Graphical Analysis of Kinematics

Physics Topics

If necessary, review the following topics and relevant textbook sections from Serway / Jewett "Physics for Scientists and Engineers", 10th Ed.

- Velocity and Acceleration (Serway 2.1 and 2.5)
- Motion under constant acceleration in 1D (Serway 2.7)
- Motion under constant acceleration in 2D (Serway 4.2)

Introduction

Understanding motion and how it changes over time is crucial to understanding the world around us. Whether you're playing a round of golf, driving a car, or trying to shoot your crumpled up physics syllabus into the trash (a joke - don't get any ideas!), every day you subconsciously analyze the motion of different bodies in order to predict their future behavior.

In today's lab you will be using motion detectors and video analysis software to analyze the motion of carts and projectiles. By the end of lab, you should have an understanding of how the graphical representation of motion complements the mathematical representation of the same thing.

Pre-Lab Questions

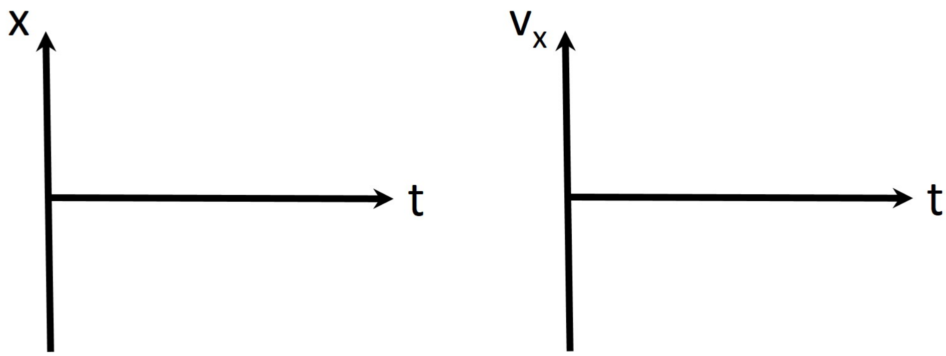
Please complete the following questions prior to coming to lab. They will help you prepare for both the lab and the pre-lab quiz (Found on D2L).

1.) Read through the entire lab writeup before beginning

2.) What is the **specific** goal of this lab? Exactly what question(s) are you trying to answer? Be as specific as possible. ("To learn about topic X..." is **not** specific!)

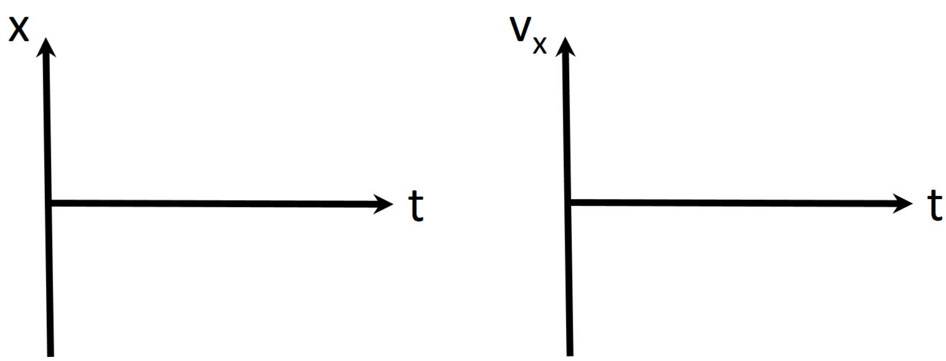
3.) What **specific** measurements or observations will you make in order to answer these questions?

4.) A cart is released from rest from the top of an inclined ramp. Ignoring friction, sketch your prediction for the graphs of x-position vs. time and x-velocity vs time as it rolls down the ramp. *Assume $x = 0$ is at the top of the ramp, $t = 0$ occurs at the moment the cart is released, and the $+x$ axis points directly down the ramp.* Draw your graphs on the axes below, or draw them neatly on a separate sheet of paper.



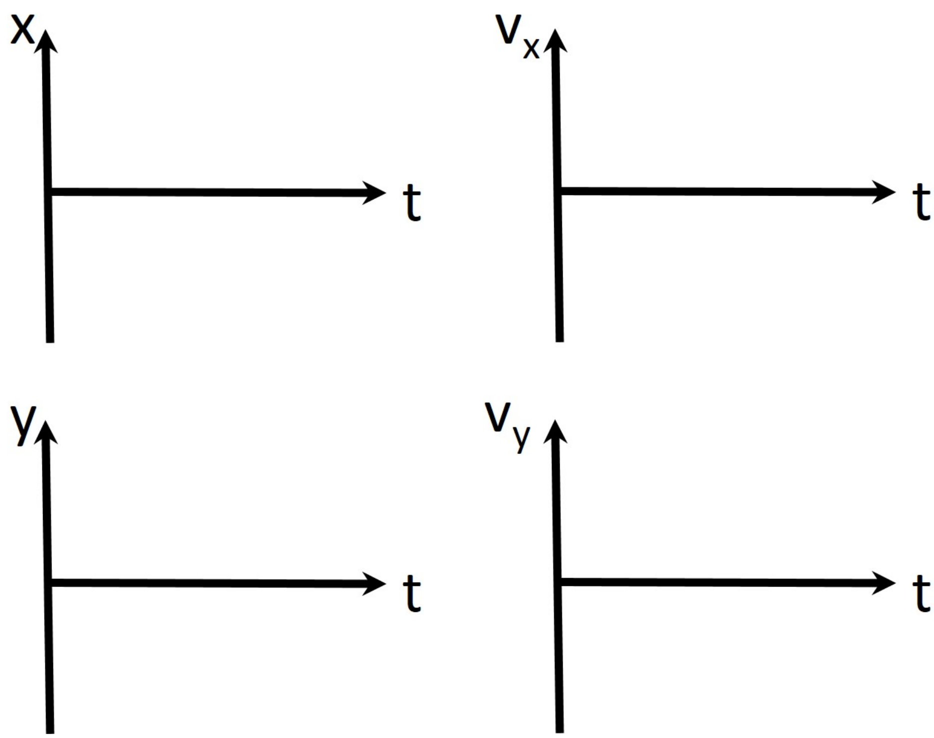
Graphs for question 4

5.) A cart is initially at rest at the bottom of an inclined ramp. It is given a quick initial push so that it rolls up and then back down the incline. Ignoring friction, sketch your prediction for the graphs of x-position vs. time and x-velocity vs. time as it rolls down the ramp. *Assume $x = 0$ is at the top of the ramp, $t = 0$ occurs at the moment the cart is released, and the $+x$ axis points directly down the ramp.* Draw your graphs on the axes below, or draw them neatly on a separate sheet of paper.



Graphs for question 5

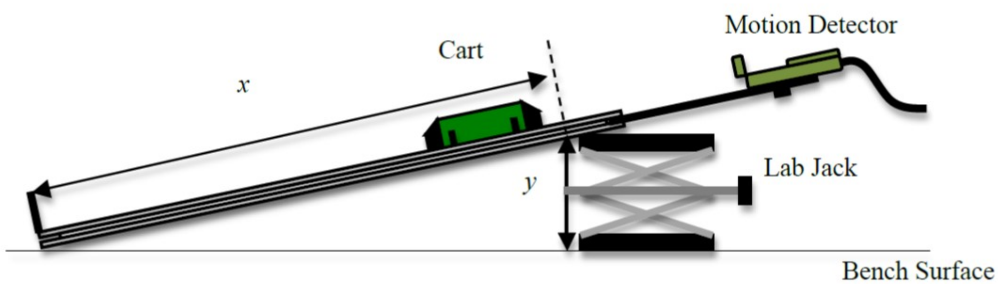
6.) You toss a ball underhand and it flies through the air in an arc. Ignoring air resistance, sketch your prediction for the graphs of x-position vs. time and x-velocity vs. time, y-position vs. time and y-velocity vs. time as the ball flies through the air. *Assume $x = 0, y = 0$ is the place where the ball leaves your hand, $t = 0$ occurs at the moment the ball leaves your hand. The $+x$ axis points horizontally in the direction of motion of the ball, and the $+y$ axis points vertically upward.* Draw your graphs on the axes below, or draw them neatly on a separate sheet of paper.



Graphs for question 6

Apparatus

- Vernier Dynamics cart
- Vernier Motion Sensor
- Vernier LoggerPro software
- Vernier Computer interface
- Aluminum track
- Lab Jack (in order to angle track)
- Protractor / angle finder
- Video of tossed ball (provided to students)



Part I - Cart Rolling Down a Ramp

Procedure I

1.) Connect the motion detector to the DIG/SONIC-1 channel of the computer interface. Make sure the Motion Detector's switch is set to "cart" mode.

2.) Use the jack to angle the track at a small angle (no more than 15 degrees). Use the protractor to measure the exact angle. Record this value *including an estimate of uncertainty.*

3.) Fix the motion detector's position at the top of the incline so that the cart will never be closer than 15cm to it.

4.) Bring the cart up the ramp to a starting position (chosen by you). Be sure to note and record this starting position.

5.) Click the ▶ button to start collecting data. Release the cart after the motion detector starts to click. Try to get your hand out of the path of the motion detector as quickly as possible so it can track the cart only.

6.) You should see two plots form on LoggerPro, position vs. time and velocity vs. time.

7.) If the data does not look as expected, try adjusting the angle and aim of the motion detector and repeating the previous step. Once you are satisfied with your setup, proceed with the next step.

8.) Fit a straight line to your velocity graph as follows:

(a) Select the portion of your data to be fit (it should be the portion when the cart was freely rolling down the ramp) by clicking and dragging on the graph.

(b) Select **Analyze** → **Linear Fit**

(c) You should be able to read off the equation for the line from your graph. Record this fit equation in your notebook.

9.) Store the data by selecting **Experiment** → **Store Latest Run**.

10.) Hide the data set by selecting **Data** → **Hide Data Set** → **Run 1**.

11.) Go back to step 5 and repeat this procedure 3 more times. Make sure you start the cart from the same position each time. Record the fit equation, store and hide the data each time.

12.) Export all of your data as a .txt with an easily recognizable name (i.e. *PCS211_KineticsPart1_YOURNAME.txt*), you should then upload this file to the Lab 2 assignment folder on D2L.

Analysis I

1.) Using your four trials, come up with an experimental *measurement* of the acceleration of the cart. Include uncertainty in your result. When you measure the same thing multiple times, a good estimate of the uncertainty is the standard deviation of all of the trials.

2.) The theoretical prediction for an object sliding without friction down a ramp angled at θ above the horizontal is $|\vec{a}| = g \sin\theta$. Compute the predicted acceleration *including uncertainty*. To do this, you will need an estimate of the uncertainty in $\sin\theta$. For small angles, the uncertainty in the sine of the angle is approximately equal to the uncertainty in the angle itself $\delta \sin(\theta) \approx \delta\theta$, provided the angle is measured in radians [remember $180° = \pi$ rad].

Part II - Cart rolling up and down a ramp

Procedure II

1.) Place the cart at the bottom of the ramp.

2.) Practice giving the cart a soft, quick push so that it freely goes up and comes back down the ramp without hitting the motion detector.

3.) Once you are satisfied with your technique, using the same LoggerPro file, click ▶ to start collecting data and then immediately afterward, give the cart a quick push causing it to travel up and back down.

4.) Using the same techniques as in the previous part, fit a line to your velocity vs. time graph. Make sure to only fit the part of the data where the cart was not in contact with your hand. Record your resulting fit equation in your notebook.

5.) Export all of your data as a .txt with an easily recognizable name (i.e. *PCS211_KineticsPart2_YOURNAME.txt*), you should then upload this file to the Lab 2 assignment folder on D2L.

Analysis II

1.) Using your trial data, come up with an experimental *measurement* of the acceleration of the cart going up and down the track. Include uncertainty in your result.

Part III - Video Analysis of 2D kinematics

Procedure I

1.) Locate and download the files *PCS211_KinematicsVideo.cmbl* and *ball_bouncing_across_stage.mov* from D2L.

2.) Open *PCS211_KinematicsVideo.cmbl* in LoggerPro, after a few seconds a new screen and the video should pop up.

3.) Take a moment to get familiar with the controls on the video. You will use this video to analyze the motion of the metal cylinder attached to the string.

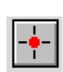
(a) You can play the video at regular speed by clicking || ▶

(b) To return the video to the first frame, click | ◀◀.

(c) To step forward or backward one frame at a time, use ◀ | or | ▶ respectively.

4.) The video is taken of a ball bouncing across a stage. Logger Pro allows you to track the position of the ball. Try playing the video once at normal speed to get a sense of the ball's motion.

5.) You will analyze a single bounce of the ball. Advance the video to the point where the ball just leaves contact with the ground for the first time.

6.) Click the button , and then click on the center of the ball to plot a point. A blue dot will appear on the video, and you will see the x-y positions of the point show up on the graph. A coordinate system has been chosen for you, with the origin at the point where the ball first makes contact with the ground. The +x axis points *left*, and the +y axis points up.

7.) Each time you click, the video will advance 5 frames. Continue plotting the position of the center of the ball throughout the entire bounce. Stop when the ball is in contact with the ground again.

8.) If you make a mistake, you can select certain data points by clicking and dragging on the graph. A gray region will be highlighted on both the graph and the data table. You can “delete” these points by selecting **Edit** → **Strike Through Data Cells**. You can then advance/rewind the video using the ◀◀ and ▶▶ buttons and re-take points.

9.) If you want to start over completely, you can choose **Data** → **Clear All Data**, or simply close and re-open the original LoggerPro file.

10.) Fit a curve to your x-data as follows:

(a) Select **Analyze** → **Curve Fit**. A dialog box will pop up, make sure that **VideoAnalysis|X** is selected, then click OK.

(b) Choose the type of equation you would like to use to fit the data from the choices on the right. You can choose a linear fit, polynomial, exponentials, logs, etc...

(c) Once you have chosen the proper function, click Try Fit. The parameters of the fit are shown in the boxes on the right side. Be sure to record the fit function and its values in your notebook.

11.) Fit a curve to your y-data using the same method as in the previous step. Record the equation and the parameters of the fit in your notebook.

12.) Save your LoggerPro file with an easily identifiable name such as *PCS211_KinematicsMotion_YOURNAME.cmbl*

13.) Export your data as a .txt with a similar name.

14.) Upload these files to the Lab 2 Assignment folder on D2L. All files left on the lab iMac will be erased upon restart.

Analysis III

1.) Using your fit equation(s), determine the ball’s acceleration while it is in the air. Explain how you determined it.

2.) Using your fit equation(s), determine the ball’s **speed** right after it leaves the ground for the first time. Explain how you determined it.

Wrap Up

The following questions are designed to make sure that you understand the physics implications of the experiment and also to extend your knowledge of the physical concepts covered. Your report should answer these questions in the noted section in a seamless manner.

1.) [Results & Calculations] You measured the acceleration of a cart when it traveled down a ramp, and when it traveled up and then back down the ramp. Compare these two accelerations (remember, you need to include uncertainty to make a meaningful comparison). Are they consistent with one another, or is there a difference in acceleration when the cart is traveling up/down compared to it only traveling down?

2.) [Results & Calculations] When the cart was traveling down the ramp, compare the measured acceleration to the predicted one. Are they consistent with each other (within uncertainty)? If not, can you think of any reasons for the discrepancy?

3.) [Discussion] An object undergoing constant acceleration in one dimension can be modeled with the equation $y(t) = At^2 + Bt + C$. What physical quantities do A, B and C represent? Be as specific as possible, explain in words.

4.) [Discussion] Gravity was the force responsible for the acceleration of both the cart and the ball, but you probably found that the magnitude of the acceleration of the cart and the ball are not the same. Why are these accelerations different even though they have the same underlying cause? Explain in words without referencing any mathematical equations.

Report

Labs will be completed in groups, you will enroll in a group with your lab partner at the beginning of each lab session. Each group will submit a single report through the assignment section on D2L.

- **Introduction**
  - What is the experiment's objective?
- **Theory**
  - You may be able to show a derivation of the physics you're investigating, or you may want to reference a source that provides a description/equation representing the physics you're investigating.
  - You may want to provide graphs that illustrate or predict how you expect the system under study to behave.
- **Procedure**
  - Explain the systematic steps required to take any measurements.

- **Results and Calculations**
  - Tabulate your measurements in an organized manner.
  - Based on your procedure, you should know what your tables
  - Provide examples of any calculations.
- **Discussion and Conclusions**
  - Discuss the main observations and outcomes of your experiment.
  - Summarize any significant conclusions.
- **References**
- **(Appendices)**