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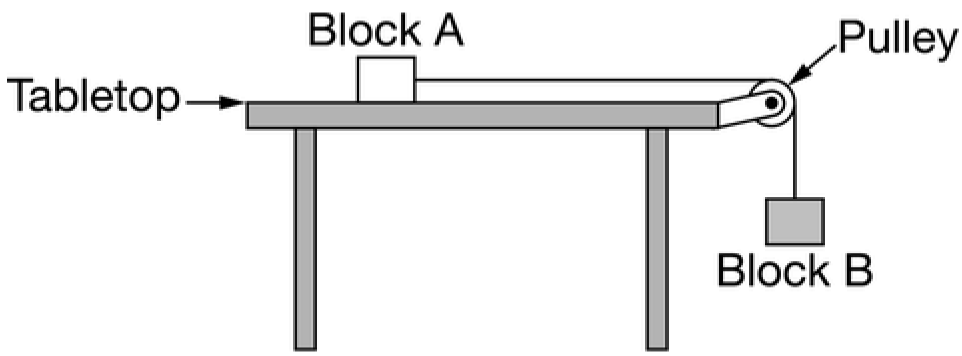
1. This question is a long free-response question. Show your work for each part of the question.



(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 greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Please respond on separate paper, following directions from your teacher.

Briefly explain your reasoning without deriving or using equations.

Please respond on separate paper, following directions from your teacher.

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.

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Please respond on separate paper, following directions from your teacher.

Briefly explain your reasoning without deriving or using equations.

Please respond on separate paper, following directions from your teacher.

(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

Please respond on separate paper, following directions from your teacher.

(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).

Please respond on separate paper, following directions from your teacher.

(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

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Please respond on separate paper, following directions from your teacher.

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.

Please respond on separate paper, following directions from your teacher.

(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?

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

Please respond on separate paper, following directions from your teacher.

Briefly explain your reasoning.

Please respond on separate paper, following directions from your teacher.

Part A(i)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Correct Answers: “Zero”, “small”, “negligible”, “much less than “g ”, or “$<< g$ ”.

0	1	2

The response accurately includes **both** of the following criteria:

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- ☐ For a correct answer and attempt at a consistent justification.
- ☐ For correct reasoning.

Example 1 Point Response:

Nearly zero. Because block A is much heavier than block B .

Example 2 Point Responses:

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 Statements: Very small. Because block A has a large inertia, it won't speed up much or close to zero because block B is so light that it can hardly budge block A .

Part A(ii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Correct Answer: g , $9.8\ \mathrm{m/s^2}$, or $10\ \mathrm{m/s^2}$ (or just 9.8 or 10)

0	1 ✔

The response does not accurately include:

- ☐ An indication that the acceleration is nearly equal to g and a correct justification.

Example Response:

Nearly equal to g . Because block B is almost in free fall.

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$10\ \mathrm{m/s^2}$, 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 Statements: Nearly equal to g . Because block B is almost in free fall or $10\ \mathrm{m/s^2}$, because block A has negligible mass and the tension in the string is nearly zero.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Note: N , F_{N} , “normal force,” F_{Table} , “table force,” or any other label can be used to indicate the force is “normal” or comes from the table.

Note: F_{g} , F_{grav} , W , mg , $m_A g$, “gravity,” “grav force,” may be used.

Note: G or g are not acceptable.

Note: “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 may be used.

Note: $m_B g$, F_{mB}, “force from block B ” or other indications that the force is “created” by block B are NOT acceptable.

0	1	2	3 ✔

The response accurately includes **three** of the following criteria.

- ☐ A correct normal force on block A with acceptable label.
- ☐ Correct gravitational forces with acceptable label on both diagrams, and no extraneous forces on either diagram.
- ☐ Correct tension forces with acceptable label on both diagrams.

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Example Response:

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Note: Writing a “whole system” equation is also sufficient to earn the first two points.

0	1	2	3

The response accurately includes **three** of the following criteria.

- ☐ For using separate Newton’s second law equations for each block.
- ☐ 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.
- ☐ For a correct equation for a with supporting work.

Example Response:

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$$\sum F_B = m_B a$$

$$m_B g - F_T = m_B a$$

$$\sum F_A = m_A a$$

$$F_T = m_A a$$

$$m_B g - m_A a = m_B a$$

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

$$a = \frac{m_B g}{(m_B + m_A)}$$

Part C - Alternate Solution

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Note: *Writing the correct whole-system equation is sufficient to earn the first two points of part (c).*

0	1	2	3

The response accurately includes ***three*** *of the following criteria.*

- ☐ *For writing a "whole-system" equation for the total mass that does not contain internal forces.*
- ☐ *For substituting the net force and system mass with correct quantities.*
- ☐ *For a correct equation for a with supporting work.*

Example Response:

$F_{\text{net}} = m_{\text{total}} a$

$m_B g = (m_A + m_B)\, a$

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

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Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Correct Answer: "Yes"

Note: "No" is acceptable if the equation is inconsistent with the answer in (a)(ii).

0	1

The response accurately includes

- ☐ A valid reasoning that addresses the result in part (c) and the reasoning in part (a)(ii).

Example Response:

Claim:
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 Statements 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 Statements 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 Statements for "No" claim, if the answer in part (c) is wrong:

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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).

Part E

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Correct Answer: $T_2 > T_1$.

Note: A maximum of 1 point can be earned for part (e) if an incorrect selection is made.

0	1	2

The response accurately includes **both** of the following criteria:

- ☐ For reasoning that the acceleration of both blocks is smaller.
- ☐ 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

Example Response:

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.

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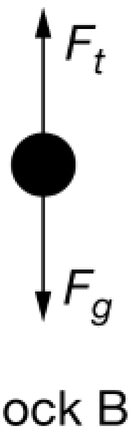
$\vec{a} = \frac{\sum \vec{F}}{m}$



Reasoning Statements:

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).