Experiment 3

Motion with Constant Velocity

I. Purpose

The purpose of this experiment is to first develop some intuition for thinking about and plotting velocity, and then to apply that understanding to the study of motion with constant speed, as approximated by the motion of gliders on an air track. The gliders slide on a cushion of air blown out through tiny holes on the track, resulting in nearly frictionless motion. The constant velocity results you obtain and study today will become initial velocity input for Experiment 3. Consider as you finish today how what you've done will generalize to motion with acceleration as indicated by the kinematic equations to which you've been introduced in lecture.

II. Preparing for the Lab

You need to prepare before going to the lab and trying to do this experiment. Start by reading through this lab write-up before you get to the lab. Finally, don't forget to do the Pre-Lab questions and turn them in to Expert TA before your lab starts.

III. Pre-lab Questions (You must submit answers to Expert TA before your section meets)

Questions and multiple choice answers on Expert TA may vary from those given below. Be sure to read questions and choices carefully before submitting your answers on Expert TA.

#1. The plot below shows the position x versus time t for an object that is moving



- (a) What is the position of the object at time t = 3.0 seconds? Give answer in m.
- (b) What is the velocity of the object at t = 5.0 seconds? Give answer in m/s.
- (c) What is the acceleration of the object at time t = 5.0 seconds? Give answer in m/s².
- #2. The plot below shows the position x versus time t for another object that is moving.
 - (a) What is the position of the object at time t = 5.0 seconds? Give answer in m.
 - (b) What is the velocity of the object at t = 5 seconds? Give answer in m/s.
 - (c) What is the acceleration of the object at time t = 5 seconds? Give answer in m/s².



- #3. A student writes in their Lab report for this experiment on constant velocity: "the velocity was measured to be 3.0 m/s as the cart reached the middle of the track". Why did the student lose points in their report? Choose best answer from the following: (a) It is not clear where the middle of the track is. (b) Velocity is a vector and the student did not give a direction. (c) Velocities should be measured in cm/s. (d) The student used too many significant figures. (e) The student used too few significant figures. (f) In this experiment, you can't measure the velocity of an object if it is in the middle of the track.
- **#4.** A student writes in their Lab report for an experiment: "After the ball was dropped, its velocity was measured to be 1.3 downward". Why did the student lose points in their report? Choose best answer from the following: (a) Velocity is a vector and the student did not give a direction. (b) The student left out a minus sign. (c) The student did not include units of m/s along with their reported numerical value of the velocity. (d) The student used too few significant figures.(e) The student used too many significant figures. (f) You can't measure the velocity of a dropped ball because of air resistance.

IV. Equipment

air-track with unique number identifier and spring launcher glider with unique number identifier blower ruler Excel Linear Regression Analysis template

stopwatch tape measure

V. References

For background on the physics of motion with constant velocity see for example Chapter 2 from *College Physics a Strategic Approach* by Knight, Jones and Field. For additional tutorials on motion with constant velocity see, for example, Physics by Inquiry, L.C. McDermott et al. ©1996 Wiley, NY.

VI. Short Tutorial on Interpreting Motion with Graphs

1. The graph at right shows a graph of the position x of a cart versus time t.



- (d) What is the cart's position at t = 6 s?
- (e) What is the slope of the inclined section of the graph after t = 0.

- (f) What are the units on this number you found for the slope?
- (g) What is the physical significance or physical meaning of the slope in this graph?

2. A cart travels with a constant velocity of 0.5 m/s and then at t = 4 s it starts speeding up. Measurements show that it takes 5 seconds to speed up from 0.5 m/s to 3 m/s. The figure below shows a plot of the velocity versus time for this situation, except it looks like we forgot to put the numbers on the x and y axes. Hint: when answering the following questions, try filling in numbers on the axes based on the information given.



(c) At what time does the cart have a velocity of 1.5 m/s?

- (d) What is the value of the slope of the inclined section of the graph?
- (e) What are the units on this number you found for the slope?
- (f) What is the physical significance or physical meaning of the slope in this graph?

VII. Experiment: Motion with Constant Velocity

- 1. In this part of the lab you will study force-free motion of gliders on the air track by measuring how long it takes a glider to travel various distances.
- 2. Examine your cart and air track. Find the unique identifier number written on each and record this for your lab report.
- 3. To level the air track, turn on the airflow so that the cart slides easily above the track. Place the glider near the middle of the air track and release it from rest; if the glider begins to move, turn the leveling knob (see Figures 1 and 2) and start again until the glider remains reasonably stationary when released. If the glider remains stationary, its acceleration must be zero, and by Newton's law, the net force acting on it must be zero. If you cannot get your air track to level before the screw is at the end of its range, let your TA know and a riser will be provided to be placed under the foot of the leveling knob.

Note: The air-tracks are not perfectly flat, so you may want to check for zero acceleration in different places along the track. Try aiming for flatness on average or the middle of the track.



CAUTION: Do not drop the glider!

Figure 1. Schematic of the air-track.



Figure 2. Photo of the air-track.



Figure 3: Top view of Launcher Bracket

- 4. Examine the track and note that there is a bracket at one end with two thin pieces of steel mounted, as shown in Fig. 3. These pieces act as a spring that you will use to launch the glider. Move the glider until it just touches the spring. Record the reading x₀, measured from the back edge of the glider from the centimeter scale mounted along the air track. Do not write on the air track.
- 5. Determine the location x_f on the scale that is 25 cm from the point x_o . That is, such that $d = |x_f x_0| = 25$ cm

Note that x_0 and x_f must both be measured from the same end of the track! Do not write on the air track.

- 6. Your setup comes with an angled piece of aluminum that will sit securely on the track behind the spring and act as a stop for the glider when it is pulled back, compressing the spring. The length of this stop is such that the spring is compressed about 1.5 cm when the glider is brought back against the stop. This will keep the launch compression distances consistent from trial to trial.
- 7. Compress the spring about 1.5 cm by bringing the glider up against the stop. Release the glider, and use the stopwatch to measure the time t that it takes the glider to travel the 25 cm to the predetermined location x_f. It takes practice to be precise and consistent in your method for measuring the time. Once you are comfortable with the process, take 5 time measurements and record your data in the "Additional Data" area of the Excel Linear Regression Analysis template.
- 8. Assign an uncertainty value δd to the distance by estimating how accurately you were able to stop the watch as the glider reached x_f. One contribution to the uncertainty is how precisely you can use the ruler to determine location x_f, as discussed in Experiment 2. However, in this case, that contribution should be small compared to ability to judge the location of the moving glider. If you aren't sure what δd should be, try observing while your partner launches the cart and uses the stopwatch. Did you agree with his/her timing based on the location of the cart at that moment? Work together to choose a reasonable value. Record the values d and δd in the "dep variable" and "dep var uncert" columns, respectively, in the Excel template.

9. Repeat steps 5 and 7 for three more values of x_f up to about d = 90 cm. You may use the same uncertainty δd for all of your values of d.

VIII. Analysis

- 1. In your Excel spreadsheet, for each of your distances d calculate the average time t_{avg} and the standard deviation σ_t for the corresponding set of times you measured for that distance. Record the values for t in the "**indep variable**" column in your template.
- 2. In your Excel spreadsheet, for each of your average times, find the corresponding uncertainty δt_{avg} in the average time using:

$$\delta t_{avg} = \frac{\sigma_t}{\sqrt{N}}$$

where N is your number of data points. Record the values in the "**indep var uncert**" column. Make sure each value is in the appropriate row with its corresponding t_{avg} value.

- 3. Plot your data with d on the vertical axis and t on the horizontal axis. Put horizontal and vertical error bars on each data point using the values for d and t (you may use a median or other representative value for t since they are all different).
- 4. Add a fit line to your plot by right-clicking your data and choosing "Add Trendline". Make sure you choose the "linear" option, and also choose to "display equation on chart".
- 5. Click on the **macro button** in the template to run the linear regression fitting on your d and t_{avg} data, and note the resulting slope and intercept values, and their uncertainties. Note that the slope and intercept values should closely match the values in the equation on your plot.
- 6. Examine the spreadsheet and find the section that reports the $\Sigma \chi^2$ or "**sum of chi-squares**" value for your fit to the data. Chi-square is a statistical function that is used to test whether data and theory are consistent with each other, given that there is uncertainty in the measurements. In this case your data is a set of distances d versus times t_{avg} , the theory is a straight line, and the data and theory might disagree because there are uncertainties δ_d in the distances and δt_{avg} in the times. Be sure to report your value for $\Sigma \chi^2$ in your lab report. In this case for a good fit $\Sigma \chi^2$ should be approximately equal to the number of data points N minus 2. Here N is the number of values of d and the 2 comes about because you are fitting to a straight line by varying the slope and intercept (2 adjustable parameters). If $\Sigma \chi^2 \ll N-2$, then something is wrong and one possibility is that you have grossly overestimated the uncertainty in your data. If $\Sigma \chi^2 \gg N-2$, then the data is in significant disagreement with the theory.
- 7. Since you used the same launcher and same compression distance for every trial, the resulting velocity should be the same for every trial. The lack of friction implies the speed should remain nearly constant and the distance d should be related to the corresponding time t_{avg} by: $d=v_0 t_{avg}$.

As a result, the slope of your plot should be equal to the (constant) velocity v_o of the glider, the uncertainty in the slope should be the uncertainty in the velocity δv_o , and the y-intercept

should be zero. Examine the output from the spreadsheet's fit and determine whether the intercept from your fit is in fact statistically consistent with zero. That is, does the origin lie within your uncertainty? Include your answer and reasoning in your report.

8. In next week's experiment, you will use this same equipment to observe motion with constant acceleration. Make sure that you save your value for the initial velocity v_o and the uncertainty in the initial velocity δv_o that you found (put them into your lab report for example) and also the unique identifier number for your air track and cart. Next week make sure you work at the same lab station. If you end up working somewhere else, you will need to figure out the velocity that for that equipment.

IX. Finishing Up

- Make sure you get your lab partner's name and his or her contact information.
- Make sure that you record in a place that you can find it your value for the initial velocity v for the cart, the uncertainty in the initial velocity δv_0 and the unique identifier numbers for your air track and cart.
- Make sure you save a copy of your spreadsheets on a memory stick or e-mail yourself a copy.
- In addition, don't forget that you need to prepare a Lab Report for this Experiment and it must be submitted before it is due (see the syllabus). Also, make sure to review the Guidelines for Writing a Lab Report, right after the main introduction in this Lab Manual.
- Finally, don't forget to prepare for the next lab and submit your answers to the prelab questions for the next lab before they are due.