

### 3. FORCE AND ACCELERATION

*Read Appendices C and E before coming to the laboratory*

#### OVERVIEW

In this laboratory exercise you will use the Ultrasonic Motion Detector to track the position of a glider as a function of time as it moves along an air track. The glider is connected to a small mass by a lightweight string via a pulley system. When released, the mass will begin to fall, exerting a force on the glider through the string. You will examine the relationship of the applied force (i.e. the gravitational force on the falling mass) to the observed acceleration of the system.

There are two ways to find the mass of something:

1. Weigh it on some sort of scale.
2. Apply a force to it and measure how it accelerates. From Newton's 2<sup>nd</sup> Law, mass is the proportionality constant between the force and the acceleration.

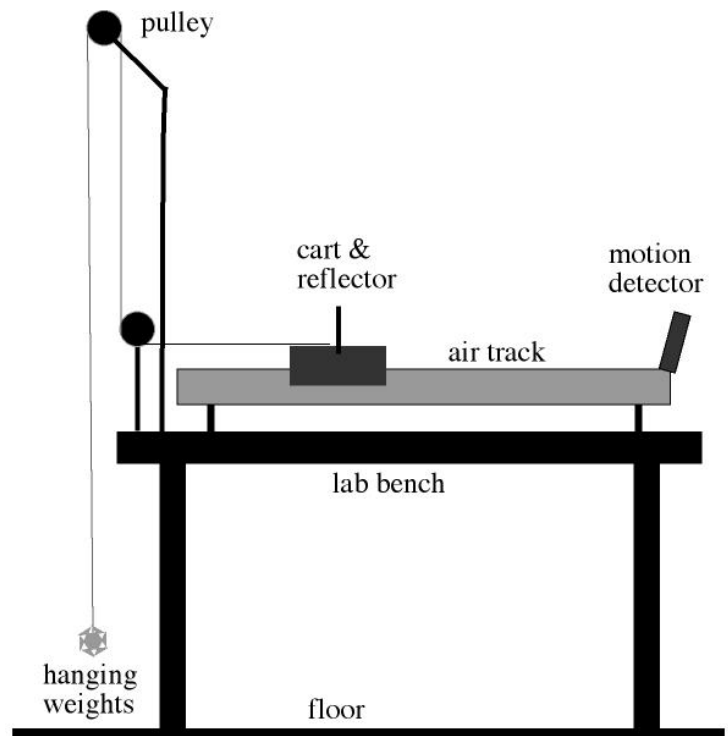
You will use both these methods and see how they compare.

#### LEARNING OBJECTIVES:

- Test Newton's 2<sup>nd</sup> Law as applied to a system.
- Observe and understand the relationship between applied force and observed acceleration.

#### APPARATUS:

- Air track
- Glider with reflector
- Motion detector
- Lightweight string
- Pulley system
- Set of precision weights totaling 50-g



**Figure 3.1.** A glider on an air track is accelerated horizontally using a pulley system with a weight suspended vertically. The position of the glider as a function of time is determined by the motion detector.

## I. CLASS EXERCISE & DISCUSSION

We will draw free-body diagrams of each of the masses to determine the tension in the string and the acceleration of the glider/hanging weights.

We will also discuss how to analyze the glider and hanging weight as a single system.

## II. SET UP THE TRACK AND PULLEY SYSTEM

- a. Find the mass of the system using the simple method of using a scale. Take your glider, the string, the hanging weights, and the paperclip that holds the weights to the scale and determine their masses. Write these on your report form. Take note of the uncertainty in the mass of each. [Note: when using an instrument to make a measurement, if the measurement is made perfectly the uncertainty is assumed to be half the smallest division].
- b. **Align and calibrate the motion detector** using the Logger Pro software found on the computer desktop and the instructions in Appendix E. The purpose of the alignment is to make sure that the sound waves emitted by the motion detector reflect from the glider all along the air track. The purpose of the calibration is to make sure that the distances the motion detector measures are correct. The calibration must be accurate to within 2 mm; otherwise, repeat the calibration by rechecking the temperature and the alignment. After everyone has calibrated their motion detectors, the air to the tracks will be turned on.
- c. **Level the track:** When the air track is turned on, place the glider on the track and watch it for a little while. If it accelerates, the track may not be level and/or it may be warped. Place the glider in several places. If you find consistent acceleration in one direction, the track is probably not level: adjust the level using the foot screw on the air track until the unwanted motion is minimized. If you find the track to be warped, draw a picture on the Report Form of the how the track is warped.
- d. Use a string to attach the glider to the weight hanger over a pulley. Be sure that the string is exactly horizontal as it runs along the surface of the track. Why is this important?
- e. Under the menu “Experiment/Data Collection” set the data collection time to be 5 seconds and the sampling rate to 20 measurements per second.

## III. APPLY A FORCE AND TRACK THE MOTION OF THE GLIDER.

- a. To start with, all 50-g of the weights are on the glider. Take 10-g from the glider and hang it from the paperclip. This will provide the force to accelerate the system.
- b. Position the glider as far away from the end of the track as possible, but make sure that the knot on the end of the string is not in contact with the pulley.
- c. Press the Start button in the software first, and then release the glider after the computer starts taking data (approximate 0.5 seconds).

- d. *At least one member of your data-gathering team should carefully monitor the pulley system during the experiment. It is important that the string remains threaded smoothly around each of the two pulley wheels and that the string does not get tangled. If the string slips off of either of the pulley wheels, you will need to collect your data again.*
- e. When the run is complete, examine the  $(x,t)$  data plotted by Logger Pro. If the plot looks smooth and reasonable, copy the position and time data from LoggerPro into Excel. If not, repeat the run. You are interested only in the data after the glider has been released and before your partner catches it—in Excel strip off any data before or after.
- f. Analyze the data in Excel as shown below for your first set of data. **Do not collect more data until you have analyzed the first set.**
- g. After analyzing the first set of data, you will collect data for 4 additional arrangements of weights with 10-g removed from the glider each time. Place the weights that have been removed from the glider onto the paperclip. *In each case, there will be 50-g of weight distributed between the paperclip and the glider so that the total mass of the system is constant.*

### III. ANALYZE THE $x(t)$ DATA

- a. For each run, calculate the instantaneous velocity for each point in time,  $v(t)$ , from your  $x(t)$  data using the spreadsheet as you did in Lab Exercise 2. Note that you can save yourself time by rationally choosing where you put each data set on your spreadsheet. Then you can just copy and paste formulas from one set to the next.
- b. Next, make a single graph of  $v(t)$  versus  $t$  for all of the data sets (plot your data from each of the four runs on the same graph using different plot symbols for each run). **What does this graph tell you about the motion of the glider? Do you expect the graph from each run to be linear? Why or why not? How does the slope of the graph vary with the mass of the hanging weights? Does this make sense? Discuss on your Lab Report.**
- c. If the graph appears to be linear, in your spreadsheet perform a linear regression on the linear portion of the calculated  $v(t)$  and plot a best-fit line for the data (see Appendix D) for each of the 5 data sets. If the data is not linear for a run, retake the data for that run. What you have done at this point is measure the acceleration of the system (the slope of the  $v(t)$  vs  $t$  graph) for 5 different forces (the weight of the hanging mass).
- d. Click “Sheet 2” at the bottom of your spreadsheet and begin a new table. Rename this sheet “Accelerations.” Set up two columns named “hanging mass” and “acceleration”. The first column contains the mass of the hanging weights for each run. For the second column, copy over the values of the slopes of the  $v(t)$  vs.  $t$  graphs (i.e., the accelerations) found with the regression routine for each of the 5 data sets. In a third column labeled “force”, use the hanging mass to calculate the (net) force acting on the system. Assume  $g = 9.803 \text{ m/s}^2$ , which is an experimental value representative of the Chicago area.

- e. Plot the observed accelerations versus the forces acting on the system. Finally, on the “Acceleration” spreadsheet, perform a linear regression of the acceleration vs. the force. **What does the slope of the graph of  $a$  vs.  $F$  tell you (think about Newton’s 2<sup>nd</sup> Law)?**
- f. You have now “massed” the system in two different ways as discussed in section (II.a) above. Compare your values. In order to do so, you need to know the uncertainty in the mass of the system as determined through the force and acceleration method. This is related to (but not the same as!) the “standard error” for the slope output of the regression analysis. Your instructor will assist you in calculating the uncertainty in the mass of the system, using the method explained in Appendix C.
- g. **What does the intercept of the  $a$  vs  $F$  graph tell you? What value would you expect to find, and why? How well does your value agree with the expected result?**
- h. Don’t forget to save your spreadsheet in your directory on the **F:** drive using a descriptive filename.

#### IV. EXTEND YOUR EXPERIMENTAL WORK

Here are some ideas for the second week of this lab:

- a. Five data points for your  $a$  vs.  $F$  graph is not many for a good evaluation of the slope or the uncertainty in the slope. Improve upon this by obtaining more data points for different amounts of hanging weight. Be sure to keep the total mass of the system constant by moving the precision weights between the paperclip and the glider.
- b. If the masses obtained using the two different methods do not agree, evaluate the possible sources of systematic error in the glider experiment. For example, if air resistance is your suggested problem, try increasing the air resistance of the cart to see if it has an effect. One way to do this would be to attach a sheet of paper as a “sail” to the metal reflector; take 5 data points as in the first week’s lab, and see if there’s a difference in the measured mass (beyond the additional weight of the paper). Other possibilities include changing the angle of the string by raising the lower pulley, or tilting the air track.

#### TURN IT IN:

Turn in your Lab Report Form, your  $v$  vs.  $t$  graph (all on a single graph), a copy of your “Acceleration” spreadsheet, and your  $a$  vs.  $F$  graph.