Lab 3 – Atwood Machine

Objectives:

The objective of this lab is to measure the acceleration of a given mass produced by a given force and to compare it with that calculated by Newton's Second Law of Motion.

Theory:

According to Newton's First Law of Motion, when the resultant of all the forces acting on a body is zero, if the body is at rest, it will remain at rest. If it is in motion, it will continue to move with uniform speed in a straight line. Newton's Second Law of Motion describes what happens if the resultant is not zero. The law states that if an unbalanced force is acting on a body, it will produce an acceleration in the direction of the force, the acceleration being directly proportional to the force and inversely proportional to the mass of the body. If the acceleration is constant, the body is said to be moving with *uniformly accelerated motion*.

The Atwood machine consists of two weights connected by a light, flexible string which passes over a light pulley; the pulley should be as nearly frictionless as possible. The machine is used in measuring the acceleration produced by an arbitrarily chosen force acting upon a given mass. Once the mass and the force have been chosen, the acceleration produced is determined by Newton's Second Law of Motion, $\vec{F} = m\vec{a}$, where F is a vector representing the net force (measured in Newtons) acting on the body, m is the mass of the body (in kilograms), and a is a vector representing the acceleration of the body (in meters per second squared).

In the Atwood machine, the total mass that is being accelerated is the sum of the two masses. The driving force, which is expressed in Newtons, is the difference in the weights on the two ends of the string. The objective in performing this experiment is to bring out the dependence of acceleration on force when the mass is kept constant. The only way in which the force can be varied without varying the total mass is to transfer masses from one side of the moving system to the other. Making use of Newton's Second Law, we can predict what the acceleration of the system should be for m_2 being a descending mass and m_1 being an ascending mass:

$$a_{theoretical} = \frac{g(m_2 - m_1)}{(m_2 + m_1)} \qquad \text{Eq. (1)}$$

Experimentally, the force of friction must be overcome first, and that is done by adding masses to the descending side until the descending mass moves downward with uniform velocity when it is given a very light push.

In uniformly accelerated motion, the velocity is increased by the same amount in each succeeding second. Because the starting velocity is zero in this experiment, the acceleration can be calculated using the measured time, t, and a measured falling distance, d:

$$a_{experimental} = \frac{2d}{t^2} \qquad \text{Eq. (2)}$$

For convenience, the distance of travel should be the same in all of the observations. The starting point is taken as the position of the moving system in which one of the masses rests on the floor. As this mass ascends, the other will descend an equal distance, and the stopping point is taken as the instant at which this mass strikes the floor. The distance traversed should be about one and a half meters. The time required for the mass to move through this distance is measured with a timer.

Procedure:

1. Place equal masses of about 500 g on each side of the pulley, including at least five 2 gram masses on the ascending side. Be sure to include the mass of the hangars. In your data notebook, label the ascending mass as m_1 and the descending mass as m_2, and record the exact values of both masses. Note: Use an electronic balance to find the exact mass of each of your masses to the nearest 0.1 gram and record the exact values of both. Your goal is to make both masses the same to within no more than one gram. Add or subtract small masses as needed to achieve this goal.

2. In an attempt to compensate for the friction within the pulley, with the weights suspended from the pulley and both about mid-level, very lightly tap the top of the descending mass. If it moves downward with a constant speed, friction in the pulley is negligible. If not, add a 1 gram mass to the descending mass side, and repeat the lightly-tapping process until you achieve a more-or-less constant downward motion. If 1 gram is not enough, replace it with a 2 gram mass and repeat the process. **Note**: **Do not include this added mass in your recorded value for m_2.**

3. Measure and record the distance the falling mass will traverse.

4. **CAUTION: Always stand clear of the suspended weights, for the string may break. Be careful to keep masses from falling off the descending side when it strikes the ground. To do this, the lab partner not releasing the falling mass should "tend" the falling mass as it strikes the floor.** Transfer four grams from the ascending side to the descending side and measure the time required for the descending mass to fall from rest. Note that the mass difference (m_2–m_1) is actually eight grams, not four. Begin the observation when the ascending mass is on the floor, starting the timer at the instant when you let the masses go, and stopping it at the instant when the descending mass strikes the floor. Make and record 5 independent observations and calculate an average descent time.

5. Repeat Step 3 for mass differences of 12 g and 16 g.

Calculations:

1. Use Eq. (2) along with the experimentally determined average time measured and the known distance of travel to calculate the experimental accelerations for the 8 g, 12 g, and 16 g mass differences.

2. Use Eq. (1) along with the mass differences and total mass to calculate a theoretical value for the accelerations predicted by Newton's Second Law of Motion. (Ignore any additional mass that was added to account for friction).

3. Calculate the percent errors between the experimental and theoretical acceleration values.

4. Plot a graph with the experimental accelerations on the ordinate (y axis) and the mass difference (in kilograms) on the abscissa (x axis). After correctly plotting the points, find a best-fit line for this data. From the slope, calculate an experimental value for g (slope times the total mass) and calculate the percent error in your experimental value for g.