# *The Atwoods Machine*

*Physics 114*

*Fall 2025*

The goal of this lab is to test the predictions of Newton's 2nd Law when applied to an Atwoods machine. You will use the Vernier "smart pulley" (see Figure 1) which will accurately measure the system's motion and allow you to test the prediction.

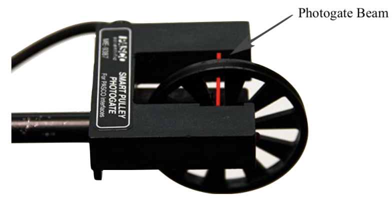


Figure 1: The Vernier "smart pulley" uses an infrared beam to time the rotational motion and it returns to you the linear motion of the falling masses.

## *Pre-Lab*

The physics relevant to this lab is Newton's second law. The system consists of two masses connected by a very light string (linear mass density roughly $\sim 0.249$ grams per meter). Let's work out a reasonable approximation to the motion of the masses using Newton's Laws. Figure 2 shows a schematic for the system. We will make several approximations:

- the pulley mass is negligible (later in the semester, you will see that it's easy to include pulley mass, but for now we ignore it).
- the string mass can be neglected (its linear mass density is 0.249 g/m).
- the tension is uniform throughout the string.

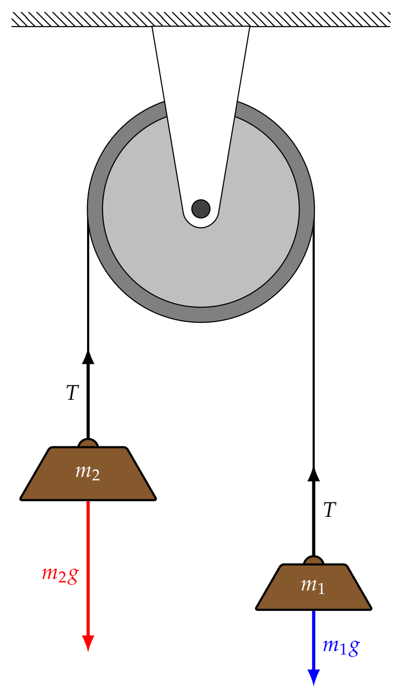


Figure 2: Forces on the masses of the Atwoods machine. The total mass of the system will be constant, but you will transfer mass from $m_1$ to $m_2$ as you take data.

### *Second Law for each mass*

Mass $m_2$ will always be heavier than $m_1$ in this lab, so it will accelerate downward. Choosing the positive direction to be downward for mass $m_2$, we write down Newton's 2nd law for this mass:

$$m_2g - T = m_2a$$

Now, choosing the positive direction to be upward for mass $m_1$, we write down Newton's 2nd law for this mass:

$$T - m_1g = m_1a$$

Now we have two equations and two unknowns (the tension $T$ and the acceleration $a$, which will be the same magnitude for each mass). Solve this system of equations by eliminating the tension T:

$$(m_2 - m_1)g = (m_1 + m_2)a$$

Note that the left hand side is simply the net force on the combined system of two masses; we can make this model more reasonable by saying that there is a small frictional force, $f$, that also acts on the system, so that a slightly better model is

$$(m_2 - m_1)g - f = (m_1 + m_2)a$$

If we rewrite this by adding $f$ to both sides, we have our model for the system in equation 1:

$$\underbrace{(m_2 - m_1)g}_{F_{\text{grav}}} = (m_1 + m_2)a + f \tag{1}$$

where the effective gravitational force, $(m_2 - m_1)g$, has been labelled $F_{\text{grav}}$ for convenience. Hence, if we plot $F_{\text{grav}}$ vs $a$, we expect to obtain a straight line whose slope is the the total mass of the system $(m_1 + m_2)$, and whose intercept represents the frictional force $f$.

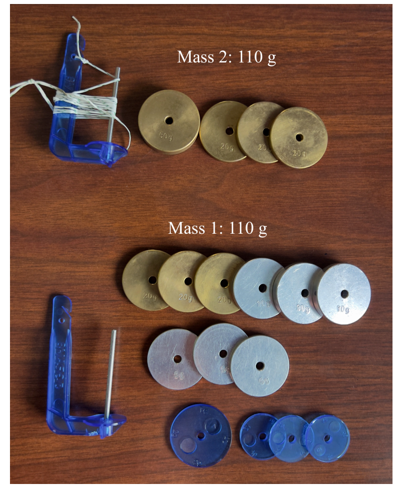


Figure 3: Here are the masses to place on each hanger.Mass 1: 3@20g, 3@10g, 3@5g, 1@2g, 3@1g, Mass 2: 1@50g, 3@20g

## *Part 1: Initial Setup*

Your instructor will give you a brief introduction to the apparatus. You will need to configure the mass hangers each with 110 grams of mass as shown in Figure 3. Start the Vernier Graphical Analysis software, then click the Mode button in the bottom left corner of the window. Set “Mode” to “Photogate Timing”, select “Linear Motion” as the measurement, and choose “Ultra Pulley - in groove” for the measurement object. Select “Done” to return to the data collection window, and change the plot to a velocity vs. time plot by clicking on the vertical axis label.

Figure 4: Setup for the Atwoods machine; you will start with 110 grams of added mass on each hanger and be able to take data for many mass differences. This apparatus was tested with mass differences of 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, and 26 grams. Masses are transferred from mass 1 to mass 2.

## *Part 2: Acceleration Measurement*

You will start by transferring 1 gram from $m_1$ to $m_2$. This will make $m_1$'s mass 109 g, and $m_2$'s mass 111 g. Thus, the mass difference, $\Delta m = m_2 - m_1 = 2\,\text{g}$. Start with $m_2$ just below the pulley, holding the system in place by gently placing your finger on the pulley. Before release, make sure the masses are not swinging, then press the COLLECT button on the Graphical Analysis window, release the masses, and use your finger to stop the system before $m_1$ smashes into the pulley. Then stop Graphical Analysis and you will see a velocity vs. time plot which should be a straight line, followed by the messiness that occurred when you stopped the system with your finger. If needed, you can change the scale of the vertical axis by clicking the highest number on the axis (enclosed by a box).

Using the mouse, hold-click and drag to select most of the points in the linear region and then perform a linear fit to this line (select "Curve Fit" from the window that appears after selecting data, then choose linear). The slope of the line is the acceleration of the system. In order to get the uncertainty on this acceleration, run the same trial four more times, and find the acceleration for each trial. Your measurement of the acceleration for each mass difference is the mean acceleration of the five trials, and its uncertainty is the standard error of the trials. Record the results of the five trials in a well-organized spreadsheet (use Excel or Google Sheets), and use spreadsheet formulas to calculate the mean acceleration $a$ and standard error $\Delta a$.

Next, transfer another 1g mass from $m_1$ to $m_2$. This will make $m_1$'s mass 108 g, and $m_2$'s mass 112 g. Thus, the mass difference, $m_2 - m_1 = 4\,\mathrm{g}$, and notice that the total mass of the system hasn't changed. Take five trials and record the accelerations in a new table within the spreadsheet you created for the first mass difference, and obtain the acceleration and its uncertainty for this mass difference. Continue to repeat this process to obtain acceleration measurements for *at least* 8 different mass differences uniformly spread between 2 and no more than 30 grams.

When finished, your spreadsheet should contain at least eight tables, each one corresponding to a particular mass difference and containing five acceleration measurements with the calculated mean and standard error. These tables comprise your raw data. Next, add a summary table to this spreadsheet with three neighboring columns that hold (1) the mass differences, (2) the mean accelerations, and (3) the standard errors of the accelerations. Copy these values from your raw data tables to the summary table; each row of the summary table should correspond to one of your raw data tables.

## *Part 3: Data Analysis*

After you have taken all of your data, use the summary table in your spreadsheet to make a plot of $F_{\text{grav}}$ vs. $a$. You'll need to add a fourth column that computes

$$F_{\text{grav}} = (\Delta m)g/1000,$$

where the factor of 1000 is to convert $\Delta m$ to kilograms so that the force is measured in Newtons. Add a linear trend line to your plot, then find the slope with its error and the y-intercept with its error. Use the LINEST spreadsheet formula to find the errors (or the equivalent command if you are using something other than Excel or Google Sheets).

## *Part 4: Questions*

**Question 1:** Is the slope of your best fit line consistent with the theoretical expectation, predicted by Newton's Laws, to within the uncertainties? Explain, and clearly state the your measured value and the theoretical expected value for the slope as part of your answer to this question.

**Question 2:** Does the value of the y-intercept of your trend line seem reasonable? Explain your reasoning, including the physical interpretation of the y intercept, and don't forget to consider the uncertainty.

## *Formal Lab Report*

This week, you will write a formal lab report for this lab. Below, I list all of the sections required in the report and the data, plots, and calculations from this lab's procedure that you need to include. Refer to the general lab report guidelines that are provided on Brightspace for more details on what to include in each section.

1. **Heading**: Your full name, your partners' full names, the date, and a title which includes the number and name of the experiment.

2. **Introduction**: Describe the goal(s) of the lab. Introduce and describe any theory or models that you will use or test to achieve those goals.

3. **Procedure**: Describe the apparatus and how you collected the data. Include a picture or detailed sketch of the apparatus. Include enough detail that a student could reproduce your measurements without referencing this lab handout. The procedure must be in your own words; don't copy text from this handout.

4. **Raw Data**: All of your mass difference and acceleration data. There should be at least 40 measurements, in groups of at least 5, because you used 5 trials for each of the 8 mass differences. These should already be organized into the raw data tables described in Part 2 of the procedure. Be sure that each column of the table has a descriptive heading that also the indicates the units. Display a consistent and reasonable number of significant figures.

5. **Data Analysis**:

   (a) The summary table with the mass differences, average accelerations $a$, $\Delta a$, and $F_{\text{grav}}$. Make sure that each column of the table has a heading with units. Show one sample calculation for $a$, $\Delta a$, and $F_{\text{grav}}$.

   (b) The plot you made in Part 3. Make sure it has a descriptive title, axis labels with units, and the linear trend line.

6. **Results and Discussion**:

   (a) Report the slope with uncertainty and y-intercept with uncertainty from the linear trend line. Be sure to include correct units and use plus-minus notation with correct number of figures kept. These are your primary quantitative results!

   (b) Answer the two questions in Part 4 as part of your discussion.

   (c) Discuss the most important sources of uncertainty and explain how they affect your data and results. If your measurements do not agree with the theoretical expectation, you must propose a source of systematic uncertainty that was not accounted for by your error analysis that could reasonably cause the discrepancy.

7. **Conclusions**: One paragraph that summarizes the important results and discoveries made in this lab.