

PHYS 1P91 Experiment 03

Kinematics 2 : Velocity and Acceleration

Notes

- Words in **blue** are links to additional reading or videos.
- Text in **gray** boxes are hints and things to take note of.
- Text in **red** boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

1 Lab Objectives

- Use the iOLab to produce graphs of position, velocity and acceleration as a function of time.
- Use the software to measure averages, slope, and areas under curves of recorded data.
- To understand measurement uncertainty.
- To quantitatively explore how the average change in position with time is the speed, and the average change in speed over time is the acceleration.

2 Introduction

In the previous lab (Experiment 2), we looked at how the rise and fall of position-time graphs indicated the velocity of a moving object, and similarly, how the rise and fall of a velocity-time graph indicated the acceleration of a moving object.

So for a position-time graph x vs. t ;

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_0}{t_f - t_0} = \frac{\text{rise}}{\text{run}} = \text{slope of position-time graph} \quad (1)$$

and for a velocity-time graph v vs. t ;

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0} = \frac{\text{rise}}{\text{run}} = \text{slope of velocity-time graph} \quad (2)$$

It is hard to roll the iOLab by hand to get the perfect position-time graphs you find in textbooks, such as graphs that have an exact, constant velocity. The data you will get with real measurements like the iOLab will be quite noisy and curvy.

But we still need to show that the slope of the position-graph matches the measured velocity of the iOLab, and how the slope of the velocity-time graph matches the measured acceleration. Basically, we will demonstrate equations 1 and 2.

There is another important relationship between position- and velocity-time graphs. When **motion is uniform** (the simplest kind of motion), we can re-arrange equation 1 to be

$$\Delta x = \bar{v} \times \Delta t \quad (3)$$

On a simple velocity-time graph, such as in Figure 1, where the average velocity is constant, equation 3 indicates that the *area under the curve* is equal to the distance traveled. We should try to prove that true as well with the iOLab, even considering our inability to move the iOLab with a truly constant velocity.

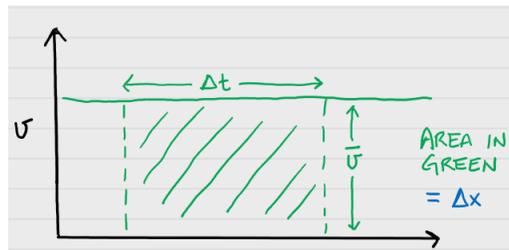


Figure 1: Velocity-time graph of uniform, constant velocity motion. The area under the graph is equal to the distance travelled.

3 Procedure

In this lab report you will be asked to use the error propagation rules to determine the uncertainty in some calculated quantities.

On a separate piece of paper write out your derivation(s) of the uncertainty propagation equation s, scan and submit it as a second file with your lab on Sakai. (In

many cases this will simply be you restating the equations from the propagation sheet using the correct variable names from your experiment.

There are lots of free document scanner apps which can be used to scan and create files with your phone. Follow the instructions found [here](#).

This lab will be more quantitative, and quite a bit longer. In addition to providing screen shots of the data collected by the iOLab, you will learn to use the iOLab Online software's built in ability to analyze recorded data.

3.1 Prepare the iOLab.

Insert the iOLab USB dongle into your computer and turn on the iOLab. Connect to the iOLab Online software.

You will need almost 1 m of straight, flat space to roll the iOLab back and forth.

Important: Note that the orientation of the axes that the iOLab thinks of x, y, z are indicated on both sides of the iOLab. Also note that the wheels roll in the direction of the y -axis, but we typically use the x variable in talking about 1D motion.

Do not get confused between the y -axis of a graph, which may represent any number of variables, and the y -position of the iOLab, which most textbooks will usually call x !

Include a picture of your iOLab setup as part of your lab report. Have something in the picture (pencil, coin, etc.) mark the general area of the “start” and “end” points of the distance traveled.

4 Take data

4.1 Finding the correct acceleration-time curve

Set the iOLab wheels-down on a table. Select the Wheel sensor.

In the previous lab, you were asked to move the iOLab such that the measured acceleration produced a graph like that in Figure 2 below.

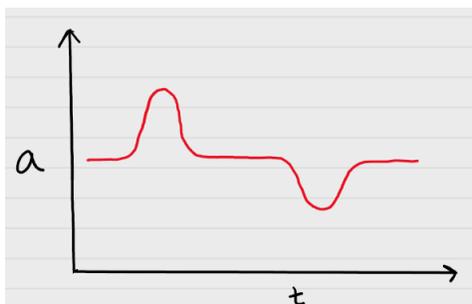


Figure 2: A hypothetical graph of the iOLab acceleration.

Hint: it will be helpful to watch the acceleration graph as it is being made. Just like Experiment 2, select $y=a, m/s^2$ in iOLab Online.

Reminder: Live-display is a coarse approximation of the final data. Wait for the full image to render before you try a new run. **YOU WILL NOT SEE A SMOOTH CURVE UNTIL IT RENDERS IN FULL**

One way to reproduce this graph is to very quickly roll the iOLab from one hand to the other. A wooden surface works best, where there is little slip of the wheels.

Starting at rest, you should almost “flick” the iOLab so it travels straight along the y-axis. This quick push provides the large positive acceleration. Once it is rolling along freely, the acceleration will be near zero, until it’s caught by your other hand, or by a soft bumper (this can be your other hand, a cushion, or another soft object. Just don’t let it be a hard wall!). Try to catch the iOLab firmly without letting it bounce back or scoot forward. The sudden stop will provide the large negative acceleration.

Note the velocity will not be constant during its free-rolling because of friction slowing it down.

Try it a few times before recording data to make certain the iOLab doesn’t skid sideways, slip, or spin out, but travels in a straight line. The farther apart your hands are, the more space you will have recorded between the two peaks.

Help! It doesn’t look like it should!

- Are you looking at the wheel acceleration data? Make sure you select $y=a, m/s^2$ in iOLab Online and hit Draw again to refresh the graph.

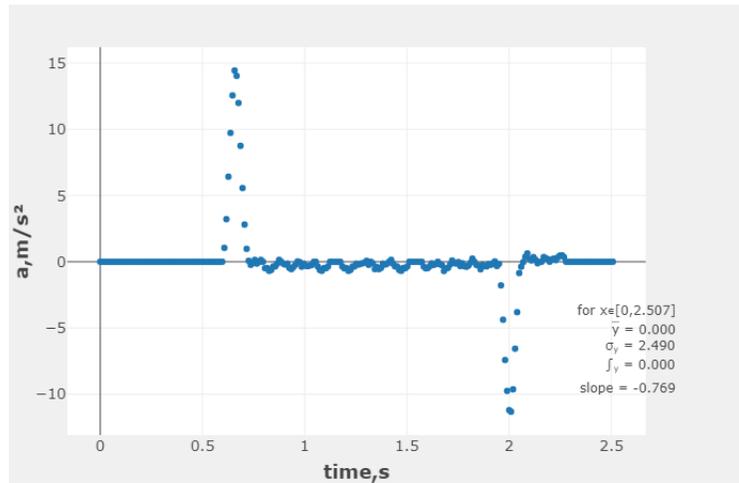


Figure 3: An example successful data run, showing the desired acceleration-time graph.

- To see an example, watch [making the acceleration graph](#)
- **Be sure to visit a live help session to get help from one of the TAs if you're stuck.**

When you're happy with your results, save your data to a file on your computer. This will save the position, velocity, *and* acceleration data. Saving the data is always good practise in case your software crashes, or your analysis takes a long time.

Zoom in to the interesting time interval and save a picture of the graph to include in your lab report. It might look something like Figure 3.

For that very same run, save a picture of velocity-time (variable $y=v, \text{m/s}$) and position-time (variable $y=x, \text{m}$) graphs as well to include in your report.

4.2 Calculating the average velocity from the distance travelled

Let's start by calculating the **average velocity from the total distance traveled**. Maybe this should be called the average *speed*, but since the iOLab did not make a return trip back to the start, in this experiment **they are the same thing**.

How far did the iOLab travel? Select only the variable $y=x, m$ or $y\#1$ (position) and then click Draw to plot the distance traveled.

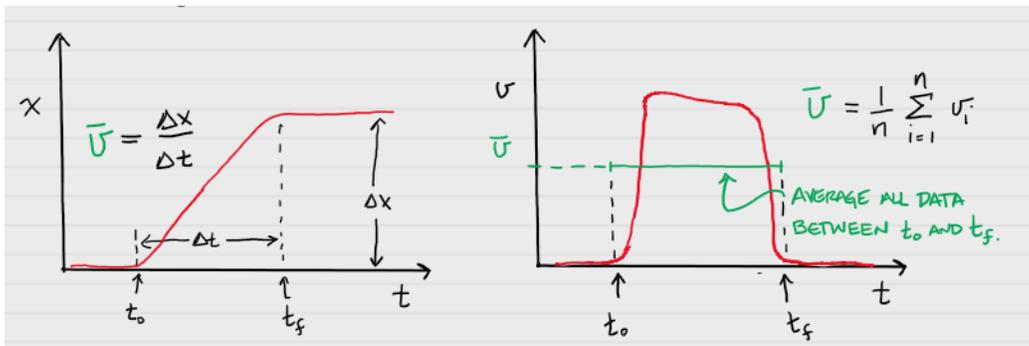


Figure 4: (Left figure) One way to find the average velocity from a position-time graph is to find the total distance traveled and divide by the travel time, $\bar{v} = \Delta x / \Delta t$.

(Right figure) Another way to find the average velocity is to take the average of the velocity data over the same time interval.

Using Figure 4 as a guide, you will be recording the following values:

- The time the iOLab really started to move, from when the position data started to rise from zero, which is t_0 .
- The time when the iOLab fully stopped, and the position data became constant, which is t_f .
- The total distance traveled of the iOLab, which is Δx .

To select a time point in iOLab online, you hover the cursor over the data in the plot window. Your cursor will highlight the value of both the x - and y -axis at that specific data point. Figure 5 shows an example of this. Since time is plotted along the x -axis, you record the x value for the two time points. Similarly, to get the value for the distance travelled, hover the cursor over the end plateau and record the y value.

These three values are in essence *measured* values, and therefore have uncertainty associated with them. As discussed in the, measurement uncertainty video, is typically taken to



Figure 5: When you hover your cursor over the data in the plot, you will find two labels listed. In iOLab online, the x -value is displayed in the black box, while the y -value is displayed in the blue box.

be *half* of the smallest unit of measure. The wheel sensor operates at 100 Hz; it collects 100 data points per second. If you look at the data window, you will see that each data point is recorded in steps of 0.01 s. This means the measurement uncertainty for the time points (σ_{t_0} and σ_{t_f}) will be half of this value, or 0.005 s. The wheel sensor records distance in mm. The measurement uncertainty for the distance travelled ($\sigma_{\Delta x}$) is therefore half of 1 mm, or 0.0005 m.

When you need to perform a calculation using values that contain uncertainty, you must follow a series of rules that combine the uncertainty properly.

Record these values in your lab report:

- $t_0 \pm \sigma_{t_0}$
- $t_f \pm \sigma_{t_f}$
- $\Delta x \pm \sigma_{\Delta x}$

In the following steps you will be calculating quantities from values that have uncertainty. Therefore, to determine the uncertainty of your new values you will have to use [Error Propagation Rules](#). Make sure to watch the video (Video button at the top of the page) if you are uncertain how to use the rules from the document.

What was the elapsed time in that interval, $\Delta t = t_f - t_0$? What is the uncertainty in this value?

What was the average velocity, $\bar{v} = \Delta x / \Delta t$, of the iOLab from these measurements? What is the Uncertainty?

Now we are going to compare the calculated average velocity to the statistics we get from the software. Switch to the velocity-time data in by selecting variable $y=V, \text{m/s}$.

Using the Box Select tool in iOLab online, select the data range as close to between t_0 and t_f as you can. The statistics (average and standard deviation) of all the data visible in this range will be displayed on the graph. An example of the range you are averaging over is shown in the right hand side of Figure 4.

What is the actual average velocity \bar{v} from the reported average of the data in the same time interval? What is the uncertainty from the reported standard deviation?

Do the two values of \bar{v} agree with each other? - If you are unsure how to compare values with uncertainty please watch our videos on [Understanding Uncertainty](#) AND [Comparing values with Uncertainty](#).

Remember, percent difference between measurements A and B is calculated as

$$\% \text{ difference} = 100 \times \frac{2 * |A - B|}{(A + B)} \quad (4)$$

Does it really matter that the velocity was changing, rising and falling, in this time interval if you wanted to calculate the total distance traveled?

4.3 Calculating the average velocity from the slope of the position-graph

Instantaneous velocity is different from the average velocity of the whole trip. It is defined as the slope of the position-time graph, at a particular point in time. We will try to be as “instantaneous” as we can get by narrowing down the time interval to look at, but we still have to do some averaging of several data points, so we will still call it the “average velocity”

Plot the acceleration data ($y=a, \text{m/s}^2$) again. This time, record the start and end points of a narrow region of time where you think the iOLab was in free rolling motion and the acceleration was nearly zero, something like the top part of Figure 6.

Make a note of new start and end times, of when the iOLab was rolling free of external forces, in your report: $t_0 \pm \sigma_{t_0}$ and $t_f \pm \sigma_{t_f}$.

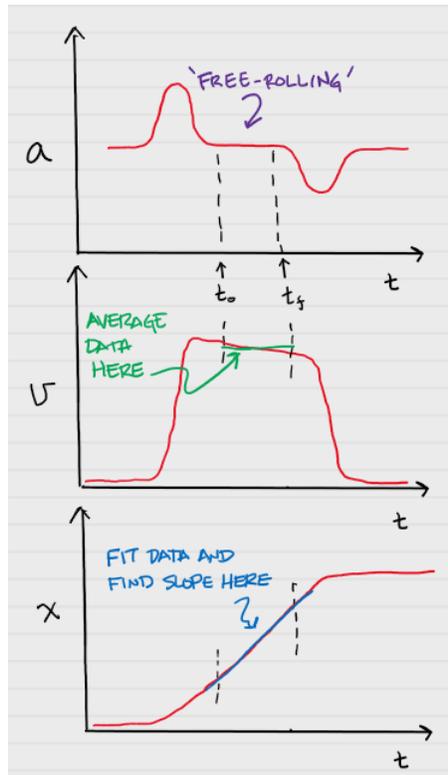


Figure 6: (Top) Measurement points of the acceleration-time graph. (Middle) The average velocity \bar{v} over the same time region. (Bottom) The region of the position graph to find the slope.

Now we need to calculate the slope of the position ($y=x, m$) data in exactly this narrow interval, i.e. $\Delta x/\Delta t$. Using your cursor, make a note of the corresponding values for x_0 and x_f . Use these values along with the new start and end time points to calculate the average velocity. Calculate the uncertainty.

Record the slope as the average velocity value $\bar{v} = \Delta x/\Delta t$ in this narrow region with its uncertainty. This is calculated the same way as listed in section 4.2.

Now switch to the velocity data ($y=v, m/s$), and like you did before, zoom into the same “free-rolling” region and look at the graph statistics.

Record the average velocity \bar{v} and the standard deviation (σ) in this narrow region.

Does it agree with the slope of the position-time graph? Calculate the percent difference.

4.4 Average velocity, or average velocity?

You've now calculated the average velocity by two methods, first considering the total distance traveled, and second, by looking at only the time the iOLab was in motion without any force acting on it (zero acceleration). It is true that equation 1 holds for both cases. So why don't they agree on an average velocity value?

It may be because we used equation 1 with quite different ideas of what Δx is. In the first case Δx was the total distance traveled, including the times when it was speeding up and slowing down. In the second case it was the near instantaneous "rise" of the position-time slope.

Think about Figure 7. Why is it not correct to compute an average or line slope over a wide range of data, such as the green value, if you want the more "instantaneous" value, such as the blue value?

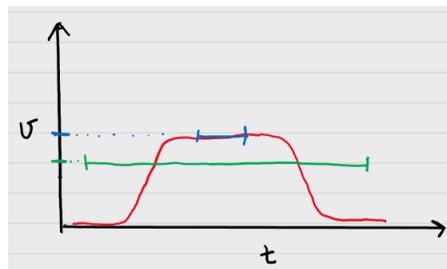


Figure 7: Hypothetical velocity graph. Blue and green lines are the averages of the data over their respective regions.

4.5 Average acceleration

Notice that over the "free-rolling" region you have selected, the velocity is not really constant. It really should be constant, if Newton's first law were true that objects in motion tend to remain in motion, unless acted upon by a force.

The force of friction is slowing the iOLab. The force comes mostly from the rubbing between the axle and wheels, and is therefore a kinetic friction. We'll look more closely at this force in a later lab, but for now, this is a great opportunity to explore equation 2, and calculate \bar{a} .

You will find two values of \bar{a} from the data:

First, use the cursor method and find the slope of the velocity-time graph in the “free-rolling” region as the average acceleration $\bar{a} = \Delta v / \Delta t$. Do not calculate the uncertainty for this slope.

Second, use the Data Selection method and record the average value of the acceleration-time graph as \bar{a} in this same region from the statistics. Record the uncertainty for this acceleration from iOLab Online.

What is the percent difference between the two accelerations? Are the values within uncertainty?

What direction ($\pm x$, $\pm y$, or $\pm z$) is the friction force and acceleration? Is the acceleration fairly constant? Does equation 2 hold true?

There is a lot of noise in the acceleration data in this region. Do you trust the average? Is there a statistical measure you could use to estimate how certain the average value is?

4.6 Distance travelled from the velocity-time graph

Look back at equation 3. In Figure 1, the green rectangle of width Δt and height \bar{v} has an area that is the product $\bar{v} \times \Delta t$, the same as the right hand side of equation 3. Thus the *area* under the velocity-time graph should represent the distance traveled.

(In general, the area under a [rate function gives the total change of that variable](#). Since velocity is the rate of change of position, this holds true here.)

Your velocity-time graph (variable $y = v, \text{m/s}$) should be kind of rectangle shaped, but the noise and rounded edges make the area under the curve hard to calculate. The software can measure the area under graphs pretty well, and includes that as part of the statistics in the graph (in iOLab online, area is written as \int_y). Because of averaging, the values should still work out, such as in Figure 8.

Use the time interval you found for the total distance traveled in section 4.2 to cover the whole time the iOLab was moving. Zoom into this time interval and from the reported statistics, record the area under the velocity-graph curve.

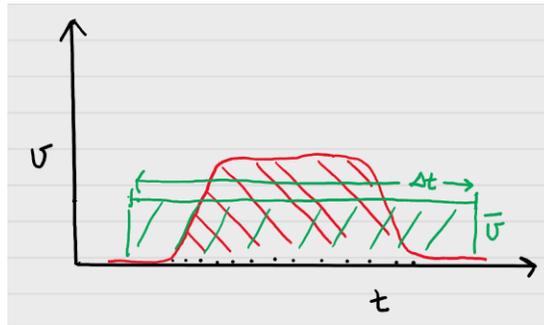


Figure 8: Hypothetical velocity graph. The area of the data in red is the same as the area of the rectangle in green, because \bar{v} is the average of the data points of the red curve.

What are the units of area in a velocity-time graph? How does the area under the velocity graph compare with the total distance traveled from before in section 4.2?

4.7 Average velocity from the acceleration-time graph

The average acceleration is related to the change in velocity in the same way;

$$\Delta v = \bar{a}\Delta t . \quad (5)$$

Thus the area under the acceleration-time graph should represent the total change in velocity.

If you had selected the entire region of the acceleration graph (all of Figure 2), and assuming the acceleration and deceleration peaks were more ideally the same shape, approximately what total area $\Delta v = \bar{a}\Delta t$ would you have found? In that case, what would be the total change in velocity? Please explain.

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found on Sakai), include figures, and develop a robust discussion using prompts found throughout the manual.

Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P91@brocku.ca.