LAB SECTION: ______________________________ NAME: ______________________________

EXPERIMENT 3: NEWTON'S SECOND LAW

Introduction: In this lab, you will use an ink-jet timer to record the position, as a function of time, of a cart moving along a frictionless track. You will test Newton's Second Law by analyzing the ink-jet records for a series of experiments; the accelerated mass in each experiment will be the same, but the net force will vary.

IMPORTANT: Special concerns for frictionless air track and ink-jet timer

1. Don't slide cart on track with the blower off.
2. Be careful not to drop the carts. Any defects in the cart surface can create excess friction. If you drop one of the carts please alert your TA.
3. Timer voltage is 30,000 volts - although not lethal, a shock from the timer is quite uncomfortable. Do not touch any metal parts of the air track when the timer is active (on). Turn the timer off between runs.

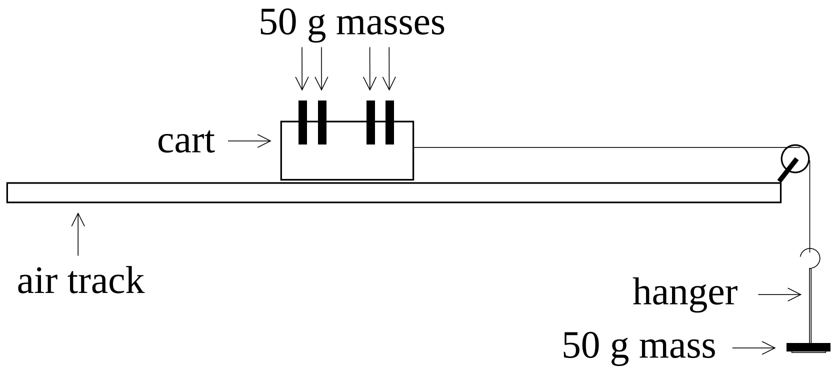
Newton's Second Law gives the relationship between the total mass M of a system of objects, the amount of total force F_{net} acting on the system, and the amount of acceleration a of the system. The Second Law is usually written

$$F_{net} = Ma$$

If we arrange, in a series of experiments, to keep the mass M of the system of objects always the same, then a graph of F_{net} versus a for those experiments should be a straight line with a slope equal to the mass M. To understand this statement, recall (from high-school algebra) that the equation for a straight line on an x-y graph is $y = mx + b$, where m is the slope and b is the y-intercept. In our case (if there is truly no friction), the y-intercept is zero (because there is no acceleration if there is no net force), so the equation of a line becomes $y = mx$. Comparing $y = mx$ with $F_{net} = Ma$, it is easy to see that the mass in our experiment will be the slope of the graph of F_{net} versus a (with F_{net} on the y-axis and a on the x-axis).

Procedure

A crude sketch of the apparatus is shown at the top of the next page. The ink-jet timer is not shown. The positions of the 50.0 g masses in the sketch are appropriate for the second of the six experiments described in the steps following the figure.



1. Record the mass of your air track cart at the top of Data Table 3.7. Also record the number on the side of your air track cart. Verify that the mass of your hanger is 50 g.
2. Using the string provided, connect the air track cart over a pulley to a hanger.
3. Tape a strip of paper to the side of the air track. The ink-jet dots will be recorded on this strip. Set the ink-jet timer for 20 dots per second (0.05 s between dots).
4. Arrange five 50.0 g masses on the cart so that they are evenly distributed. You will make six separate runs. For the first run, the net force on the system of objects is due only to the force of gravity on the hanger by the Earth (*i.e.* the weight of the hanger). For each consecutive run, a 50.0 g mass is removed from the cart and placed on the hanger. No matter how many 50.0 g masses remain on the cart, ALWAYS KEEP THE MASSES ON THE CART SYMMETRICALLY DISTRIBUTED (an appropriate distribution for Run #2 is shown in the figure above). The mass of the system of accelerated objects is thus kept constant from run to run, while the net force acting on the system of objects is continually increased. After each run, first make sure that the ink-jet timer is turned off; then, mark the position of the last usable dot (you cannot use any dots that were marked after the falling hanger has reached the ground or after the air track cart has encountered the strips of black tape near the end of the track). Finally, remove the ink-jet recording from the track, label that strip with the appropriate run number, and replace it with a new strip of paper for the next run.
5. Follow the procedures that you learned in "Free Fall" to analyze the ink-jet records from each run. Record your measurements and calculations for each run in Data Tables 3.1-3.6. For the first and/or second run, you may wish to use every other dot (this will change the value of Δt for that run). Use at least six intervals for the analysis of each run. Record the average acceleration for each run in any available space near the bottom of the Data Table for that run.

Data Table 3.1 2nd Law Run Number One $\Delta t =$ ________

Interval	Δd (cm)	v_{av} (cm/s)	Δv (cm/s)	a (cm/s^2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Data Table 3.2 2nd Law Run Number Two $\Delta t =$ ________

Interval	Δd (cm)	v_{av} (cm/s)	Δv (cm/s)	a (cm/s^2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Data Table 3.3 2nd Law Run Number Three $\Delta t =$ __________

Interval	Δd (cm)	v_{av} (cm/s)	Δv (cm/s)	a (cm/s^2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Data Table 3.4 2nd Law Run Number Four $\Delta t =$ __________

Interval	Δd (cm)	v_{av} (cm/s)	Δv (cm/s)	a (cm/s^2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Data Table 3.5 2nd Law Run Number Five $\Delta t =$ __________

Interval	Δd (cm)	v_{av} (cm/s)	Δv (cm/s)	a (cm/s^2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Data Table 3.6 2nd Law Run Number Six $\Delta t =$ __________

Interval	Δd (cm)	v_{av} (cm/s)	Δv (cm/s)	a (cm/s^2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Results

1. Compute the total accelerated mass (*i.e.* the total mass of your system of cart, hanger, and 50.0 g masses), which should be the same for each of your six runs, and record this number at the top of Data Table 3.7.
2. Compute the hanging mass m for each of your six runs and enter the results in Data Table 3.7. If your hanger mass is 50.0 g, then m for each run is simply the run number times 50.0 g.
3. Compute the net force F_{net} acting on your system of objects for each run in newtons. This is simply m in kg times 9.8 m/s^2. Record these numbers in Data Table 3.7.
4. Enter the average acceleration a (in m/s^2) for each run in Data Table 3.7. As you enter the values, convert from cm/s^2 to m/s^2. Be sure that you have correctly followed the procedures from "Free Fall" in determining the six average acceleration values.
5. Using the values from Data Table 3.7, make a graph of F_{net} versus a, *i.e.* put the F_{net} values on the y-axis of your graph and the a values on the x-axis. Calculate the slope of your line (numbers and units). Show your calculation in the space below and write your result somewhere on your graph.

6. The slope of your graph is your experimental value of the total mass of your system of accelerated objects. Find the percent error between your experimentally-determined value of total mass and the measured value as recorded at the top of Data Table 3.7.

7. Does your experiment successfully demonstrate that the amount of acceleration of a system of objects is directly proportional to the amount of net force acting on that system? Why or why not?

8. Suggest a design for an alternative experiment to test whether or not the amount of acceleration is inversely proportional to the mass of a system.

9. Suppose the string were to break when the cart was one-third of the way along the track. What would be the acceleration of the cart for the remaining length of track (before the cart encountered the strips of black tape). Explain your answer.

Going Further

1. In this experiment, we selected the values of F_{net} and measured the resulting values of a; in other words, F_{net} was our independent variable and a was our dependent variable. A serious experimentalist would therefore graph a versus F_{net} instead of F_{net} versus a. Make a new graph of the data in Data Table 3.7 with a on the y-axis. Find the slope (number and units), show the calculation below, and write the result on the graph. How is the slope of this new graph related to the slope of your original graph?

Data Table 3.7 cart mass = ________ g cart # = ____ total mass = ________ g

Run #	hanging mass (g)	net force (N)	acceleration (m/s^2)
1			
2			
3			
4			
5			
6