LABORATORY I:
DESCRIPTION OF MOTION IN ONE DIMENSION

In this laboratory you will measure and analyze one-dimensional motion; that is, motion along a straight line. With digital videos, you will measure the positions of moving objects at regular time intervals. You will investigate relationships among quantities useful for describing the motion of objects. Determining these kinematic quantities (position, time, velocity, and acceleration) under different conditions allows you to improve your intuition about their quantitative relationships. In particular, you should identify which relationships are only valid in some situations and which apply to all situations.

There are many possibilities for one-dimensional motion of an object. It might move at a constant speed, speed up, slow down, or exhibit some combination of these. When making measurements, you must quickly understand your data to decide if the results make sense. If they don't make sense to you, then you have not set up the situation properly to explore the physics you desire, you are making measurements incorrectly, or your ideas about the behavior of objects in the physical world are incorrect. In any of the above cases, it is a waste of time to continue making measurements. You must stop, determine what is wrong and fix it.

If your ideas are wrong, this is your chance to correct them by discussing the inconsistencies with your partners, rereading your text, or talking with your instructor. Remember, one of the reasons for doing physics in a laboratory setting is to help you confront and overcome your incorrect ideas about physics, measurements, calculations, and technical communications. Pinpointing and working on your own difficulties will help you in other parts of this physics course, and perhaps in other courses. Because people are faster at recognizing patterns in pictures than in numbers, the computer will graph your data **as you go along**.

OBJECTIVES:

After you successfully complete this laboratory, you should be able to:

- Describe completely the motion of any object moving in one dimension using position, time, velocity, and acceleration.
- Distinguish between average quantities and instantaneous quantities for the motion of an object.
- Write the mathematical relationships among position, time, velocity, average velocity, acceleration, and average acceleration for different situations.
- Graphically analyze the motion of an object.
- Begin using technical communication skills such as keeping a laboratory journal and writing a laboratory report.

PREPARATION:

Read Serway & Vuille: Chapter 2. Also read *Appendix D*, the instructions for doing video analysis. Before coming to the lab you should be able to:

- Define and recognize the differences among these concepts:
  - Position, displacement, and distance.
  - Instantaneous velocity and average velocity.
  - Instantaneous acceleration and average acceleration.
- Find the slope and intercept of a straight-line graph. If you need help, see *Appendix C*.
- Determine the slope of a curve at any point on that curve. If you need help, see *Appendix C*.
- Use the definitions of sin θ, cos θ, and tan θ for a right triangle.

PROBLEM #1: CONSTANT VELOCITY MOTION

Since this physics laboratory design may be new to you, this first problem, and only this one, contains both the instructions to explore constant velocity motion and an explanation of the various parts of the instructions. The explanation of the instructions is in this font and is preceded by the double, vertical lines seen to the left.

These laboratory instructions may be unlike any you have seen before. You will *not* find any worksheets or step-by-step instructions. Instead, each laboratory consists of a set of problems that you solve before coming to the laboratory by making an organized set of decisions (a problem solving strategy) based on your initial knowledge. The **prediction and warm-up** are designed to help you examine your thoughts about physics. These labs are your opportunity to compare your ideas about what "should" happen with what really happens. The labs will have little value in helping you learn physics unless you take time to predict what will happen before you do something.

While in the laboratory, take your time and try to answer all the questions in this lab manual. In particular, answering each of the **exploration** questions can save you time and frustration later by helping you understand the behavior and limitations of your equipment before you make measurements. Make sure to complete the laboratory problem, including all **analysis** and **conclusions**, before moving on to the next one.

The first paragraphs of each lab problem describe a real-world situation. Before coming to lab, you will solve a physics problem to predict something about that situation. The measurements and analysis you perform in lab will allow you to test your prediction against the behavior of the real world.

You have taken a job with the Minneapolis Grand Prix to simulcast one of their races on the Internet, using a digital video camera that stores images directly on a computer. Viewers are interested in the speeds the cars will be going during the race. Your goal is to determine these speeds from the recorded videos. However, you notice that the image is distorted near the edges of the picture and wonder if this affects the measurement of a car's speed from the video image. You decide to model the situation using a toy car, which moves at a constant velocity.

EQUIPMENT

This section contains a **brief** description of the apparatus you can use to test your prediction. Working through the exploration section will familiarize you with the details. If any lab equipment is missing or broken, submit a problem report from to the lab coordinator by clicking the *Labhelp* icon on any lab computer desktop. Be sure to include a complete description of the problem. You can also file a report containing comments about this lab manual (for example, when you discover errors or inconsistencies in statements). If you are unable to, please ask your TA to submit a problem report.

For this problem you will use a motorized toy car which moves with a constant velocity on an aluminum track. You will also have a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL, described in *Appendix D*) to help you analyze the motion.

PREDICTION

Everyone has "personal theories" about the way the world works. One purpose of this lab is to help you clarify your conceptions of the physical world by testing the predictions of your personal theory against what really happens. For this reason, you will always predict what will happen *before* collecting and analyzing the data. **Your prediction should be completed and written in your lab journal *before* you come to lab.** The "Warm-up" questions in the next section are designed to help you make your prediction and should also be completed before you come to lab. This may seem a little backwards. **Although the "Prediction" section appears before the method questions, you should complete the Warm-up *before* making the prediction.** The "Prediction" section merely helps you identify the goal of the lab problem.

Spend the first few minutes at the beginning of the lab session comparing your prediction with those of your partners. Discuss the reasons for differences in opinion. It is not necessary that your predictions are correct, but it is absolutely crucial that you understand the basis of your prediction.

How would each of the graphs of *position vs. time*, *velocity vs. time*, and *acceleration vs. time* show a distortion of the position measurement? Sketch these graphs to illustrate your answer. How would you determine the speed of the car from each of the graphs? Which method would be the most sensitive technique for determining any distortions? *Appendix B* might help you answer this question.

Sometimes, your prediction is an "educated guess" based on your knowledge of the physical world. In these problems exact calculation is too complicated and is beyond this course. However, for every problem it's possible to come up with a qualitative prediction by making some plausible simplifications. For other problems, you will be asked to use your knowledge of the concepts and principles of physics to calculate a mathematical relationship between quantities in the experimental problem.

WARM-UP

The Warm-up section is intended to help you solve the problem stated in the opening paragraphs. The statements may help you make the prediction, help you plan how to analyze data, or help you think through the consequences of a prediction that is an educated guess. **Warm-up questions should be answered and written in your lab journal *before* you come to lab.** In this case, the Warm-up helps you plan what data to take and how to analyze it.

To determine if the measured speed is affected by distortion, you need to think about how to measure and represent the motion of an object. The following questions should help with the analysis of your data.

Read: Serway & Vuille Chapter 2, Sections 2.1 to 2.5

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. Write an equation that describes this graph. What is the meaning of each quantity in your equation?
2. How would you expect an *instantaneous acceleration vs. time graph* to look for an object moving with a constant velocity? Make a rough sketch and explain your reasoning. Remember axis labels and units. Write down an equation that describes this graph. What is the meaning of each quantity in your equation? What is the relationship between velocity and acceleration?
3. 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. Write down an equation that describes this graph. What is the meaning of each quantity in your equation? What is the relationship between position and velocity?
4. How would video image distortion near the edges of the picture affect these graphs? Use a dotted line (or a different color) to draw the expected distortion effects on each of your graphs. How would it affect the equations that describe these graphs? How will the uncertainty of your

measurements affect the graphs? How might you tell the difference between uncertainty and distortion?

5. Use the simulation "Lab1Sim" to approximate the conditions of the cart's motion. (See *Appendix F* for a brief explanation of how to use the simulations.) Look at the graphs produced by the simulation. You will need to experiment with the settings to find conditions that will produce a similar constant velocity motion. (See *Appendix F* for an introduction to the Simulation Programs.) The simulations allow you to create real time graphs that will help you understand the relationships between velocity, position, acceleration and time further. Produce simulated *position vs. time* and *velocity vs. time* graphs of constant velocity motion, and verify that they meet your expectations. Add a small amount of uncertainty to the position measurements by pressing "Add Error" in the "Graph frame." Note the effect of error in the *position vs. time* graph and in the *velocity vs. time* graph.

EXPLORATION

This section is extremely important—many instructions will not make sense, or you may be led astray, if you fail to carefully explore your experimental plan.

In this section you practice with the apparatus and carefully observe the behavior of your physical system before you make precise measurements. You will also explore the range over which your apparatus is reliable. Remember to always treat the apparatus with **care and respect**. Students in the next lab section will use the equipment after you are finished with it. If you are unsure about how equipment works, ask your lab instructor. If at any time during the course of this lab you find a piece of equipment is broken, please submit a problem report using the *LabHelp* icon on the desktop.

Most equipment has a range in which its operation is simple and straightforward. This is called its range of reliability. Outside that range, complicated corrections are needed. Be sure your planned measurements fall within the range of reliability. You can quickly determine the range of reliability by making **qualitative** observations at what the extremes of your measurement plan. Record these observations in your lab journal. If the apparatus does not function properly for the ranges you plan to measure, you should modify your plan to avoid the frustration of useless measurements.

At the end of the exploration you should have a plan for doing the measurements that you need. **Record your measurement plan in your journal.**

This exploration section is much longer than most. You will record and analyze digital videos several times during the semester.

Place one of the metal tracks on your lab bench and place the motorized toy car on the track. Turn on the car and observe its motion. Qualitatively determine if it actually moves with a constant velocity. Use the meter stick and stopwatch to determine the speed of the car. Estimate the uncertainty in your speed measurement.

Turn on the video camera and look at the motion as seen by the camera on the computer screen. Go to *Appendix D* for instructions about using the VideoRECORDER software.

Do you need to focus the camera to get a clean image? Move the camera closer to the car. How does this affect the video image? 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 toy car. *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 the best movie possible, save it in the Lab Data folder. Quit VideoRECORDER and open VideoTOOL to analyze your movie.

Although the directions to analyze a video are given during the procedure in a box with the title "INSTRUCTIONS", the following is a short summary of them that will be useful to do the exploration for this and any other lab video (for more reference you should read *Appendix D* at least once).

Warning: Be very careful in following these steps, if you make a mistake you may not be able to go backwards; you might need to restart from the first step.

1. Open the video that you are interested in by clicking the "Open Video" button.

2. Select "Begin calibration" and advance the video with the "Step >" button to the frame where the first data point will be taken. This step is very important because it sets up the origin of your time axis (t=0).

3. To tell the analysis program the real size of the video images, select some object in the plane of motion that you can measure. Drag the green cursor, located in the top left corner of the video display, to one end of the calibration object. Click the "x0, y0" button when the green cursor is in place. Move the green cursor to the other end and select "x1, y1". Enter the length of the object in the "Length" box and specify the "Units". Select the "OK" button twice to complete the calibration sequence.

4. Enter your prediction equations of how you expect the position to behave. Notice that the symbols used by the equations in the program are *dummy letters*, which means that you have to identify those with the quantities involved in your prediction. In order to do the best guess you will need to take into account the scale and the values from your practice trials using the stopwatch and the meter stick. Once that your x-position prediction is ready, select "Accept x–prediction" and repeat the previous procedure for the y-position.

5. To start your data collection, click the "Acquire data" button. Select a specific point on the object whose motion you are analyzing. Drag the green cursor over this point and click the "Accept Data Point" button and you will see the data on the appropriate graph on your computer screen, after this the video will advance one frame. Drag again the green cursor over the same point selected on the object and accept the data point. Keep doing this until you have enough data.

6. Click the "Analyze Data" button and fit your data. Decide which equation and constants are the best approximations for your data and accept your "x-fit" and "y-fit".

7. At this level the program will ask you to enter your prediction for velocity in the x- and y-directions. Choose the appropriate equations and give your best approximations for the constants. Accept your v_x- and v_y-predictions and you will see the data on the last two graphs.

8. Fit your data for these velocities in the same way that you did for position. Accept your fit and click the "Print Results" button to view a PDF document of your graphs that can be e-mailed to you and your group members.

Make sure everyone in your group gets the chance to operate the camera and the computer.

Now you are ready to answer some questions that will be helpful for planning your measurements.

What would happen if you calibrate with an object that is not on the plane of the motion? What would happen if you use different points on your car to get your data points?

MEASUREMENT

Now that you have predicted the result of your measurement and have explored how your apparatus behaves, you are ready to make careful measurements. To avoid wasting time and effort, make the minimal measurements necessary to convince yourself and others that you have solved the laboratory problem.

1. Use a stopwatch to measure the time the car takes to travel a known distance. Estimate the uncertainty in time and distance measurements. How many measurements should you make to accurately determine the car's speed?

2. Take a good video of the car's motion using VideoRECORDER. Analyze the video with VideoTOOL to predict and fit functions for position vs. time and velocity vs. time.
    a. Measure some object you can see in the video so that you can tell the analysis program the real size of the video images when it asks you to calibrate. The larger the object you use the less uncertainty there will be in your calibration. Try a meter stick or the car itself.
    b. When you digitize the video, why is it important to click on the same point on the car's image? You might want to use a piece of tape on the car so that you can determine this point consistently.
    c. Be sure to take measurements of the motion of the car in the distorted regions (edges) of the video.
    d. Set the scale for the axes of your graph so you can see the data points as you take them. Use your measurements of total distance the car travels and total time to determine the maximum and minimum value for each axis before taking data.

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 so that you can understand them a month from now. Some future lab problems will require results from earlier ones.

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix A) and with your estimated uncertainty (see Appendix B). Otherwise, the data are nearly meaningless.

ANALYSIS

Data alone is of very limited use. Most interesting quantities are those *derived* from the data, not direct measurements themselves. Your predictions may be qualitatively correct but quantitatively very wrong. To see this you must process your data.

Always complete your data processing (analysis) before you take your next set of data. If something is going wrong, you shouldn't waste time taking a lot of useless data. After analyzing the first collection of data, you may need to modify your measurement plan and re-perform the measurements. If you do, be sure to **record how you changed your plan in your journal**.

Calculate the average speed of the car from your stopwatch and meter stick measurements. Determine if the speed is constant within your measurement uncertainties.

As you analyze data from a video, make sure to *write down* each of the prediction and fit equations for position and velocity.

When you have finished making a fit equation for each graph, rewrite the equations in a table but now matching the *dummy letters* with the appropriate *kinematic quantities*. If you have constant values, assign them the correct units.

Why do you have fewer data points for the velocity vs. time graph than the position vs. time graph?

CONCLUSIONS

After you have analyzed your data, you are ready to answer the experimental problem. State your result in the most general terms supported by your analysis. **This should all be recorded in your journal in one place before moving on to the next problem assigned by your lab instructor. Make sure you compare your result to your prediction.**

Compare the car'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? If not, why? Do your graphs match what you expected for constant velocity motion? What are the limitations on the accuracy of your measurements and analysis?

Do measurements near the edges of the video give the same speed as that as found in the center of the image within the uncertainties of your measurement? What will you do for future measurements?

SIMULATION

If your graphs did not perfectly represent what you expect for constant velocity motion, use the simulation "Lab1Sim" (See *Appendix F* for an introduction to the Simulation Programs) to see the effects of uncertainty in position measurement.

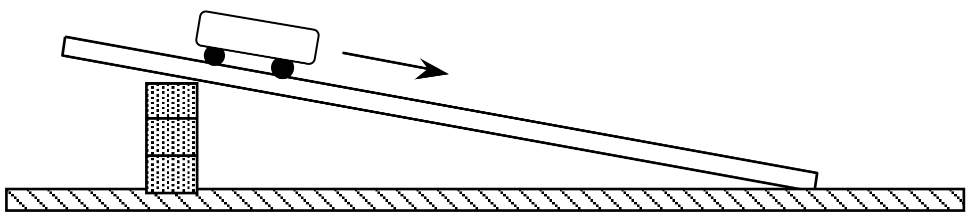
In VideoTOOL and "Lab1Sim", how do you think the computer generates data for a velocity graph? How is this related to the effect of measurement uncertainty on velocity (compared to position) graphs? Why is there one less data point in a *velocity vs. time* graph than in the corresponding *position vs. time* graph?

PROBLEM #2:
MOTION DOWN AN INCLINE

You have a summer job working with a team investigating accidents for the state safety board. To decide on the cause of one accident, your team needs to determine the acceleration of a car rolling down a hill without any brakes. Everyone agrees that the car's velocity increases as it rolls down the hill. Your team's supervisor believes that the car's acceleration also increases as it rolls down the hill. Do you agree? To resolve the issue, you decide to measure the acceleration of a cart moving down an inclined track in the laboratory.

EQUIPMENT

For this problem you will have a stopwatch, meter stick, an adjustable end stop, wood blocks, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL applications). You will also have a PASCO cart to roll down an aluminum track.



Remember that if you have broken or missing equipment, submit a problem report using the icon on the lab computer desktop.

PREDICTION

Sketch the *instantaneous acceleration vs. time graph* for a cart released from rest near the top of an inclined track. Do you think the cart's instantaneous acceleration **increases, decreases,** or **stays the same** (is constant) as it moves down the track? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 2, Sections 2.1 to 2.5.

1. Sketch *instantaneous acceleration vs. time graphs* for a cart moving (1) with a constant acceleration, (2) with increasing acceleration, and (3) with decreasing acceleration. For easy comparison, draw these graphs next to each other. Write down the equation that best represents each of these graphs. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph? Which graph do you think best represents a cart rolling down an incline?

2. Write down a relationship between the acceleration and the velocity of the cart. Use this to sketch a rough graph of *instantaneous velocity vs. time* for each of the three accelerations you drew in question one. Write down an equation that best represents each of these graphs. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph? Can any of the constants be determined from the equation representing the acceleration vs. time graphs? Which graph do you think best represents the velocity of a cart rolling down an incline? Change your prediction if necessary.

3. Write down a relationship between the velocity and the position of the cart. Use this to construct *position vs. time graphs* from the instantaneous velocity graphs for the 3 situations above. Write down an equation that best represents each of these graphs. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph? Can any of the constants be determined from your equation representing the velocity vs. time graphs? Which graph do you think best represents the position of a cart moving down an incline? Change your prediction if necessary.

4. Use the simulation "Lab1Sim" to approximate the conditions of the cart's motion. (See *Appendix F* for a brief explanation of how to use the simulations.) Look at the graphs produced by the simulation. In the real world, friction or air resistance may affect your results. Try increasing and decreasing the friction and air resistance. Uncertainty in position measurements may affect your results. Try increasing and decreasing the measurement uncertainty. Use the simulation to compare the results with and without measurement uncertainties. Looking at these graphs, will reasonable uncertainty affect your ability to test the supervisor's statement?

EXPLORATION

You will use a wood block and an aluminum track to create an incline. What is the best way to change the angle of the incline in a reproducible way? How are you going to measure this angle with respect to the table? *Hint: Think about trigonometry!*

Start with a small angle and with the cart at rest near the top of the track. Observe the cart as it moves down the inclined track. Try a range of angles. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP!** If the angle is too large, you may not get enough video frames, and thus enough position and time measurements to measure the acceleration accurately. If the angle is too small the acceleration may be too small to measure accurately with the precision of your measuring instruments. Select the best angle for this measurement.

When placing the camera, consider which part of the motion you wish to capture. Try different camera positions until you get the best possible video. *Hint: Your video may be easier to analyze if the motion on the video screen is purely horizontal. Why? It could be useful to rotate the camera!*

Where is the best place to release the cart so it does not damage the equipment but has enough of its motion captured on video? **Be sure to catch the cart before it collides with the end stop.** Take a few practice videos using VideoRECORDER and play them back to make sure you have captured the motion you want.

What is the total distance through which the cart rolls? How much time does it take? These measurements will help you set up the graphs for your computer data taking. Write down your measurement plan.

MEASUREMENT

Use a meter stick and a stopwatch to determine the average acceleration of the cart. Under what condition will this average acceleration be equal to the instantaneous acceleration of the cart? How much accuracy from the meter stick and stopwatch is necessary to determine the acceleration with at least two significant figures?

Make a video of the cart moving down the inclined track. *Don't forget to measure and record the angle of the track (with estimated uncertainty). You may use it for later labs.*

Choose an object in your picture for calibration. Choose your coordinate system. Is a rotated coordinate system the easiest to use in this case? Try the measurement with and without a rotated coordinate system.

Why is it important to click on the same point on the car's image to record its position? Estimate your accuracy in doing so.

Make sure you set the scale for the axes of your graph so that you can see the data points as you take them. Use your measurements of total distance the cart travels and total time to determine the maximum and minimum value for each axis before taking data.

Are any points missing from the position vs. time graph? If too many points are missing, make sure that the size of your video frame is optimal (see *Appendix D*). It may also be that your background is too busy.

Make sure everyone in your group gets the chance to operate the camera and the computer.

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix A) and with your estimated uncertainty (see Appendix B). Otherwise, the data are nearly meaningless.

ANALYSIS

In VideoTOOL, choose a fit function to represent the *position vs. time graphs* in the x and y directions. How can you estimate the values of the constants of the function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Choose a fit function to represent the *velocity vs. time graphs* in the x and y directions. How can you calculate the values of the constants of this function from the function representing the position vs. time graph? Check how well this works. You can also estimate the values of the constants from the graph. Just trying to guess the constants can waste a lot of your time. What kinematic quantities do these constants represent?

Why do you have fewer data points for the velocity vs. time graphs compared to the position vs. time graphs? Use the data tables generated by the computer to explain how the computer generates the graphs.

Look at your graphs in VideoTOOL and rewrite all of the fit equations in a table, but now matching the *dummy letters* with the appropriate kinematic quantities. If you have constant values, assign them the correct units and explain their meaning.

From the velocity vs. time graphs determine if the acceleration is constant, increasing, or decreasing as the cart goes down the ramp. Use the fit equation representing the velocity vs. time graph to calculate the acceleration of the cart as a function of time. Make a graph of the acceleration vs. time. Is the average acceleration of the cart equal to its instantaneous acceleration in this case?

Calculate the average acceleration of the cart from your stopwatch and meter stick measurements. Compare the accelerations for the cart you found with your video analysis to your acceleration measurement using a stopwatch.

CONCLUSION

How does a cart accelerate as it moves down an inclined track? In what direction is the acceleration? State your result in the most general terms supported by your analysis. Did your measurements agree with your initial predictions? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

Was your team supervisor right about how a cart accelerates down a hill? If yes, state your result in the most general terms supported by your analysis. If no, describe how you would convince your supervisor.

Address (or re-address if you have already considered them) the following questions. In VideoTOOL and “Lab1Sim”: How do you think the computer generates data for a velocity graph? How is this related to the effect of measurement uncertainty on velocity (compared to position) graphs? Why is there one less data point in a velocity vs. time graph than in the corresponding position vs. time graph?

PROBLEM #3:
MOTION DOWN AN INCLINE WITH AN INITIAL VELOCITY

You have a summer job with a company designing a new bobsled for the U.S. team to use in the next Winter Olympics. You know that the success of the team depends crucially on the initial push of the team members – how fast they can push the bobsled before they jump into the sled. You need to know in more detail how that initial velocity affects the motion of the bobsled. In particular, your boss wants you to determine if the initial velocity of the sled affects its acceleration down the track. To solve this problem, you decide to model the situation using a cart moving down an inclined track.

EQUIPMENT

For this problem you will have a stopwatch, meter stick, a wood block, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL). You will also have a PASCO cart to roll down an inclined aluminum track.

You will slant the ramp at the same angle you used in Problem #2 (Motion Down an Incline) and give the cart a gentle push down the inclined track instead of releasing it from rest.

Remember that if you have broken or missing equipment, submit a problem report using the icon on the lab computer desktop.

PREDICTION

From your results for Problem #2, make a rough sketch of the *acceleration vs. time graph* for a cart released from rest on an inclined track. On the same graph sketch how you think the *acceleration vs. time graph* will look when the cart is given an initial velocity down the track.

Do you think the cart launched down the inclined track will have a **larger acceleration**, **smaller acceleration**, or **the same acceleration** as the cart released from rest? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 2, Sections 2.1 to 2.5.

1. Sketch a graph of the *instantaneous acceleration vs. time graph* for a cart moving down the inclined track **after** an initial push. Next to this graph, sketch an instantaneous acceleration vs. time graph for a cart released from rest using the same scale for the time axes. Explain your reasoning for each graph. Write down an equation for each graph. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

2. Use your acceleration vs. time graphs to sketch *instantaneous velocity vs. time graphs* for each case using the same scale for the time axes. Write down an equation for each graph. If there are

constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graph? Can any of the constants be determined from the equations representing the acceleration vs. time graphs?

3. Use your velocity vs. time graphs to sketch *instantaneous position vs. time graphs* for each case using the same scale for the time axes. Write down an equation for each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graph? Can any of these constants be determined from the equations representing the acceleration vs. time or velocity vs. time graphs?
4. Use the simulation "Lab1Sim" to explore the approximate the conditions of your experiment. Use a range of initial velocities and check the affect on the graphs. If you believe air resistance or friction affected the results, explore the effects of each with the simulation. If you believe that uncertainty in position measurements may affect your results, use the simulation to compare the results with and without error. Remember to check for the effects of measurement uncertainty in your VideoTOOL measurements later in lab.

EXPLORATION

Slant the track at the ***same*** angle you used in Problem #2: Motion Down an Incline.

Determine the best way to gently launch the cart down the track in a consistent way without breaking the equipment. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP!**

When placing the camera, consider which part of the motion you wish to capture. Try different camera positions until you get the best possible video. *Hint: Your video may be easier to analyze if the motion on the video screen is purely horizontal. Why? It could be useful to rotate the camera!*

What is the total distance through which the cart rolls? How much time does it take? These measurements will help you set up the graphs for your computer data taking. Write down your measurement plan.

MEASUREMENT

Using the plan you devised in the Exploration section, make a video of the cart moving down the track at your chosen angle. Make sure you get enough points for each part of the motion to determine the behavior of the acceleration. *Don't forget to measure and record the angle (with estimated uncertainty).*

Choose an object in your picture for calibration. Choose your coordinate system. Is a rotated coordinate system the easiest to use in this case? Why is it important to click on the same point on the car's image to record its position? Estimate your accuracy in doing so.

Make sure you set the scale for the axes of your graph so that you can see the data points as you take them. Use your measurements of total distance the cart travels and total time to determine the maximum and minimum value for each axis before taking data.

Make sure everyone in your group gets the chance to operate the camera and the computer.

ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the *position vs. time graphs* in the x and y directions. How can you estimate the values of the constants of the function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Choose a fit function to represent the *velocity vs. time graphs* in the x and y directions. How can you calculate the values of the constants of this function from the function representing the position vs. time graph? Check how well this works. You can also estimate the values of the constants from the graph. Just trying to guess the constants can waste a lot of your time. What kinematic quantities do these constants represent? Are any of the quantities related to the position vs. time graphs?

From either the velocity or position versus time graph, determine the acceleration of the cart as a function of time as it goes down the ramp **after** the initial push. Make a graph of that function.

CONCLUSIONS

Did the cart launched down the inclined track have a **larger acceleration**, **smaller acceleration**, or **the same acceleration** as the cart released from rest?

Did your measurements agree with your initial predictions? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

What will you tell your boss? Does the *acceleration* of the bobsled down the track depend on the initial velocity the team can give it? Does the *velocity* of the bobsled down the track depend on the initial velocity the team can give it? State your result in the most general terms supported by your analysis.

If your data did not match your expectations, you should use the simulation to explore what could have happened. A scheme for doing so is outlined at the end of Problem 2 in this lab.

PROBLEM #4:
MOTION UP AND DOWN AN INCLINE

A proposed ride at the Valley Fair amusement park launches a roller coaster car up an inclined track. Near the top of the track, the car reverses direction and rolls backwards into the station. As a member of the safety committee, you have been asked to compute the acceleration of the car throughout the ride and determine if the acceleration of an object moving up a ramp is different from that of an object moving down the same ramp. To check your results, you decide to build a laboratory model of the ride.

EQUIPMENT

You will have a stopwatch, meter stick, an end stop, a wood block, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL). You will also have a PASCO cart to roll on an inclined aluminum track.

Remember that if you have broken or missing equipment, submit a problem report using the icon on the lab computer desktop.

PREDICTION

Based on your results for Problem #2, make a rough sketch of the *acceleration vs. time graph* for the cart moving **down** the inclined track. On the same graph, sketch how you think the *acceleration vs. time graph* will look for the cart moving **up** the track at the same angle.

Do you think the *magnitude* of the cart's acceleration as it moves **up** an inclined track will increase, decrease, or stay the same? What about the *magnitude* of the cart's acceleration as it moves **down** a track inclined at the same angle? Explain your reasoning. Does the *direction* of the cart's acceleration change throughout its motion, or stay the same? Remember, for a direct comparison to Problem #2, you should use the same coordinate system.

WARM-UP

Read: Serway & Vuille Chapter 2, Sections 2.1 to 2.5

1. Draw a picture of the cart rolling **up** the ramp. Draw arrows above the cart to show the direction of the velocity and the direction of the acceleration. Choose a coordinate system and include this in your picture.

2. Draw a new picture of the cart rolling **down** the ramp. Draw arrows above the cart to show the direction of the velocity and the direction of the acceleration. Label your coordinate system.

3. Sketch a graph of the *instantaneous acceleration vs. time* for the entire motion of the cart as it rolls up and then back down the track after an initial push. Label the instant where the cart reverses its motion near the top of the track. Explain your reasoning. Write down the equation(s) that best represents this graph. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

4. From your acceleration vs. time graph, answer Warm-up question 3. for *instantaneous velocity vs. time* instead. *Hint: Be sure to consider both the **direction** and the **magnitude** of the velocity as the cart rolls up and down the track.* Use the same scale for your time axes. Can any of the constants in the velocity equation(s) be determined from the constants in the acceleration equation(s)?

5. Now do the same for *position vs. time*.

6. Use the simulation "Lab1Sim" to approximate the conditions of the cart's motion. (See *Appendix F* for a brief explanation of how to use the simulations.) Look at the graphs produced by the simulation. If you believe friction or air resistance may affect your results, explore the effects of each with the simulation. If you believe that uncertainty in position measurements may affect your results, use the simulation to compare the results with and without error. Note the difference in the effect in the *position vs. time* and *velocity vs. time* graph. Remember to check for the effects of measurement uncertainty in your VideoTOOL measurements later in lab.

EXPLORATION

What is the best way to change the angle of the inclined track in a reproducible way? How are you going to measure this angle with respect to the table? *Hint: Think about trigonometry*. How steep of an incline do you want to use?

Start the cart up the track with a gentle push. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP ON ITS WAY DOWN!** Observe the cart as it moves up the inclined track. At the instant the cart reverses direction, what is its velocity? Its acceleration? Observe the cart as it moves down the inclined track. Do your observations agree with your prediction? If not, this is a good time to discuss with your group and modify your prediction.

When placing the camera, consider which part of the motion you wish to capture. Try different camera positions until you get the best possible video. *Hint: Your video may be easier to analyze if the motion on the video screen is purely horizontal. Why? It could be useful to rotate the camera!*

Try several different angles. If the angle is too large, the cart may not go up very far and give you too few video frames for the measurement. If the angle is too small it will be difficult to measure the acceleration. Determine the useful range of angles for your track. Take a few practice videos and play them back to make sure you have captured the motion you want.

What is the total distance through which the cart rolls? How much time does it take? These measurements will help you set up the graphs for your computer data taking. Write down your measurement plan.

MEASUREMENT

Follow your measurement plan from the Exploration section to make a video of the cart moving up and then down the track at your chosen angle. Make sure you get enough points for each part of the motion to determine the behavior of the acceleration. Record the time duration of the cart's trip, and the distance traveled. *Don't forget to measure and record the angle (with estimated uncertainty).*

Choose an object in your picture for calibration. Choose your coordinate system. Is a rotated coordinate system the easiest to use in this case?

Why is it important to click on the same point on the car's image to record its position? Estimate your accuracy in doing so.

Make sure you set the scale for the axes of your graph so that you can see the data points as you take them. Use your measurements of total distance the cart travels and total time to determine the maximum and minimum value for each axis before taking data.

ANALYSIS

From the time given by the stopwatch (or the time stamp on the video) and the distance traveled by the cart, calculate the average acceleration. Estimate the uncertainty.

Using VideoTOOL, determine the fit functions that best represent the *position vs. time graphs* in the x and y directions. How can you estimate the values of the constants of the function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent? Can you tell from your graph where the cart reaches its highest point?

Do the same for the *velocity vs. time graphs* in the x and y directions. Compare these functions with the position vs. time functions. What was the velocity when the cart reached its maximum height on the track? How do you know?

Determine the acceleration as a function of time as the cart goes up and then down the ramp. Make a graph of the *acceleration vs. time*. Can you tell from your graph where the cart reaches its highest point? Is the average acceleration of the cart equal to its instantaneous acceleration in this case?

As you analyze your video, *make sure everyone in your group gets the chance to operate the computer.*

Compare the acceleration function you just graphed with the average acceleration you calculated from the time and the distance the cart traveled.

CONCLUSIONS

How do your position vs. time and velocity vs. time graphs compare with your answers to the warm-up and the prediction? What are the limitations on the accuracy of your measurements and analysis?

How did the acceleration of the cart **up** the track compare to the acceleration **down** the track? Did the acceleration change magnitude or direction at any time during its motion? Was the acceleration zero, or nonzero at the maximum height of its motion? Explain how you reached your conclusions about the cart's motion.

If your data did not match your expectations, you should go back and use the simulation to explore what could have happened. A scheme for doing so is outlined at the end of Problem 2 in this lab.

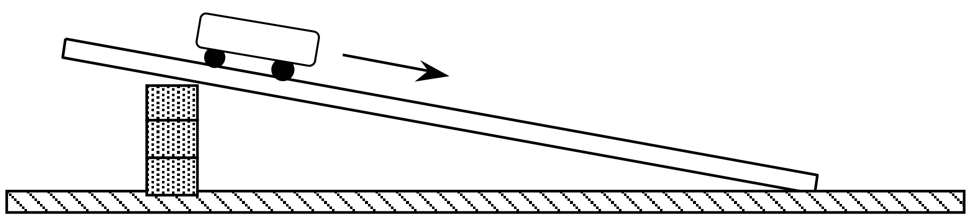
PROBLEM #5:
MASS AND MOTION DOWN AN INCLINE

Before the end of summer arrives, you and some friends drive to a local amusement park to ride the new roller coaster. During the busy afternoon, the roller coaster is always full of people. But as the day comes to an end and the park is less crowded, you want to go down the roller coaster once more. However, your friends say that the ride down the first hill won't be as fast as it was earlier, because there is less mass in the roller coaster, so they don't want to go. What do you think? To determine how the acceleration of an object down a ramp depends on its mass, you decide to model the situation using a cart moving down an inclined track.

EQUIPMENT

You will have a stopwatch, meter stick, an adjustable end stop, a wood block, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL). You will also have a PASCO cart to roll down an inclined aluminum track and a mass set to vary the mass of the cart.

For this problem you will slant the ramp at the same angle you used in Problem #2 (Motion Down an Incline) and release the cart from rest.



PREDICTION

Make a sketch of how you think the *acceleration vs. mass graph* will look for carts with different masses released from rest from the top of an inclined track.

Do you think the acceleration of the cart **increases**, **decreases**, or **stays the same** as the mass of the cart increases? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 2, Sections 2.1 to 2.5

1. Sketch a graph of how you would expect an instantaneous acceleration vs. time graph to look for a cart released from rest on an inclined track. Next to this graph, sketch a new graph of the acceleration vs. time for a cart with a much larger mass. Explain your reasoning. Write down the equation(s) that best represent each of these graphs. If there are constants in your

equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

2. Sketch a graph of instantaneous velocity vs. time for each case. Use the same scale for the time axes as the acceleration graphs. Write down the equation(s) for each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graph? Can any of the constants be determined from the equations representing the acceleration vs. time graphs?
3. Now do the same for position vs. time. Can any of the constants in your functions be determined from the equations representing the acceleration vs. time or velocity vs. time graphs?
4. Use the simulation “Lab1Sim” to explore the approximate the conditions of your experiment. Use a range of values for the mass of the cart and check the affect on the graph.

EXPLORATION

Slant the track at the *same* angle you used in Problem #2: Motion Down an Incline.

Observe the motion of several carts of different mass when released from rest at the top of the track. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP!** From your estimate of the size of the effect, determine the range of mass that will give the best results in this problem. Determine the first two masses you should use for the measurement.

How do you determine how many different masses do you need to use to get a conclusive answer? How will you determine the uncertainty in your measurements? How many times should you repeat these measurements? Explain.

When placing the camera, consider which part of the motion you wish to capture. Try different camera positions until you get the best possible video. *Hint: Your video may be easier to analyze if the motion on the video screen is purely horizontal. Why? It could be useful to rotate the camera!*

What is the total distance through which the cart rolls? How much time does it take? These measurements will help you set up the graphs for your computer data taking. Write down your measurement plan.

Make sure everyone in your group gets the chance to operate the camera and the computer.

MEASUREMENT

Using the measurement plan you devised in the Exploration section, make a video of the cart moving down the track at your chosen angle. Make sure you get enough points for each part of the motion to determine the behavior of the acceleration. Record the time duration of the cart’s trip, and the distance traveled. *Don't forget to measure and record the angle (with estimated uncertainty).*

Choose an object in your picture for calibration. Choose your coordinate system. Is a rotated coordinate system the easiest to use in this case?

Why is it important to click on the same point on the car's image to record its position? Estimate your accuracy in doing so.

Make sure you set the scale for the axes of your graph so that you can see the data points as you take them.

Make several videos with carts of different mass to check your qualitative prediction. If you analyze your data from the first two masses you use *before* you make the next video, you can determine which mass to use next. As usual you should minimize the number of measurements you need.

ANALYSIS

From the time given by the stopwatch (or the time stamp on the video) and the distance traveled by the cart, calculate the average acceleration. Estimate the uncertainty.

Using VideoTOOL, determine the fit functions that best represent the *position vs. time graphs* in the x and y directions. How can you estimate the values of the constants of the function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the *velocity vs. time graphs* in the x and y directions. Compare these functions with the position vs. time functions.

Determine the acceleration as the cart goes down the track for different masses. Make a graph of the *acceleration vs. mass*. Is the average acceleration of the cart equal to its instantaneous acceleration in this case?

As you analyze your video, *make sure everyone in your group gets the chance to operate the computer.*

Compare the acceleration of the cart you found from the video analysis with the average acceleration you calculated from the time and the distance the cart traveled.

Do you have enough data to convince others of your conclusion about how the acceleration of the cart depends on its mass? If the acceleration does indeed depend on the mass of the cart, what might be causing this difference?

CONCLUSION

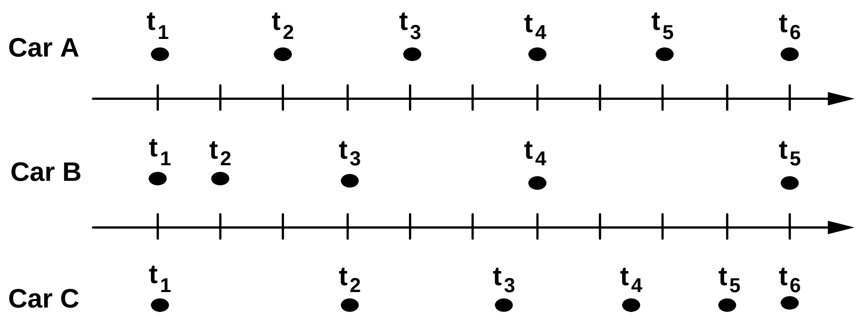
How will you respond to your friend? Does the *acceleration* down a nearly frictionless roller coaster depend on the mass of the people in the coaster? Does the *velocity* of the coaster depend on its mass? (Will the roller coaster be just as fast with fewer people?) State your result in the most general terms supported by your analysis.

Did your measurements of the cart agree with your initial predictions? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

If your data did not match your expectations, you should use the simulation to explore what could have happened. *A scheme for doing so is outlined at the end of Problem 2 in this lab.*

☑ CHECK YOUR UNDERSTANDING:

1. Suppose you are looking down from a helicopter at three cars traveling in the same direction along the freeway. The positions of the three cars every 2 seconds are represented by dots on the diagram below.



a. At what clock reading (or time interval) do Car A and Car B have very nearly the same speed? Explain your reasoning.

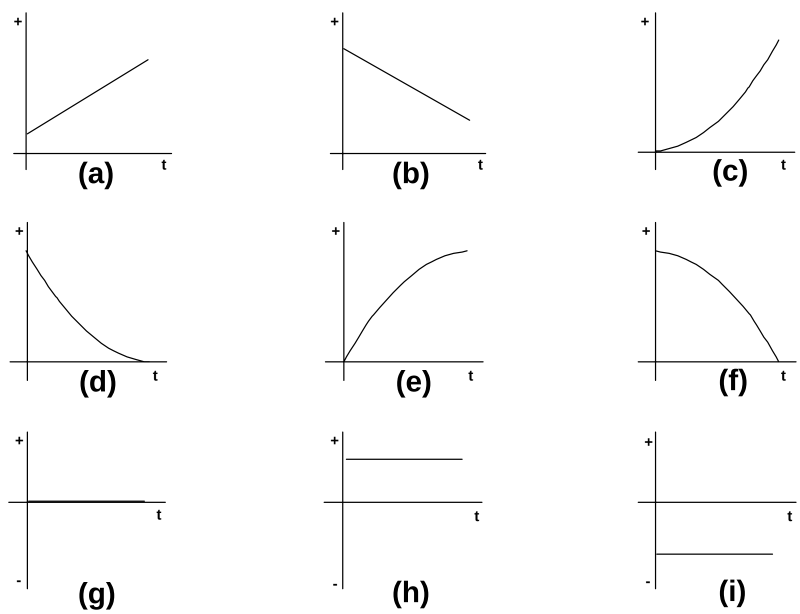
b. At approximately what clock reading (or readings) does one car pass another car? In each instance you cite, indicate which car, A, B or C, is doing the overtaking. Explain your reasoning.

c. Suppose you calculated the average velocity for Car B between t_1 and t_5. Where was the car when its instantaneous velocity was equal to its average velocity? Explain your reasoning.

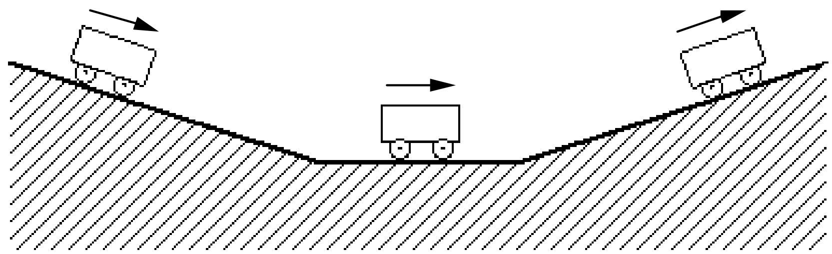
d. Which graph below best represents the position-versus-time graph of Car A? Of Car B? Of car C? Explain your reasoning.

e. Which graph below best represents the *instantaneous velocity vs. time graph* of Car A? Of Car B? Of car C? Explain your reasoning. (HINT: Examine the distances traveled in successive time intervals.)

f. Which graph below best represents the *instantaneous acceleration vs. time graph* of Car A? Of Car B? Of car C? Explain your reasoning.



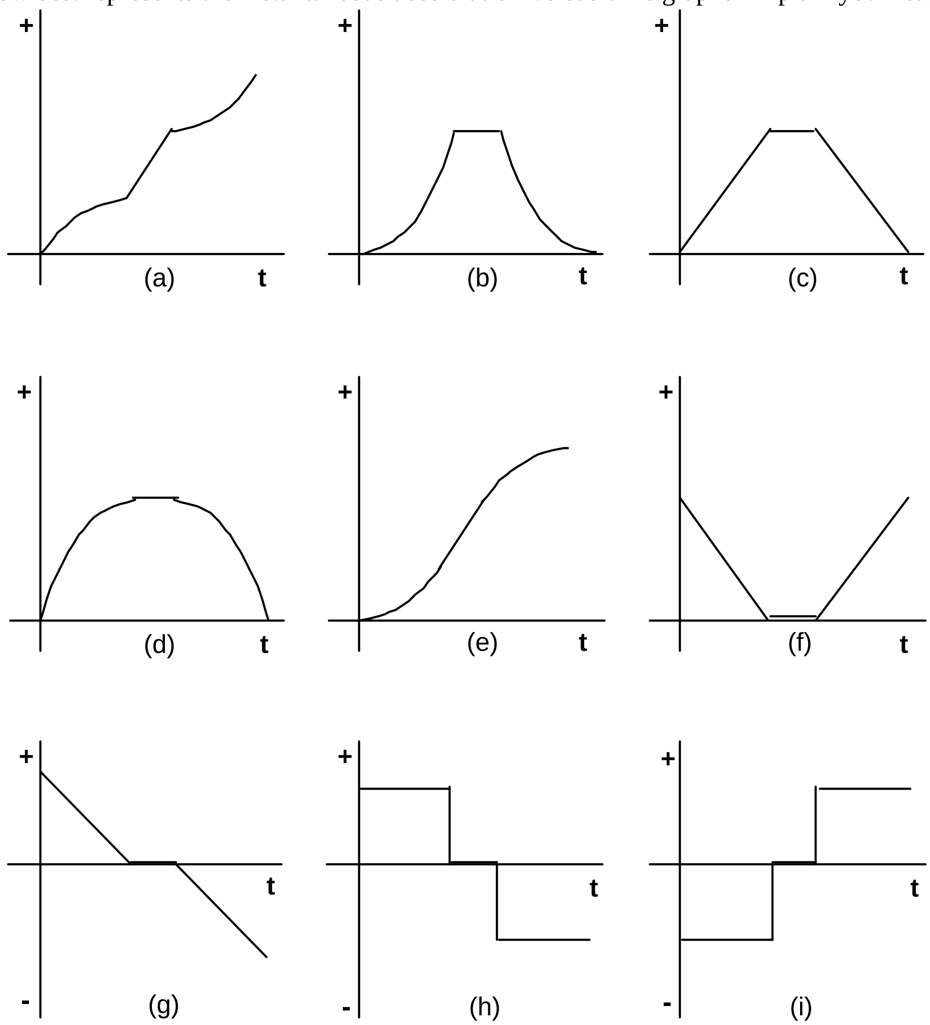
2. A mining cart starts from rest at the top of a hill, rolls down the hill, over a short flat section, then back up another hill, as shown in the diagram above. Assume that the friction between the wheels and the rails is negligible.



a. Which graph below best represents the position-versus-time graph? Explain your reasoning.

b. Which graph below best represents the instantaneous velocity-versus-time graph? Explain your reasoning.

c. Which graph below best represents the instantaneous acceleration-versus-time graph? Explain your reasoning.



TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory I

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ______________________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: __________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.