Atwood Machine

Apparatus

The Atwood machine is a simple device consisting of two unequal masses that are connected by a cord run over a pulley. The larger mass m_2 is suspended above the smaller mass m_1 , and sits upon a platform that is equipped with a mechanical trip release. Upon release, the heavier mass accelerates down to a platform a measured distance $\Delta y = y - y_0$ below. Each group will measure the time t required for m_2 to move from the upper to the lower platform.

Theory

The masses in the Atwood machine are subject to a number of forces, all of which are constant. The net constant force will produce a constant acceleration. We know that a constant acceleration will cause an object (starting from rest) to move a distance equal to $\Delta y = \frac{1}{2}at^2$. If we measure the distance and time we can solve for the magnitude of the acceleration.

$$a = \frac{2|\Delta y|}{t^2} \tag{1}$$

A perfect Atwood machine is a massless and frictionless pulley. In such a case the forces acting on the heavy mass m_2 and light mass m_1 are:

$$T - m_1 g = m_1 a \tag{2}$$

$$T - m_2 g = -m_2 a \tag{3}$$

where T is the tension in the string, and the acceleration of each mass is equal (but in opposite directions). Subtracting Eq. (3) from Eq. (2) gives:

$$(m_2 - m_1)g = (m_1 + m_2)a \tag{4}$$

A real Atwood machine has a pulley having a nonzero mass that resists acceleration (that is, it has rotational inertia). The mass of the pulley m_p is accelerated by the pull of the string at its rim. Then the acceleration changes to: $(m_1 + m_2)a \rightarrow (m_1 + m_2 + \frac{M_p}{2})a$.

How should we deal with the frictional force? If it acts like kinetic friction it should be a constant force f. If we include this as an additional force opposing the downward motion of m_2, then: $(m_2 - m_1)g \rightarrow (m_2 - m_1)g - f$. With these modifications, the equation for Newton's second law becomes:

$$(m_2 - m_1)g - f = \left(m_1 + m_2 + \frac{M_p}{2}\right)a \tag{5}$$

In our experiment we will determine the acceleration verses the mass difference $(m_2 - m_1)$. If we rearrange Eq. (5) to solve for a

$$a = \frac{g}{\left(m_1 + m_2 + \frac{M_p}{2}\right)}(m_2 - m_1) - \frac{f}{(m_1 + m_2 + \frac{M_p}{2})} \tag{6}$$

The equation for a straight line is $y = mx + b$, (y is the *vertical axis*, x is the *horizontal axis*) where m is the slope and b is the y-intercept. Eq. (6) has a similar form. If we plot a (*vertical axis*) vs $(m_2 - m_1)$ (*horizontal axis*), the result should be a straight line with a slope equal to $\frac{g}{\left(m_1+m_2+\frac{M_p}{2}\right)}$ and a y-intercept at $\frac{-f}{(m_1+m_2+\frac{M_p}{2})}$.

Setup:

1. Navigate to https://www.wolfram.com/player/

   and download the Wolfram Player. Install it, and then download the Atwood simulation on the Physics 210 Lab Website (called *Atwood-NIU.cdf*), and then run the experiment.

Data collection

1. Let m_1 be the total mass hanging on one side of the string and m_2 be the total mass hanging on the other side of the string. Record (by making a 6 column table) in your lab notebook (or in Excel) m_1, m_2, the mass difference $(m_2 - m_1)$, time t, acceleration a, and the mass of the pulley, M_p.

2. Set the mass of the pulley to be 150 kg.

3. Set the mass of m_1 to be 0.1 kg and that of m_2 to be 2.1 kg. Record these values in the table in your lab notebook (or Excel). Start the measurement and record the time it takes for mass m_2 to go 1.5 m. Using Eq. (1), determine the acceleration of the blocks and record this in your table.

4. Keeping the total mass $(m_1 + m_2)$ the same (2.2 kilograms), exchange weight(s) between the blocks such that the mass difference $(m_2 - m_1)$ is 1.8 kilograms. Start the measurement and record the acceleration and the time. Repeat this process for mass differences of 1.6 kg to 0.2 kg in steps of 0.2 kg. Make certain that the total mass $(m_2 + m_1)$ is always the same (2.2 kilograms). Thus the denominator in Eq. (6) is a constant (it does not vary between measurements).

m_1(kg)	m_2(kg)	$(m_2 - m_1)$(kg)	t(sec)	$a(m/s^2)$	M_p(kg)
0.1	2.1	2.0			
0.2	2.0	1.8			
0.3	1.9	1.6			
0.4	1.8	1.4			
0.5	1.7	1.2			
0.6	1.6	1.0			
0.7	1.5	0.8			
0.8	1.4	0.6			
0.9	1.3	0.4			
1.0	1.2	0.2			

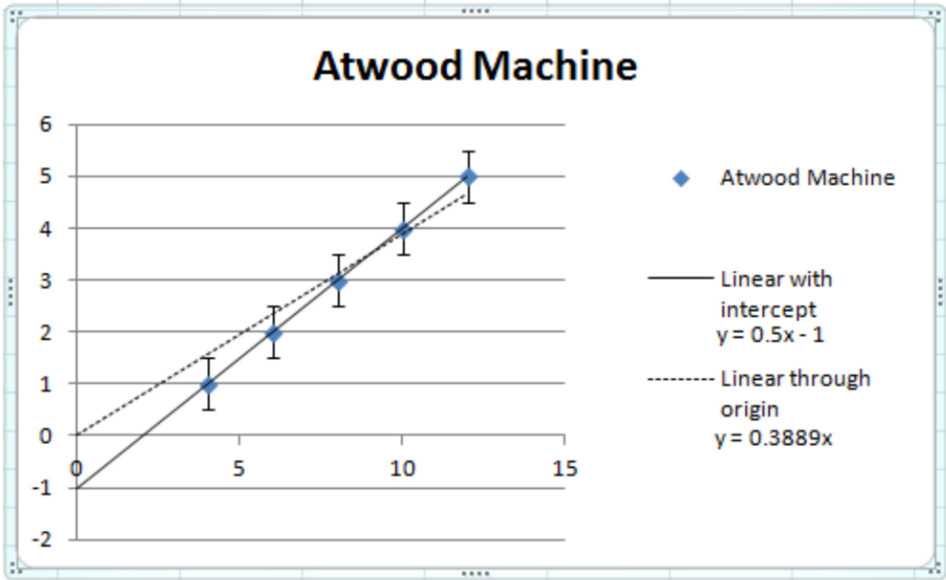
Data Analysis

1. Plot using Excel the acceleration a in m/sec^2 versus the mass difference $(m_2 - m_1)$ in kilograms for the ten data points. The acceleration should be the vertical axis. Include what you believe are reasonable error bars in your plot.

2. Using Excel, fit the data with a straight line (showing the fitting equation on the plot).

3. Write the y-intercept and slope values in your lab notebook.

4. Find the gravitational acceleration g using your value for the slope and Eq. (6).



5. Compute a percent error between your experimentally measured value of g and the accepted value of 9.8 m/sec^2.

$$\%Error = \left| \frac{Experimental - AcceptedValue}{AcceptedValue} \right| \times 100$$

6. Determine the frictional force exerted on the axle of the pulley using your value for the y-intercept and Eq. (6).

7. Does increasing the mass of the pulley increase or decrease the time required for m_2 to go 1.5 m? Carefully explain why.

A lab writeup is to be turned in next week. What will be due are:

1. **upload your lab writeup as a Word document to Blackboard** (before the beginning of the next lab). In your lab writeup there should be a picture of the experimental setup, equations used, tables, the plot with a straight line fit using Excel, how you determined g and the frictional force f, and a discussion of why your value of g is different than the expected value. Make certain you answer all questions 1-7 in the **Data Analysis** section in your lab writeup. Also, discuss the possible sources of error in an actual experiment (in the real world) that may lead to measured values that do not agree with g.

2. **upload your Excel spreadsheet to Blackboard** before lab starts next week.