M16d: Newton's Second Law

Introduction:

One of the founding cornerstones of all of physics is Sir Isaac Newton's three laws of motion. This current experiment focuses on a closer examination of Newton's Second Law. Newton's Second Law of motion describes what happens to a single body when an unbalanced force acts on it. The unbalanced (net) force causes an acceleration of the body. This experiment examines the relationship between the net force and the resulting acceleration, attempting to provide confirmation of Newton's Second Law. A common joke among physicists is that every equation can be derived from Newton's Second Law, which is funny because it is true in a way. Since many of the actual physical situations that physics seeks to approximate are the result of unbalanced forces acting on an object, Newton's Second Law does present a way to derive many of the different equations one makes use of.

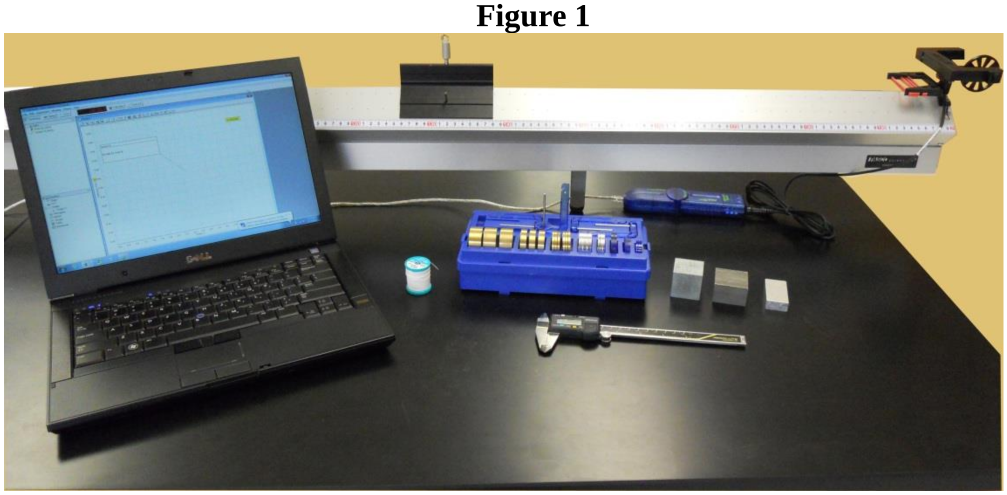
In order to examine the second law in its simplest form an air track will be used. The air track limits the possible directions of motion for the cart and also elevates it on a cushion of air which effectively reduces friction to a negligible influence. These simplifications to the problem help focus the attention on the net force and the resulting acceleration.

The experiment will be analyzed using kinematics and dynamics. The kinematical analyses will be accomplished with the aid of a computer. The computer is connected to the air track and will record time intervals as the cart accelerates. These time intervals together with the displacement will allow the computer to do a graphical analysis of the data and compute the acceleration. The dynamical analysis will be completed by applying Newton's second law and deriving an equation for the acceleration based upon the masses involved and gravitational acceleration. For each of the different trials, the net force acting on the cart will be varied by changing the descending mass attached to the string or by changing the height of the air track at one end. For the trials with the change of the height, in essence making the track an incline, this creates a component of gravitational force that will act down the incline opposing the force from the tension in the string.

Apparatus:

- Air Track System with Accessories
- Digital Caliper
- Mass Set with Hanger
- Elevation Blocks
- Pulley System
- Support Rods & Clamps
- Computer timing system

Figure 1



Discussion:

The dynamical analysis is conducted by applying Newton's second law individually to both the mass of the cart and then to the descending mass. The linking factor is the tension in the string connecting the two masses. The pulley that the string moves across is small, has very little mass and is almost frictionless; therefore the pulley's influences are going to be neglected. The descending mass is confined to motion in only one dimension labeled as the Y-axis. The cart has motion in two directions, both the X and the Y axis, due to the fact that the air cart is being raised to heights of varying angles via the elevation blocks. The motion of the cart in the X direction is the primary dimension that needs to be analyzed and is assumed parallel to the track. For simplicity call the X-axis to the right as the positive direction and the Y-axis down as the negative direction. The sum of the forces on each body would be as follows.

For the Cart:

$$\sum F_y = N - Mg\cos\theta = 0$$
$$\sum F_x = T - Mg\sin\theta = Ma$$
$$T = Mg\sin\theta + Ma$$

For the descending mass:

$$\sum F_y = T - mg = -ma$$
$$T = mg - ma$$

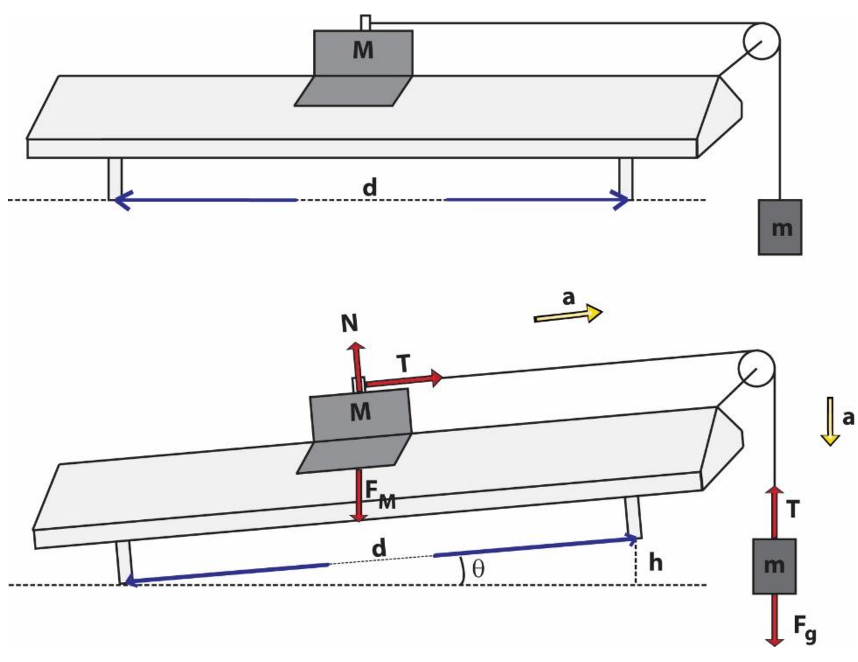
Combine the expressions for Tension and solve for the acceleration.

$$a = \frac{mg - Mg\sin\theta}{M + m}$$

This is the equation used to solve for the dynamical acceleration.

Force Diagram:

- M = mass of cart
- m = descending mass
- T = tension in string
- Fg = force due to gravity on descending mass
- a = acceleration of cart
- g = acceleration due to gravity (9.792 m/s^2)
- N = normal force upon cart
- F_M = force due to gravity on cart
- θ = angle of elevation
- d = distance between track supports



Procedures:

1. **1.** Measure the mass of the cart as accurately as possible.
2. **2.** Using the caliper measure the height of each block that will be used to elevate one end of the track. Also, measure the height of two combinations of the blocks. You should have a total of five different heights. Measure the distance between the centers of the track supports.
3. **3.** Using trigonometry solve for the angles of incline between the air track and the table for the five different heights.
4. **4.** Start up the appropriate computer software routine for the interface which is connected to a photogate monitoring the pulley**.**
5. **5.** Place the first mass on the descending mass hanger, measure and record the total. See Table 1 for a list of masses to use for the descending mass trials.
6. **6.** Connect the descending mass to the cart with the string. Position the cart on the track placing the string across the pulley with the descending mass hanging below.
7. **7.** Pull the cart back until the mass hanger is almost at the pulley. Check that the string remains parallel to the air track and that it doesn't touch the photogate.
8. **8.** Click start on the computer program to start the data collection, and then release the cart. Note the first five trials are with the air track level (zero degree angle).
9. **9.** Stop the data collection once the descending mass hits the ground or the cart hits the bumper at the end (this doesn't have to be exact).
10. **10.** Represented on the computer should be a graph of velocity (m/s) vs. time (s). On this graph should be a linear line which ascends then may become rough. The linear portion of the graph is what should be analyzed to find the correct data. The rough part represents when the mass hit the floor. Grab the linear part of the graph which needs to be analyzed by highlighting it with the left click on the mouse and dragging a box around this region. Obtain the statistical slope of the line to find the kinematical acceleration and the standard deviation. **Make sure to collect at least five significant digits for the kinematical acceleration**.
11. **11.** Repeat this sequence (steps 5-10) adding additional mass for each different trial, 5 trials total. Remember to measure each total mass (including the hanger) and record it on the data sheet before conducting each trial.
12. **12.** For the next five trials use the same mass as the last trial (the 5th trial for varying the descending mass). Repeat the sequence (steps 7 -10), now changing the inclination angle by using the combinations of the elevation blocks for each trial. Note, these trials will not have a zero degree angle but will have a constant mass. There are a total of five trials for changing the angle of incline while keeping all of the masses constant.
13. **13.** For the last five trials return the air track to level (zero degree angle of elevation). Also keep the descending mass constant, the same as the previous five trials. Now the varying factor is the mass of the cart. Each trial, repeat the sequence (steps 7-10) and change the mass of the cart by adding masses. See Table 1 for the list of the masses to use for the changing cart mass trials. Be certain to distribute the additional masses equally between the two sides of the cart.

Analyses:

1. **1.** Calculate the dynamical acceleration using the prior derived equation. Confirm that the values for the dynamical acceleration (the acceleration calculated using Newton's Second Law) compare closely to the values obtained for the kinematic acceleration (the actual physical resultant acceleration).
2. **2.** Using your dynamical acceleration calculate the net force on the cart for all the trials.
3. **3.** Graph in excel the kinematic acceleration as a function of the net force for the trials Changing the Descending Mass.
4. **4.** Graph in excel the kinematic acceleration as a function of the net force for the trials Changing the Angle.
5. **5.** Graph in excel the kinematic acceleration as a function of the cart mass for the trials Changing the Cart Mass.
6. **6.** Fit each of the three graphs with the appropriate type of trendline in excel, including the equation and R^2 value.
7. **7.** Using the trendline equations from excel confirm that you have successful verified Newton's second Law.

Table 1

Changing the Descending Mass	
Trial #	**Descending Mass (g)**
1	**5**
2	**10**
3	**15**
4	**20**
5	**25**
Changing the Cart Mass	
Trial #	**Additional Cart Mass (g)**
1	**20**
2	**50**
3	**100**
4	**150**
5	**200**

Experiment M16d: Newton's Second Law

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheet: M16d: Newton's Second Law

NAME: ______________________________ DATE: __________________

Distance between track supports (mm): ______________________

Changing the Descending Mass				
Cart Mass =				
Descending Mass	Kinematic Acceleration	Standard Deviation	Dynamic Acceleration	Net Force on Cart

Changing the Angle					
Cart Mass =			Descending Mass =		
Height	Angle	Kinematic Acceleration	Standard Deviation	Dynamic Acceleration	Net Force on Cart

Changing the Cart Mass				
Descending Mass =				
Cart Mass	Kinematic Acceleration	Standard Deviation	Dynamic Acceleration	Net Force on Cart