LAB SECTION: ______________________________ NAME: ______________________________

EXPERIMENT 3: NEWTON'S SECOND LAW

Introduction: In this lab, we will minimize friction on a moving cart by using carts having small wheels with nearly frictionless bearings. You will use a computer together with an ultrasound motion detector to measure the position, as a function of time, of such a cart moving along a level track. You will test Newton's Second Law by analyzing the cart motions for a series of experiments; the accelerated mass in each experiment will be the same, but the net force causing the acceleration will vary.

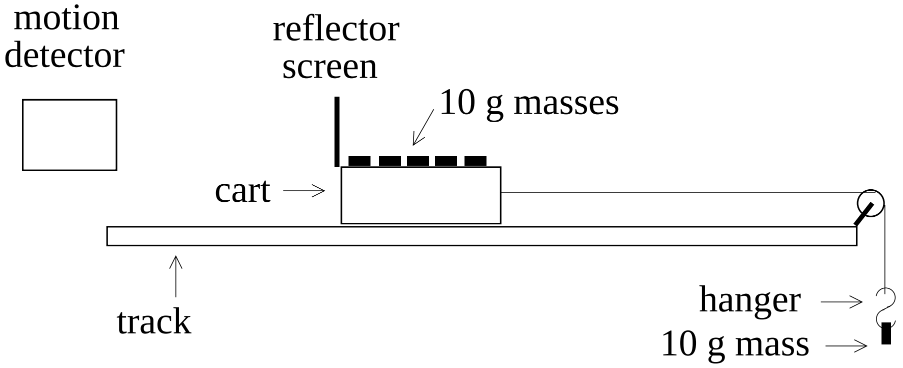
Newton's Second Law gives the relationship between the total mass M of a system of objects, the amount of total force F_{net} acting on the system, and the amount of acceleration a of the system. The Second Law is usually written

$$F_{net} = Ma$$

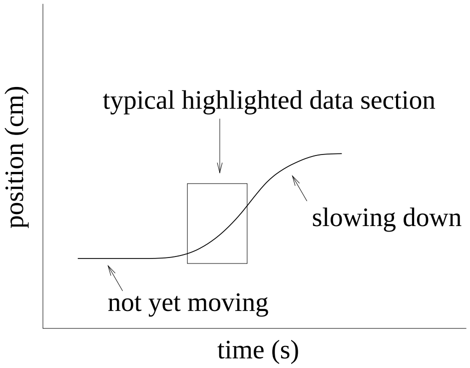
If we arrange, in a series of experiments, to keep the mass M of the system of objects always the same, then a graph of F_{net} versus a for those experiments should be a straight line with a slope equal to the mass M. To understand this statement, recall (from high-school algebra) that the equation 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 sketch of the apparatus is shown below. The computer is not shown. The positions of the 10.0 g masses in the sketch are appropriate for the first of the six experiments described in the steps following the figure.



1. Measure the mass of your cart; record your measurement at the top of Data Table 3.7. Also measure and record the mass of your hanger (an S-shaped hook).
2. Using the string provided, connect the cart over a pulley to the hanger.
3. For Run #1, arrange five 10.0 g masses on the cart so that they are evenly distributed; hang one 10.0 g mass on the S-shaped hanger. Pull the cart along the track as far as possible away from the pulley. Use the computer mouse to start recording positions with the motion detector, and immediately release the cart; stop the cart by hand BEFORE it bangs into the pulley mount and stop recording positions as soon as possible after the cart is touched. We wish to exclude any data which was taken before the cart was released and also any data taken after the cart has been touched; use the mouse and the graph on the computer screen to highlight the desired part of the position-versus-time data. Copy the highlighted position-versus-time data into Data Table 3.1; for Run #1, you should easily have eleven position data points.



4. Repeat the above steps to make five additional runs. For each consecutive run, remove a 10.0 g mass from the cart and place it on the hanger. No matter how many 10.0 g masses remain on the cart, always keep the masses on the cart symmetrically distributed. 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, copy the highlighted position-versus-time data into the appropriate Data Table; you should have at least seven position data points for each run.
5. On page 8, use the position-versus-time data for runs 1, 3, and 5 to create motion diagrams for those three runs using a scale factor of 2:5 (2.0 cm on paper equivalent to 5.0 cm on the track).
6. Follow the procedures that you learned in “Free Fall” to analyze the data from each run; record your measurements and calculations in Data Tables 3.1-3.6. Record the average acceleration for each run in any available space near the bottom of the Data Table for that run. Use no less than six intervals for the analysis of any run.

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

Position (cm)	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 $\Delta t =$ _________

Position (cm)	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 $\Delta t =$ __________

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

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

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

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

Position (cm)	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 $\Delta t =$ _________

Position (cm)	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 10.0 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. The hanging mass m is simply your hanger mass plus any masses added to the hanger.
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 is touched near end-of-track). 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 hanger mass = ____ g total mass = ________ g

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

Motion Diagrams

20 ticks on paper is about 4 cm and is equivalent to 10 cm on track

Motion Diagram for Run #1

Motion Diagram for Run #3

Motion Diagram for Run #5