

## Experiment 5: Atwood's Machine

In 1784, George Atwood created a device to calculate force and tension and to verify the laws of motion of objects under constant acceleration. His device, now known as an Atwood's Machine, consisted of two masses,  $m_1$  and  $m_2$ , connected by a tight string that passes over a pulley, as seen in Figure 1. When the masses are equal, the pulley system is in equilibrium, i.e. balanced. When the masses are not equal, both masses will experience an acceleration (indicated with red arrows in Figure 1). For simplification, we will assume the *ideal pulley* scenario, where the mass of the string is negligible and we ignore any frictional effects acting on the pulley. With these assumptions, the accelerations  $a_1$  and  $a_2$  are equal.

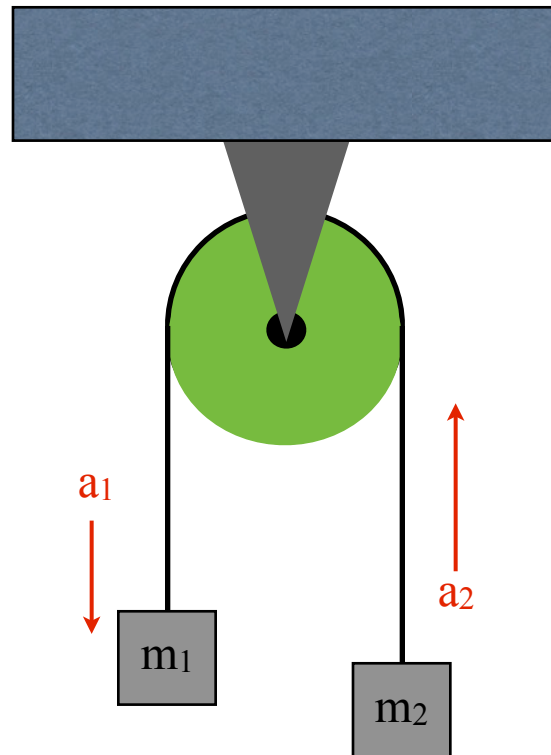


Figure 1: An Atwood Machine.

When  $m_1 > m_2$ , the sign convention used is such that  $m_1$  accelerates in the downwards  $\mathbf{y}$  direction and  $m_2$  moves upwards. Here we let the acceleration be positive. On the other hand, if  $m_1 < m_2$ , we will set the acceleration as negative. With this convention, we can derive a system of equations describing the acceleration of each mass by applying Newton's second law,  $\mathbf{F} = m\mathbf{a}$ , to each mass individually. Looking at the free body diagrams for the masses of the Atwood machine (see Figure 2), we can write the forces as

$$m_1 a = m_1 g - T \quad (1)$$

$$m_2 a = T - m_2 g \quad (2)$$

where  $T$  is the tension in the string and  $g$  is the acceleration due to gravity ( $g = 9.8 \text{ m/s}^2$ ).

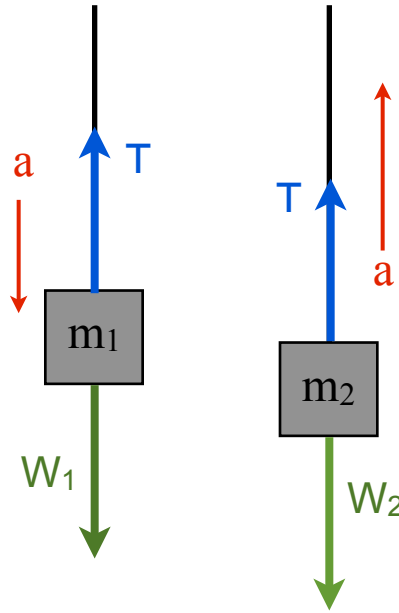


Figure 2: Free body diagrams for the masses of the Atwood Machine. The tension  $T$  is shown in blue and the weight of each mass  $W$  is in green. Note that the tensions are the same and the direction of motion is indicated by red arrows.

Solving our system of equations for the acceleration:

$$a = \frac{(m_1 - m_2)g}{m_1 + m_2} \quad (3)$$

The numerator  $(m_1 - m_2)g$  is the net force causing the system to accelerate, and the denominator  $(m_1 + m_2)$  is the total mass being accelerated. Thus,

$$\mathbf{a} = \frac{\mathbf{F}_{net}}{M_{total}} \quad (4)$$

## Experimental Objectives

The object of this lab is to study Newton's laws of motion and to measure the acceleration due to gravity using the Atwood machine. In this lab you are given various masses, string and a "Photogate with Pulley" sensor that allows you to calculate and graph the position, velocity and the acceleration of the masses of the Atwood's machine. To measure the acceleration using the pulley, you must select the "Photogate with Pulley" sensor from Hadeaware setup in the software and then view the velocity vs. time graph of each run/trial (ask the lab instructor for help). You will notice a steady linear increase of the velocity as the mass falls, followed by sharp drop as the mass comes to a rest. Highlight the appropriate region when the mass is free falling and then select "linear fit" from the fit tab. This will give you the slope of the line which is a direct measurement of the acceleration.

- Devise an experimental procedure to measure the acceleration of the masses on the Atwood's machine for 5 different mass combinations of  $m_1$  and  $m_2$ , but keeping the sum of the masses  $m_1 + m_2$  constant. That is, if you decrease  $m_1$  by a set amount, increase the other mass ( $m_2$ ) so that the total mass is always the same. You should compare the measured accelerations with those calculated from Eq. 3. Verify that a plot of  $\mathbf{F}$  vs  $\mathbf{a}$  will give you a straight line with a slope equal to the total mass (see Eq. 4). Don't forget to include error bars on your graph.
- Devise an experiment to measure the gravitational acceleration constant  $g$ . Do at least 6 different runs where one mass is held constant while the other mass increases by 10 g increments. Make a plot of  $\mathbf{a}$  vs  $(m_1 - m_2)/(m_1 + m_2)$  in your lab report. Explain what the slope of this graph represents.

## Questions

Answer these questions in your lab report. Show all work.

1. Calculate the tensions in the string for the second experiment.
2. What is the relationship between the acceleration and the total mass when the force is held constant?
3. How do these measurements compare with calculations using equation 3? What sources of error are most likely the cause of the discrepancies between your experimental data and your theoretical calculations? How well does the "ideal pulley" scenario hold? Explain.