Testing Newton’s 2nd Law

**Goal:** To test Newton’s 2nd law ($\Sigma F = ma$) and investigate the relationship between force, mass, and acceleration for objects.

**Lab Preparation**

To prepare for this lab you will want to review what a velocity vs. time graph looks like if the acceleration is constant. You should also read through the following material.

The main set-up for this experiment is similar to the picture below in Figure 1. A mass ($m_1$) is on a frictionless surface and is accelerated to the right by a smaller mass ($m_2$) hanging over the table.

![Figure 1](image1.png)

Application of Newton’s second law to this system is straightforward. Draw separate free-body diagrams for each mass and apply Newton’s second law to each. The free-body diagrams for each are in Figure 2.

![Figure 2](image2.png)

Summing forces in the x direction for mass 1 and the y direction for mass 2 yields the following:

- $\Sigma F_x = m_1a_x$
- $\Sigma F_y = m_2a_y$
- $T = m_1a$
- $W_2 - T = m_2a$
Note that since the masses are attached that they each will have the same magnitude of acceleration. Also, if we assume the mass of the pulley is negligible, the tension is the same throughout the string. Substituting $T = m_1a$ into the equation for the falling mass yields:

$$W_2 - m_1a = m_2a$$

Substituting in $W_2 = m_2g$ and rearranging for $a$ gives us the following:

$$m_2g - m_1a = m_2a$$

$$m_1a + m_2a = m_2g$$

$$(m_1 + m_2)a = m_2g$$

$$a = \frac{m_2g}{m_1 + m_2}$$

$$a = g \left( \frac{m_2}{m_1 + m_2} \right)$$

If we compare this equation to the general form of an equation for a straight line, $y = mx + b$

then the variable $y$ is the acceleration $a$, the slope $m$ is equal to $g$, the variable $x$ is the quantity $\left( \frac{m_2}{m_1 + m_2} \right)$, and the y-intercept $b$ is 0.

During this experiment you will be varying the masses that in turn will produce different accelerations. You can then graph this data putting $a$ on the y-axis and the ratio $\left( \frac{m_2}{m_1 + m_2} \right)$ on the x-axis. According to the above equation the data should form a straight line with a slope of $g$ if Newton’s 2nd law is correct.

**Equipment**

This lab uses an **air track** and an **ultrasonic motion detector**, both of which were used in the one-dimensional motion lab. Remember to leave your air supply on until measurements are completed. Also recall that the motion detector does not detect objects that are close to it (within about 40 cm).
Procedure

Please handle the air-track gliders with care and do not slide them without the air supply on.

I. Set-up and mass data
Turn on the air supply for the air-track. While the air-track is warming up find and record the masses of each of the gliders and the washers (note they are labeled 1 through 5).

Next, place a glider in the middle of the air-track. Level the air-track by adjusting the supporting legs at one end of the track until the glider moves no more than 1 cm in 4 or 5 seconds when released from rest.

After the track is leveled, attach a string to one glider and adjust its length so that when the glider reaches the bumper at the end of the air-track, the string with a washer hanging on it will just reach the floor (this may already be done for you).

Set the motion detector to track the glider’s motion as shown in Figure 3. Place the motion detector 40-50 cm behind your glider release point.

II. Single glider
A. Testing your set-up.
Open the newtons2nd file. You will want to start the data collection but wait 1-2 seconds before releasing the glider. The movement of the glider will trigger the motion detector to start collecting data. Release the glider and observe the velocity vs. time graph. Since the acceleration is constant you should know what the general shape of the graph should look like.

If the data looks scattered or there are irregularities, you may need to do one of the following:
*Check to make sure the string passes through the guide hole without rubbing the sides of the hole or hitting the side of the table.
*Check that the string passes through the pulley correctly. The string and pulley should be parallel to the track.
*Make sure there are no objects on the table that the motion detector might detect.
*Realign your motion detector. Good alignment can require a bit of patience in making small adjustments.

Continue repeated trials until you have a good trial. Check this with your lab instructor.

B. Finding acceleration from the graph.
Recall that the slope of a velocity vs. time graph gives the average acceleration for the given time range. Highlight the portion of the graph with constant acceleration with your mouse and determine the slope of this portion of your graph using the tools available on the computer. Record your acceleration ($a_1$) in a table similar to the one below. Once recorded, store this trial by selecting “Store Latest Run” under “Experiment” for comparison with subsequent trials.

<table>
<thead>
<tr>
<th>Washers</th>
<th>Gliders</th>
<th>$m_1$ (kg)</th>
<th>$m_2$ (kg)</th>
<th>$a_1$ (m/s²)</th>
<th>$a_2$</th>
<th>$a_{av}$</th>
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</table>

C. Additional Trials.
Make additional trials. First do another trial with 1 glider and 1 washer and if the graphs look good, find $a_2$ and record in your table. Once again store your latest run on the computer. You can now find the average of your two accelerations.

Repeat the process of taking two trials for 1 glider with 2 washers attached and 1 glider with 3 washers attached. You should be able to predict what will happen to the graphs as you add more washers. After each trial record the data in your table and store your latest run on the computer. When finished with all the trials with 1 glider you should have one graph with all of your velocity vs. time trials. Close any boxes showing results of fitting the data and print this graph to include in your report.

III. Two gliders
Repeat the measurement and analysis cycle using two gliders coupled together being pulled by 1, 3, and 5 washers. Once again store all of your runs.

When finished with all the trials with 2 gliders you should have one graph with all of your velocity vs. time trials. Close any boxes showing results of fitting the data and print this graph to include in your report.
Analysis
If you did not read through your lab preparation you should look that over now before proceeding.

You now want to test the validity of Newton’s 2\textsuperscript{nd} law by graphing your accumulated acceleration data. Open the newtons2ndanalysis file. Make a graph of $a_{av}$ on the y-axis and $\left(\frac{m_2}{m_1 + m_2}\right)$ on the x-axis for your data. You can make a table with $m_1$, $m_2$, and $a$ manually, then create a new calculated column that calculates $\left(\frac{m_2}{m_1 + m_2}\right)$. Determine the slope of your graph using the tools on the computer. Print out a copy of the graph for your report.

Answer the following questions about your results.

1. If the data plotted in your graph forms a straight line, then Newton’s 2\textsuperscript{nd} law is supported by the experiment. Explain why this is the case.

2. What should have been the expected slope of your line?

3. Compare your slope to the expected slope by calculating the percentage difference between them.

4. What is your y-intercept? Explain why your value might be different from the expected value.

5. You can also apply Newton’s 2\textsuperscript{nd} law ($\Sigma F = ma$) to the system as a whole. It is the hanging masses weight ($m_2g$) that accelerates the system so that is our net force ($\Sigma F$). The mass that is accelerated is the total mass of the system ($m_1 + m_2$). Put these values into Newton’s 2\textsuperscript{nd} law and rearrange for $a$ to show you get the same equation as in the lab preparation section.

When finished with your lab clean up your lab station.

Homework
The forces needed to accelerate the pulley as it rotates are neglected in this experiment and in the development of the equation $a = g \left(\frac{m_2}{m_1 + m_2}\right)$. We assumed the pulley was frictionless and had no mass. Do you expect the presence of the pulley to cause an increase or decrease in the measured acceleration compared to the value predicted by the above equation? Explain your reasoning with the help of Newton’s 2\textsuperscript{nd} law. Later on when rotation is discussed such things will be taken into account.