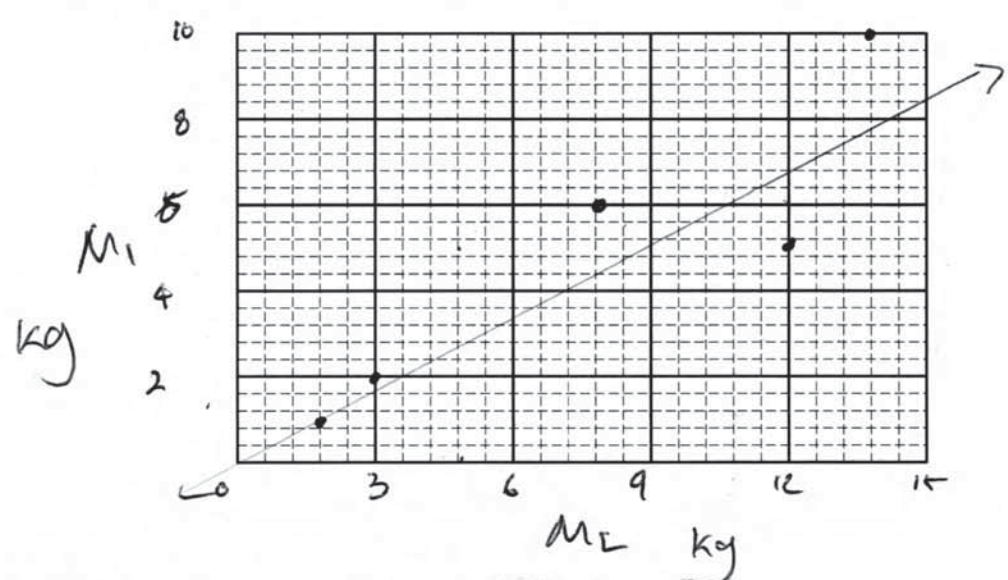
(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity g.

Vertical axis: M_1

Horizontal axis: M_2

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

(d) Plot the data points for the quantities indicated in part (c) on the graph below. Clearly scale and label all axes including units, if appropriate. Draw a straight line that best represents the data.

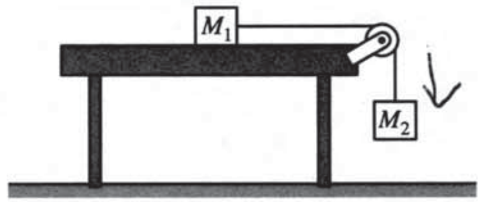


(e) Using your straight line, determine an experimental value for g.

$g = 9.8\ m/s^2$

Question 1 continues on the next page.

GO ON TO THE NEXT PAGE.



The experiment is now repeated with a modification. The Atwood's machine is now set up so that the block of mass M_1 is on a smooth, horizontal table and the block of mass M_2 is hanging over the side of the table, as shown in the figure above.

(f) For the same values of M_1 and M_2, is the magnitude of the tension in the string when the blocks are moving higher, lower, or equal to the magnitude of the tension in the string when the blocks are moving in the first experiment?

____ Higher ✓ Lower ____ Equal to

Justify your answer.

because M2 is hover than M1

(g) The value determined for the acceleration due to gravity g is lower than in the first experiment. Give one physical factor that could account for this lower value and explain how this factor affected the experiment.

Last time M1 and M2 both are affected by gravity, so it gave us $F_1 - F_2$. However now, M1 doesn't strong with gravity, therefore, only M2 is affecting by gravity.

GO ON TO THE NEXT PAGE.

Question 1

Overview

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

- An understanding of forces acting on two objects.
- The ability to use free-body force diagrams.
- The ability to correctly write Newton's second law from a free-body force diagram.
- The ability to manipulate related equations in order to express the relationship between physical quantities associated with two objects.
- An understanding of how to use graphs to express a relationship between quantities.
- The ability to draw graphs, including labelling axes, including units and using an appropriate scale.
- An understanding of the information that can be derived from the slope of the best-fit line.
- An understanding of the effect on the acceleration of an object when the applied forces change.
- The ability to identify and explain possible physical factors that can affect an experimental result.

Sample: M Q1 A
Score: 13

Parts (a), (b), (c), (d), and (e) earned full credit. In part (a) the vectors are of appropriate length and properly labeled. In part (b) the two equations are clearly written and combined. In part (c) appropriate variables are chosen for both axes. In part (d) the axes are properly labeled with units, the scale uses more than half the graph, and an appropriate best-fit line is drawn. In part (e) the slope is calculated from the circled points on the best-fit line and not data points and is correctly related to the acceleration due to gravity g. In part (f) the correct selection is made, but there is no discussion of the difference in acceleration before and after, and there is no connection to the tension force, so no credit was earned. In part (g) a correct physical factor is indicated, and the justification is correct, so full credit was earned.

Sample: M Q1 B
Score: 7

In part (a) the vectors are correctly drawn for each block, but the tension forces are not the same length, so 2 points were earned. In part (b) the correct Newton's second law equation is written for each block, but they are not combined correctly, so 2 points were earned. The variables in part (c) are not appropriate to calculate the acceleration due to gravity, so no credit was earned. In part (d) the graph has axis labels and units consistent with part (c), the data points are correctly plotted, and the best-fit line is drawn, but the scale does not use half the graph, so 2 points were earned. In part (e) the slope is calculated using data points (not the best-fit line), and there is no connection between the slope and the acceleration due to gravity, so no credit was earned. In part (f) the correct selection is made, but there is no discussion of the difference in acceleration before and after, and there is no correct connection to the tension force, so no credit was earned. In part (g) a correct physical factor is indicated, and the justification is correct, so full credit was earned.

Question 1 (continued)

Sample: M Q1 C
Score: 4

In part (a) the vectors lengths for the individual blocks are incorrect, but the tension forces are the same length, so 1 point was earned. In part (b) the Newton's second law equation is not written for each block, so no points were earned. The variables in part (c) are not appropriate to calculate the acceleration due to gravity, so no credit was earned. The graph in part (d) is labeled consistently with part (c), the data points are also consistent with part (c), and the best-fit line is drawn, so full credit was earned. In part (e) the slope is not calculated, so no points were earned. Parts (f) and (g) both have incorrect justifications, so no points were earned for either part.