1 Background

1.1 Netwon's laws

In the 1600s, Isaac Newton discovered three laws governing interactions between objects:

I. An object's velocity does not change unless the object is acted on by a force.

II. The acceleration of an object directly proportional to its mass, and inversely proportional to the vector sum of all forces acting on the object.

III. When one object exerts a force on another, the second object exerts a force with the same strength but in an opposite direction on the first object.

The first law can be seen as a consequence of the second—if there is zero force acting on an object, it will have zero acceleration. When you study the quantity called *momentum*, you'll see that the third law is a consequence of *momentum conservation*.

Mathematically, the second law can be represented as

$$\sum \vec{F} = m\vec{a} \tag{1}$$

This gives us a quantitative tool that can be used to analyze an object's motion.

Note that acceleration, which is one way of describing the motion of an object, is an effect of all forces acting on the object. There may be many forces acting on an object; along with the object's mass, these forces determine how an object's motion will change.

1.2 Atwood's machine

George Atwood was a physics instructor from the late 1700s who was well-known for developing effective demonstrations. One of these devices is now simply called *Atwood's Machine*, and a simplified version can be used to investigate Newton's laws.[1] Atwood's Machine consists of two masses connected by a light string, hung over a pulley, as shown in figure 1. If one side has more mass than the other, the system will accelerate.

In this project, you will be investigating Netwon's second law in particular, but you will need to consider Newton's third law in some of your theoretical analysis.

2 Tools

We have pulleys and photogates that are designed to work together. Once the photogate is connected to your computer and you have opened Logger Pro, open the file "10 Atwoods Machine" in the *Physics with Vernier* folder. This file is configured to determine the linear speed of a mass using information about the photogate and pulley. You can use the linear speed to determine the acceleration.

[1] For more information, ask Professor Roth for a copy of a short article about Atwood and his machine.

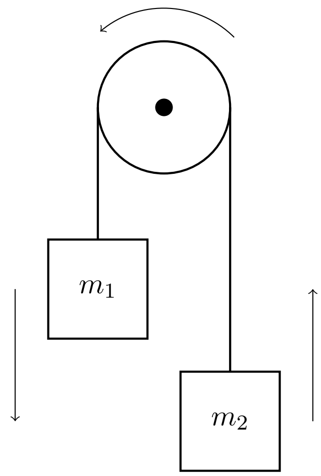

Figure 1: Schematic of Atwood's machine

3 Task

You have two goals:

1. Determine how the acceleration of the system depends on the *total* mass hanging over the pulley, and how the acceleration depends on the *difference* in mass hanging from either side.
2. Apply Newton's 2^{nd} law to find an expression for the acceleration in terms of the two masses, and compare your theoretical results to the experimental results: does this expression predict the same behavior you observed? Are the results similar to each other? Are you experimental results consistently higher than the theory predicts? Are they consistently lower? What could explain discrepancies, if there are any?

Here's are some considerations to make:

- You need to isolate the variables to test them separately. This means you'll need to take two series of data: one where the difference in mass between each side stays the same but the total mass changes; and one where the difference between the two masses changes but the total mass stays the same. Isolating experimental variables like this is an important part of designing a valid experiment.
- You need to consider experimental uncertainty. For each set of hanging masses, perform at least ten measurements; apply statistics to find the mean and standard deviation of the acceleration for that set of masses. The mean acceleration will be what you report as "the acceleration" for that combination of masses, and the standard deviation is your experimental uncertainty.

- To accurately evaluate how the acceleration depends on each variable, you need to plot your data on a graph. Make a graph of acceleration vs. total mass, and acceleration vs. mass difference. (Because the horizontal axis is different, you will need to make two separate graphs.) Plot the average acceleration for each trial, and use the standard deviation for the error bars.

- To accurately compare experiment to theory, plot the theoretical prediction on the same graph as the experimental results. For the theory, use an uncertainty of $\pm 0.02\,\mathrm{m/s^2}$. (This uncertainty has been determined based on the lab equipment available to you.)