Lab 3

Constant Acceleration

Experimental Objectives

- Using position versus time and velocity versus time graphs, verify
  - that the equations of constant acceleration accurately describe the behavior of objects under constant acceleration and
  - that it is possible to distinguish acceleration due to gravity from acceleration due to friction.

3.1 Student Outcomes

Knowledge developed: In this exercise, the student should develop an understanding of the relationships between the position and the instantaneous velocity of an object, as well as how each of these can vary as functions of time. We will only consider the special case where the object experiences constant acceleration.

Skills developed:

- Evaluate the data for sources of uncertainty. Can you see an effect, such as a level track or the presence of friction, in the result?
- Using Pasco Capstone software
- Interpreting the slope and intercept of graphs

3.2 Procedure

Materials: An aluminum track, a low-friction cart, computer interface with PASCO Capstone^{tm} software, a sonic motion sensor, a small steel ball.

You should notice that the subsections in this section parallel the subsections in Analysis.

3.2.1 Cart and Flat Track

Note The Pasco Capstone interface is also used in Lab 4, Lab 5, and Labs 7–8. You should start becoming familiar with the hardware and software.

Log into the computer (so you can save your data to your network drive) and then open Pasco Capstone. (Appendix C will provide some instructions for setting up the software and connecting the equipment.) Connect the motion sensor to the computer interface. Set the data rate of the motion sensor at 50 Hz. Place a steel ball on the track and adjust the leveling screw at one end of the track to see if the ball rolls one way or the other. This will roughly level your track. Place the sensor about 20 cm from the end of the track, because this is the minimum distance detected by the sensor. (You might need to use the "sail" for the sensor to see the cart.)

Place the cart on the track. Capstone, via the sonic ranger, can measure the position and velocity of the cart as a function of time. (This is explained in Appendix C.)

Exercise 3.2.1. Assume the track is frictionless and predict how the cart will move if the track is not perfectly level; include a comment about how the velocity versus time graph will look when it goes uphill versus when it goes downhill. Should these be the same?

Hint 1. If the track is not level, sending the cart in one direction, it will be going uphill; but in the other direction it will be going downhill. If you measure the motion in both directions, you should be able to see the difference.

Hint 2. You may still have an effect due to friction. (See Exercise 3.2.3.)

Hint 3. It is probably useful to describe this using terms such as "speeding up" or "slowing down". You may also want to practice describing this by comparing how the direction of the acceleration compares to the direction of the velocity.

Exercise 3.2.2. What do you expect the graph to look like if the track *is* perfectly level? Will it be the same going left versus going right?

Hint 1. If the track is level and then you compare the motion of the cart in one direction versus another, you should be able to see if there is a difference. You should also be able to predict how the motion in each direction for this case is similar or different from the case when the track is not level.

Hint 2. You may still have an effect due to friction. (See Exercise 3.2.3.)

Hint 3. It is probably useful to describe this using terms such as "speeding up" or "slowing down". You may also want to practice describing this by comparing how the direction of the acceleration compares to the direction of the velocity.

Exercise 3.2.3. Now, assuming it is perfectly level, what will friction do to the motion? How do you expect this to affect the graphs?

Hint 1. If the track is level and there is friction, then when you compare the motion of the cart in one direction versus another, you should be able to see if there is a difference. You should also be able to predict how the motion in each direction for this case is similar or different from the case when the track is not level.

Hint 2. If the track is tilted with no friction then describe the motion in each direction using the phrases "speeding up" or "slowing down".

If the track has friction with no tilt then describe the motion in each direction using the phrases "speeding up" or "slowing down". You should be able to indicate how you would see each effect in the graphs of the motion.

We will take four sets of data: a slow, constant velocity towards the ranger; a slow, constant velocity away from the ranger; a faster, constant velocity towards the ranger; and a faster, constant velocity away from the ranger. The two slow speeds should be about the same and the two faster speeds should be about the same. For each case, start the sonic ranger and then bump the cart firmly, but not violently(!).

On Capstone, you should have four curves of velocity versus time. Fit each with a trendline and display the equation of the trendline on the screen. Interpret the coefficients (slope and intercept) by noting their units, values, and uncertainties. You should also print out (in landscape mode) the position versus time graph, the velocity versus time graph, and the acceleration versus time graph. (You should notice that the acceleration versus time graph is *very* noisy.)

3.2.2 Cart and Sloped Track

Place a small block under one end of the track, so that the track is now tilted at a small angle with the sensor at the top of the incline. Measure the angle using a protractor or calculate it by measuring the two legs of the triangle and using the inverse sine. (Be careful about measuring the height.)

We will consider *three cases* for the sloped track: *First*, allow the cart to roll (without an initial push) down the ramp. *Second*, gently push the cart down the ramp. DON'T let it fly off or crash into anything.

Exercise 3.2.4. Should these two cases have the same acceleration while rolling down the ramp? How will that affect the shape of the velocity versus time graphs?

Hint. Do the graphs have the same slope?
Do the graphs have the same intercept?

Exercise 3.2.5. Should these have the same initial velocity? How will that affect the graphs?

Hint. Do the graphs have the same slope?
Do the graphs have the same intercept?

In the *third* case, start the cart at the bottom of the incline and roll it up the ramp, allowing it to roll back down on its own. Push it hard enough to get mostly up the ramp, but not so hard that it hits the sonic ranger at the top of the incline, because we want to watch it return to the bottom of the ramp. *This case is similar to throwing a ball into the air and allowing it to fall back down.*

Exercise 3.2.6. Should this case have the same acceleration while it goes up the ramp as while it goes down the ramp? How can we see that on the velocity versus time graphs?

Hint. If the track is tilted with no friction then describe the motion in each direction using the phrases "speeding up" or "slowing down".

If the track has friction with no tilt then describe the motion in each direction using the phrases "speeding up" or "slowing down".

In this case, there may be tilt *and* friction. You should be able to indicate how you would see each effect in the graphs of the motion.

Exercise 3.2.7. Should this case have the same acceleration (either while it goes up the ramp or while it goes down the ramp) as the previous two cases of rolling down the ramp?

In Capstone, you should be able to display all three graphs (position v time, velocity v time, and acceleration v time). You should also be able to display all three cases of data on each of these graphs. On the velocity versus time graph, fit each of the three graphs with a linear trendline. The next section will ask you to analyze how well the data match up to these lines. (It might be interesting to also fit the position vs time curves to parabolas. Be sure to print out copies of your three graphs.

Your lab should note the following results and explain their meaning: slope and y-intercept, the uncertainties (precision) in both the slope and intercept, and the r value (correlation coefficient).

3.3 Analysis

You should notice that the subsections in this section parallel the subsections in Procedure.

3.3.1 Cart and Flat Track

Based on the results of Subsection 3.2.1, write a short analysis of the relationship between these two graphs (x and v versus time). From the velocity versus time graph (specifically from the trendline) determine the value of the acceleration of the cart down the track; be sure to include the uncertainty of the acceleration and the units.

Exercise 3.3.1. Do you see any evidence that the track was not perfectly level?

Exercise 3.3.2. Do you see any evidence that there is any friction as the cart moves along the track?

Exercise 3.3.3. What does the intercept of the velocity versus time graph tell you?

Exercise 3.3.4. If the slopes are different, then discuss any pattern that you see. If the slopes are (essentially) the same, then find an average and a standard deviation of the four values.

Exercise 3.3.5. Does the speed of the cart affect the slope of the velocity vs time graph?

Discuss any evidence observed in your data when answering these questions. Also consider the magnitude of the uncertainties when writing your conclusions.

3.3.2 Cart and Sloped Track

Based on the results of Subsection 3.2.2, write an analysis of the relationship between the two graphs (x and v versus time). From the velocity versus time graph determine the value of the acceleration of the cart down the track.

Exercise 3.3.6. For the two downhill cases, use your uncertainty analysis to determine if the acceleration of the cart changed when it was given a small push.

Exercise 3.3.7. Is there an accuracy that can be computed for this part of the experiment?

Hint. If the track were frictionless, then the acceleration should be $a = (9.81\ {}^{\mathrm{m}}\!/_{\mathrm{s}^2})(\sin\theta)$, where θ is the angle that the incline makes.

Inspect the line/curve that is defined by the data on the Distance traveled vs. time graph.

Exercise 3.3.8. What is its shape? Is the shape of the graph what you would expect for constant acceleration (straight line, parabola, etc.)? Explain your reasoning.

Exercise 3.3.9. Consider the trendline that you added. Does/should the trendline line go through the origin? What is the value of y-intercept of the X vs T graph? What physical quantity does the intercept represent? Explain why it has that value.

Hint. Think about where the sensor was located.

Exercise 3.3.10. What does the slope (whether it's constant or not) of the line on this graph signify?

Now consider the Instantaneous Velocity vs. Time graph.

Exercise 3.3.11. Does the curve/line on this graph have the shape you would expect for an object undergoing constant acceleration? Explain.

Exercise 3.3.12. What was the value of the y intercept on this graph (include units and uncertainty!)? Explain its significance. To what does it refer?

Hint. Think carefully about what you plotted on the X-axis!

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A PDF version might be found at acceleration.pdf (115 kB)