UNIFORMLY ACCELERATED MOTION - THE ATWOOD MACHINE

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, and 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 purpose of this experiment is to measure the acceleration of a given mass produced by a given force and to compare it with that calculated from Newton's second law of 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 $\underline{F} = m\underline{a}$, where $\underline{F}$ is the net force in newtons acting on a body, m is the mass of the body in kilograms, and $\underline{a}$ is the acceleration 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 immediate object 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:

$$a_{theoretical} = \Delta m\, g \,/\, m_{total}$$

where Δm is the assumed mass difference, g is the acceleration of gravity, and m_{total} is the sum of the ascending and descending masses.

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 measured falling distance, d:

$$a_{exp} = 2d/t^2$$

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 <u>about</u> 1000 grams on each side, including at least five 2-gram masses on the ascending side. Include the masses of the hangers.

2. Adjust for friction in the machine by *adding* 1-gram masses to the descending side until the descending mass moves downward with uniform velocity when given a very slight push but doesn’t start by itself. Calculate and record the force of friction (added mass times g). Record the mass on the descending side and the mass on the ascending side. *Be sure to include the mass of each weight hanger*. **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.**

3. Measure the distance traversed.

4. Transfer two grams from the ascending side to the descending side and measure the time required for the descending mass to fall from rest. From this time you can determine the acceleration produced by a net force from the weight of four grams mass. (Note that the mass difference used here ignores the difference produced by the friction adjustment of Procedure 2.) 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 other mass strikes the floor. Make and record 6 independent observations and calculate an average time.

5. Refine the friction adjustment as follows (this procedure step is done only 1 time in the experiment): Calculate both $a_{theoretical}$ and a_{exp} for the 4-gram difference data from procedure 4. Calculate $(a_{theoretical} - a_{exp})m_{total}$. This is the error in frictional force. Now divide this by *g*. This is the mass (in units of kilograms), which should be added to the descending side. Round the mass to the nearest gram. If this is negative, remove mass from the descending side, to the nearest gram. Calculate the new friction force (extra mass on descending side, not including the 2 grams from procedure 4, times *g*).

6. Repeat procedure 4 (with the 4-gram difference) if you changed the friction adjustment. (Keep your original data. Don't throw it away.)

7. Measure the descent time (as in Procedure 4) using mass differentials of 8, 12, 16, and 20 grams, by transferring two additional grams each time. Make 4 independent observations for each of these accelerating forces and calculate the average times.

CALCULATIONS:

1. Using the average time measured with each accelerating force and the known distance, compute the experimental acceleration for each mass difference (4, 8, 12, 16, and 20 grams).

2. Compute the theoretical value for the acceleration from Newton's second law of motion using the *assumed* mass differences (ignore the difference caused by the friction adjustments, but use the actual total mass). Assuming this to be the correct value, compute the percent error of the observed value for each case, including the original 4-gram difference data.

3. Plot a graph with the experimental accelerations on the ordinate and the *assumed* mass difference (in kilograms) on the abscissa. After correctly plotting the points, sketch the best straight line which describes the points. (Plot the original 4-gram difference point but do not consider it when drawing your best line).

4. Using your calculator, a computer spreadsheet or other program, calculate the best linear equation for this data. Ideally, the y-intercept will be zero (yours probably isn't). From the slope, calculate an experimental value for *g* (slope times $m_{total.}$). Calculate the experimental error in *g*.

QUESTIONS:

1. (a) State what this experiment tested. (b) State the relation between force and acceleration observed in this experiment.

2. What is the difference between uniform motion and uniformly accelerated motion?

3. If you gave the system an initial velocity different from zero, how would this affect your results?

4. What is the advantage of transferring masses from one side to the other, instead of adding masses to one side?