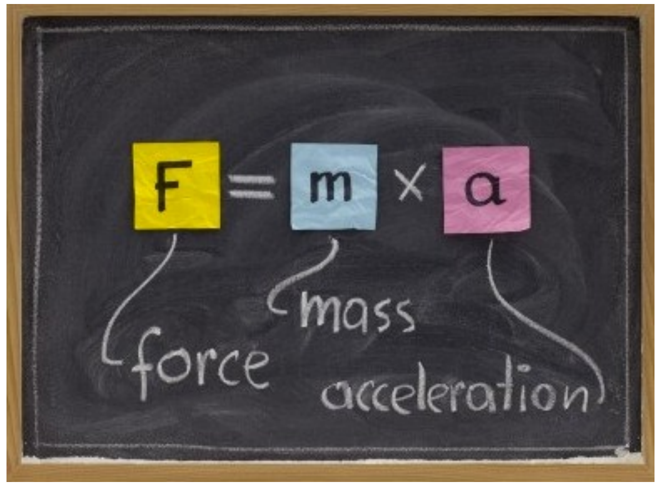
George Mason University

Physics for Life Sciences

Lab 4

Newton's Second Law of Motion[1]



Learning Goals:

- **Be able to identify proportionality between force, mass, and acceleration for Newton's 2nd Law.**
- **Be able to identify these relationships by analysis of graphs of Force vs. Mass and Force vs. Acceleration.**
- **Be able to recognize graphically and in tables when acceleration is constant in a system.**

Introduction and Procedure Outline:

As quoted from Physics Classroom[i], Newton's Second Law of motion is written as:

"The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object."

We can write this as in the figure to the right: F = ma or if we want to show 'proportionality' we can use the symbol $' \propto '$ and write:

$F \propto$ $F \propto$ ***F*** is proportional to 1***a*** and ***F*** is proportional to ***m***

$a \propto \frac{1}{m}$ reads a is proportional to $\frac{1}{m}$

Question to answer in report:

Think about what the graphs of 'F vs. a' and 'a vs. m' would look like. Make sure to include a sketch of these graphs in the report submitting for grading. Finally, discuss what shape the graph 'a vs. 1/m' would have if the data followed this theory model equation; is there any reason why someone would rather graph 'a vs. 1/m' than 'a vs. m', explain.

In this lab, you will be using the PASCO cart system to verify Newton's second law of motion. A cart of mass m_{cart} will be placed on the horizontal track. A string will be attached to the cart and taken over a pulley (positioned at the end of the cart), so that a mass hanger and a slotted mass can be attached to the other end of the string. A sketch of this experimental setup is on the following page.

[1] Image from: http://physics.tutorvista.com/motion/newton---s---second---law---of---motion.html

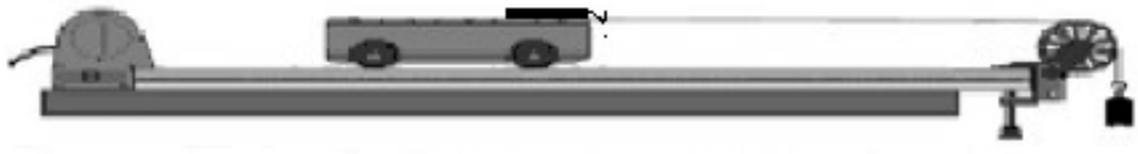


Figure 1: Experimental Setup --- cart/track mass system

Think: Include in your analysis:
Your group should be aware that although the pulley is near frictionless, that frictional forces could influence your data rather than being considered too small, and thus ignored. Be sure to discuss in your group how frictional forces could affect results (by showing an free body diagram of the cart including the frictional force) and discuss in the analysis section of your write up if in fact your group feels frictional forces affected results.

A motion sensor is placed on the other side of the cart for detecting the position and velocity of the cart. Force, F on the cart will be provided by the weight of the hanging mass $m_{hanging}$ (the total mass of the hanger and the slotted mass). This can be written as

$$F = m_{hanging}\,g$$

where g is the acceleration due to gravity.

As the cart is released, both the cart (of mass m_{cart}) and the hanging mass will slide until the hanging mass hits the ground.
Recognize that since the cart and the mass system is attached via a string, their common acceleration, a, from the fact that F = Tension of the string is given by the force

$$F = (m_{hanging} + m_{cart})\,a$$

Combining these two equations, we get

$$m_{hanging}\,g = (m_{cart} + m_{hanging})\,a$$

$$a = \frac{m_{hanging}}{(m_{cart} + m_{hanging})}\,g$$

Experimental Procedure and Analysis:

Determine the mass of the cart and mass hanger using scales provided in the lab room. Select a graph display of the position, velocity, and acceleration of the cart as a function of time in the Capstone software. Setup equipment as shown in Figure 1. Notice that there is a Force sensor on the cart as well as a motion sensor attached to the track. Finally – make sure to level the track. Move the cart around the track – does it move? If so – it cannot be level, level it by placing pieces of cardboard available in center table under the appropriate end of middle of the track. Now – if available place a level on the track – how level is the track?

Question: If the track is not quite level BUT the cart is motionless – how could that happen? What can be hypothesized to explain this phenomenon?

Start the data collection as you release the cart to record the position of the cart as a function of time. Stop the data collection when the hanging mass hits the ground. Data collection sampling rate is at a default of 20Hz – note it is likely that this sampling rate will need to be increased. Make sure to note if this is done in your report and why your group felt it was needed.

Determining Acceleration:

There are several ways to determine the acceleration of the cart/mass system just like the falling ball from the Free Fall laboratory and when not falling as in the amoeba laboratory.

1. As in the Free Fall laboratory – find the acceleration by determining the experimental acceleration from the slope of the velocity versus time graph by adding a linear fit to the portion of the graph where the cart is moving and the mass is falling. Record this value for the first experimentally determined acceleration. Repeat and be sure to determine an average value for the experimental acceleration.

2. We also know that the acceleration should be constant and smaller than the acceleration of gravity by inspection of the model equation shown above for the mass system acceleration. (Discuss how the equation predicts this fact.)

3. Look at the acceleration vs. time graph – find the max, min, mean, and standard deviation of the graph when the cart was moving. Note that the standard deviation of this data set is the estimate of the uncertainty in the individual data points of the acceleration. Inspect that graph and note how many of the acceleration data points collected fall within this uncertainty or 1 standard deviation. Is the number as expected? Discuss.

4. How do these acceleration values with the associated uncertainty agree with the slope of

the velocity graph? What does it mean to agree? Discuss. Finally state whether the data, if not in agreement, may be consistent with the velocity graph acceleration value. What does it mean to be consistent yet not agree? Explain.

5. Change the mass of the cart by adding additional masses on top of the cart (250g masses are on the table that fit snuggly into the cart) – be careful to center the masses so that the cart is balanced. Why is this important? Repeat the experiment. Does the acceleration change? How could you have anticipated this by inspection of the model equation and the free body diagram for the forces in this experiment? Explain and include free body diagram in report (hand drawn is sufficient – don't waste time doing on the computer). Be clear in the explanations what variables in the model equation change and HOW these changes would change the acceleration value and finally if this change is seen in the data.

6. Repeat the experiment one more time with an additional mass on the cart (an additional 250g or 500g mass). Does the acceleration change again? Does this change follow the logic outlined in #5 explain.

7. Create a graph of the average force vs. the average acceleration from the 3 experimental scenarios. How do these two variables compare visually in the graph (how are they related by inspection of the graph)? Is this predicted by the model theory equation? Explain.

8. Remove all masses on the cart (returning it to its original weight) and now increase the mass on the mass hanger by the same amount of added mass in #5. Rerun the experiment. Explain how or if the results change and again, how this would have been anticipated by the free body diagram and the model equation for the acceleration provided above.

9. Rerun experiment in #6 (adding the same additional mass) now to the hanging mass. Discuss the results of the average and standard deviation of acceleration compared to the initial run values. Discuss the %uncertainty in terms in precision and if results found indicated that repeated runs for all data acquired would be suggested if adequate time was available.

10. Create a graph of average acceleration vs. total mass for the data runs with changing hanging mass but equal cart mass. Now create another graph of the average acceleration vs. the inverse of the total mass. Is either graph linear? Would you expect either graph to

be linear? Explain.

11. Finally, discuss frictional forces. Are these forces sufficiently small such that ignoring this force was reasonable? Can frictional forces be ignored for some scenarios above but not for others? Hypothesize and Explain.

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[i] Quote on page 1 from: Physics Classroom online at:
http://www.physicsclassroom.com/class/newtlaws/Lesson---3/Newton---s---Second---Law