2019

AP® CollegeBoard

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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General Notes About 2019 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.

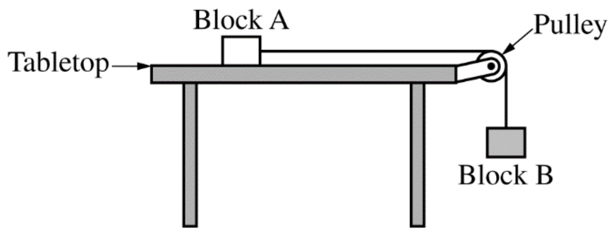
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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 Course and Exam Description* and the *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 the 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 2

12 points



This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a) LO 3.A.1.1, SP 1.5; LO 3.B.1.1, SP 6.4, 7.2

i.
2 points

Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

Examples of correct answers: "Zero", "small", "negligible", "much less than g", or "<<g"		
For a correct answer and attempt at a consistent justification		1 point
For correct reasoning		1 point
Example earning 1 point: Nearly zero. Because block A is much heavier than block B.		
Examples earning 2 points: "Very small. Because block A has a large inertia, it won't speed up much." "Close to zero because block B is so light that it can hardly budge block A."		
Claim: The acceleration of the blocks is zero/small/negligible/ "<<g". Evidence: The mass of block A is much greater than the mass of block B. Reasoning: See two-point examples above.		

ii.
1 point

Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

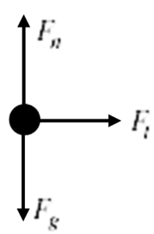
Question 2 (continued)

(a) (continued)
ii. (continued)

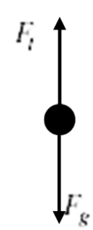
Examples of correct answers: g or 9.8 m/s^2 or 10 m/s^2 (or just 9.8 or 10)		
For a correct answer and correct justification		1 point
Examples: Nearly equal to g. Because block B is almost in free fall. 10 m/s^2, because block A has negligible mass and the tension in the string is nearly zero.		
Claim: The acceleration of the blocks is close to g. Evidence: The mass of block A is much less than the mass of block B. There is negligible friction between block A and the tabletop. The pulley has negligible mass and spins with negligible friction about its axle. Reasoning: See examples above.		

(b) LO 3.A.2.1, SP 1.1; LO 3.A.3.1, SP 6.4
3 points

Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.



Block A



Block B

For a correct normal force on block A with acceptable label: N, F_N, "normal force," F_{table}, "table force," or any other label indicating the force is "normal" or comes from the table		1 point
For correct gravitational forces with acceptable label on both diagrams: F_g, F_{grav}, W, mg, $m_A g$, "gravity," "grav force," but NOT G or g, and no extraneous forces on either diagram		1 point
For correct tension forces with acceptable label on both diagrams: "tension," "string force," F_T, $F_{tension}$, F_{string}, F_S, T, or some other label indicating that the force comes from the string or from tension. NOT acceptable: $m_B g$, F_{m_B}, "force from block B" or other indications that the force is "created" by block B		1 point

Question 2 (continued)

(c) LO 2.B.1.1, SP 2.2; LO 3.A.1.1, SP 1.5, 2.2; LO 3.B.1.3, SP 1.5, 2.2; LO 3.B.2.1, SP 1.4, 2.2; LO 4.A.2.1, SP 6.4
3 points

Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

For using separate Newton's second law equations for each block		1 point
For combining the equations with correct notation, including correctly using m_A and m_B, indicating that the same tension force acts on both blocks, *and* that they share the same acceleration		1 point
For a correct equation for a with supporting work: $a = \dfrac{m_B}{m_A + m_B} g$		1 point

Alternate Solution:

For writing a "whole-system" equation for the total mass that does not contain internal forces. $F_{net} = m_{total} a$		*1 point*
For substituting the net force and system mass with correct quantities $m_B g = (m_A + m_B) a$		*1 point*
<u>Note:</u> *Writing the correct whole-system equation is sufficient to earn the first two points.*		
For a correct equation for a with supporting work: $a = \dfrac{m_B}{m_A + m_B} g$		*1 point*

(d) LO 3.A.1.1, SP 2.2; LO 3.A.3.1, SP 6.4; LO 3.B.1.3, SP 2.2
1 point

Consider the scenario from part (a)(ii), where the mass of block A is much <u>less</u> than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii)?

____ Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much <u>less</u> than m_B.

Correct answer: "Yes"		
<u>Note:</u> "No" is acceptable if the equation is inconsistent with the answer in (a)(ii).		
For valid reasoning that addresses the result in part (c) and the reasoning in part (a)(ii)		1 point

Question 2 (continued)

(d) (continued)

Claims: Yes, the equation for the acceleration of the blocks from part (c) agrees with the reasoning in part (a)(ii). or No, the equation for the acceleration of the blocks from part (c) does not agree with the reasoning in part (a)(ii). Evidence: The mass of block A is much less than the mass of block B. $a = \frac{m_B}{m_A + m_B} g$ (derived as part (c) answer) Reasoning for "Yes" claim: When m_A is much less than m_B, it can be neglected in the equation derived in part (c), giving an acceleration close to g as stated in (a)(ii). Reasoning for "No" claim, if the answer in part (a)(ii) is wrong: When m_A is much less than m_B, it can be neglected in the equation derived in part (c), giving an acceleration close to g. This disagrees with the value of ___ stated in (a)(ii). Reasoning for "No" claim, if the answer in part (c) is wrong: When m_A is much less than m_B, it can be neglected in the equation derived in part (c), giving an acceleration of ___. This disagrees with the value of g stated in (a)(ii).		

(e) LO 3.A.1.1, SP 2.2; LO 3.B.1.1, SP 6.4,7.2; LO 3.B.1.3, SP 2.2
2 points

While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

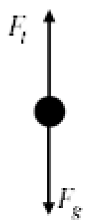
____ $T_2 > T_1$ ____ $T_2 = T_1$ ____ $T_2 < T_1$

Briefly explain your reasoning.

Correct answer: $T_2 > T_1$. Note: A maximum of 1 point can be earned if an incorrect selection is made.		
For reasoning that the acceleration of both blocks is smaller		1 point
For doing any one of the following, consistent with the answer selection and Newton's second law for block B • Concluding that a smaller acceleration implies that T_2 is greater than T_1 • Concluding that an unchanged acceleration implies that T_2 is the same as T_1 • Concluding that a larger acceleration implies that T_2 is less than T_1		1 point

Question 2 (continued)

(e) (continued)

Claim: $T_2 > T_1$ Evidence: The pulleys spin with negligible friction about the axle. The original pulley has negligible mass. The second pulley's mass is not negligible. $\vec{a} = \frac{\sum \vec{F}}{m}$  Reasoning: The rotational inertia of the second pulley results in a smaller acceleration for the blocks. Block B must have a smaller net force to have a smaller acceleration, so the rope tension must be larger than before (closer in magnitude to the gravitational force on block B).		

Learning Objectives

LO 2.B.1.1: The student is able to apply F = mg to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. [See Science Practices 2.2, 7.2]

LO 3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [See Science Practices 1.5, 2.1, 2.2]

LO 3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See Science Practice 1.1]

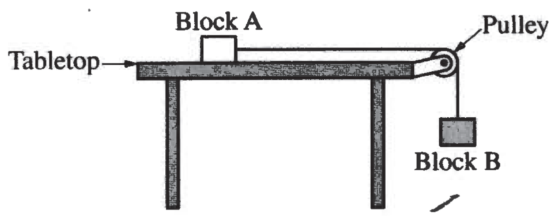
LO 3.A.3.1: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [See Science Practices 6.4, 7.2]

LO 3.B.1.1: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension. [See Science Practices 6.4, 7.2]

LO 3.B.1.3: The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See Science Practices 1.5, 2.2]

LO 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]

LO 4.A.2.1: The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [See Science Practice 6.4]



2. (12 points, suggested time 25 minutes)

This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a)

i. Suppose the mass of block A is much <u>greater</u> than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

The magnitude of acceleration would be near 0 m/s²

Briefly explain your reasoning without deriving or using equations.

Imagine a human pulling a mountain w/ a rope. The mass of Block a is so much greater that the weight of Block B is not sufficient enough to make a movement. No movement = No change in velocity = No acceleration.

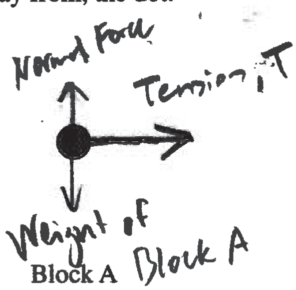
ii. Now suppose the mass of block A is much <u>less</u> than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

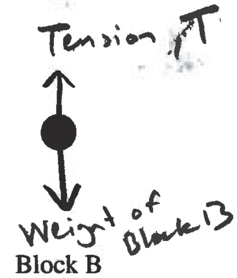
9.8 m/s²

Briefly explain your reasoning without deriving or using equations.

Block B would pretty much be droping due to its weight and gravity pulling it down; that would be the "only" force present (Tension's there, but negligeble if $M_{Block A} < M_{Block B}$ by a huge amount

(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.





(c) Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

A: F_{net} (Tension) = $m_A a$

B: $F_{net} = (m_B g - \text{Tension}) = m_B a$

$m_B g - m_A a = m_B a$

$m_B g = m_A a + m_B a$

$m_B g = a(m_A + m_B)$

$$a = m_B g / (m_A + m_B)$$

(d) Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii) ?

__✓__ Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B.

$a = \frac{m_B g}{m_A + m_B} = \frac{9000 g}{9000.01} \approx .999 g \approx 1g = 9.8$

If $m_A = 0.01$ $m_B = 9000$

As you can see from the work, if m_A is incredibly small, the equation pretty much becomes $\frac{m_B}{m_B} g$ which equals 1g.

(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

____ $T_2 > T_1$ ____ $T_2 = T_1$ __✓__ $T_2 < T_1$

Briefly explain your reasoning.

If the mass of the pulley is not negligible, energy is required to turn it, meaning acc. decreases from original. If acceleration decreases, tension decreases as well due to constant mass of block A. So, T_2 is less than T_1.

Block A. Tension = (m) a
↓ ↓

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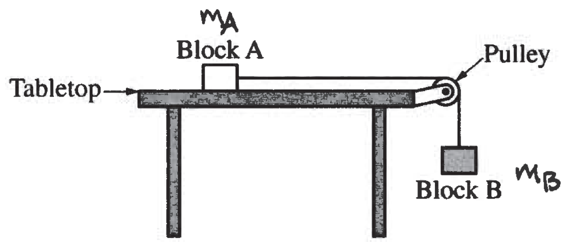


2. (12 points, suggested time 25 minutes) $V_1 = 0$

This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a)

i. Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

The acceleration of the blocks is zero.

Briefly explain your reasoning without deriving or using equations.

The force of block A has both the mass and gravity combined. Since gravity is constant in these two blocks then a very small mass and smaller force of block B would have little effect on block A, so no movement.

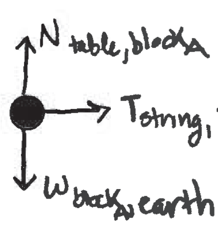
ii. Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

The acceleration is equal to gravity (9.8 m/s²).

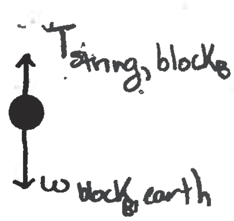
Briefly explain your reasoning without deriving or using equations.

The force of block B is larger than block A. Therefore block B can move block A by the string. Block B acceleration is 9.8 m/s² downwards and so through the string, block A moves at the same acceleration.

(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.



Block A



Block B

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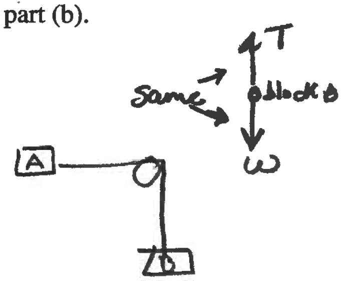
(c) Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

$F_{block A} = T$ (mg)

$\frac{m_A a}{m_A} = \frac{m_B g}{m_A}$

$a = \frac{m_B g}{m_A}$



(d) Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii) ?

X Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B.

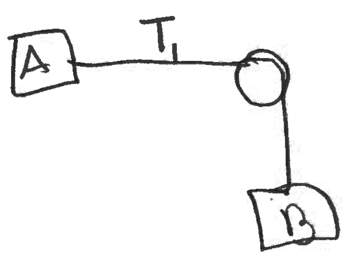
The magnitude of the acceleration is based on how large the mass of block A is. If block A is less then the number that m_B and g is divided by is less. That means the acceleration will be equal to the tension force of block B on the string which in turn is the same tension force on block A. Therefore the acceleration is close to gravity.

(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

____ $T_2 > T_1$ X $T_2 = T_1$ ____ $T_2 < T_1$

Briefly explain your reasoning.

The mass of the pulley does not matter. The string is part of the blockA-blockB system. Therefore the tension is made up of the weight of block B.



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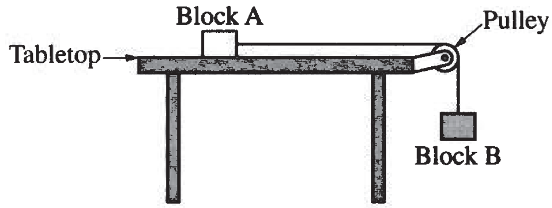

2. (12 points, suggested time 25 minutes)

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(a)

i. Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Block B will accelerate to the floor at a ~~rate~~ acceleration of mass of Block B times gravity ($M_B g$).

Briefly explain your reasoning without deriving or using equations.

This is because there is no friction to resist the pull of Block B and the fact Block A is attached has no effect. B will will accelerate down with no external forces acting against it.

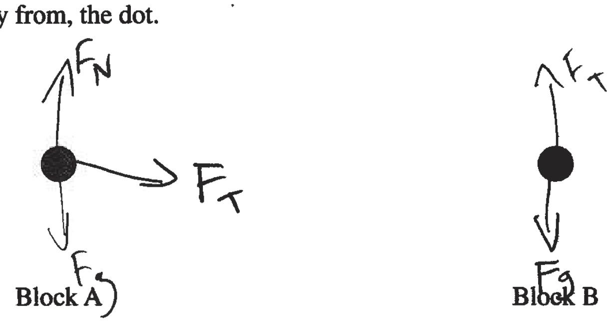
ii. Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Block B will still accelerate at mass of block B times gravity ($M_B g$)

Briefly explain your reasoning without deriving or using equations.

Because the frictionless surface means that Block B will accelerate to the ground with no external forces acting on it since Block A moves frictionlessly.

(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.



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(c) Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

$a = \frac{F}{m}$ $F = mg = m_B \cdot g$

$a = \frac{m_B \cdot g}{m_B}$ $a = g$

(d) Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii) ?

✓ Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B.

Because when Block A and the Tabletop have no friction there is no force acting against the force of gravity and therefore the blocks will accelerate at the force of gravity.

(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

____ $T_2 > T_1$ ✓ $T_2 = T_1$ ____ $T_2 < T_1$

Briefly explain your reasoning.

The mass of the pulley doesn't affect the tension on block B. If there was friction in the pulley then the blocks acceleration would change but the change in the pulley's mass doesn't effect the tension.

Question 2

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

Overview

This question asked students to describe the limiting case behavior of a modified Atwood machine: a mass on a table connected across a pulley to a hanging mass. The responses to this question were expected to demonstrate an understanding of the following concepts:

- The hanging mass will exert a force to accelerate the entire mass of the two-body system. A hanging mass much smaller than the mass on the surface corresponds to a very small force acting on a large total mass and therefore very small acceleration. A hanging mass much larger than the mass on the surface will essentially be in free fall, with an acceleration close to g.
- Free-body diagrams can be drawn, indicating the type and direction of forces acting on each mass. This demonstrates skill in producing a common, pictorial representation of forces.
- Newton's second law can be applied to each block or the entire system to determine the acceleration of the blocks, requiring that students demonstrate skill in writing mathematical equations representing physical laws, and then manipulating those equations.

Sample: 2A
Score: 11

In part (a)(i) both points were earned for stating that acceleration is near zero with justification and for correctly reasoning that a small force (weight of block B) exerted on a large mass will lead to an acceleration close to zero. In part (a)(ii) the point was earned for reasoning that tension is negligible on block B such that it falls as if only gravity was acting on it, with an acceleration of g. In part (b) the full 3 points were earned for correctly drawing and labeling vectors for the normal force, the tension forces, and the gravitational forces. In part (c) the full 3 points were earned. The student writes Newton's second law equations for each block on the left side of the response, correctly combines these equations in terms of m_A, m_B, and g using the fact that the tensions and accelerations are the same, and writes a correct final answer. The answer is sufficiently clear to earn the point for a correct final equation, although it would be advisable to include parentheses around the total mass or write the numerator above the denominator for clarity. In part (d) the point is earned for using mathematical reasoning to show that the equation derived in part (c) approaches $a = g$ in the case that m_A is much smaller than m_B, which is equivalent to the answer stated in (a)(ii), and checking "yes." In part (e) 1 of the 2 points was earned for recognizing that the acceleration of the system is smaller but incorrectly concluding that T_2 must, therefore, be smaller than T_1 based on Newton's second law.

Sample: 2B
Score: 6

In part (a)(i) both points were earned for stating that acceleration is zero with justification and for correctly reasoning that a small force exerted by block B would have little effect and produce no movement of block A in the case that m_A is much greater than m_B. In part (a)(ii) the point was earned for reasoning that block B would simply fall with an acceleration of g and pull block A at the same acceleration. In part (b) the full 3 points were earned for correctly drawing and labeling vectors for the normal force, the tension forces, and the gravitational forces. In part (c) none of the 3 points were earned because the student does not clearly use Newton's second law for both blocks or write a correct equation for the entire system. Therefore the second point for combining two Newton's second law equations or writing a system equation with the correct net force and total mass was not earned. The final answer is not correct. In part (d) the point was not earned because the student incorrectly

Question 2 (continued)

concludes that the equation derived in part (c) approaches $a = g$ in the case that m_A is much smaller than m_B. In part (e) neither of the 2 points were earned because the student does not indicate that the acceleration of the system is smaller and does not relate T_2 to T_1 consistent with a change (or lack thereof) in acceleration and Newton's second law for block B.

Sample: 2C
Score: 3

In part (a)(i) neither point was earned because the student does not state that the acceleration will be very small, or zero, and incorrectly reasons that the mass of block A has no effect. In part (a)(ii) the point was not earned because the student concludes that the acceleration is $m_B g$ and that block B has no external forces acting on it. In part (b) the full 3 points were earned for correctly drawing and labeling vectors for the normal force, the tension forces, and the gravitational forces. In part (c) none of the 3 points were earned because the student does not clearly use Newton's second law for both blocks or write a correct equation for the entire system. Therefore the second point for combining two Newton's second law equations or writing a system equation with the correct net force and total mass was not earned. The final answer is not correct. In part (d) the point was not earned because the student does not use mathematical reasoning from an equation derived in part (c) to conclude an answer consistent with the acceleration listed in part (a)(ii). In part (e) neither of the 2 points were earned. The first point was not earned because the student does not indicate that the acceleration of the system is smaller. The student indicates that if there was friction the acceleration would change but does not explicitly indicate whether acceleration changes in this case and relate T_2 and T_1 accordingly, consistent with Newton's second law for block B; therefore, the second point was not earned.