You are working in a research lab that uses gel phase electrophoresis for separating protein molecules by mass. In this process, the molecules move slowly across a gel substrate. You have been asked to measure their velocity. One technique to get the velocity is to measure the time the protein takes to travel a set distance. To determine if this is valid, you decide to videotape the protein motion and analyze the video. You will then compare the video analysis to the distance and time measurements using a meterstick and stopwatch.

To develop your technique, you decide to practice using a cart as the moving object. You decide to give a cart a push so that it moves down a horizontal track, and then make a video of its motion. You then compare your video analysis for velocity to a distance and time measurement using a stopwatch and a meter stick. Your video analysis can generate position-vs.-time from the velocity-vs.-time graphs. Before you do your first video you predict the result by sketching a graph of what you think the position-vs-time graph will be for the cart and then use that graph to make a velocity-vs-time graph.

*Instructions: Before lab, read the laboratory in its entirety as well as the required reading in the textbook. In your lab notebook, respond to the warm up questions and derive a specific prediction for the outcome of the lab. During lab, compare your warm up responses and prediction in your group. Then, work through the exploration, measurement, analysis, and conclusion sections in sequence, keeping a record of your findings in your lab notebook. It is often useful to use Excel to perform data analysis, rather than doing it by hand.*

Read Sternheim & Kane: sections 1.1-1.3.

Equipment

You have a cart, track, stopwatch, meterstick and a computer with video analysis software.

Read the section *MotionLAB & VideoRECORDER* in the **Software** appendix. You will be using the software throughout the semester, so please take the time now to become familiar using them.

Read the section *Video Cameras – Installing and Adjusting* in the **Equipment** appendix.

Read the appendices titled a **Review of Graphs, Significant Figures** and **Accuracy, Precision & Uncertainty** to help you take data effectively.

**If equipment is missing or broken, submit a problem report by sending an email to** [**labhelp@physics.umn.edu**](mailto:labhelp@physics.umn.edu)**. Include the room number and brief description of the problem.**

Warm up

**Special Note on Functions:**

In this lab problem you will need to fit mathematical functions to gathered data. Understanding how different functions look and behave is important. Here are the names of some common functions with some simple example equations.

* Line (or “linear function”, though sometimes this phrase can mean other things): An example equation for a straight line is . The constant is the line slope, the constant is the value of the function at .
* Parabola: An example equation for a parabola is . What makes a function a parabola is that the variable is squared (and not raised to some other power; for example another function called a “cubic” function has the variable raised to the power 3 instead of 2). A parabola is **not** an exponential function.
* Polynomial: An example equation for a polynomial is . Here ,, etc. are constants. A polynomial is a sum of terms involving a variable raised to an integer power. You may notice that a parabola is a specific type of polynomial.
* Power Law: An example equation for a power law function is . Here and are constants. It is called a *power* law function because the variable is raised to the *power* . could be a positive or negative number, and is not necessarily an integer though it could be. You may notice that a parabola is a specific type of power law function. A power law function is **not** the same as an exponential function.
* Exponential: An example equation for an exponential function is . Here ,, and  are constants. It is called an *exponential* function because the variable  appears in the *exponent* of a constant ; is called the *base* of the exponential. Most commonly the number  is used as the base for exponential functions (). If some quantity is described as increasing or decreasing *exponentially* it means that it could be described by an *exponential* *function*. Parabolas and power law functions are **not** exponential functions.

To make your prediction, you need to think about how to measure and represent the motion of an object. The following questions should help.

1. How would you expect an *instantaneous velocity vs. time graph* to look for an object with constant velocity? Make a rough sketch and explain your reasoning. Assign appropriate labels and units to your axes and write an equation that describes this graph. What is the meaning of each quantity in your equation? How does each quantity in your equation show up on your graph? Does your graph and equation represent a type of function with a common name?

2. How would you expect a position vs. time graph to look for an object moving with constant velocity? Make a rough sketch and explain your reasoning. What is the relationship between this graph and the instantaneous velocity versus time graph? Write down an equation that describes this graph and describe the meaning of each quantity in your equation. How does each quantity in your equation show up on your graph? In terms of the quantities in your equation, what is the velocity? Does your graph and equation represent a type of function with a common name?

3. Repeat the first two steps if the cart is slowing down slightly as it moves along the track.

4. Repeat the first two steps if the cart is speeding up slightly as it moves along the track.

5. Is it correct to say that a hypothetical function  increases exponentially with ? Does the function  increase exponentially with ?

Prediction

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that describes the relationship between position and velocity. Make sure that you state any approximations or assumptions that you are making. What do you wish to be able to determine about the motion of the cart? How will the data available (position-vs.-time and velocity-vs.-time graphs) allow you to determine this? Sketch the position-vs-time graph and explain why it should have this shape. Sketch the velocity-vs-time graph and explain its shape.

What assumptions are you making to solve this problem?

Exploration

If necessary, try leveling the table by adjusting the levelers in the base of each table leg. You can test that the table is level by observing the motion of a cart on a level track.

Place the metal tracks on your lab bench and place the cart on the track. Give it a push and observe its motion. Does it appear to move with a constant velocity? Use the meter stick and stopwatch to determine the average speed of the cart. Try pushing the cart so that it has the same velocity each time you push it. Estimate how consistent its velocity can be.

Turn on the video camera and look at the motion as seen by the camera on the computer screen. If necessary, refer to the appendix for VideoRECORDER instructions.

Do you need to focus the camera to get a clean image? The camera can be focused by turning the housing around the lens. How do the room lights affect the image? Which controls help sharpen the image? Record your camera adjustments in your lab journal.

Move the position of the camera closer to the cart. How does this affect the video image on the screen? Try moving it farther away. Raise the height of the camera tripod. How does this affect the image? Decide where you want to place the camera to get the most useful image.

Practice taking videos of the cart. You will make and analyze many videos in this course! Write down the best situation for taking a video in your journal for future reference. When you have a quality movie, save it for analysis.

What would happen if you calibrate using an object that is closer to your camera than the object of interest? Could this introduce error?

What would happen if you click on a different part of the moving object to get each data point? Could this introduce error?

Is it better to calibrate on a small object that takes up a small proportion of the image, or a larger object?

Measurement

1. Take a good video of the cart’s motion using the video cameras and the VidoeRECORDER software.
2. Analyze the video with the MotionLab software, predicting and fitting functions for *position vs. time* and *velocity vs. time*.

Instructions to analyze a video are shown in a dialog box within the MotionLab analysis software. These instructions will step you through the analysis of a video; read them carefully. You can also refer back to the appendix material for further instructions.

If possible, every member of your group should analyze a video.

Record your procedures, measurements, prediction equations, and fit equations in a neat and organized manner.

A convenient way to save your MotionLab data is to “print” it to a pdf file. Once your analysis is complete, select “print” followed by “print to pdf”. After selecting “print to pdf” a window showing a preview of the pdf file will appear. From the pdf preview window select “save as” and choose a file name. Distributing pdf files by email can be a good way to share and back up your data.

You can also save Motionlab sessions as a .txt file. The text file contains all the data taken during a session and also allows you to later restart Motionlab to continue an incomplete analysis. You will be required to have access to BOTH the session text file AND the video to restart analysis.

Note: Be sure to record your measurements with the appropriate number of significant figures and with your estimated uncertainty. Otherwise, the data is nearly meaningless. Refer to the appendix material if necessary.

Analysis

Analyze your video to find the instantaneous speed of the cart as a function of time. Determine if the speed is constant within your measurement uncertainties.

When you have finished making a fit equation for each graph, rewrite the equations in your lab journal changing the *general letters* to those appropriate for the *kinematic quantities* they represent. Make sure all quantities are assigned the correct units.

Conclusion

Compare the cart’s speed measured with video analysis to the measurement using a stopwatch. How do they compare? Did your measurements and graphs agree with your answers to the Warm-up Questions? If not, why? What are the limitations on the accuracy of your measurements and analysis? Are the techniques used in this lab problem applicable to analyzing the motion of protein molecules moving through gel? How is the motion of protein molecules similar to the motion of the cart? How would it differ?