Experiment 3

The Inclined Plane

3.1 INTRODUCTION

In this experiment, you will measure the acceleration of two masses attached to each other via a rope and pulley. One mass moves downward, suspended from the rope; the other mass, called a glider, moves upward along a slightly tilted and nearly frictionless air track (see Figure 3.1).

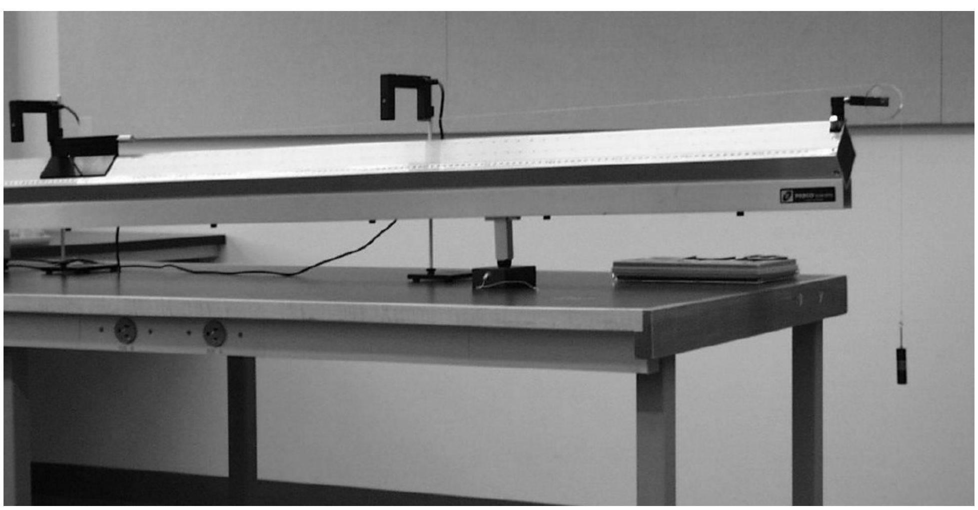

Figure 3.1: The inclined plane. The suspended mass pulls the glider up the incline.

You will determine the experimental acceleration of the system using measurements of the velocity of the glider at two points along the air track. You will then calculate the expected theoretical acceleration according to Newton's second law, and compare your two results.

3.2 EXPERIMENTAL SETUP

The air track blower should be running before you place the glider on the track, and whenever you move the glider along the track. This protects the track and the glider from scratches.

1. Level the air track by adjusting the feet under the crossbar so that a glider remains motionless at several positions all along the track. If your track is bowed, make it as level as possible and record your findings in your lab notebook.

2. A block is provided to prop up one end of the air track. Measure the thickness of the block using a digital caliper, and then use the block to raise the pulley end of the track. Calculate the angle of the track using the thickness of the block and the separation between the feet of the air track. Include a detailed diagram in your lab write-up that shows how you determined the angle.

3. Launch the program `LoggerPro` by double-clicking on its icon on the computer desktop. From the menus, select `File` → `Open` and then click through to `Probes & Sensors/Photogates/Two Gate Timing`. A sensor confirmation pop-up window will open for each of the two photogates. Click the `Connect` button in each of these windows to continue. In Two Gate Timing mode, the computer will record two separate times for each experimental trial: t_1 is the time interval during which Gate 1 is blocked, and t_2 is the time interval during which Gate 2 is blocked.

4. Install a flag, around 2 cm in width, on top of your glider. Measure and record the total mass of the glider and flag.

5. Measure the width x_{flag} of the flag as accurately as you can. *Hint:* use the photogates and the markings along the track. Note that the red LED on top of the photogate turns on when the gate is blocked by the flag.[1] Estimate the uncertainty $\sigma_{x_{\text{flag}}}$ in your measurement. There are no statistics required here, just an estimate of the uncertainty based on what you observe as you make the measurement.

6. Double click on the `Photogate Distance` number for each of the two photogates and enter your measured value for x_{flag}. (You will enter the same number in two different

[1] Use the photogates rather than the caliper so that you are sure to use the width as recorded by the photogate. After all, that's the width that will be used to determine the velocity later on. (For example, you don't know what fraction of the photogate beam has to be blocked before the photogate will switch "on" or "off.")

places.) The number you enter will be used by `LoggerPro` to calculate the velocity of the glider as it passes through each photogate.

7. Increase the number of significant figures displayed by selecting the appropriate number from the Places dropdown menu.

8. You also need to ensure that rounding errors in the velocity calculations don't cause you any troubles. To do that, go to the main menu and select `Data` → `Column Options` → `Velocity 1`. Then click on the `Options` tab and set the `Displayed Precision` to 3 `Significant Figures`. (The default of 4 decimal places causes excessive round-off errors if your velocities are quite slow.) Repeat this setting for the `Velocity 2` column.

9. Set `Experiment`→`Data Collection`→`Duration` to 300 seconds. This way, you can do multiple trials without pressing `Stop` and `Collect` between each one.

10. Attach a small mass to the glider as shown in Figure 3.1 above. A mass in the range of 10 to 20 grams is appropriate; it should be heavy enough to pull the glider up the track. Record the value of the hanging mass.

11. Position the two photogates along the track. They should be about 60 cm apart, arranged so that the glider can be released a few cm below the first photogate and so that the hanging mass doesn't hit the floor until after the glider has passed through the second photogate. Check that the heights of the photogates are set so that they measure the flag and not the whole glider. *Try to place the photogates so you won't bump them during the course of the experiment!*

12. Measure the distance between the photogates as precisely as possible. *Hint:* Slide the glider along the track and note its position when each photogate is blocked.

As the glider slides up the track, the flag (length x_{flag}) will interrupt the beam in each photogate for a brief time, t_1 or t_2. The average velocity, $v_1 = x_{\text{flag}}/t_1$ or $v_2 = x_{\text{flag}}/t_2$, is a good approximation to the instantaneous velocity at the instant the glider is half-way through the photogate.[2] `LoggerPro` will compute these velocities for you. Press `Collect` to try it out.

Experiment with the system until you understand the meaning of each of the columns of data.

[2] The approximation can be improved by making x_{flag} smaller, but if x_{flag} gets too small, then the times Δt_i become too short for `LoggerPro` to measure accurately. In addition, the uncertainty in x_{flag} becomes the dominant uncertainty in the experiment.

3.3 GLIDER WITH AN ATTACHED MASS

3.3.1 Data Acquisition

Release the glider from rest from a position a few centimeters below the lower photogate. Record the velocities v_1 and v_2. Repeat this for a total of ten runs, using a range of initial positions. Since you are ultimately after the *acceleration*, you don't have to start from the same initial position each time.

Hint: As with all experiments, do not dismantle the apparatus until you have completed the analysis. You never know when you might want to go back and re-measure something.

For each of your ten runs, calculate the acceleration a of the glider. (You may find it convenient to use an `Excel` formula for this.) You should write the formula you used to do the calculation in your notebook, but you do not have to show every numerical step. *Note:* You should use the two speeds v_1 and v_2 along with the distance between photogates to calculate a. Do not use the time between gates as reported by `LoggerPro`.

3.3.2 Analysis

Calculate the average acceleration a for the 10 runs. This is your best estimate of the true value a of the acceleration.

In this experiment, both random and systematic uncertainties play an important role. We will take a look at each in turn.

What is your best estimate of the uncertainty $\sigma_{a,\text{rand}}$ due to random trial-to-trial measurement variation? (Refer to Appendix A or to the first experiment if you can't recall how to calculate this.)

The uncertainty in x_{flag} can be important in this experiment. The uncertainty in the value of x_{flag} is a systematic uncertainty, because it biases each acceleration measurement in the same way. You can estimate its effect on your acceleration measurements by

$$\frac{\sigma_{a,\text{sys}}}{a} = 2\frac{\sigma_{x_{\text{flag}}}}{x_{\text{flag}}}$$

where $\sigma_{x_{\text{flag}}}$ is your estimate of the uncertainty in your measurement of the flag width, and where the 2 arises because the velocity is squared in the algebraic equation used to determine the acceleration. What is your best estimate of the uncertainty $\sigma_{a,\text{sys}}$ due to this systematic effect?

A reasonable estimate of the total uncertainty σ_a in acceleration is simply

$$\sigma_a = \sigma_{a,\text{rand}} + \sigma_{a,\text{sys}}.$$

What is your best estimate of the total uncertainty in acceleration, σ_a? Record your final experimental value for acceleration, including uncertainty. Don't forget the rules for significant figures.

3.3.3 Theoretical Prediction

Draw free body diagrams for the glider and the hanging mass. Solve Newton's laws for these two objects, keeping in mind that they accelerate at the same rate. It is safe to make the usual assumptions that friction is negligible, that the string is massless and does not stretch, and that the pulley is massless and frictionless. What is your predicted value a_{theory} for the acceleration of the glider? Include the entire derivation of this value in your lab write-up.

3.3.4 Comparison of Experimental and Theoretical Values

Compare your mean value a with your theoretical value a_{theory} using the uncertainty analysis rules discussed previously in this course. Is your experimental result consistent with the theoretical prediction?

3.3.5 Coefficient of Kinetic Friction

You have likely determined that the experimental value for the acceleration was lower than the theoretical value. While the friction in this system is small, it is possible that it still had an noticeable effect on your experimental acceleration. Draw a new free body diagram for your system that includes a frictional force. Use Newton's second law to determine the coefficient of kinetic friction, assuming that the difference between a_{theory} and a stems from friction. No uncertainty analysis is required in this part of the experiment. Compare this coefficient of kinetic friction to others you have encountered in this course. Does its relative magnitude make sense?

3.3.6 Questions

Consider each of the following questions in your lab write-up. For some of them, you can do a quick trial and see the results for yourself.

1. What effect would friction in the pulley have on your results? Did there seem to be much friction in your pulley?

2. If you inadvertently pushed the glider as you released it, but before it went through the first photogate, would this affect your results? (Assume your hand was no longer touching it when it reached the first photogate.)

As always, discuss sources of uncertainty and ways in which the experiment or write-up could be improved.