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 objects' motion. Determining these kinematics quantities (position, time, velocity, and acceleration) under different conditions allows you to develop an intuition about relationships among them. 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 Paul M. Fishbane: 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.
- Determine the derivative of a quantity from the appropriate graph.
- Use the definitions of sin ?, cos ?, and tan ? 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 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 questions** 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 an internship managing a network of closed-circuit “Freeway cameras” for MnDOT Metro Traffic Engineering, Freeway Operations. Your boss wants to use images from those cameras to determine velocities of cars, particularly during unusual circumstances such as traffic accidents. Your boss knows that you have taken physics and asks you to prepare a presentation. During the presentation, you must demonstrate possibilities for determining a car’s average velocity from graphs of its position vs. time, instantaneous velocity vs. time, and instantaneous acceleration vs. time. You decide to model the situation with a small digital camera and a toy car that 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.

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.

If equipment is missing or broken, please submit a problem report using the icon on the lab computer desktop. If you are unable to, please ask your TA to submit a problem report.

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 warm up questions, you should complete the warm up questions *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.**

Sketch graphs of position vs. time, instantaneous velocity vs. time, and instantaneous acceleration vs. time for the toy car. How could you determine the speed of the car from each graph?

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

Warm Up Questions are a series of questions intended to help you solve the problem stated in the opening paragraphs. They 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 and time should be taken to complete the labSims before each lab period.**

Read: Fishbane Chapter 2. Sections 2.1-2.4

To find schemes for determining a car's velocity, you need to think about representing its motion. 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. Write an equation that describes this graph. What is the meaning of each quantity in your equation? In terms of the quantities in your equation, what is the velocity?

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. In this case, what can you say about the velocity?

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. What is the relationship between this graph and the instantaneous velocity versus time graph? Write down an equation that describes this graph. What is the meaning of each quantity in your equation? In terms of the quantities in your equation, what is the velocity?

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. 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 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 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 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 on the desktop.

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 at least once the *Appendix D*).

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 predictions for velocity in 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 get a hard copy of your graphs.

   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. Record the time the car takes to travel a known distance. Estimate the uncertainty in time and distance measurements.

2. Take a good video of the car's motion. Analyze the video with VideoTOOL to predict and fit functions for *position vs. time* and *velocity vs. time.*

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.

ANALYSIS

Data by itself 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 data, you may need to modify your measurement plan and re-do the measurements. If you do, be sure to **record the changes in 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, be 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 *kinetic quantities*. If you have constant values, assign them the correct units.

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. Did your measurements and graphs agree with your answers to the Warm Up Questions? 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?

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 job working with a team studying accidents for the state safety board. To investigate 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 but your team's supervisor believes that the car's acceleration also increases uniformly as it rolls down the hill. To test your supervisor's idea, you determine the acceleration of a cart as it moves down an inclined track in the laboratory.

EQUIPMENT

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

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

PREDICTION

Consider the questions printed in italics, below, to make a rough sketch of how you expect the *acceleration vs. time* graph to look for a cart under the conditions given in the problem. Explain your reasoning.

Do you think the cart's acceleration ***changes*** *as it moves down the track? If so, how does the acceleration change (increase or decrease)? Or, do you think the acceleration is constant (does not change) as the cart moves down the track?*

WARM UP

Read: Fishbane Chapter 2. Sections 2.1-2.4

The following questions should help you to explore three different scenarios involving the physics given in the problem.

1. How would you expect an *instantaneous acceleration vs. time graph* to look for a cart moving with a constant acceleration? With a uniformly increasing acceleration? With a uniformly decreasing acceleration? Make a rough sketch of the graph *for each possibility* and explain your reasoning. To make the comparison easier, it is useful to draw these graphs next to each other. Remember to assign labels and units to your axes. Write down an equation for

each graph. Explain what the symbols in each of the equations mean. What quantities in these equations can you determine from your graph?

2. Write down the relationship between the acceleration and the velocity of the cart. Use that relationship to construct an instantaneous velocity versus time graph just below each of your acceleration versus time graphs from question 1, with the same scale for each time axis. Write down an equation for each graph. Explain what the symbols in each of the equations mean. What quantities in these equations can you determine from your graph?
3. Write down the relationship between the velocity and the position of the cart. Use that relationship to construct a position versus time graph just below each of your velocity versus time graphs from question 2, with the same scale for each time axis. Write down an equation for each graph. Explain what the symbols in each of the equations mean. What quantities in these equations can you determine from your graph?
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

In order to have an incline you will use the wood block and the aluminum track. This set up will give you an angle with respect to the table. How are you going to measure this angle? *Hint: Think 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.

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.**

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. Make sure you have a good object in your video to calibrate with.

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.

You may wish to follow the steps given in the "Exploration" section of problem 1 to work with your video. Write down your measurement plan.

MEASUREMENT

Follow the measurement plan you wrote down.

When you have finished making measurements, you should have printouts of position and velocity graphs and good records (including uncertainty) of: your determination of the incline angle, the time it takes the cart to roll a known distance down the incline starting from rest, the length of the cart, and prediction and fit equations for position and velocity.

Make sure that every one gets the chance to operate the computer.
Record all of your measurements; you may be able to re-use some of them in other lab problems.

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 is nearly meaningless.

ANALYSIS

Calculate the cart's average acceleration from the distance and time measurements you made with a meter stick and stopwatch.

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

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

Compare the accelerations for the cart you found with your video analysis to your acceleration measurement using a stopwatch.

CONCLUSION

How do the graphs of your measurements compare to your predictions?

Was your boss right about how a cart accelerates down a hill? If yes, state your result in the most general terms supported by your analysis. If not, describe how you would convince your boss of your conclusions. What are the limitations on the accuracy of your measurements and analysis?

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 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 describe the acceleration of the car throughout the ride. (The launching mechanism has been well tested. You are only concerned with the roller coaster's trip up and back down.) To test your expectations, you decide to build a laboratory model of the ride.

EQUIPMENT

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

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

PREDICTION

Make a rough sketch of how you expect the acceleration vs. time graph to look for a cart with the conditions discussed in the problem. The graph should be for the entire motion of going up the track, reaching the highest point, and then coming down the track.

Do you think the acceleration of the cart moving up an inclined track will be ***greater than****,* ***less than****, or* ***the same as*** *the acceleration of the cart moving down the track? What is the acceleration of the cart at its highest point? Explain your reasoning.*

WARM UP

Read: Fishbane Chapter 2. Sections 2.1-2.4

The following questions should help you examine the consequences of your prediction.

1. Sketch a graph of the *instantaneous acceleration vs. time graph* you expect for the cart as it rolls up and then back down the track **after** an initial push. Sketch a second *instantaneous acceleration vs. time graph* for a cart moving up and then down the track with the direction of a constant acceleration always down along the track **after** an initial push. On each graph, label the instant where the cart reverses its motion near the top of the track. Explain your reasoning for each graph. Write down the equation(s) that best represents each graph. If

there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs?

2. Write down the relationship between the acceleration and the velocity of the cart. Use that relationship to construct an *instantaneous velocity vs. time graph* just below each of acceleration vs. time graph from question 1, with the same scale for each time axis. (The connection between the derivative of a function and the slope of its graph will be useful.) On each graph, label the instant where the cart reverses its motion near the top of the track. Write an equation for each graph. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs? Can any of the constants be determined from the constants in the equation representing the acceleration vs. time graphs?

3. Write down the relationship between the velocity and the position of the cart. Use that relationship to construct an *instantaneous position vs. time graph* just below each of your velocity vs. time graphs from question 2, with the same scale for each time axis. (The connection between the derivative of a function and the slope of its graph will be useful.) On each graph, label the instant where the cart reverses its motion near the top of the track. Write down an equation for each graph. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs? Can any of the constants be determined from the constants in the equations representing velocity vs. time graphs?

4. Which graph do you think best represents how position of the cart will change with time? Adjust your prediction if necessary and explain your reasoning.

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. 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? (Think about trigonometry.)

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, discuss it with your group.

Where is the best place to put the camera? Which part of the motion do you wish to capture?

Try different angles. **Be sure to catch the cart before it collides with the end stop at the bottom of the track.** If the angle is too large, the cart may not go up very far and will give you too few video frames for the measurement. If the angle is too small it will be difficult to measure the acceleration. Take a practice video and play it back to make sure you have captured the motion you want (see the "Exploration" section in Problem 1, and appendix D, for hints about using the camera and VideoRECORDER / VideoTOOL.) *Hint: To analyze motion in only one dimension (like in the previous problem) rather than two dimensions, it could be useful to rotate the camera!*

What is the total distance through which the cart rolls? Using your stopwatch, how much time does it take? These measurements will help you set up the graphs for your computer data taking, and can provide for a check on your video analysis of the cart's motion.

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan to make a video of the cart moving up and then down the track at your chosen angle. Record the time duration of the cart's trip, and the distance traveled. 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).*

Work through the complete set of calibration, prediction equations, and fit equations for a single (good) video before making another video.

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

ANALYSIS

From the time given by the stopwatch and the distance traveled by the cart, calculate its average acceleration. Estimate the uncertainty.

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

Can you tell from your graph where the cart reaches its highest point?

From the *velocity vs. time graph* determine if the acceleration changes as the cart goes up and then down the ramp. Use the *function* representing the velocity vs. time graph to calculate the acceleration of the cart as a function of time. Make a graph of that function. Can you tell from this *instantaneous acceleration vs. time graph* where the cart reaches its highest point? Is the average acceleration of the cart equal to its instantaneous acceleration in this case?

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

CONCLUSION

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

Did the cart have the same acceleration throughout its motion? Did the acceleration change direction? Was the acceleration zero at the top of its motion? Describe the acceleration of the cart through its entire motion **after** the initial push. Justify your answer with kinematics arguments and experimental results. If there are any differences between your predictions and your experimental results, describe them and explain why they occurred.

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 #4:
MOTION DOWN AN INCLINE WITH NON-ZERO INITIAL VELOCITY

Because of your physics background, you have a summer job with a company that is 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 ramp. To solve this problem, you decide to model the situation using a cart moving down an inclined track.

EQUIPMENT

You will have a stopwatch, a meter stick, an end stop, a wood block, a video camera and a computer with a video analysis application written in LabVIEW™. You will also have a cart to roll down an inclined track.

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

PREDICTION

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?

WARM UP

Read: Fishbane Chapter 2. Read carefully Sections 2-3, 2-4 and Examples 2-7, 2-8.

The following questions should help you (a) understand the consequences of your prediction and (b) interpret your measurements.

1. Sketch a graph of *instantaneous acceleration vs. time graph* when the cart rolls down the track **after** an initial push (your graph should begin **after** the initial push.) Compare this to an *instantaneous acceleration vs. time graph* for a cart released from rest. (To make the comparison easier, draw the graphs next to each other.) Explain your reasoning for each graph. Write down the equation(s) that best represents each of the graphs. If there are constants in your equations, what kinematics quantities do they represent? How would you determine the constants from your graphs?

2. Write down the relationship between the acceleration and the velocity of the cart. Use that relationship to construct an *instantaneous velocity vs. time graph*, **after** an initial push, just

below each of your *acceleration vs. time graphs* from question 1. Use the same scale for your time axes. (The connection between the derivative of a function and the slope of its graph will be useful.) Write down the equation that best represents each graph. If there are constants in your equations, what kinematics quantities do they represent? How would you determine the constants from your graphs? Can any of the constants be determined from the equations representing the *acceleration vs. time graphs*?

3. Write down the relationship between the velocity and the position of the cart. Use that relationship to construct a *position vs. time graph*, **after** an initial push, just below each *velocity vs. time graph* from question 2. Use the same scale for your time axes. (The connection between the derivative of a function and the slope of its graph will be useful.) Write down the equation that best represents each graph. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs? Can any of these constants be determined from the equations representing the *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 an angle. (Hint: Is there an angle that would allow you to reuse some of your measurements and calculations from other lab problems?)

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!**

Where is the best place to put the camera? Is it important to have most of the motion in the center of the picture? Which part of the motion do you wish to capture? Try taking some videos before making any measurements. **Be sure to catch the cart before it collides with the end stop at the bottom of the track.**

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 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.

ANALYSIS

Choose a function to represent the *position vs. time* graph. How can you estimate the values of the constants of the function from the graph? You may waste a lot of time if you just try to guess the constants. What kinematics quantities do these constants represent?

Choose a function to represent the velocity versus time graph. How can you calculate the values of the constants of this function from the function representing the position versus 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 kinematics quantities do these constants represent?

From the velocity versus time graph, determine the acceleration as the cart goes down the ramp **after** the initial push. Use the function representing the velocity versus time graph to calculate the acceleration of the cart as a function of time. Make a graph of that function.

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

CONCLUSIONS

Look at the graphs you produced through video analysis. How do they compare to your answers to the warm up questions and your predictions? Explain any differences. 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 #5:
MASS AND MOTION DOWN AN INCLINE

Your neighbors' child has asked for your help in constructing a soapbox derby car. In the soapbox derby, two cars are released from rest at the top of a ramp. The one that reaches the bottom first wins. The child wants to make the car as heavy as possible to give it the largest acceleration. Is this plan reasonable?

EQUIPMENT

You will have a stopwatch, a meter stick, an end stop, a wood block, a video camera and a computer with a video analysis application written in LabVIEW™. You will also have a cart to roll down an inclined track and additional cart masses to add to the cart. Submit any problems using the icon on the desktop of the lab computers.

PREDICTION

Do you think that increasing the mass of the cart increases, decreases, or has no effect on the cart's acceleration?

WARM UP

Read: Fishbane Chapter 2. Read carefully Sections 2-3, 2-4 and Examples 2-7, 2-8.

The following questions should help you (a) understand the consequences of your prediction and (b) interpret your measurements.

1. Make a sketch of the *acceleration vs. time graph* for a cart released from rest on an inclined track. On the same axes sketch an *acceleration vs. time graph* for a cart on the same incline, but with a much larger mass. Explain your reasoning. Write down the equations that best represent each of these accelerations. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs?

2. Write down the relationship between the acceleration and the velocity of the cart. Use that relationship to construct an *instantaneous velocity vs. time* graph for each case. (The connection between the derivative of a function and the slope of its graph will be useful.) Write down the equation that best represents each of these velocities. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs? Can any of these constants be determined from the equations representing the accelerations?

3. Write down the relationship between the velocity and the position of the cart. Use that relationship to construct a *position vs. time* graph for each case. The connection between the derivative of a function and the slope of its graph will be useful. Write down the equation that best represents each of these positions. If there are constants in your equations, what kinematics quantities do they represent? How would you determine these constants from your graphs? Can any of these constants be determined from the equations representing the velocities?

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 an angle. (Hint: Is there an angle that would allow you to reuse some of your measurements and calculations from other lab problems?)

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.

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 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 the total time to determine the maximum and minimum value for each axis before taking data.

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

Choose a function to represent the *position vs. time* graph. How can you estimate the values of the constants of the function from the graph? You may waste a lot of time if you just try to guess the constants. What kinematics quantities do these constants represent?

Choose a function to represent the *velocity vs. time* graph. 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 kinematics quantities do these constants represent?

From the *velocity vs.time* graph determine the acceleration as the cart goes down the ramp. Use the function representing the velocity-versus-time graph to calculate the acceleration of the cart as a function of time.

Make a graph of the cart's acceleration down the ramp as a function of the cart's mass. Do you have enough data to convince others of your conclusion about how the acceleration of the cart depends on its mass?

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

CONCLUSION

Did your measurements of the cart's motion 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 the neighbors' child? Does the **acceleration** of the car down its track depend on its total mass? Does the **velocity** of the car down its track depend on its mass? 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 #6: MOTION ON A LEVEL SURFACE WITH AN ELASTIC CORD

You are helping a friend design a new ride for the State Fair. In this ride, a cart is pulled from rest along a long straight track by a stretched elastic cord (like a bungee cord). Before building it, your friend wants to you to determine if this ride will be safe. Since sudden changes in velocity can lead to whiplash, you decide to find out how the acceleration of the cart changes with time. In particular, you want to know if the greatest acceleration occurs when the sled is moving the fastest or at some other time. To test your prediction, you decide to model the situation in the laboratory with a cart pulled by an elastic cord along a level surface.

EQUIPMENT

You will have a stopwatch, a meter stick, a scissor, a video camera and a computer with a video analysis application written in LabVIEW™. You will also have a cart to roll on a level track. You can attach one end of an elastic cord to the cart and the other end of the elastic cord to an end stop on the track. Submit any problems using the icon on the lab computers desktop.

PREDICTION

Make a qualitative sketch of how you expect the *acceleration vs. time* graph to look for a cart pulled by an elastic cord. Just below that graph make a qualitative graph of the *velocity vs. time* on the same time scale. Identify on each graph where the velocity is largest and where the acceleration is largest.

WARM UP

Read: Fishbane Chapter 2. Read carefully Section 2-4.

The following questions should help you (a) understand the consequences of your prediction and (b) interpret your results.

1. Make a qualitative sketch of how you expect an *acceleration vs. time graph* to look for a cart pulled by an elastic cord. Explain your reasoning. For a comparison, make an *acceleration vs. time graph* for a cart moving with constant acceleration. Point out the differences between the two graphs.

2. Write down the relationship between the acceleration and the velocity of the cart. Use that relationship to construct a qualitative *velocity vs. time graph* for each case. (The connection between the derivative of a function and the slope of its graph will be useful.) Point out the differences between the two *velocity vs. time* graphs.

3. Write down the relationship between the velocity and the position of the cart. Use that relationship to construct a qualitative *position vs. time* graph for each case. (The connection between the derivative of a function and the slope of its graph will be useful.) Point out the differences between the two graphs.

EXPLORATION

Test that the track is level by observing the motion of the cart. Attach an elastic cord to the cart and track. Gently move the cart along the track to stretch out the elastic. **Be careful not to stretch the elastic too tightly.** Start with a small stretch and release the cart. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP!** Slowly increase the starting stretch until the cart's motion is long enough to get enough data points on the video, but does not cause the cart to come off the track or snap the elastic.

Practice releasing the cart smoothly and capturing videos.

Write down your measurement plan.

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

MEASUREMENT

Using the plan you devised in the exploration section, make a video of the cart’s motion. Make sure you get enough points to determine the behavior of the acceleration.

Choose an object in your picture for calibration. Choose your 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.

ANALYSIS

Can you fit your position-versus time data with an equation based on constant acceleration? Do any other functions fit your data better?

From the *position vs. time* graph or your fit equation for it, predict an equation for the *velocity vs. time* graph of the cart.

From the *velocity vs. time graph*, sketch an *acceleration vs. time graph* of the cart. Can you determine an equation for this *acceleration vs. time* graph from the fit equation for the *velocity vs. time* graph?

Do you have enough data to convince others of your conclusion?

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

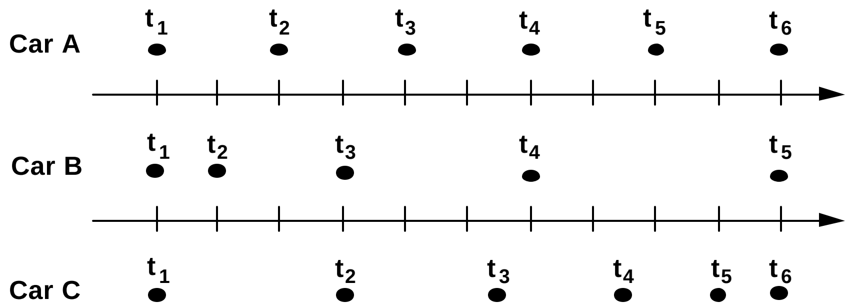
CONCLUSION

How does your acceleration-versus-time graph compare with your predicted graph? Are the position-versus-time and the velocity-versus-time graphs consistent with this behavior of acceleration? What is the difference between the motion of the cart in this problem and its motion along an inclined track? What are the similarities? What are the limitations on the accuracy of your measurements and analysis?

What will you tell your friend? Is the acceleration of the cart greatest when the velocity is the greatest? How will a cart pulled by an elastic cord accelerate along a level surface? State your result in the most general terms supported by your analysis.

☑ 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. The positive direction is to the right.



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

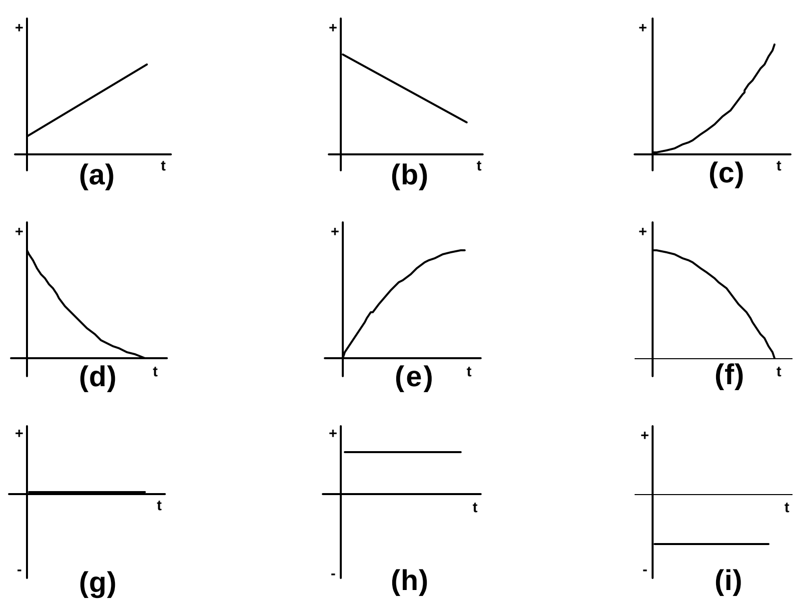
b. At approximately what clock reading (or readings) does one car pass another car? In each instance you cite, indicate which car, A, B or C, is doing the overtaking. Explain your reasoning.

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 vs. time graph of Car A? Of Car B? Of car C? Explain your reasoning.

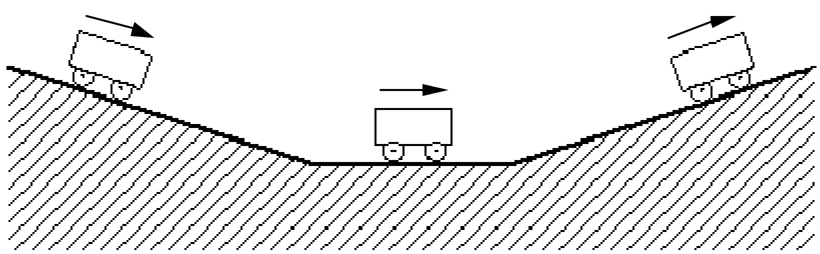
e. Which graph below best represents the instantaneous velocity vs. time graph of Car A? Of Car B? Of car C? Explain your reasoning. (HINT: Examine the distances traveled in successive time intervals.)

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



☑ CHECK YOUR UNDERSTANDING

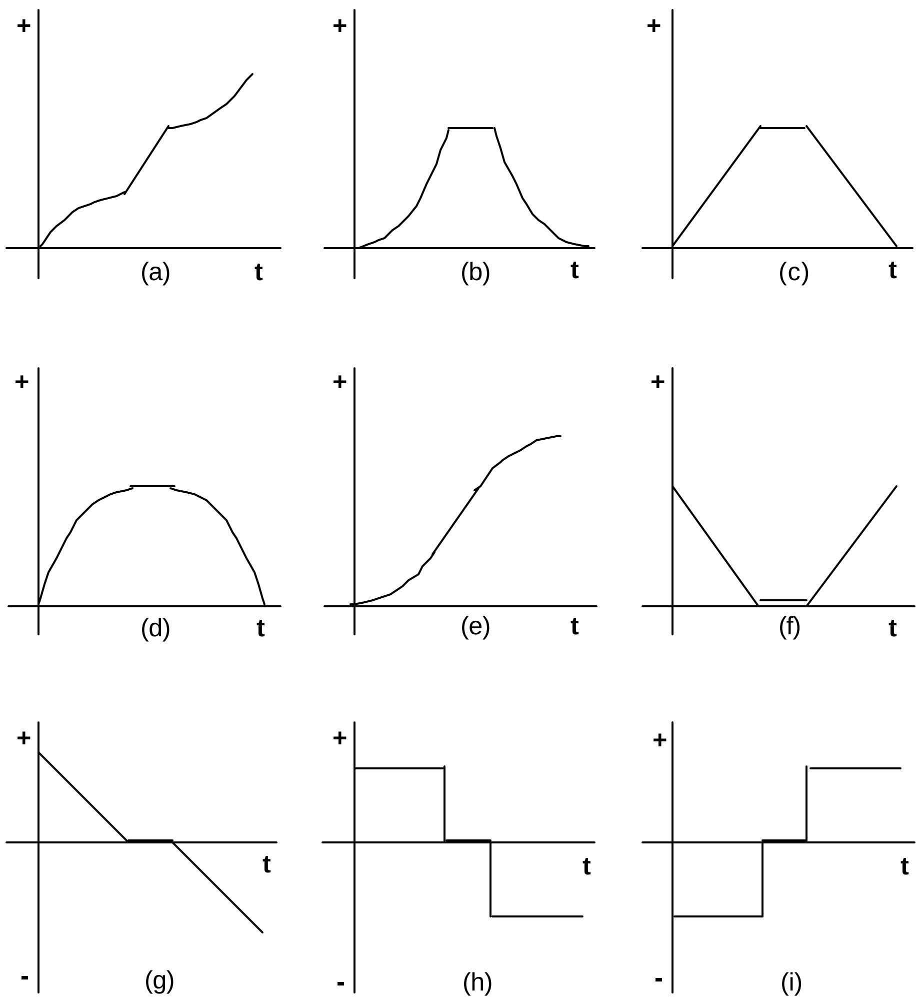
2. A cart starts from rest at the top of a hill, rolls down the hill, over a short flat section, then back up another hill, as shown in the diagram above. Assume that the friction between the wheels and the rails is negligible. The positive direction is to the right.



a. Which graph below best represents the position vs. time graph for the motion along the track? Explain your reasoning. (Hint: Think of motion as one-dimensional.)

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

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



TA Name:____________________________

PHYSICS 1301 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.