# PHYS101 Lab: Forces
# Instructor: James Cutright

## Part 1: The Atwood Machine

**Introduction:** In this lab you will be testing/verifying Newton's Three Laws with a device called Atwood's Machine.

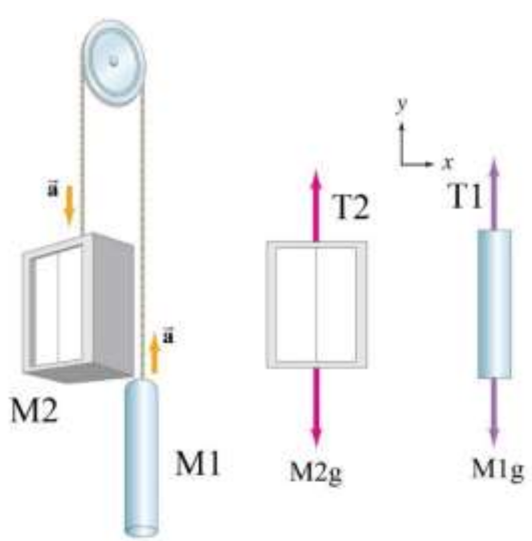
### Materials:

| | |
|---|---|
| Computer Work Station | PASCO 850 Universal Interface |
| Rod Stand (End of Table) | Metal Right Angle Clamp (End of Table) |
| Smaller Metal Rod (End of Table) | Photogate |
| Photogate Rod | Photogate Pulley |
| Photogate Cable | Plastic Right Angle Clamp |
| Mass Set with Hangers (At Station) | Thin Black String (2.5 meters) |
| No Bounce Pad | |

### Section 1: Theory

The Atwood Machine is effectively a counterweighted elevator. To this day, this system is used to make elevators more efficient: counterbalancing some of the weight of the elevator means the motor that operates the elevator does not need to work very hard. Below is the mathematical analysis of the system. You will be using the equations derived to make predictions about how the system should react to having different amounts of mass placed on either end of the system (mass1 and mass2).

We know that the net acceleration on an object depends upon the net amount of force applied to it, and the mass of the object. From the diagram, we see that the net force of the system is based on the difference of the two masses, since one of them will fall downwards while the other rises. To calculate the acceleration, you would expect from the system, you do the following, where T is the tension in the string. Note: the friction in the pulley and the mass of the string are considered negligible.




$$T_1 - M_1 = M_1 a$$

$$T_2 - M_2 g = M_2(-a)$$

$$T_1 = T_2$$

$$a = g\frac{(M_2 - M_1)}{(M_2 + M_1)}$$

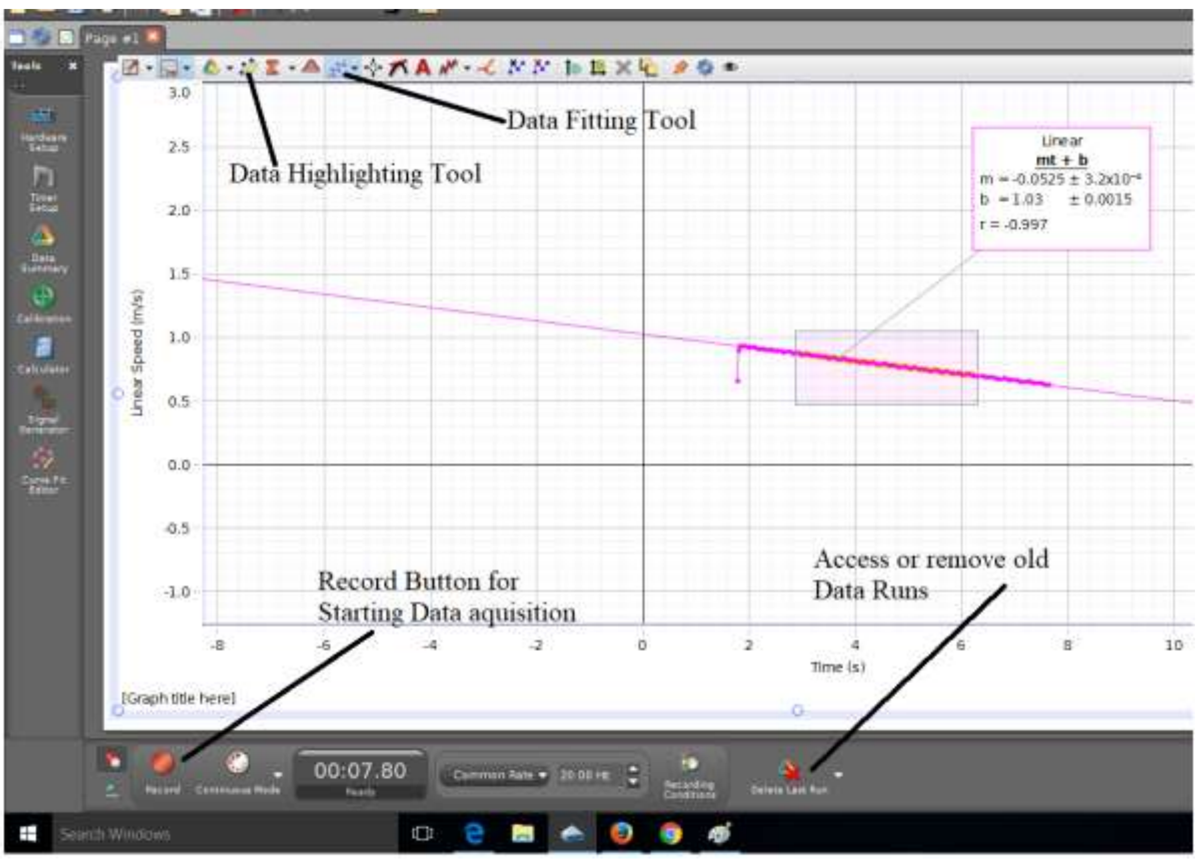
$$F_{net} = M_{total}a = (M_2 + M_1)a$$

## Section 2: Building the Apparatus

1. Assemble the rod stand: place the tapered end of the large metal rod in the hole in the table. Attach the smaller metal rod to that with the right-angle clamp, so that it hangs over the edge of the table.
2. Attach the plastic right angle clamp to the end of the smaller metal rod.
3. The photogate rod has a small threaded section. Push that through the small plastic hole on top of the photogate. Screw on the photogate pulley, so that the photogate, its rod, and the pulley are all one unit.
4. Attach the photogate unit to the plastic right angle clamp. Attach that to the metal rod on your stand, so that the pulley hangs over the edge of the table.
5. Find your piece of black thread. Thread it through the pulley, and attach two mass hangers to it on either end. Make sure you thread the string first. If you attach the hangers first you won't be able to hand the string on the pulley.
6. Place the no bounce pad under the hangers, so that they can land gently on it during the experiment.
7. Turn on the PASCO 850 Universal Interface, if you have not yet.
8. Connect the Photogate cable to the photogate and Digital Port 1 on the PASCO Interface.
9. Go to IvyLearn and find the Labs Module. There is a program called "Atwood and Friction.cap". Download that onto your desktop and then double click on it.
10. The computer may prompt you for the PASCO access code: that is on a piece of paper on the monitor. You need to enter the access code to use the program.
11. Once the program is open, make sure that the small red LED on the back of the photogate is illuminated. Spin the pulley slowly: you should see the LED turn on and off.

## Section 3: Instructions for Taking and Analyzing Data

1. In the lower right-hand corner is a button that says “record”. If you click on that button it will start the computer collecting data.
2. If you spin the pulley, just to get some sample data, you should see data points appear on the graph.
3. Click on the data highlighting tool. You can drag the box around, and resize it to select the section of data that you are interested in.
4. Click on the Data Fitting Tool and select linear fit. This will give you the best fit line for the data that you just took.
5. In this lab, we are interested in the acceleration of the system as a whole. Notice that you have the equation of a line. The line is velocity vs time data, so the slope of that line will be the acceleration of the system. Record this acceleration for each data run that you complete. You don’t need to keep the error on the measurement, just the measurement itself.
6. You also need to calculate the theoretical value for the acceleration that you expect to get. That calculation is also done in the suggested data tables given below. The calculation is explained in Section 1.



## Section 4: Acceleration for Constant Total Mass

1. Now that you know how to take your data, we want to calculate and measure the acceleration of the Atwood machine when the mass stays the same. Place 100 grams on M1, and 105 on M2. Note that it does not matter which hanger is M1 and M2. Do not forget that the hangers themselves have mass.
2. Do the data run, and then move 5 grams of mass from M1 over to M2. Record your data.
3. Do this for each data run, so you will be decreasing the mass of one hanger by 5 grams, but increasing the other by 5 grams. This keeps the total mass of the system the same, but slowly increases the net force acting on the system.
4. When you are collecting your data be careful of units: make sure that you are using MKS units.

**Data Table: Constant Total Mass**

| Run | M1 (kg) | M2 (kg) | $a_{exp}$ (m/s²) | $F_{net}$ (N) | $a_{theory}$ (m/s²) | % error |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |

## Section 5: Acceleration for Constant Total Force

1. You will record data for this section in the same way that you did in Sections 3 and 4.
2. Start out again with 80 grams on M1 and 85 grams on M2.
3. Once you have your first set of data, add 5 grams to **each** of the hangers. This will increase the total mass of the system, but the total net force acting on the system will not change.

**Data Table: Constant Total Force**

| Run | M1 (kg) | M2 (kg) | $a_{exp}$ (m/s²) | $F_{net}$ (N) | $a_{theory}$ (m/s²) | % error |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |

## Section 6: Questions

1. Compare the experimental acceleration with theoretical acceleration by determining the percentage error in your data table. What are some reasons that would account for this error?
2. For the Constant Total Mass data, plot a graph of $F_{net}$ vs. $a_{exp}$. Note: You can arbitrarily make all of your accelerations positive, since that will make the graph a little easier to look at.
3. Draw the best-fit line on your plot. What does the slope of the best-fit line represent?
4. How does the Force vs Acceleration plot relate to Newton's Second Law? How does it support Newton's Second Law?

# Part 2: Kinetic Friction

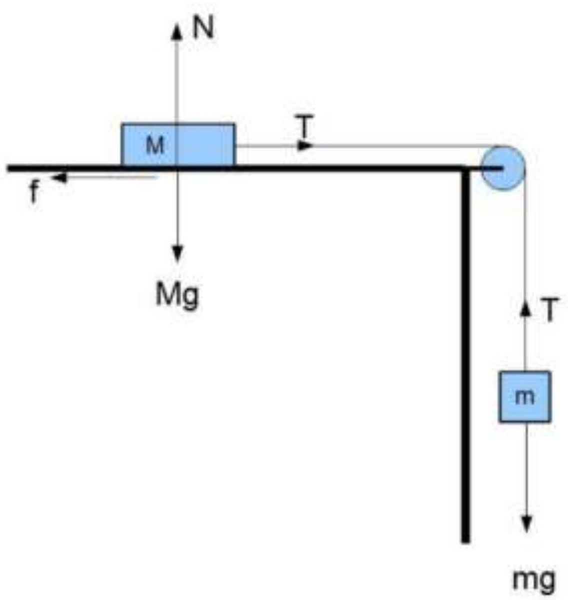
**Introduction:** This experiment is very similar to the atwood machine. The difference is you will include kinetic friction in your calculations.

## Materials:

| | |
|---|---|
| Computer Work Station | PASCO 850 Universal Interface |
| Aluminum Track | Wood Block with Felt |
| Thin Black String (2.5 meters) | No Bounce Pad |
| Photogate Rod | Photogate |
| Photogate Cable | Photogate Pulley |
| Mass Set with Hangers (At Station) | Metal Table Clamp |
| | |

## Section 1: Theory

In this lab, you will build the apparatus shown below. The apparatus will allow you to calculate the kinetic coefficient of friction between the level surface and the large block labeled "M". In this case, the level surface will be the aluminum track, and the mass "M" is the wooden block. The analysis of the problem is shown below. You may use that to help you calculate the coefficient of kinetic friction.




The analysis for the y direction forces acting on the wooden block is the same for both problems.

$$\sum \vec{F}_y = 0 = N - Mg$$

$$N = Mg$$

Once you know the normal force acting on the block you can use that to find the frictional force, since:

$$f = \vec{F}_{fr} = \mu N$$

**Finding μ$_k$**

$$\sum \vec{F}_x = (m+M)\vec{a}_x = mg - f$$

$$(m+M)\vec{a}_x = mg - \mu_k M g$$

$$\mu_k M g = mg - (m+M)\vec{a}_x$$

$$\mu_k = \frac{mg - (m+M)\vec{a}_x}{Mg}$$

$$\mu_k = \frac{m}{M} - \left(1 + \frac{m}{M}\right)\frac{\vec{a}_x}{g}$$

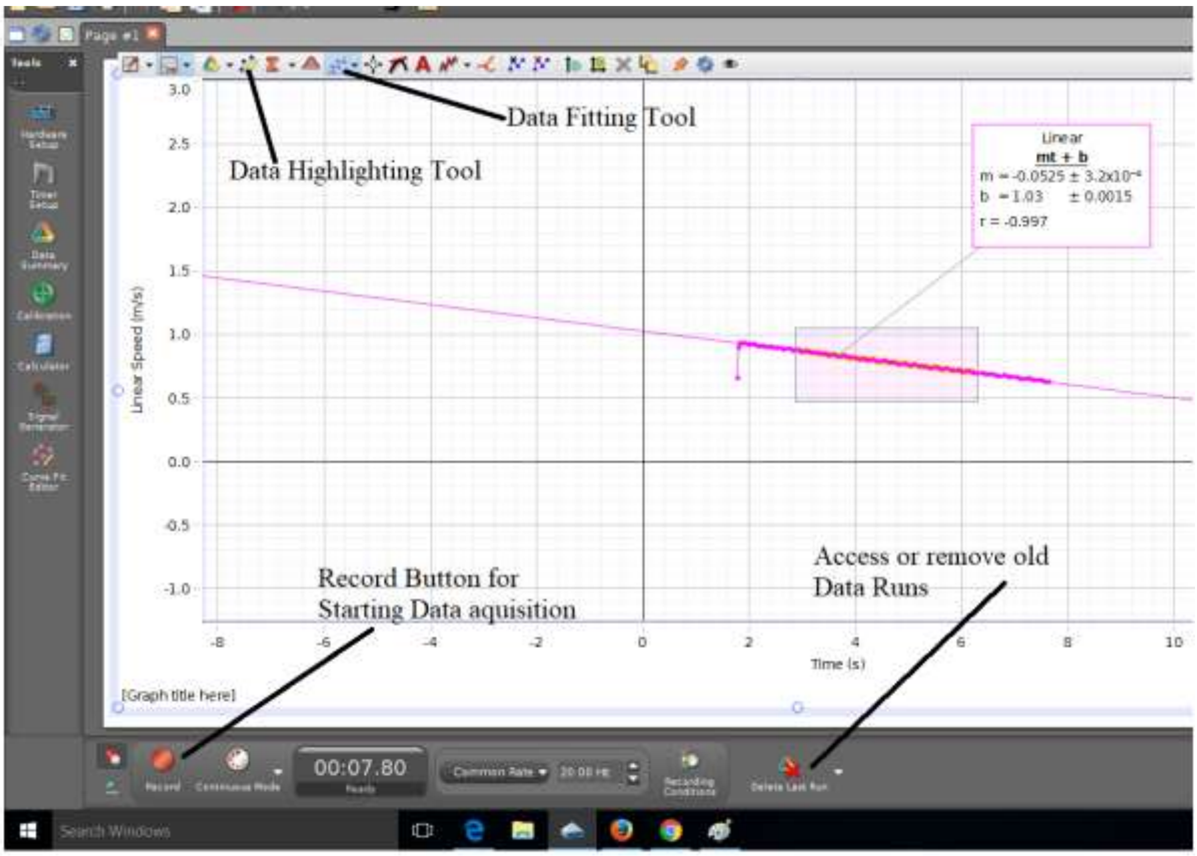
## Section 2: Building the Apparatus

1. Find an aluminum track and set it down on the table. Use the table clamp to hold the aluminum track to the table. The track should have one end hanging just a little over the edge.
2. Assemble the photogate, photogate pulley, and photogate rod together, so they are one unit. The entire unit fits into the table clamp, such that the pulley will allow a string to run parallel to the track and perpendicular to the floor.
3. Put your heavy book on one end of the track to hold it down.
4. Tie one end of your string to the wooden block, and the other to one of your mass hangers. The string should run over the pulley, so that the mass hanger is hanging over the edge of the table.
5. Connect the photogate assembly to the PASCO 850 Universal Interface's Digital Input 1. Make sure to turn on the interface, if you have not already.
6. Go to Ivy Learn and look for the module called "Labs". There is a program there called "PHYS101_Atwood and Friction.cap". Download that program from Ivy Learn and open it. From here you can start taking data.

## Section 3: Instructions for Taking and Analyzing Data (Same as Atwood)

1. In the lower right-hand corner is a button that says "record". If you click on that button it will start the computer collecting data.
2. If you spin the pulley, just to get some sample data, you should see data points appear on the graph.
3. Click on the data highlighting tool. You can drag the box around, and resize it to select the section of data that you are interested in.

4. Click on the Data Fitting Tool and select linear fit. This will give you the best fit line for the data that you just took.
5. In this lab, we are interested in the acceleration of the system as a whole. Notice that you have the equation of a line. The line is velocity vs time data, so the slope of that line will be the acceleration of the system. Record this acceleration for each data run that you complete. You don't need to keep the error on the measurement, just the measurement itself.
6. You also need to calculate the theoretical value for the acceleration that you expect to get. That calculation is also done in the suggested data tables given below. The calculation is explained in Section 1.



## Section 4: Measuring the Coefficients of Friction

1. Now that the apparatus is built, you need to take your data. You are going to take the data you need to find the coefficient of static friction and the coefficient of kinetic friction at the same time. Suggested Data Tables for each set of experiments is given below. For all of the tables "m" represents the mass of the hanger total. "M" will be the mass of the block.
2. You need to complete the list of experiments below. The data runs do not take long to complete, if you are smart about when you do the data runs.
    a. Coefficient of Kinetic Friction with Constant Normal Force: Large Felt Side
    b. Coefficient of Kinetic Friction with Constant Normal Force: Small Felt Side
    c. Coefficient of Kinetic Friction with Constant Normal Force: Large Wood Side
    d. Coefficient of Kinetic Friction with Constant Normal Force: Small Wood Side
    e. Coefficient of Kinetic Friction with Variable Normal Force: Large Felt Side
    f. Coefficient of Kinetic Friction with Variable Normal Force: Large Wood Side
3. To measure the Coefficient of Kinetic Friction with Constant Normal Force you will add the amount of weight indicated on the data tables below to the small mass hanger
4. Push the record button on the computer and allow the wooden block to slide along the track. Use the program to find the acceleration of the block by putting a linear regression through the data. This is the acceleration that you will need to use to find $\mu_k$. Note: make sure that the window you use to select the data is centered around the velocity indicated in the data table.
5. To measure the Coefficient of Kinetic Friction with Variable Normal Force you will add the amount of weight indicated on the data tables below to the small mass hanger, and you will add mass to the block. For the first run, don't add any mass. That means you can use your data from before. For the second and third data runs, add 50 g and 100 g respectively.
6. Once you have all of your data, you should fill out the last data table called "Percentage Difference Comparisons". The equation for % Difference uses two values, neither of which is an accepted value. Instead, you will use measurement 1 and measurement 2. That means you can find a number that simply compares how close two values are, rather than comparing a measurement to an accepted value:

$$\%\ Difference = \frac{m_2 - m_1}{\frac{1}{2}(m_1 + m_2)} \times 100$$

7. After filling out all the data tables, answer the questions at the end of the lab.

# Suggested Data Tables

**Sliding Mass: ________________g**

**Coefficient of Kinetic Friction with Constant Normal Force: __________**

| M (g) | m (g) | $V_{ave}$ (m/s) | $a_x$ (m/s$^2$) | $\mu_K$ |
|---|---|---|---|---|
| | 75 | 1 | | |
| | 100 | 1.25 | | |
| | 125 | 1.5 | | |
| | | | Average = | |

**Coefficient of Kinetic Friction with Variable Normal Force: __________**

| M (g) | $M_{add}$ (g) | m (g) | $V_{ave}$ (m/s) | $a_x$ (m/s$^2$) | $\mu_K$ |
|---|---|---|---|---|---|
| | 0 | 75 | 1 | | |
| | 50 | 100 | 1.25 | | |
| | 100 | 125 | 1.5 | | |
| | | | | Average = | |

**Percentage Difference Comparisons**

| | | % Difference |
|---|---|---|
| Felt | | |
| | $\mu_{K,\ large}$ vs $\mu_{K,\ small}$ | |
| | $\mu_{K,large\ const.\ normal}$ vs $\mu_{K,\ large\ variable\ normal}$ | |
| | | |
| Wood | | |
| | $\mu_{K,\ large}$ vs $\mu_{K,\ small}$ | |
| | $\mu_{K,large\ const.\ normal}$ vs $\mu_{K,\ large\ variable\ normal}$ | |

## Section 5: Questions

1. Using the Percentage Difference Table, how does the surface area of contact between the two surfaces affect the coefficient of kinetic friction?
2. Using the Percentage Difference Table, how does the normal force affect the coefficient of kinetic friction? What does your intuition tell you should happen?
3. Look at the original data that you took for the $\mu_k$ of the large felt surface and the large wood surface with constant normal force. Did the velocity of the block play a large role in the coefficient of friction? Does your intuition tell you it should? Explain.