# Newton's 2$^{nd}$ Law Activity

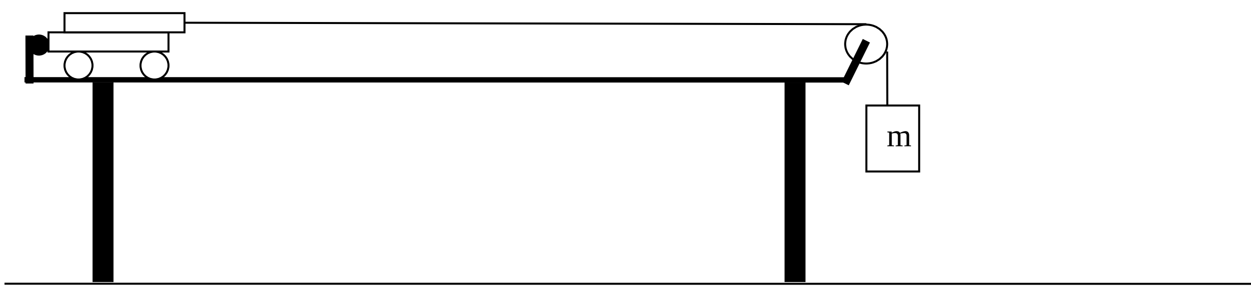
## Purpose

Students will begin exploring the reason the tension of a string connecting a hanging mass to an object will be different depending on whether the object is stationary or accelerating. Students will also use Newton's 2nd Law to experimentally predict the mass of a PASCO cart.

## Part I: Description of the Equipment and how it will be used to Collect Data

Data will be collected using Data Studio. After starting Data Studio, locate the labdocs folder and open the file called *Newtons 2$^{nd}$ Law Lab*. After the file opens, there should be two graphs ready to collect data. One graph will be Position vs time, and the other graph should be Force vs time. Drag and resize the graphs so that both graphs can be viewed at the same time.

A Force Sensor attached to a Cart, a Track, a Smart Pulley, some masses, and a string will be provided. The cart and track are designed to be nearly frictionless.




The force sensor attached to the cart will collect Tension data. The force sensor should be plugged into 'port A' of the PASCO Interface. Tension is a force, and the data collected will have units of Newtons. It is very important that the force sensor be TARED (zeroed) before each run. Before each run, the TARE button on the side of the force sensor must be pressed and held for a couple of seconds without any force or tension acting on the hook. While data is being collected, it is very important to hold the cord of the force sensor such that it does not drag or exert any forces on the cart. After a run, check the force data to make sure it seems reasonable. The force should not be zero or negative. If the data is suspect, go to "Experiment" on the top menu bar, and "Delete Last Data Run", and rerun the trial making sure the force sensor was TARED and the cord is not exerting a force on the cart.

The Smart Pulley at the end of the track will collect position vs time data. After the start button is pressed, data will be collected over a distance of 0.25m. Data Studio will automatically stop collecting data after the cart has traveled 0.25m. Make sure the cart and hanging mass can move unobstructed for 0.25m after the Start Button has been pressed. Do not allow the cart to crash into the end stop and/or the Smart Pulley. The Smart Pulley must be connected to 'port #1' of the PASCO Interface via a photogate cord. The cord should be hanging in the room. Set the height of the pulley such that the portion of the string that is over the track will be parallel to the track.

## Part II: Verifying the Calibration of the Force Sensor and Exploring Static vs Dynamic Tensions (20pts total)

If the cart is prevented from moving either by holding the cart or due to frictional forces when a hanging mass is attached, the tension in the string should be equal to ***mg***, where ***m*** is the hanging mass and ***g*** is the acceleration due to gravity. For our purposes this tension will be defined as the Static Tension.

However if the cart is accelerating, the tension in the string will not be equal to the static tension. For our purposes, the tension of the string when the cart is accelerating will be defined as the Dynamic Tension.

If you have not already learned how to use Free Body Diagrams to set-up equations of motion, you will in the near future. For a level, frictionless surface, you will be able to determine the following equations of motion for the cart and the hanging mass from your free body diagrams.

$$F_{Net\ cart} = Ma = T \qquad\qquad F_{Net\ hanging\ mass} = ma = mg - T$$

Where ***T*** is the tension of the string, ***M*** is the mass of the cart, ***m*** is the hanging mass, ***a*** is the acceleration of the cart and the hanging mass, and ***g*** is the acceleration due to gravity.

Note that $F_{Net\ cart}$ is not equal to $F_{Net\ hanging\ mass}$ when the cart is accelerating. The equations above can simply be expressed as:

$$Ma = T \qquad \text{and} \qquad ma = mg - T$$

If these equations are solved simultaneously, the dynamic tension can be shown to be:

$$T = \left(\frac{Mm}{M+m}\right)g \quad or \quad T = \left(\frac{M}{M+m}\right)mg$$

You will now collect some Static Tension Data and Dynamic Tension Data. Make sure that the Force Sensor and the Smart Pulley are connected to the PASCO Interface.

TARE the force sensor and hang 55g on the string. While the cart is being held in place, press the start button and collect data for approximately 2 seconds. After 2 seconds, press the Stop button. Neither the string nor the hanging mass should be touched during the 2 seconds. Record the average Static Tension on your Data Sheet. Calculate the Static Tension and compare it to the force sensor's measurement. If there is a significant difference, re-TARE the force sensor and collect data again. Also, check the hanging mass to make sure it is 55g. After the group is satisfied that the two values are comparable, data will be collected while the cart is in motion, and the two tensions on the graph will be compared. Before releasing the cart, TARE the force sensor. Remember to TARE the force sensor without any force or tension acting on the hook.

Now, collect data while the cart is in motion. After your lab partner releases the cart and the cart begins to roll forward, the Start Button should be pressed. The Start Button should be pressed fairly quickly; however, make sure that your lab partner is no longer touching the cart, and the cart is moving forward.

Record the average Dynamic Tension on your data sheet. Is the Dynamic Tension equal to the Static Tension? Use an Algebraic expression to explain why the Dynamic Tension always has to be less than the Static Tension when a cart is accelerated by a hanging mass on a frictionless, level track. Before printing the plots of the Static and Dynamic Tensions, ask your TA to verify your data. After your TA verifies your Data, you can print the Static and Dynamic Tension graph, and delete the data runs.

## Part III: Data Collection for Newton's 2$^{nd}$ Law (20pts total)

By changing the hanging mass, the cart will accelerate at different rates.

The acceleration of the cart for each run can be determined from the position vs time plots. (Hint: Fit each plot with an appropriate line and/or curve and use the fit data to determine the acceleration.)

The average Tension for each run can be found within the table located on the Force vs time plot.

Record the masses, accelerations, and tensions in the table on the Data Sheet.

## Part IV: Data Analysis (30pts total)

Use the acceleration and tension data to create two scatter plots of Acceleration vs Tension in Excel.

The first plot should use the data point (0, 0) in addition to the data you collected. However, do not force your fit through zero. Display the equation of your fit on the plot. Each axis should have an appropriate label.

The second plot should only be made with the data you collected. Do not use (0, 0) as a data point. Again, do not force your fit through zero. Display the equation of your fit on the plot, and label each axis with an appropriate label.

Using the Acceleration vs Tension plots, determine the mass of your cart without weighing it, and record the mass in grams on the Data Sheet.

## Part V: Error Analysis (30pts total)

Bring your cart to the front of the room, and request your TA to weigh your cart. Your TA will record the mass in grams on your data sheet and calculate the percent error.

**Name:** _______________________________ **Banner ID:** _______________________________

**Lab Group ID:** _______________________ **Number of Lab Partners:** _________________

# Data Sheet
# Newton's 2nd Law Activity

Hints:

1. Be mindful of the cord connected to the force sensor. The cord must be held such that it does not drag or otherwise exert a force on the cart.
2. The Force Sensor must be TARED before each data run.
3. The Start Button should be pressed quickly after the cart begins to roll forward. However, make sure the hand of your lab partner is no longer touching the cart before pressing the Start Button.
4. Adjust the pulley such that the string over the track will be parallel with the track.
5. The plastic mass hanger weighs 5g.
6. Use a Torpedo Level to level the track.

## Part I Equipment

After the Start Button is pressed, How far will the cart travel when data will stop being collected? ____________________

What units will Tension be measured in? ________________________________

How much force should be applied to the hook of the force sensor while TARING the Force Sensor? ______________

Where can you find the photogate cords? ______________________________________________

## Part II Data Collection (20pts total)

| Static Tension with 55g Hanging (N) | Calculated Static Tension with 55g Hanging (N) | Dynamic Tension with 55g Accelerating the Cart (N) |
|---|---|---|
| | | |

Use an Algebraic expression(s) to show why the Dynamic Tension always has to be less than the Static Tension when a cart is accelerated by a hanging mass on a frictionless, level track.

TA's Initials verifying your Static and Dynamic Tension Data and Plot: ________________________

Print and attach your Static and Dynamic Tensions vs time plot to the data sheet.

## Part III Data Collection for Newton's 2nd Law (20pts total)

| Mass (g) | mg (N) | Acceleration ($m/s^2$) | Dynamic Tension (N) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 15 | | | |
| 25 | | | |
| 35 | | | |
| 45 | | | |
| 55 | | | |

Carefully compare your mg and Dynamic Tension data as you make each run, and repeat runs as necessary.

## Part IV Data Analysis (30pts total)

Print and attach both plots of Acceleration vs Tension.

Predicted Mass of the Cart [Using (0, 0) as a Data point] in grams: __________________________ (B)

Predicted Mass of the Cart [Without using (0, 0) as a Data point] in grams: __________________________ (C)

Describe how your group determined the mass of the cart.

## Part V Error Analysis (30pts total)

| | | |
|---|---|---|
| Actual Mass as weighed by TA in grams (A) | | |
| Predicted Mass of cart in grams [Using 0,0 as a Data point] (B): | | Percent Difference = $\frac{\lvert A-B \rvert}{A} x100\%$ = |
| Predicted Mass of cart in grams [Without using 0,0 as a Data Point (C): | | Percent Difference = $\frac{\lvert A-C \rvert}{A} x100\%$ = |

| | | | | | | |
|---|---|---|---|---|---|---|
| Percent Difference | <=6% | <=9% | <=12% | <=15% | >15% | |
| Points | 30 | 25 | 20 | 15 | 10 | |