

Atwood Machine

Equipment

- Computer, PASCO Interface
- Universal Clamp with Double pulley (one smart pulley)
- Smart Pulley Data Cable
- String
- Two Mass Hangers
- One Mass Set (1×500, 2×200, 1×100, 1×50, 2×20, 1×10, 1×5, 2×2, 1×1)
- Styrofoam Pad

Objectives

- *To verify Newton's Second Law as applied to an Atwood Machine.*

Introduction

According to Newton's 2nd Law the acceleration of an object depends on the net applied force and the object's mass.

$$\Sigma \vec{F} = m\vec{a} \quad (1)$$

In an Atwood Machine, there are two objects, each one is a mass hanging from one end of a string. The string is hung over a pulley so that both masses are hanging. The weight of one mass pulls the system in one direction, while the weight of the other mass pulls in the other direction.

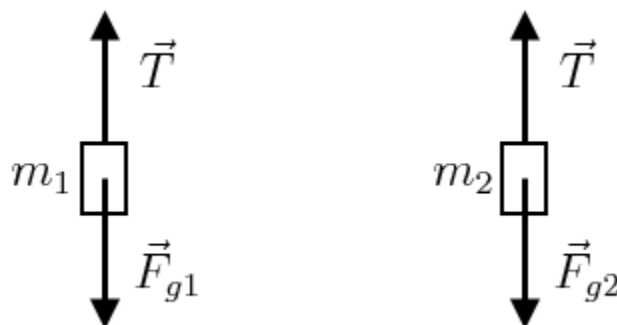


Figure 1. Individual free body diagrams of each of the hanging masses.

In the above free body diagrams, T is the tension in the string. Assuming that the pulley is massless and frictionless, and the string has no mass and does not stretch, the tension T will be the same throughout the string. The weights are $F_{g1} = m_1g$ and $F_{g2} = m_2g$ where g is the

acceleration due to gravity. Taking the convention that up is positive and down is negative, the net force equations for m_1 and m_2 are:

$$\sum F_{1y} = T - m_1g = m_1a_1 \quad (2)$$

$$\sum F_{2y} = T - m_2g = m_2a_2 \quad (3)$$

The key to solving this is to realize that in the system of m_1 and m_2 , one mass accelerates upward while the other accelerates downward. So, for mass m_2 , **we flip the coordinates** and then the accelerations of m_1 and m_2 are the same and we can just call them both a .

$$\sum F_{1y} = T - m_1g = m_1a \quad (4)$$

$$\sum F_{2y} = -T + m_2g = m_2a \quad (5)$$

We can add equations (4) and (5) to obtain:

$$m_2g - m_1g = m_1a + m_2a \quad (6)$$

$$(m_2 - m_1)g = m_{\text{tot}}a \quad (7)$$

Solving for a , the acceleration of the system of both masses, the theoretical acceleration is g times the difference in mass divided by the total mass:

$$a = g \left(\frac{m_2 - m_1}{m_{\text{tot}}} \right) \quad (8)$$

If $m_2 > m_1$, then F_{g2} is stronger, and the net force on the system accelerates m_2 downward and m_1 upward.

Treating the Atwood Machine as a System.

Notice that Eq. 7 looks a lot like Newton's 2nd Law (Eq. 1). The "object" is the pair of masses attached to either end of a string.

On the right side of Eq. 7, the mass of the system is the total mass of the two hangers, m_{tot} . The acceleration of the system is directly proportional to the exerted force and inversely proportional to the mass of the system.

On the left side of Eq. 7, we have the net force on the system $\sum F = (M - m)g$. The net force acting on the system of both masses is just the difference in gravitational force on two hanging masses. This net force accelerates both suspended masses. The heavier mass is accelerated downward, and the lighter mass is accelerated upward.

The Design and Set up of the Experiment.

Important Note: Read about the design and set up of the experiment before watching the video of the experiment. While watching video, pay attention to the way the actual experiment was done because you will need to address in the abstract how the experiment from the video was conducted; paraphrasing the description from the Instructions in the report will be treated as plagiarism.

Newton's 2nd Law can be verified by setting up the Atwood Machine under various conditions. By carefully selecting the masses, we can graph:

- (1) ΣF vs. a while keeping the system mass Σm constant.
- (2) a vs. $1/\Sigma m$ while keeping the net force, $\Sigma F = (M-m)g$, constant.

To support Newton's 2nd Law, the graph (1) should be linear with the slope of the graph equal to the total mass and the graph (2) should be linear with the slope of the graph equal to the exerted net force $(M - m)g$. If the actual graphs produce such result withing 5% margin of error, then Newton's 2nd Law is verified.

The Photogate/pulley system will be used to measure the motion of both masses as one moves upward and the other moves downward. Capstone software will monitor the changing speed of the masses as they move. The recorded data will be displayed as a velocity vs. time graph, where the slope of the graph is the acceleration of the system.

The Photogate/pulley system is constructed by mounting the universal clamp to the edge of the table and inserting the connecting rod of the pulley into the clamp. After plugging the photogate cable into port of the PASCO Interface, a piece of string is placed over the pulley and two mass hangers are suspended from each end of the string, as shown in Figure 2.

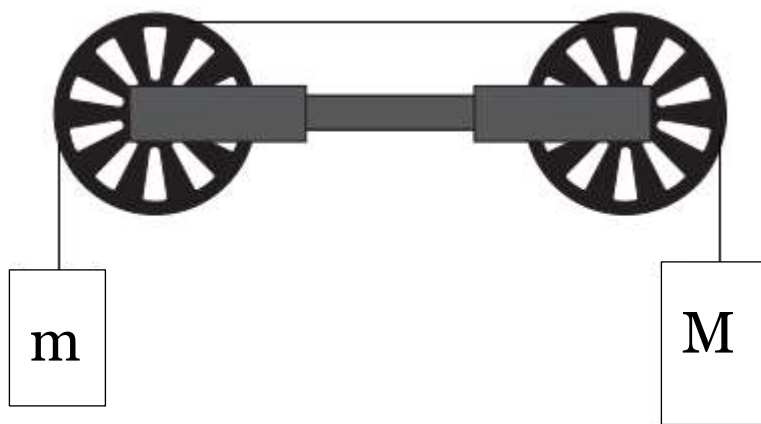


Figure 2. Schematic representation of the Atwood Machine. (Image source: PASCO)

Part 1: Constant Total Mass

1. Open the video file and watch how the experiment was conducted. Focus on how the difference in the net force was achieved without changing the total mass of the system.
2. While watching the video, record the data in the columns of the Table 1.
 - m , and M : The individual masses including the hanger.
 - a : the experimental acceleration recorded by Capstone.
 - $\Sigma F = (M - m)g$: net force acting on the system.
 - Σm : the total mass of the system.

Pay attention to significant figures in the calculated values. If needed, review rules of significant figures posted in the Auxiliary files.

Trial	m (kg)	M (kg)	a (m/s ²)	ΣF (N)	Σm (kg)
1					
2					
3					
4					
5					

Table 1. Example table for recording run parameters, results, and calculations for Part 1.

3. Re-write the caption to Table 1 so it clearly explains the content of the table. The caption should describe how the values were obtained (was it measured or calculated?) and reference formulas used in calculation.
4. Plot ΣF vs. a and fit it into linear trendline. Obtain the value of the slope from the trendline equation and record it in Table 2 along with the value of the total mass of the system. To validate 2nd Law of Motion, the slope of the linear trendline should be equal to the total mass of the system in kilograms. Compare the two by calculating % Error = $\text{ABS}(\text{Slope} - \Sigma \text{Mass}) / \Sigma \text{Mass}$

Total Mass (kg)	
Slope of ΣF vs. a	
% Error	

Table 2. Experimental and expected total mass.

5. Re-write the caption to Table 2 so it clearly explains the content of the table. The caption should describe how the values were obtained and reference formulas used in calculation.

Part 2: Constant Net Force

1. Open the video file and watch how the experiment was conducted. Focus on how the difference in the total mass of the system was achieved without changing the net force.
2. While watching the video, record the data in the columns of the Table 3.
 - m , and M : The individual masses including the hanger.
 - a : the experimental acceleration recorded by Capstone.
 - $\Sigma F = (M - m)g$: net force acting on the system.
 - $1/\Sigma m$: the reciprocal of the total mass of the system.

Trial #	m (kg)	M (kg)	$\frac{1}{\Sigma m}$ (kg^{-1})	a (m/s^2)	ΣF (N)

Table 3. Example table for recording run parameters, results, and calculations for Part 2.

3. Re-write the caption to Table 3 so it clearly explains the content of the table. The caption should describe how the values were obtained (was it measured or calculated?) and reference formulas used in calculation.
4. Plot a vs. $\frac{1}{\Sigma m}$ and fit it into linear trendline. Obtain the value of the slope from the trendline equation and record it in Table 4 along with the value of the Net Force. To validate 2nd Law of Motion, the slope of the linear trendline should be equal to the net force acting on the system. Compare the two values by calculating % Error = $ABS(\text{Slope} - \Sigma F)/\Sigma F$

Net Force (N)	
Slope of a vs. $\frac{1}{\Sigma m}$	
% Error	

Table 4. Experimental and expected net force.

5. Re-write the caption to Table 4 so it clearly explains the content of the table. The caption should describe how the values were obtained and reference formulas used in calculation.

Requirements for the Report (also consult the rubric):

Record the data while watching the experiment video and complete the data analysis required in each part of the experiment.

- The **abstract section** must contain the following explanations in paragraph form:
 - How the data was collected and calculated for Table 1
 - How the data from Table 1 was analyzed including interpretation of the trendline and comparison of values in Table 2
 - How the data was collected and calculated for Table 3
 - How the data from Table 3 was analyzed including interpretation of the trendline and comparison of values in Table 4
 - A general statement based on Tables 2 and 4 about how the experimental results support Second Law of Motion ($\Sigma F = \Sigma ma$)
- The **data section** must include
 - 4 Tables (labeled and captioned)
 - 2 Graphs (title, axis labels, units, labeled and captioned)
 - ΣF vs a_{exp}
 - a_{exp} vs $\frac{1}{\Sigma m}$ (*Inverse Mass, hence inverse units*)