

Atwood's Machine ~ Project **Name:** _____**Potential Credits:** /25

Using a pencil, answer the following questions. The lab is marked based on clarity of responses, completeness, neatness, and accuracy. Do your best! Please ensure that any data measured (or recorded) includes the appropriate number of significant digits (only one uncertain digit).

This activity is divided into three sections:

- **Core** – this first section explores only the basic “core” ideas involved in understanding. Students must demonstrate a sound understanding with all of their answers in this section *BEFORE* attempting the next section.
- **Mastery** – Your instructor will *NOT* review this section if the Core section above shows any misconceptions. In this section students will make predictions and apply the concepts and ideas learned above. For complete mastery it is expected that data collection and scientific procedures will be as accurate as possible. All work shown should be clear with any units included. Answers should be rounded off to the correct number of significant figures based on the data collected.
- **Ace** – Once again, your instructor will only look at this section provided he/she is confident that the above Mastery criteria has been met. In this section students will demonstrate a deeper understanding of the concepts through error analysis, experimental design etc. Physics concepts from other units already covered will often be required here.

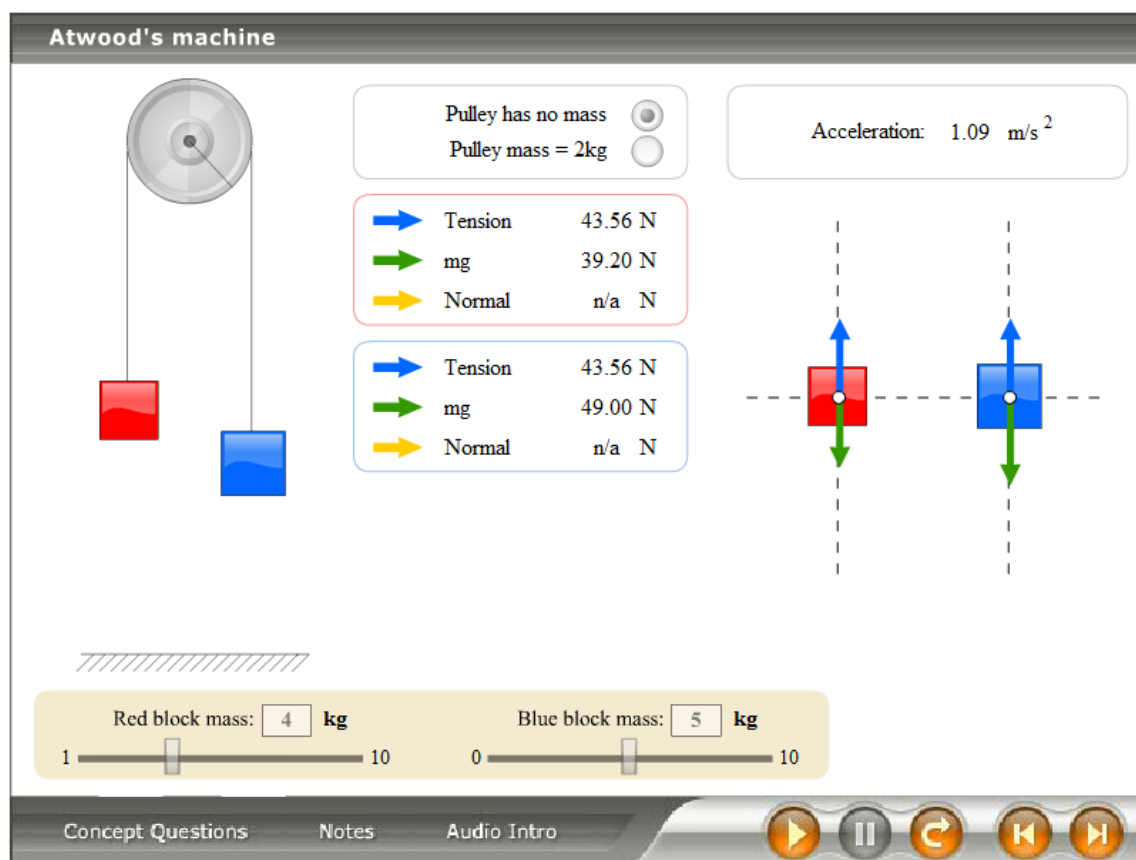
Objectives:

- To construct a free body diagram showing all forces (gravity and tension)
- To develop an equation for the net force on the entire system of objects, or on a single object
- To determine, graphically, the gravitational field strength, g

Description: (open the sim below)

<http://higheredbcs.wiley.com/legacy/college/halliday/0471758019/simulations/sim20/sim20.html>

The simulation shows two masses connected by a cord passing over a pulley. You can control the size of each mass and the simulation will calculate the acceleration of the system, the force of gravity acting on each mass, and the tension in the cord. The effects of friction and the mass of the pulley can be ignored (leave as *Pulley has no mass*).



Part 1: Core

Label all forces acting directly onto the diagram above. Be sure to identify m_1 and m_2 with appropriate subscripts.

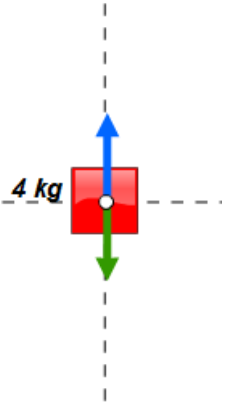
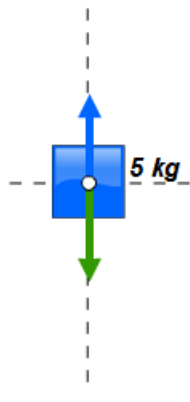
- Open the simulation file 'Atwood's Machine' and experiment with the size of each mass, then answer the questions below.
 - The mass of the blocks can be set to whole numbers between 0 kg to 10 kg. What values for m_1 and m_2 yield the maximum tension? How does the tensions in the rope compare to the weight of each mass?

- With the same mass configuration as above you should see that one block's weight pulls the system counter-clockwise, while the other pulls on the rope (with the same magnitude) clockwise. Why is the tension not double what it shows? Show how this would violate Newton's Laws by isolating one block only to examine the forces.

- Set both masses to 5 kg. What is the tension in the rope? _____. How does this compare to the weight (force of gravity) acting on each mass? _____
- What is the Net Force acting on the entire system? Show equation and magnitude.

$$F_{NET} = \text{_____} = \text{_____} \text{ N}$$

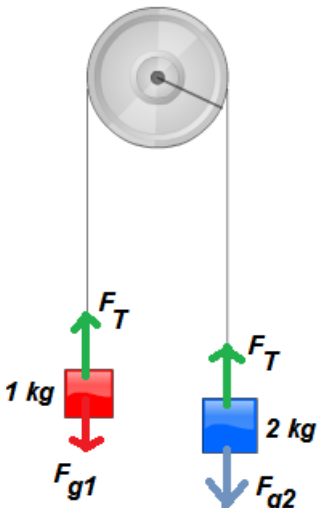
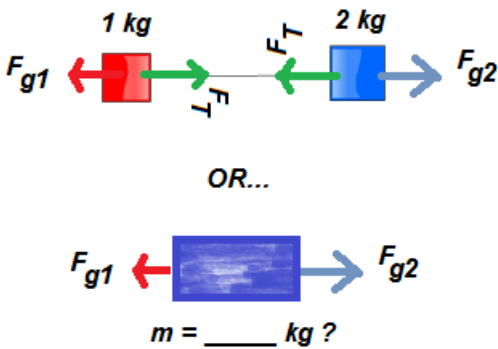
- Now *reduce the mass on the left* by 1 kg (4 kg mass on the left with a 5 kg mass on the right). Complete the free body diagrams below with appropriate labels and answer the questions:

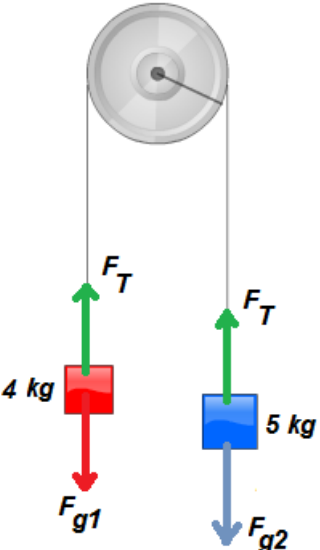
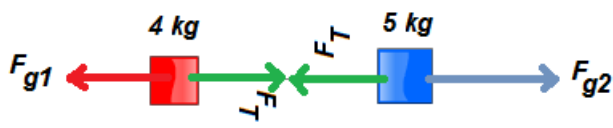
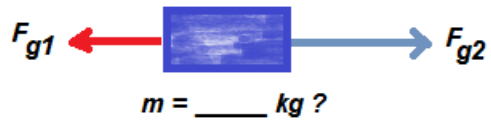
<i>Left Mass:</i> 	<i>Right Mass:</i> 
Direction of the Net Force? <u>UP/DOWN</u>? (circle) Place the <i>magnitude</i> of the values for both the tension, F_T, and the weight, F_g directly onto the diagram. Complete the inequality (use <, ≤, =, ≥, or >) F_T _____ F_g Explain why this makes sense based on what happens when you run the simulation.	Direction of the Net Force? <u>UP/DOWN</u>? (circle) Place the <i>magnitude</i> of the values for both the tension, F_T, and the weight, F_g directly onto the diagram. Complete the inequality (use <, ≤, =, ≥, or >) F_T _____ F_g Explain why this makes sense based on what happens when you run the simulation.

- Based on your findings above, what must be true for the possible value of the tension in the rope? In other words, the tension must lie between what two values?

Now let's examine the entire system.

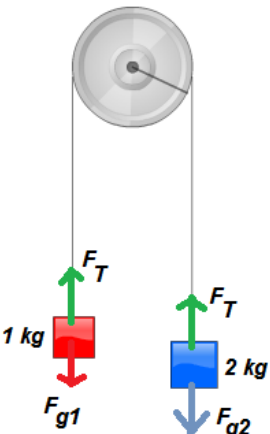
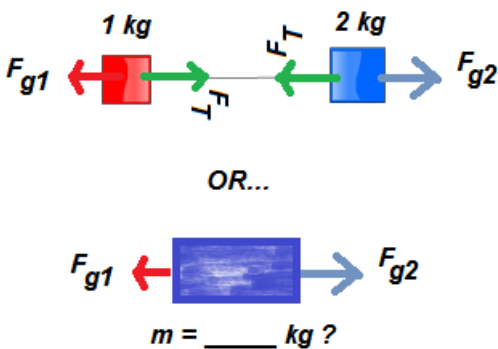
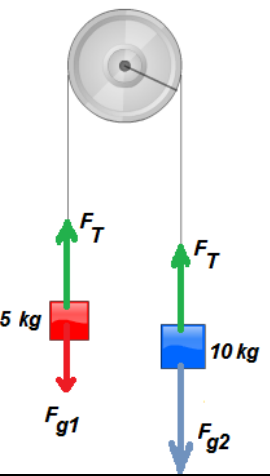
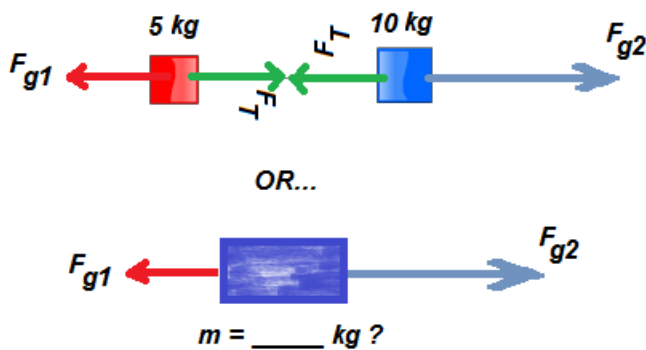
- You have seen in tutorials that one way to imagine this system is to stretch it out so that all of the forces act on a single plane (like dragging blocks along a table). Set the masses to the values shown below, complete the diagrams and determine the equations of motion.

Original Set Up (Trial 1)	"Stretched Out" (Trial 1)
	
Equation of Motion: $F_{Net} = \underline{\hspace{4cm}} = \underline{\hspace{4cm}} \text{ N}$ Solve for acceleration: $a = \underline{\hspace{4cm}} \text{ m/s}^2$	

Original Set Up (Trial 2)	"Stretched Out" (Trial 2)
	 OR... 
Equation of Motion: $F_{Net} = \underline{\hspace{2cm}} = \underline{\hspace{2cm}} \text{ N}$ Solve for acceleration: $a = \underline{\hspace{2cm}} \text{ m/s}^2$	

3. Explain, with reference to Newton's Laws, how it is possible for the above two systems to have the same **Net Force**, yet different **accelerations**.

4. Set up the systems shown below and complete the table:

Original Set Up (Trial 1)	"Stretched Out" (Trial 1)
	
Equation of Motion: $F_{Net} = \text{_____} = \text{_____} \text{ N}$ Solve for acceleration: $a = \text{_____} \text{ m/s}^2$	
Original Set Up (Trial 2)	"Stretched Out" (Trial 2)
	
Equation of Motion: $F_{Net} = \text{_____} = \text{_____} \text{ N}$ Solve for acceleration: $a = \text{_____} \text{ m/s}^2$	

5. Explain, with reference to Newton's Laws, how it is possible for the above two systems to have the same **acceleration**, yet different **Net Force**.

Summarize:

6. Two different Atwood Machines are set up with different masses on each machine. Machine one has masses m_1 and m_2 , while machine two has masses m_3 and m_4 . Both machines have the **same Net Force** for the entire system (consider all masses moving as one). What must be true of the masses to be able to claim this?

7. Two different Atwood Machines are set up with different masses on each machine. Machine one has masses m_1 and m_2 , while machine two has masses m_3 and m_4 . Both machines have the **same acceleration** for the entire system (consider all masses moving as one). What must be true of the masses to be able to claim this?

Data Collection:

Start both masses at 5kg each. Record the acceleration into the table. Reduce one mass by 1kg and add 1kg to the other **maintaining a total mass of 10kg**. Continue this process to complete the data table whilst maintaining a **constant total mass of $m_1 + m_2 = 10\text{kg}$** .

Table 2: Atwood's Machine with massless pulley

red mass, m_1 (kg)	blue mass, m_2 (kg)	Acceleration, a (m/s^2)	F_{net} (system) Calculate for Graph 1	x-axis for Graph 2 define: _____
5	5	0		
4	6			

Analysis:

1. Use Newton's Second Law to determine our F_{net} equation. Your final equation should only include F_{net} , m_1 , m_2 , and a .

$$F_{net} = \underline{\hspace{10cm}}$$

2. Plot a graph of F_{net} (system) versus acceleration, a . Be sure to add appropriate titles and axis labels.

Graph 1: F_{net} vs a



3. Determine the slope of your graph. Include any units.

$$\text{Slope} = \text{rise/run} = \Delta y / \Delta x = \Delta F_{net} / \Delta (\underline{\hspace{2cm}}) = \underline{\hspace{5cm}}$$

4. Determine the equation of your line using slope-intercept form: Don't forget to include units for any constants.

$$\text{Equation of line : } \underline{\hspace{10cm}}$$

5. Describe **precisely** what the slope of your graph represents. Support your answer with the equation of motion determined in question (1) above.

Part 2: Mastery

Analysis:

1. Rewrite the **equation of motion** in the space below (determined above in “Analysis” question (1))
Your final equation should only include m_1 , m_2 , a , and g . (hint: start with $F_{net} = ma = \sum F$)

2. Solve the equation above for acceleration, a . Simplify the equation as much as possible by factoring out any constants. **Circle** everything that remains constant on the right hand side of the formula (don't forget the main condition for the two masses described above your data table).

$a =$ _____

3. Create a straight line graph based on your equation above. The y-axis will be one variable (acceleration, a), the x-axis will be the other variable (everything BUT the constants that you circled. This can be a simple formula. Once you have determined what goes onto the x-axis, **add** this variable to the last column of your data table and calculate values for each row. Be sure to **label the graph properly**.

x-axis = _____

Graph 2:



4. Determine the slope of your graph. Include any units.

$$\text{Slope} = \text{rise/run} = \Delta y / \Delta x = \Delta \mathbf{a} / \Delta (\text{ }) = \text{ } \text{ }$$

5. Determine the equation of your line (slope intercept form with appropriate variables). Don't forget to include units for any constants.

Equation of line : _____

6. Describe **precisely** what the slope of your graph represents. Support your answer with the equation determined in question (2) above.

7. Using the value obtained for your slope, along with your answer to question (6) above, determine the value of “ g ”. DO NOT simply plug in masses and determine “ g ” from one arrangement of masses. You are to use your slope along with any constants (or experimental controls) only. Show all steps.

$g =$ _____

Part 3: Ace

On the simulation select “Pulley mass = 2 kg”.

Repeat the first experiment found in *Part 1*:

Start both masses at 5kg each. Record the acceleration into the table. Reduce one mass by 1kg and add 1kg to the other **maintaining a total mass of 10kg**. Continue this process to complete the data table whilst maintaining a **constant total mass of $m_1 + m_2 = 10\text{kg}$ (plus the additional contribution of the 2kg pulley)**

Table 2: Atwood's Machine with pulley = 2kg

red mass, m_1 (kg)	blue mass, m_2 (kg)	Acceleration, a (m/s^2)	F_{net} (system) <i>Calculate for Graph 1</i>
5	5	0	
4	6		

1. Plot a graph of F_{net} (system) versus acceleration, a . Use the axis already set up in Part 1 (Graph 1). Add this new line and label it “with 2 kg pulley”.
2. Determine the slope of your graph. Include any units.

$$\text{Slope} = \text{rise/run} = \Delta y / \Delta x = \Delta F_{\text{net}} / \Delta (\quad) = \quad$$

3. Determine the equation of your line using slope-intercept form: Don't forget to include units for any constants.

Equation of line : _____

4. In *Part 1* you were asked to discuss the significance of the slope you found. Hopefully it was concluded that your slope was equivalent to your overall mass, $m_1 + m_2$, since this value remained constant. Does your new graph have a larger or smaller slope? _____. How does this slope compare to the new overall mass of the moving system (including the pulley)? _____

5. We often refer to Newton's Second Law as an extension to his First Law (the law of inertia). In fact, if we write the second law as $\vec{a} = \frac{\vec{F}_{Net}}{m}$, we could say that as the mass of a system increases, the acceleration decreases. Examine your two data tables (*Table 1* from part 1 and *Table 2* above). Does this seem to be true? What happens to the acceleration if the mass of the pulley contributes?

6. Discuss why the additional mass of the pulley might not affect the overall mass of the system as it did with the hanging masses (i.e. We cannot simply find the value of the acceleration using $\vec{a} = \frac{\vec{F}_{Net}}{m}$, where $F_{net} = F_{g2} - F_{g1}$ and m = total mass of system). How is the pulley different from the hanging masses?

7. Mass is defined as a "measure of an object's inertia". The bigger the mass, the stronger the tendency to resist changes in motion (First Law). Pulley's also have inertia and want to resist changes in rotation. Look up *rotational inertia*, or *moment of inertia*, I . What is the general definition for **Moment of Inertia**?

8. The most general expression for calculating the Rotational Moment of Inertia is $I = \sum mr^2$. Use this equation to help discuss how an object's resistance to rotating, I , depend not only on its mass, but also how the mass is distributed. Provide an example that illustrates how the position (or distribution) of the mass can change how easily something can be set into rotation.

9. Finally, isolate just the pulley and label all forces acting on the pulley.

Free Body Diagram – Pulley of mass 2 kg on Atwood's Machine

10. Why must the tensions be different if we want the pulley to spin?
