General Physics Labs I (PHYS-2011)
EXPERIMENT MECH–4:
Atwood's Machine and Newton's 2nd Law

1 Introduction

Newton's second law ($\vec{F}_{\text{net}} = m\,\vec{a}$) can be experimentally tested with an apparatus known as an "Atwood's Machine." Figure 1 below illustrates an idealized version of the Atwood's Machine. Here, two objects, connected by a massless thread, are draped over a frictionless, massless pulley, as shown in the Figure 1. For clarity, we assume the object on the left is object 1, and the object on the right is object 2. If the mass m_1 of object 1 is greater than the mass m_2 of object 2, object 1 accelerates downward, and object 2 accelerates upward. Since the objects are connected, the magnitude of the acceleration is the same for each object. Since the pulley is frictionless and massless, and the string is massless, the tension on each side of the pulley has the same magnitude (*i.e.*, $T_1 = T_2$). Given these assumptions, the free body diagrams for the two objects are shown below:

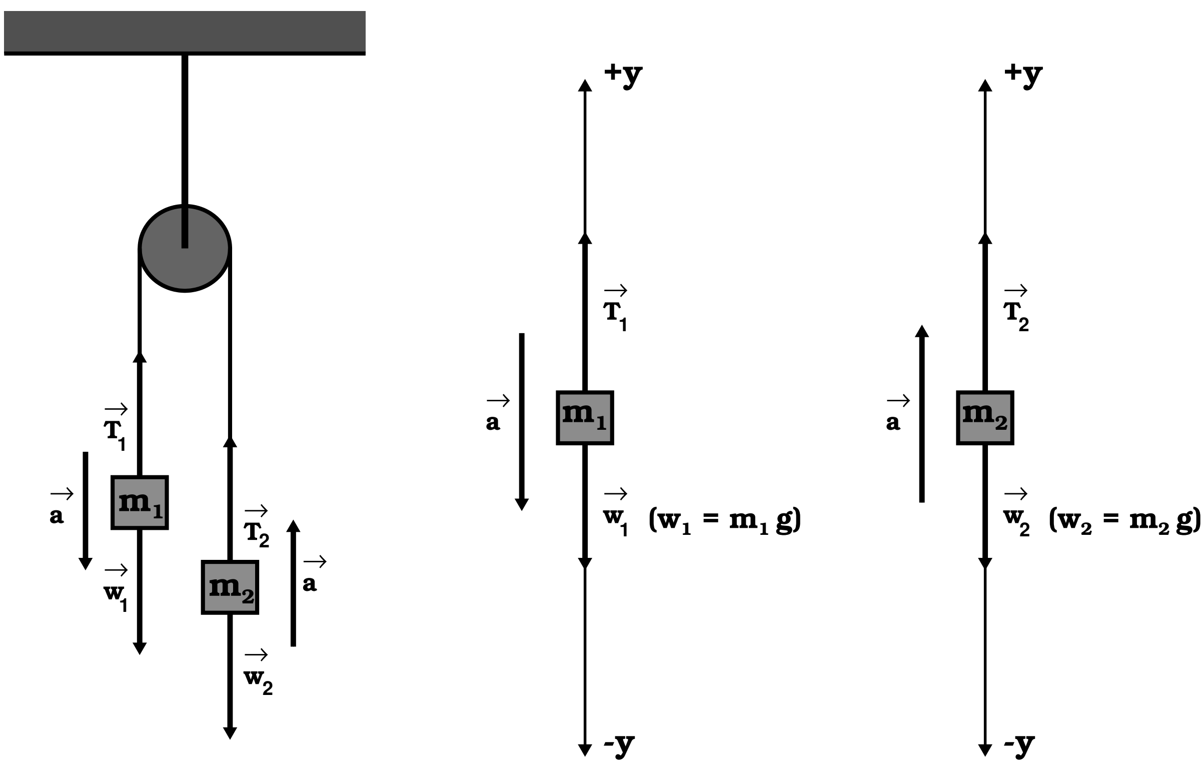

Figure 1: An idealized Atwood Machine with Free-Body Diagrams

Applying Newton's 2nd Law, $F_{\text{net, y}} = m\,a_y$ to each object, we write

$$T - m_1\,g = -m_1\,a \tag{1}$$

and

$$T - m_2\,g = m_2\,a\ . \tag{2}$$

If we eliminate the tension T, we can obtain the following expression for the magnitude of the acceleration:

$$a = \frac{(m_1 - m_2)\,g}{m_1 + m_2}\ . \tag{3}$$

The numerator is the net force causing the system to accelerate, and the denominator is the total mass being accelerated. We will call this the *theoretical expression* for the acceleration, a_{th}, which can also be written as

$$a_{\text{th}} = \frac{F_{\text{net}}}{m_{\text{tot}}}\ , \tag{4}$$

where $F_{\text{net}} = (m_1 - m_2)\,g$ and $m_{\text{tot}} = m_1 + m_2$.

In this lab session, we will be working with a pulley arrangement that only approximates the ideal pulley system pictured above. Notably, we have a two pulley arrangement which eases the strain on the pulleys. We will treat this two pulley arrangement as the idealized pulley above, but we will attempt to "compensate" for the fact that the experimental pulley system does have friction and a nonzero mass.

2 Procedure

At each station, a pulley arrangement is set up. The pulley on the left is a smart pulley arrangement. Surrounding this pulley is an apparatus which sends an infrared beam from a source to an infrared sensor on the opposite side. The beam is interrupted by the "spokes" of the pulley. The width of the spokes have been calibrated so that the time interval between interruptions of the beam can be converted to a tangential velocity at the edge of the circular pulley. This smart pulley is connected to *Digital Input 1* of the PASCO Science Workshop 850 (SW 850) interface. The SW 850 interface should also be connected to a Dell Laptop by a USB cable. Both the computer and the SW 850 interface should be turned on. If this is not the case, let your lab instructor know.

The smart pulley arrangement will be used to obtain an experimental value for the acceleration a_{exp} associated with a given mass difference $\Delta m = m_1 - m_2$. You should begin by putting equal masses on each mass holder. Counting the mass of the holder (**5 grams**) each side should have a total mass of 135 grams and $m_1 + m_2 = 270$ grams. You are now ready to take data using the Data Studio software.

2.1 Taking Data using the CAPSTONE Software

1. Start the Capstone program and Open *Hardware Setup window* (upper left of screen).
2. Click on *Digital Input 1* on the image of the 850 Interface box and Choose "*Photogate with Pulley*" for the attached sensor from the drop down list. Close *Hardware Setup Window*.
3. Click and hold on the "*Graph*" icon in the upper right of the screen, drag the graph icon to the middle of the screen to display a full page graph.
4. Click on the Y-axis "*select measurement*" and choose "*Linear Speed (m/s)*" from the list of measurement options. (Note that time will be automatically set for the X-axis once the Y-axis is set.)
5. Click on the black triangle of the "*curve fit*" icon (see Figure 2 left image) within the top toolbar of the graph window.

Figure 2: CAPSTONE Software Icons: *Curve Fit* Icon (left) and *Highlight Range of Points* Icon (right).

6. Choose the "*Linear: mt + b*" fit from the drop-down menu. The program will now automatically fit a linear regression line to the displayed data.
7. At the bottom center of the screen, click on and adjust the "*sample rate*" for data collection to "*100 Hz*".
8. To start data collection, click on the "*Record*" button at the lower left of the screen. Release the masses so they undergo acceleration and click on "*Stop*" once the falling mass has struck the foam pad. **Make certain the thread is on the pulleys before each data run!**
9. To find the value of acceleration, you need the slope of the velocity versus time graph **where the motion is uniform.**
10. Click on the "*highlight range of points*" icon (see Figure 2 right image) within the top toolbar of the graph window.

11. A grayed out box will appear on the graph. You can click on the box to drag it around the screen and resize it. Move and resize the box as needed to choose a **uniform section** of the displayed velocity versus time graph. If the box displaying the curve fit information is covering up the data points, you can also click on it to drag it to any location on the screen. Your graph screen display should now look something like that shown in Figure 3.

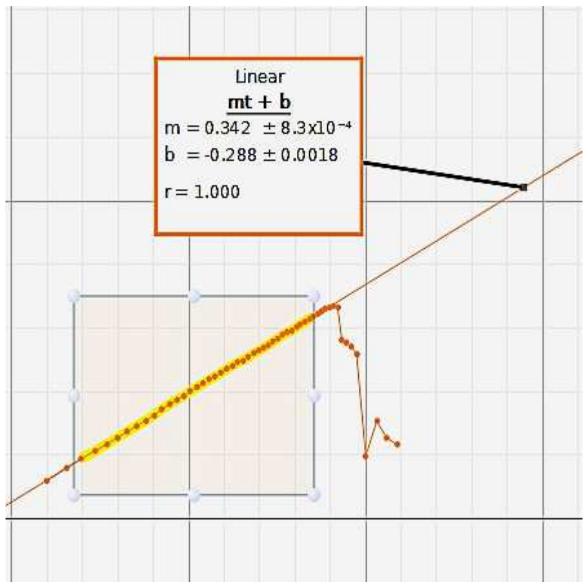

Figure 3: CAPSTONE Software: Fitted Graph Plot.

12. Record the value of the slope "m" which represents the acceleration a_{exp} in Acceleration Data Table 1 on the next page.

13. Transfer mass as necessary to acquire data for different Δm values. For each "*Run*" click on the "*Record*" button, the currently displayed data will be cleared and new data points displayed as the masses accelerate. Click on the "*highlight range of points*" icon (see Figure 2 right image) for each new data set to obtain the correct fit information and slope for the appropriate **uniform section** of the graph as above.

At this point, you should have filled in the first 2 columns of the Acceleration Data Table 1 below. Before comparing the experimentally derived accelerations with the theoretical expectations, however, we will attempt to improve our experimental accelerations by trying to compensate for the presence of friction. To do this, restore equal masses to each holder, so that the two masses balance. Now bring m_1 to a high point, and give it a downward push so that it begins to move downward. Start collecting data, as above, and record the acceleration a_f. Note that this should be negative. Repeat this an additional two times and record each result in Friction "Compensation" Data Table 2. Average the three values of a_f to get an averaged estimate $a_{f,\text{avg}}$. Subtract $a_{f,\text{avg}}$ from each value of a_{exp} that you have recorded in the Acceleration Data table (*i.e.*, Table 1). This is the magnitude of the acceleration $a_{\text{exp,c}}$. Note that this means $a_{\text{exp,c}} > a_{\text{exp}}$, as one would expect.

Table 1: **Acceleration Data**

Δ m (gm) $= \boldsymbol{m_1 - m_2}$	$\boldsymbol{a_{\text{exp}}}$ **(m/s²)**	$\boldsymbol{a_{\text{exp,c}}}$ $= \boldsymbol{a_{\text{exp}} - a_{f,\text{avg}}}$	$\boldsymbol{a_{\text{th}}}$ **(m/s²)**	**% Difference** $\boldsymbol{a_{\text{exp,c}}}$ **vs.** $\boldsymbol{a_{\text{th}}}$	**Comment**

Table 2: **Friction "Compensation" Data**

$\boldsymbol{a_{f,1}}$ **(m/s²)**	$\boldsymbol{a_{f,2}}$ **(m/s²)**	$\boldsymbol{a_{f,3}}$ **(m/s²)**	$\boldsymbol{a_{f,avg}}$ **(m/s²)**

Calculate the theoretical value a_{th} for each value of Δm. Compare $a_{\text{exp,c}}$ with a_{th} for each Δm by calculating a % Difference. Are the values of acceleration consistent? If they are not, can you suggest a reason why?

Construct a graph of $a_{\text{exp,c}}$ vs $(\Delta m)\, g$. Is the dependence consistent with Newton's 2nd Law? Explain.

2.2 Procedure Notes

Assume $g = 9.80$ m/s^2. Be careful when Δm gets large. The mass can drop quickly! Sometimes the thread will slip off the pulley. Make sure you replace it on the pulley. Practice taking data a couple of times before you start recording the data.