M16c: 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
- Cart
- Descending masses
- Elevation Blocks
- Pulley System
- Computer timing system

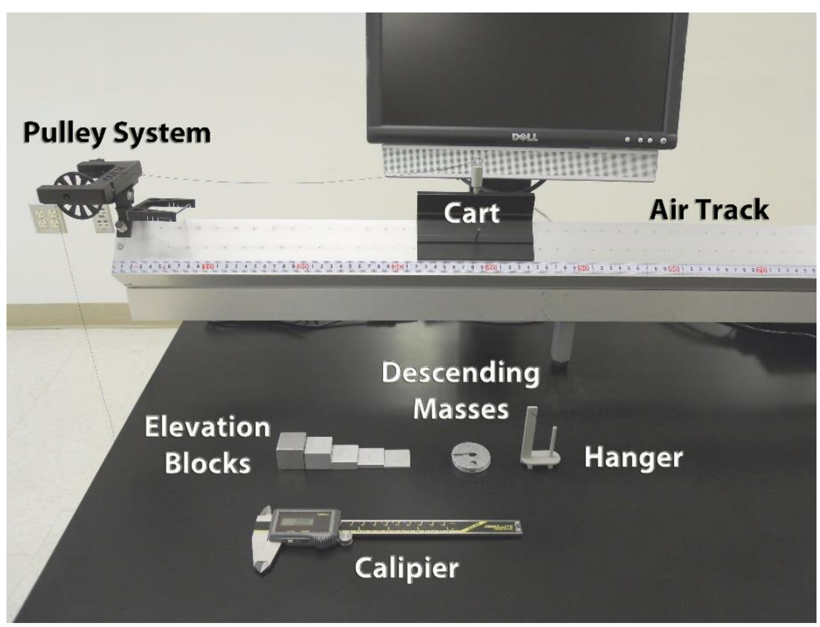


Figure 1

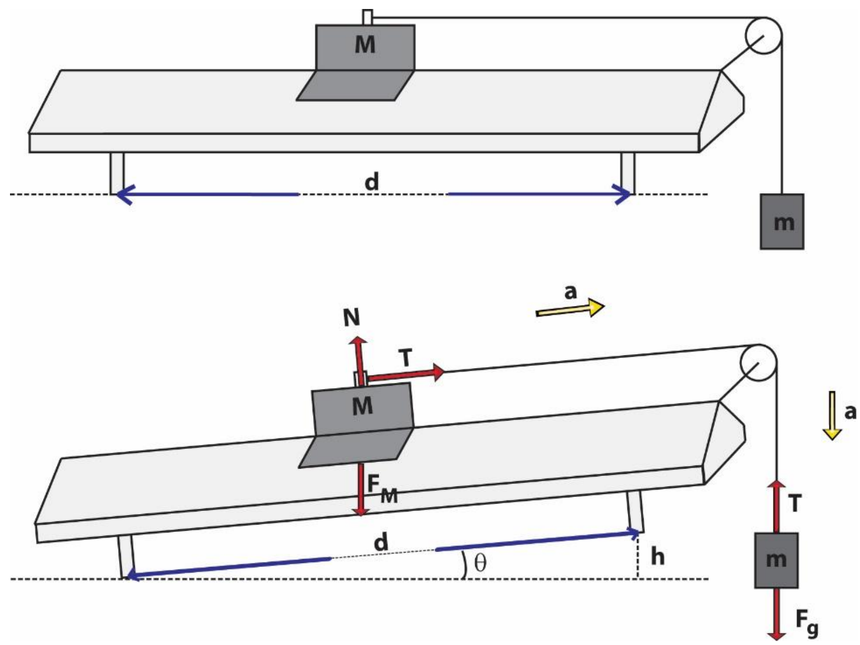
Discussion:

The dynamical analysis is conducted by applying Newton's second law individually to both the mass of the cart "*M*" and then to the descending mass "*m*". 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 following figure shows the force diagram for the cart and the descending mass.

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



The sum of the forces on each body would be as follows.

For the Cart:

$$\sum F_x = T - Mg\sin\theta$$

According to Newton's Second Law, the ***net force on the cart*** is

$$\sum F_x = Ma$$

Then

$$T - Mg\sin\theta = Ma$$

$T = Mg\sin\theta + Ma$

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.

Procedures:

1. **1.** Measure the mass of the cart as accurately as possible.
2. Using the caliper measure the heights of each step/stair. Measure the distance between track supports.
3. Using trigonometry solve for the angles of incline between the air track and the table. Confirm that the angle measurements are correct by checking with a lab instructor.
4. Start up the appropriate computer software routine for the interface which is connected to a photogate monitoring the pulley**.**
5. Place the first mass on the descending mass hanger, measure and record the total.
6. Make sure that the descending mass is connected with the string to the cart and is going over the pulley.
7. Pull the cart back until the mass hanger is almost at the pulley, start the data collection, and release. Note the first five trials are with the air track level (zero degree angle).
8. Stop the data collection once the descending mass hits the ground (this doesn't have to be exact).
9. 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**.
10. Repeat this sequence (steps 6-10) 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.
11. For trials 6 thru 10 use the same mass as trial 5 and repeat the sequence (steps 7 -9), now changing the inclination angle by using a different step for each trial. Note, these trials will not have a zero degree angle but will have a constant mass.
12. Now it is necessary to calculate the dynamical acceleration using the proper equation. The values for the dynamical acceleration (the acceleration calculated using Newton's Second Law) should compare to the values obtained for the kinematic acceleration (the actual physical resultant acceleration).
13. Using your dynamical acceleration calculate the net force on the cart.
14. Graph in excel the net force on the cart vs kinematic acceleration. This should result in a linear relationship.
15. Find the mass of the cart from the trendline equation.
16. Calculate the percent error using the measured mass and the calculated mass from the graph.

17. Experiment M16c: 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: M16c: Newton's Second Law

NAME: ____________________________ DATE: _________________

Mass of cart (kg): ____________________

Distance between track supports (mm): ____________________

	Height (mm)	Angle (θ)	Total descending mass (kg)	Kinematical Acceleration (m/s^2)	Standard deviation (m/s^2)	Dynamical Acceleration (m/s^2)	Net Force on cart (newton)
Changing mass							
Changing angle							

Mass of the cart from graph: ___________

Percent error:___________