NORTHERN ILLINOIS UNIVERSITY

PHYSICS DEPARTMENT

Physics 210 – Mechanics & Heat Fall 2022

Lab #7

Lab Writeup Due: Tue/Wed/Thu, Oct. 18/19/20, 2022
Read OpenStax: Chapter 6.1,6.2,6.3, Chapter 10.1,10.2, Lecture Notes #5

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 a 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.

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

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:

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

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

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:

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

Our 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 being accelerated by the pull of the string at its rim. We will learn later in the course that a rotating disk provides an additional inertia at its rim equal to half of its mass: $m_p / 2$. For this experiment we can use $m_p / 2$ as if it were an additional mass to be accelerated with m_1 and m_2: $(m_1 + m_2)a \to (m_1 + m_2 + m_p / 2)a$.

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: $(m_2 - m_1)g \to (m_2 - m_1)g - f$. With these modifications, the equation for Newton's second law becomes:

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

In our experiment we will determine the acceleration a compared to the mass difference $\left(m_2 - m_1\right)$. If we rearrange Eq. 2 to solve for a

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

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 $\left(m_2 - m_1\right)$ (*horizontal axis*) the result should be a straight line with a slope equal to $g \Big/ \left(m_1 + m_2 + \frac{m_p}{2}\right)$, and a y-intercept at $-f \Big/ \left(m_1 + m_2 + \frac{m_p}{2}\right)$.

Data Collection

(1) Read and record the mass of the pulley, m_p, from the side of the apparatus. DO NOT REMOVE THE PULLEY FROM THE APPARATUS.

(2) Put a *small* piece of scotch tape (to write on) on each weight to be hung from the string. Separately measure and record in your lab notebook the mass of each weight

(aluminum cylinders and disks) to be hung on the strings (and write the weight on the small piece of tape). Exercise caution: though the weights look alike, they do not have precisely the same mass (thus the reason for the labels).

(3) Adjust the two *photogates* to be about 80 cm apart. Put the upper photogate as close as possible to the mechanical trip release—we want the photogate to start recording when the initial velocity of the object is as close to zero as possible. Make certain that the weights do not make contact with the *photogates* when passing through the motion sensor. Measure and record the distance from the upper to the lower *photogate*.

(4) On one aluminum cylinder, place one 5 gram mass, three 2 gram masses, and one 1 gram mass (making a total of roughly 12 grams). 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 3 column table) in your lab notebook m_1, m_2 and the mass difference $(m_2 - m_1)$ in grams for the first data set (remember, m_1 and m_2 are the total masses of the cylinder and any aluminum disks placed on them). Also, *open up Excel* and make a table having **5** columns for: m_1, m_2, $(m_2 - m_1)$, acceleration a, and the time t_{ave}.

(5) Using the Logger Pro software, time the fall of the heavier weight from the upper to the lower *photogate* and record this value. (*Gently catch the falling mass with your hand after it passes through the lower photogate—this will prevent the masses from falling off the Atwood machine*). This should be repeated for a total of 5 trials without changing the masses. Record each trial in your lab notebook and calculate the average time t_{ave}, and enter this value into your Excel table.

(6) *Keeping the total mass* $(m_1 + m_2)$ *the same (roughly 12 grams),* exchange weight(s) between the cylinders such that the mass difference $(m_2 - m_1)$ is 10 grams instead of the current 12 grams. Record in your lab notebook your new values for m_1, m_2 and the mass difference $(m_2 - m_1)$ in grams. *Make certain you only* ***exchange*** *weights—do not remove any weights*. Repeat step (5).

(7) Repeat step (5) for mass differences of 8, 6, and 4 grams. In the end you should have a total of five sets of data, with mass differences $(m_2 - m_1)$ of about 12, 10, 8, 6, and 4 grams, but the total mass $(m_1 + m_2)$ is always the same (roughly 12 grams). Thus the denominator in Eq. 6 is a constant (it does not vary between measurements).

(8) Calculate the acceleration a using Eq. 1.

Remember: Take a picture of your experimental setup with your cell phone.

The calculations in the Analysis section are to be finished before lab ends. You must show your final result (in Part (6)) to your TA before you leave the lab.

Data Analysis

(1) *In the lab*, plot using Excel the acceleration a in cm/sec^2 versus the mass difference $(m_2 - m_1)$ in grams for the five data sets. The acceleration should be the vertical axis. Include what you believe are reasonable error bars in your plot.

(2) *In the lab*, using Excel, fit the data with a straight line (showing the fitting equation on the plot).

(3) *In the lab*, write the y-intercept and slope values in your logbook.

(4) Find the frictional force f on the pulley by calculating the product of the y-intercept with the total mass (see Eq. 6). Convert the value of the force to Newtons.

(5) Find the gravitational acceleration g by calculating the product of the slope with the total mass (see Eq. 6). Convert the value of the acceleration to m/sec^2.

(6) Compute a *percent error* between your average g and 9.8 m/sec^2.

$$\%Error = \frac{Experimental - Accepted\,Value}{Accepted\,Value} \times 100$$

Show your result to your TA before you leave the lab. A 1% error would be a good result. A 10% error is what one would expect for the instruments used in this lab.

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 both a schematic and a cell phone picture of the experimental setup, equations used, tables, plot with straight line fit using Excel, and a discussion of why your value of g is different than the expected value. Discuss the possible sources of error that may lead to this discrepancy?

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