NEWTON'S SECOND LAW

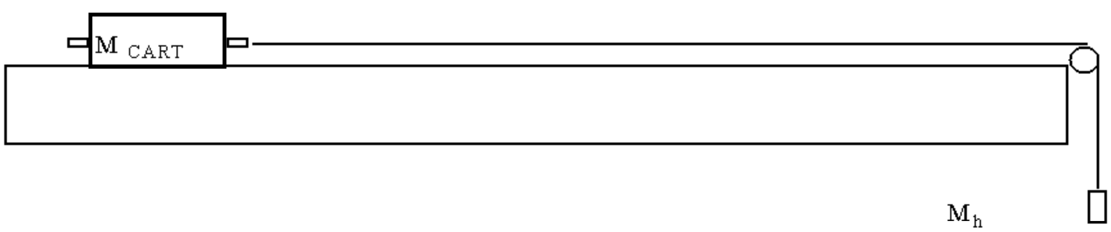
PURPOSE

The purpose of this experiment is to investigate Newton's 2^{nd} Law with an "air track/ hanging mass" system. Experimentally determined acceleration values will be compared to those predicted by Newton's Law to test the validity of Newton's 2^{nd} Law.

EQUIPMENT NEEDED

Air Track	String, Black
Air Track Kit	Mass & Hanger Set
Air Track Glider	Computer, Interface Box & Cables
Pulley, Photogate & Connecting cable	Logger Pro SW on Computer

Figure 1



THEORY

For this lab, the system is defined as the cart, the pulley and the hanging masses. However, at this point in time we will neglect contributions to the system from the pulley. Thus, the total mass M_{total} of the system will be the mass of the cart, M_c, plus the hanging mass, M_h.

Note: Don't forget to include the mass of the weight hanger (M_{wh}) in the quantity M_h

A small mass M_h will hang over a pulley at the end of the air track and will pull a larger mass M_C along the length of the air track. The computer will use the photogate to time the rotation spokes of the pulley and from this data will compute the distance, velocity and acceleration of the cart as a function of time. From Newton's 2nd law, the acceleration ***a*** of the cart is:

$$a = F_{net} / M_{total} ,$$

$$a = M_h g / (M_h + M_c) .$$

We will use this acceleration as the accepted value, $\boldsymbol{a_{accepted}}$. In each procedure we will test Newton's 2nd Law in two ways:

(1) Compare a_{exp} to a_{acc} via the % Error column in the Data Table. This is a preliminary check on the consistency of the data.

(2) **<u>Procedure 1</u>** - Graph a_{exp} vs $M_h/(M_h + M_c)$ and do a linear fit to obtain the slope of the experimental data. This slope will be compared to the accepted value of the acceleration due to gravity ($g = 9.8\ m/s^2$).

(2) **<u>Procedure 2</u>** – Graph $(1/a_{exp})$ versus (M_c/M_h) and obtain both the slope as well as the uncertainty in the slope. Compare your result (1/Slope Value) with the accepted value for the acceleration due to gravity ($g = 9.80\ m/s^2$).

WARNING: Common mistakes: (1) Forgetting to include the mass of the weight hanger ($\mathbf{M_{wh}}$) in $\mathbf{M_h}$. (2) Failure to keep the system mass constant in Procedure 1. (3) Knots in the string cause bumps (and bad data) when going over the pulley.

<u>PROCEDURE 1</u>

1. <u>AIR TRACK</u> - Attach the blower to the air track and turn it on. Level the air track by placing the glider (cart) in the middle of the air track and adjust the leveling feet on the air track until the cart is motionless in the middle of the track.

   <u>GLIDER</u> - Attach the hook accessory to one end of the cart. Add the putty accessory on the other end to balance it. Attach a string (about 1.5 m long) between the cart and the hanging mass (M_h)**.** Any masses added to the cart must be divided equally on both sides of the cart in order to balance the cart. Weigh the cart with the added accessories and record the mass as M_C.

   <u>PULLEY</u> - We will be using the pulley that comes with the air track accessory kit. There is an end mounted holder in that kit that will be installed on the air track on the opposite end from the blower hose. Place the pulley in the end mounted holder.

   <u>PHOTOGATE</u> - Mount the photogate on small ring stand and situate it over or under the pulley. Adjust the height of the photogate so that the pulley spokes will break the photogate LED beam as it rotates. Ensure that photogate will not interfere with the motion of the pulley or the hanging mass. Plug in the photogate into the Logger Pro port DG1.

   <u>LOGGER PRO</u> - Turn on the Logger Pro Interface Box and look for the green light to go one on the top of the Interface Box. Open the LoggerPro application by double-clicking on its icon and then under the **File** menu click on the **Open** menu item. Under the **Experiments** folder, double click on the **'Probes and Sensors'** folder and then double click on the **'Photogates'** folder and then finally double click of the **'Pulley.xlms'** file.

2. During this portion of the experiment we will be changing the Pulling Force while holding the Total Mass (**M**$_{total}$) constant. To achieve this constant mass the masses that will eventually be added to the weight hanger will initially need to be loaded on the glider (cart). Be sure to add this extra mass to the mass of the cart determined earlier, or just re-weigh the entire cart now with accessories and extra weights included.
3. Use **20g** added to M_h at first – don't forget *the mass of the hanger itself*. Make sure that the hanging mass accelerates the entire time the cart is traveling across the air track. Hold the cart some distance from the pulley, so that the hanging mass is freely hanging.

   The data collection operation must be running first, then the cart can be released any time after that. You must be ready to catch the cart. Click the '**Collect**' button to start the data collection, and then release the cart. After the mass hits the ground or prior to when the cart hits the pulley, catch the cart so it will not crash into the pulley. Click '**Stop**' to stop the data collection. You are now ready to analyze your data. **Practice this procedure.**

   On your computer screen should be a display showing a data table on the left and three graphs on the right. The graphs are Distance, Velocity and Acceleration, all as a function of time. Examine the velocity data that was obtained from the run. Highlight the largest region of fairly consistent data, between the start of the motion and prior to the end of the motion. This is done by "clicking and dragging," on the graph, across the relevant data points. Then click on the "stats" button or use the pull down menus to select the perform statistics option. Fit the velocity curve to a straight line. Make sure you display the slope and its uncertainty. These will be your a_{exp} for each case and the uncertainty (standard deviation).

   - Add this value of a_{exp} to the Data Table, calculate a_{acc} for this case and enter it in the Data Table.
   - Calculate the % Error and enter the value in the Data Table.
4. Repeat the procedure with 25, 30, 35, 45 grams of total mass loaded on the weight hanger. This will be done by transferring weights from the cart to the weight hanger. So the mass of the cart will decrease by exact same amount that the mass of the hanging weights (**M**$_{\mathbf{h}}$) increases and the Total Mass (**M**$_{\mathbf{total}}$) remains constant.
5. Make a graph of a_{exp} versus $M_h/(M_h+M_c)$ and obtain both the slope as well as the uncertainty in the slope. Compare your result with the accepted value for the acceleration due to gravity (g=9.80 m/s^2).

PROCEDURE 2

1. Include the third line of the **first table** (M_h = 0.030 kg + M_{wh}) in your **second table**!
2. Add an extra 100 grams to the cart and use 30 g added to the weight hanger and run the experiment as described in Procedure 1.
3. Find a_{exp} with its uncertainty, record it in your data table and compare to $a_{acc} = {M_h g}/{(M_h + M_c)}$.
4. Calculate the % Error and enter the value in the data table.
5. Add an additional 100 grams to the cart and repeat the experiment with the same 30 g. on the weight hanger. You should have a total of **three data sets** in the second table.
6. Make a graph of ($1/a_{exp}$) versus (M_c/M_h) and obtain both the slope as well as the uncertainty in the slope. Compare your result (1/Slope Value) with the accepted value for the acceleration due to gravity ($g=9.80$ m/s^2).

ANALYSIS (Slope Values)

Procedure 1

1. How did your experimental values of the acceleration in **Procedure 1** compare to the accepted values of the acceleration due to gravity? What was the percent error? Were the accepted values in the range of the experimental values with their uncertainties? You should address the question of how the experiment worked overall as well as the range of results in the experiment and you should definitely mention any outstanding experimental runs.
2. Is there a systematic trend in your data with respect to the experiments in which you changed the pulling force and kept the total system mass constant?
3. Did you verify Newton's second law within experimental uncertainty? Support your answer.

Procedure 2

4. Is there a systematic trend in your data in **Procedure 2** with respect to the data in which you changed the cart's mass and held the pulling force constant? Don't forget to include the third line of the first table (M_h = 0.030 kg + M_{wh}) in your analysis here!
5. How did your value for the acceleration due to gravity compare to the accepted value? What was the percent error. Was the accepted value within the range of the uncertainty of your experimental value?
6. Did you verify Newton's second law within experimental uncertainty? Support your answer.

REPORT

Each individual will turn in a Complete Lab Report as described in "Format for Formal Lab Reports."

DATA TABLES

Mass of Cart (without weights) _____________(kg)

Mass of Weight Hanger (M_{wh}) ___________ (kg)

Procedure 1 - Changing Pulling Force

M_h (kg)	M_C (kg)	M_{total} (M_h+M_C) (kg) (Constant)	a_{exp} (m/s^2)	Uncertanty a_{exp} (m/s^2)	F (M_hg) (N)	$a_{accepted}$ (F/M_{total}) (m/s^2)	a %error	$\frac{M_h}{(M_h+M_C)}$

Slope ________________________ Uncertainty _______________________

% Uncertainty = Uncertainty*100/Slope _____________________________

Procedure 2 - Changing cart's mass

M_h (Const.) (kg)	M_C (kg)	M_C/M_h	a_{exp} (m/s^2)	Uncertanty a_{exp} (m/s^2)	$1/a_{exp}$	F (M_hg) (N)	M_{total} (M_h+M_C) (kg)	$a_{accepted}$ (F/M_{total}) (m/s^2)	a %error

Slope ________________________ Uncertainty _______________________

% Uncertainty = Uncertainty*100/Slope _____________________________

Exp estimate of "g" = (1/Slope) ________________________________