Experiment #5: Newton's Second Law

I. About the Experiment

A. Background

Newton's second law relates the acceleration of an object to the force that produces it. This experiment uses the gravitational force on a falling mass to propel a pair of masses tied together by a string. During the experiment you will prove that the resulting acceleration is as predicted by Newton's second law, F = ma. The acceleration you measure will be very close to the calculated value of a = F/m.

Instead of measuring acceleration by the rate of change of velocity as in the last experiment, you will measure the time to travel a distance d. Then you will calculate the acceleration using the kinematics equation, $d = at^2/2$.

B. Theory

A force is a push or a pull. Its source may be gravitational, electrical, magnetic, chemical, or biological. It has units of Newtons. The gravity of the earth exerts a pulling force on any object (mass) near its surface. This force is equal to 9.8 Newtons of force on each kilogram of mass. This causes objects to be accelerated toward the center of the earth.

Mass is a resistance to movement or a change in velocity, it is different from weight in that weight is the result of the force of gravity - while mass exists without gravity. Thus, in outer space you would be weightless, but not massless. Mass has units of kilograms.

A net force (net force means the resultant of all applied force vectors as in Exp. #3) must be applied to a mass to produce an acceleration. Acceleration is a change in velocity, a positive acceleration increases velocity (speeds up a mass), a negative acceleration decreases velocity (slows down a mass). Velocity has units of meters/second, the same form as miles/hour. Acceleration is the rate of change of velocity per second, it has units of meters/second per second or meters/second^2.

Newton's Second Law relates force, mass and acceleration.

a = F/m or F = ma where: F is force in Newtons
m is mass in kilograms
a is acceleration in meters/sec^2

Or in Newton's words: "The acceleration of a body is directly proportional to the net force acting on the body and inversely proportional to the mass of the body."

II. The Experiment

This experiment is a verification of Newton's Second Law. You will be setting up forces and masses and measuring the resulting rates of acceleration. But, you won't be able to measure acceleration directly. *However, you will be able to measure distance traveled and the time required to cross it.* So you will need an equation that relates distance and time to acceleration.

Now, if the object moves a distance D in a time t:

$$D = \upsilon_o t + \frac{1}{2} at^2$$

Where υ_o is the initial velocity and a is the acceleration (if any).

Suppose an object starts at rest, so $\upsilon_o = 0$.

$D = at^2/2$ or $a = 2D/t^2$ where: D is distance in meters;
t is time in seconds
a is acceleration in meters/sec^2

Example #2: An object falls 44.1 meters in 3 seconds.
What is the rate of acceleration?

$$a = \frac{2D}{t^2} = \frac{2(44.1) \text{ meters}}{(3 \text{ seconds})^2} = \frac{88.2 \text{ meters}}{9 \text{ seconds}^2} = 9.8 \text{ meters/second}^2$$

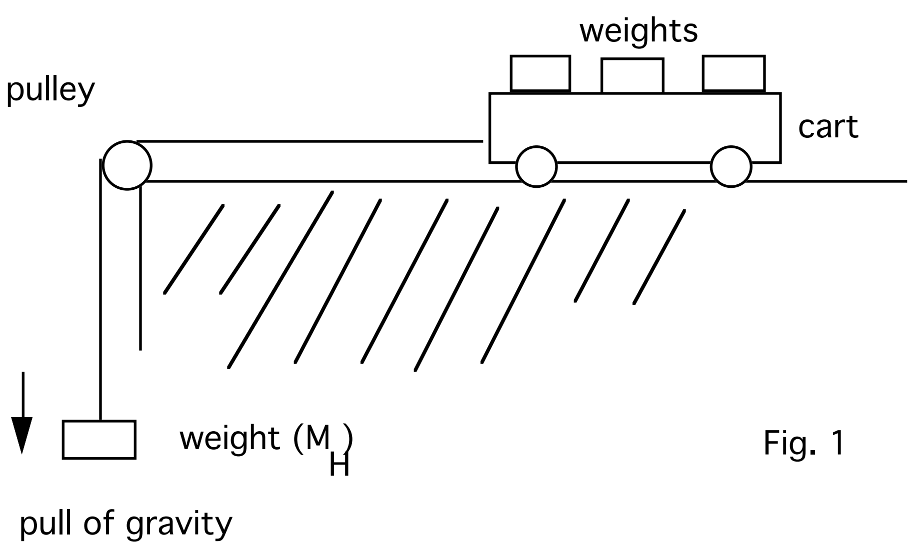

Fig. 1

In the set-up in Figure 1, the mass M_H is attracted by the earth's gravity. The force exerted on M_H is:

$F = M_H g$ where g is the acceleration provided by gravity, 9.8 meters/second^2

Example #3: If M_H is 300 gms., how much force does the earth's gravity apply to it?

Convert M_H into kilograms; $M_H = 0.3$ kg.

$F = M_H g = (0.3 \text{ kg})(9.8 \frac{\text{meters/sec}}{\text{second}}) = 2.94$ Newtons.

But the force applied by gravity to M_H has to pull many things:

M_H + the mass of the cart + the mass of the weights in the cart.

Or: $M_{total} = M_H + M_{cart} + M_{weights}$

Newton's Second Law says:

$a = \frac{F}{m}$ where: $F = (M_H)(9.8)$ in Newtons and $m = M_{total}$ in kilograms.

Summary:

•The equations in this section will give you the theoretical acceleration of the masses in the system.

•Measurements of time and distance and the equation in section III and analysis in section IV will give you the experimental acceleration of the masses in the system.

III. Procedure

1. Make sure that the track or table is as level as is possible.

2. The pulley, and the wheels of the cart have friction. We will greatly reduce the effects of friction by hanging just enough mass on the string so that the cart moves slowly at a constant velocity (i.e. without any acceleration) after being pushed. You will have to judge when the cart is just moving without gaining or losing speed. This amount of mass is called M_F. Throughout the experiment leave M_F on the string, just compensating for friction. Only additional mass attached to the string, M_H , will be responsible for acceleration of the cart and mass system.

   Distance hanging mass falls, D = _____________

3. Add 20 gm. to the cart and another 20 gm. to the hanging mass M_H. Measure the distance that M_H will fall before it is stopped (it shouldn't hit the floor). Using a laboratory timer, measure the time from when you release M_H until it is stopped.

   Cart mass M_C ________________ Friction mass M_F ________________

   Hanging mass M_H _____________ Mass added to cart M_A ____________

   Total Mass $M_T = M_C + M_F + M_H + M_A =$ __________________

4. Repeat step #4 two more times. Record each time measurement.

   Time 1 ________________ Time 2 _____________ Time 3 _____________

5. Move the 20 gram weight from the cart to M_H (This keeps the same total mass). Record the times for three runs as in part III.4.

   Time 1 ________________ Time 2 _____________ Time 3 _____________

6. Place weights on the cart equal to the total system mass in procedures III.3, 4, 5 (i.e. double the mass of the system, but not the force). Keep M_H at 40 grams. Record the times for three runs as in part III.4.

   Time 1 ________________ Time 2 _____________ Time 3 _____________

   New total mass $M_T =$ ________________

IV. Calculations and Analysis

1. Average your time values from each section.

   III.4. time average _____________ III.5. time average ________________

   III.6. time average _____________

2. Calculate the experimental acceleration values for each section, $a = 2D/t^2$ (remember to put D in meters)

   III.4. exp. acceleration ________________ III.5. exp. acceleration___________________

   III.6. exp. acceleration ________________

3. Calculate the theoretical values of acceleration for each section. $a = F/m = M_H g/M_T$, where the masses are in kilograms and g is 9.8 m/s^2.

   III.4. theo. acceleration _______________ III.5. theo. acceleration___________________

   III.6. theo. acceleration _______________

4. Calculate the percent error of the experimental value of acceleration for each section versus the theoretical value (Hint: If they don't match to within about 10%, you've done something wrong; check with your instructor).

   III.4. % error _________________ III.5. % error______________

   III.6. % error _________________

V. Questions

1. What happens to the acceleration if the net force applied on a mass is doubled?

2. What happens to the acceleration if the mass of the object is doubled and the force is unchanged?

3. What happens to the experimental value of the acceleration if the distance is doubled and the time is unchanged?

4. What happens to the experimental value of the acceleration if the time is doubled and the distance is unchanged?