

Experiment 6

Newton's Second Law (*revised Fall 2011*)

A mass is allowed to fall vertically while pulling another mass over a horizontal surface. The motion of the system is investigated, and the application of Newton's Second Law to the system allows the determination of the acceleration of the system.

Theory

Newton's Second Law states that the resultant of the forces acting on a body to accelerate in the direction of the resultant force. This can be expressed mathematically as

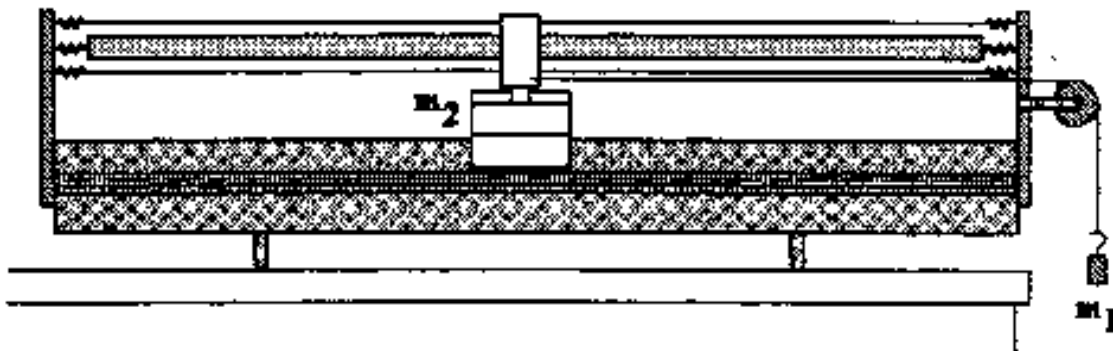
$$\sum \vec{F} = m\vec{a} ,$$

where m is the mass of the body and a is its acceleration. When expressed in terms of the force components,

where a_x and a_y represent the x and y components of the acceleration.

$$\sum F_x = m a_x ; \quad \sum F_y = m a_y ,$$

In this experiment, a body of mass m_1 falls vertically. One end of a string is attached to m_1 . The other end is attached to a body of mass m_2 which is pulled along the surface of the air track. (Refer to Figure 1.) The string passes over a pulley that is of very low mass and practically frictionless. Because of this, the effect of the pulley on the system can be neglected.



When Newton's Second Law is applied to the two bodies, the acceleration of the system is

$$a = \frac{m_1 g}{m_1 + m_2}.$$

On your write-up, draw the free-body diagrams for the glider and hanging mass and derive the above equation from Newton's second law in your theory section.

The uncertainty of the results is most easily estimated in this lab by using a velocity graph to determine the most likely acceleration of the glider.

Apparatus

- o air track with air supply and sparker
- o glider
- o meter stick
- o hanging masses
- o spark tape
- o masking tape
- o masses to be attached to glider

Procedure

- 1) Make sure that the air track is leveled. This can be done by placing the glider on the track and turning on the air. The glider alone should not accelerate toward either end.
- 2) Use masking tape to attach a one-meter length of spark tape to the pulley end of the yellow-colored mounting strip on the air track.
- 3) The instructor will assign each group a hanging mass value (m_1), and spark timer setting (T). Record these values as well as the mass of the glider (m_2).
- 4) Carefully place the glider on the air track. Pass the string over the pulley and attach to the end of the string the hanging mass.
- 5) Turn on the air supply. (The air flow is adjusted high enough so that the glider floats above the surface of the track.) Set the spark timer to the proper frequency. Prevent the glider from moving by placing a pencil or pen on the air track in front of the glider.
- 6) Start the spark timer, then release the glider. Make sure not to give the glider an initial push. Keep the spark timer engaged until the glider reaches the end of the air track.
- 7) Carefully remove the spark tape and affix it on a flat surface with masking tape. Cross out the dot corresponding to the starting position. Circle the remaining dots and number the dots successively. You should have about a dozen dots. Place the meter stick on the tape and record the position of each dot. A suggested form for the table for each set of

data is shown in Figure 2. A sample data tape is illustrated below with labeled position points, s_i 's.

Data point	Time, in multiples of $T=0.10$ sec	Position, s_1, s_2, s_3, s_4 , etc. (±0.05 cm)	Change in position, Δs (cm)	Average velocity for two time intervals v (cm/s)*	Value of tangent slopes in position graph from GraphAnalysis
1	$t_1=0$	s_1			
2	$t_2=0.10$	s_2	$s_3 - s_1$	$(s_3 - s_1) / 2T$	
3	$t_3=0.20$	s_3	$s_4 - s_2$	$(s_4 - s_2) / 2T$	
4	$t_4=0.30$	s_4	$s_5 - s_3$	$(s_5 - s_3) / 2T$	
...12	Continue for 12 data points	etc...			

Figure 2. A suggested form for the data table.

Analysis

Complete the calculations of the average velocities from the data as suggested by the table. First calculate the distance from one data point to the second data point away, Δs . Then find the average velocity by dividing Δs by the time taken to travel that distance, $2T$, which is twice the park timing interval. Because the acceleration is constant, **the average velocity is numerically equal to the instantaneous velocity at the point halfway in time between the data points.*

Graph the values of instantaneous velocity versus time on graph paper. To determine the experimental acceleration and its uncertainty, draw two lines that best fit the data: one with maximum slope, a_{\max} , and one with minimum slope, a_{\min} . Find the slopes of these lines. The best value for the acceleration of the system is then

$$a = \frac{1}{2}(a_{\max} + a_{\min}),$$

and the corresponding uncertainty in the acceleration is then

$$\delta a = \frac{1}{2}(a_{\max} - a_{\min}).$$

Calculate the best value for the experimentally derived acceleration, (4) and the uncertainty, (5).

Use equation (3) to determine the theoretical value of the acceleration. Make sure you can derive equation (3) by drawing free-body diagrams for the two masses, m_1 and m_2 , and applying Newton's Second Law.

Make a results table consisting of your theoretical acceleration value and the experimental value with its uncertainty. Also determine the uncertainty as a *percentage* of the experimental acceleration and compare it to the *percentage difference* between the experimental and theoretical values of the acceleration. Remember to use only the correct number of significant digits!

On a one-dimensional graph, use an error bar to plot $a \pm \delta a$. Be sure to displace vertically the error bar from the axis so that it is clearly visible. Plot the theoretical value of the acceleration from (3) on the graph described above so that the point is displaced slightly above the error bar.

Using the computer to analyze the data

Open the “Graphical Analysis” (GA) program on the computer desktop. You will immediately see a table for entering values and a graph.

Enter the time and position data and watch the program plot the graph for you. You can change the axes labels and even choose the number of significant digits for your data. Use the “Tangent tool” (“M=” button) in the tool kit of the program to check the values of instantaneous velocities at each plotted point. The values should agree with your previously calculated values from your data table. If they do not, check your calculations for mistakes. Enter these values in the last column of your data table.

If time permits, enter the velocity data in another column (Use the “New Manual Column” feature from the “Data” menu). You can now graph the velocity vs. time. One of the nice features of the computer is that you can use the “Linear Regression” tool to plot the best straight-line fit to your data and to give you the slope, y-intercept, and a statistical value of the correctness of the fit. Compare the slope value with your calculated acceleration from the graph. Include this value in your result table.

Conclusions and Questions

Ask yourself this basic question: Did the theory correctly predict the experimentally derived value of the acceleration to the degree of accuracy expected? What major *systematic* sources of error could there have been. Explain how the experimental value would have been affected by each source of error, and whether the experimental value of the acceleration shows evidence of systematic error. As part of your conclusion you should answer the questions below.

- 1) If resistive forces (such as friction or air resistance) were present between the glider and the air track, how would this affect your experimental results? Explain. Do you see signs of resistive forces in your results?
- 2) We assumed in the theory that the mass of the pulley was negligible. If this was not the

case, what effect would it have on the experimental results? Explain why.

3) What effect would an unlevelled track have on the experiment? Explain.

Extension

Many students find some evidence of friction (or air resistance) between the glider and the air track in this experiment. Let's *assume* that surface friction were the primary cause of the difference between your experimental and theoretical acceleration values. Using your own results, determine the *average force of friction* that was neglected. Also *estimate the average coefficient of friction* between glider and track.