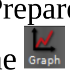
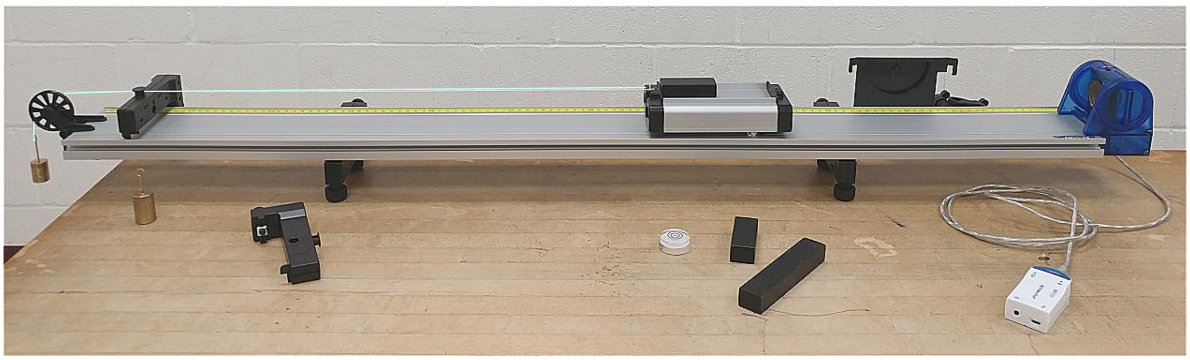
Newton's Second Law

Purpose: To understand Newton's Second Law and apply it to a moving system.

Set Up:
Choose group roles and record them for your reports. You will need a linear track with pulley, a cart, motion sensor, force sensor, 2 Airlinks, bullseye level, triple beam balance, string, 50g and 100g hooked masses, and a total of ~1000g block masses. Connect the force sensor and the motion sensor to the Airlinks and get them recognized by the computer. Position the motion sensor at one end of the linear track and an end stop at the other end as shown in Figure 1. Clamp a pulley to the end opposite the motion detector on the outside of the end stop. Check that the track is level. Prepare a display in Capstone that shows a *velocity vs. time* graph and a *force vs. time* graph using the 

"*Graph*" icon and the  "*Add a New Plot Area to the Display*" icon. Using *Data Summary*, set the velocity and force measurements to 3 decimal places.



The following activities will be performed twice, once with a 50g hanging mass and once with a 100g hanging mass.

Activity 1: Determination of the force due to a hanging mass.
Attach a 50g mass to one end of a string that is about 1 m long. Hold the force sensor vertically. Press the *Record* button on Capstone, then press the *Zero* button on the force sensor while it is held vertically. Hang the string and mass on the force sensor, then, stop the recording after about 5 seconds. Note down the force measured when the mass was hanging on the force sensor. **Check with an instructor if your measurement is reasonable.** (Hardware setup allows you to change the sign of the measurement if necessary.) Use a triple-beam balance to measure the mass of the "mass plus the string". Repeat this whole process using a 100g mass.

Question/Discussion:

1. How are the measured masses related to the corresponding forces that you have measured with the force sensor?

Activity 2: Applying Newton's Second Law to a moving system.
Measure the mass of a cart with a triple-beam balance and write this on a small piece of masking tape, and label the cart with this mass. Do the same for each of your black masses. Run the piece of string tied to the 50g mass over the pulley, through the **top** hole of the end stop and attach it to the silver cart, on the end opposite the plunger as shown in Figure 1. Adjust the position and height of

the pulley so the string has an unimpeded path through the end stop. Check that the string is level. Check that the ramp is level using a bullseye level. Adjust the feet to make it level if necessary. Set the switch on the motion sensor to cart mode, and point the sensor directly at the cart.

Place one ~250g mass in the cart. Measure the acceleration of the cart + mass + hanging mass + string, using the appropriate fit of your *velocity vs. time* graph. You will get better results if you choose a smooth portion of the graph that is as large as possible. Record the masses used and the resulting acceleration. Repeat the measurement of acceleration with ~500 g, ~750 g, and ~1000 g riding on the cart.

Find *ma* for each mass combination, where *m* is the total mass of the moving system.
Find the average of *ma* for these four systems.
Calculate the uncertainty in your average by finding the sum of the squares of the deviations of the data from their average, dividing by N-1 (the number of data minus one as the mean value is not an independent datum), and taking the square root, which for four measurements is

$$\sqrt{\frac{[(ma)_1 - average]^2 + [(ma)_2 - average]^2 + \cdots}{3}}$$

Repeat the entire experiment using a 100g mass as the hanging weight.

Question/Discussion:

2. Describe in words what makes up the total mass of this moving system.
3. Using the first trial (~250g mass in cart pulled by 50g weight), apply Newton's Second Law ($\sum F = \sum ma$) to this moving system and calculate its acceleration. Compare it to the acceleration obtained from the corresponding *velocity vs. time* graph. Is the acceleration from the graph bigger, smaller or the same as the calculated acceleration? If there is any difference between the two values of acceleration, what could possibly explain this?
4. How does the average of *ma* compare with the force you measured with the force sensor? Are your results consistent with Newton's 2nd Law?
5. Can the calculated uncertainty account for any difference you have found between the force you measured and the average? If not, think and write down any possible causes to explain this difference.

Reports

Have your recorder/checker enter the measurements (data) from the experiment into an Excel spreadsheet (be sure to label the cells, and give the units for the measurements) and use the spreadsheet to calculate the values of *ma* and their averages. Once you have finished, make sure to print **one copy** for your report. After you have discussed your results and reached conclusions, everyone in your group should answer all the numbered questions separately and hand them in with the plots (one *force vs time* plot from Activity 1 and one *velocity vs time* plot from Activity 2) and data table.

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