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Kenneth & Patricia Heller

WELCOME TO THE PHYSICS LABORATORY

Physics is our human attempt to explain the workings of the world. The success of that attempt is evident in the technology of our society. You have already developed your own physical theories to understand the world around you. Some of these ideas are consistent with accepted theories of physics while others are not. This laboratory manual is designed, in part, to help you recognize where your ideas agree with those accepted by physics and where they do not. It is also designed to help you become a better physics problem solver.

You are presented with contemporary physical theories in lecture and in your textbook. In the laboratory you can apply the theories to real-world problems by comparing your application of those theories with reality. You will clarify your ideas by: answering questions and solving problems *before* you come to the lab room, performing experiments and having discussions with classmates *in the lab room*, and occasionally by writing lab reports *after you leave*. Each laboratory has a set of problems that ask you to make decisions about the real world. As you work through the problems in this laboratory manual, remember: **the goal is <u>not</u> to make lots of measurements**. The goal is for you to examine your ideas about the real world.

The three components of the course - lecture, discussion section, and laboratory section - serve different purposes. The laboratory is where physics ideas, often expressed in mathematics, meet the real world. Because different lab sections meet on different days of the week, you may deal with concepts in the lab before meeting them in lecture. In that case, the lab will serve as an introduction to the lecture. In other cases the lecture will be a good introduction to the lab.

The amount you learn in lab will depend on the time you spend in preparation before coming to lab.

Before coming to lab each week you must read the appropriate sections of your text, read the assigned problems to develop a fairly clear idea of what will be happening, and complete the prediction and warm-up questions for the assigned problems.

Often, your lab group will be asked to present its predictions and data to other groups so that everyone can participate in understanding how specific measurements illustrate general concepts of physics. You should always be prepared to explain your ideas or actions to others in the class. To show your instructor that you have made the appropriate connections between your measurements and the basic physical concepts, you will be asked to write a laboratory report. Guidelines for preparing lab reports can be found in the lab manual appendices and in this introduction. An example of a good lab report is shown in Appendix E. Please do not hesitate to discuss any difficulties with your fellow students or the lab instructor.

Relax. Explore. Make mistakes. Ask lots of questions, and have fun.

WHAT TO DO TO BE SUCCESSFUL IN THIS LAB:

Safety comes first in any laboratory.
If in doubt about any procedure, or if it seems unsafe to you, STOP. Ask your lab instructor for help.

A. What to bring to each laboratory session:

1. Bring an 8" by 10" graph-ruled lab journal, to all lab sessions. Your journal is your "extended memory" and should contain everything you do in the lab and all of your thoughts as you are going along. Your lab journal is a legal document; you should **never** tear pages from it. Your lab journal **must** be bound (as *University of Minnesota 2077-S*) and must **not** allow pages to be easily removed (as spiral bound notebooks).

2. Bring a "scientific" calculator.

3. Bring this lab manual.

B. Prepare for each laboratory session:

Each laboratory consists of a series of related problems that can be solved using the same basic concepts and principles. Sometimes all lab groups will work on the same problem, other times groups will work on different problems and share results.

1. Before beginning a new lab, carefully read the Introduction, Objectives and Preparation sections. Read sections of the text specified in the *Preparation* section.

2. Each lab contains several different experimental problems. Before you come to a lab, complete the assigned *Prediction* and *Warm-up*. The Warm-up helps you build a prediction for the given problem, so it is usually helpful to complete the Warm-up before making the prediction. **These individual predictions will be collected 1-2 days before the lab and checked (graded) by your lab instructor. They will be returned to you immediately at the beginning of each lab session.**

   This preparation is crucial if you are going to get anything out of your laboratory work. There are at least two other reasons for preparing:

   a) There is nothing duller or more exasperating than plugging mindlessly into a procedure you do not understand.

   b) The laboratory work is a **group** activity where every individual contributes to the thinking process and activities of the group. Other members of your group will be unhappy if they must consistently carry the burden of someone who isn't doing his/her share.

C. Laboratory Reports

At the end of every lab (about once every two weeks) you will be assigned to write up one of the experimental problems. Your report must present a clear and accurate account of what you and your group members did, the results you obtained, and what the results mean. A report must not be copied or fabricated. (That would be scientific fraud.) Copied or fabricated lab reports will be treated in the same manner as cheating on a test, and will result in **a failing grade for the course and possible expulsion from the University**. Your lab report should describe your predictions, your experiences, your observations, your measurements, and your conclusions. A description of the lab report format is discussed at the end of this introduction. **Each lab report is due within two days of the end of that lab.**

D. Attendance

Attendance is required at all labs **without exception**. If something disastrous keeps you from your scheduled lab, contact your lab instructor **immediately**. The instructor will arrange for you to attend another lab section that same week. **There are no make-up labs in this course.**

E. Grades

Satisfactory completion of the lab is required as part of your course grade. **Those not completing all lab assignments by the end of the quarter at a 60% level or better will receive a quarter grade of F for the entire course.** The laboratory grade makes up 15% of your final course grade. Once again, we emphasize that each lab report is due within two days of the end of that lab.

There are two parts of your grade for each laboratory: (a) your laboratory journal, and (b) your formal problem report. Your laboratory journal will be graded by the lab instructor during the laboratory sessions. Your problem report will be graded and returned to you in your next lab session.

If you have made a good-faith attempt but your lab report is unacceptable, your instructor may allow you to rewrite parts or all of the report. A rewrite must be handed in again within two days of the return of the report to you by the instructor.

F. The laboratory class forms a local scientific community. There are certain basic rules for conducting business in this laboratory.

1. *In all discussions and group work, full respect for all people is required.* All disagreements about work must stand or fall on reasoned arguments about physics principles, the data, or acceptable procedures, never on the basis of power, loudness, or intimidation.

2. *It is OK to make a reasoned mistake. It is in fact, one of the most efficient ways to learn.* This is an academic laboratory in which to learn things, to test your ideas and predictions by collecting data, and to determine which conclusions from the data are acceptable and reasonable to other people and which are not.

What do we mean by a "reasoned mistake"? We mean that after careful consideration and after a substantial amount of thinking has gone into your ideas you simply give your best prediction or explanation as you see it. Of course, there is always the possibility that your idea does not accord with the accepted ideas. Then someone says, "No, that's not the way I see it and here's why." Eventually persuasive evidence will be offered for one viewpoint or the other.

"Speaking out" your explanations, in writing or vocally, is one of the best ways to learn.

3. *It is perfectly okay to share information and ideas with colleagues. Many kinds of help are okay. Since members of this class have highly diverse backgrounds, you are encouraged to help each other and learn from each other.*

   However, it is never okay to copy the work of others.

   Helping others is encouraged because it is one of the best ways for you to learn, but copying is inappropriate and unacceptable. Write out your own calculations and answer questions in your own words. It is okay to make a reasoned mistake; it is wrong to copy.

   No credit will be given for copied work. It is also subject to University rules about plagiarism and cheating, and may result in dismissal from the course and the University. See the University course catalog for further information.

4. *Hundreds of other students use this laboratory each week. Another class probably follows directly after you are done. Respect for the environment and the equipment in the lab is an important part of making this experience a pleasant one.*

   The lab tables and floors should be clean of any paper or garbage. Clean up your area before you leave the lab. Return equipment to the lab instructor or leave it neatly at your station, as appropriate.

   If any lab equipment is missing or broken, submit a problem report form 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).

In summary, the key to making any community work is **RESPECT**.

Respect yourself and your ideas by behaving in a professional manner at all times.

Respect your colleagues (fellow students) and their ideas.

Respect your lab instructor and his/her effort to provide you with an environment in which you can learn.

Respect the laboratory equipment so that others coming after you in the laboratory will have an appropriate environment in which to learn.

WHAT IS EXPECTED IN A LAB REPORT?
HOW IS IT HANDLED?

1. Before you leave the laboratory, have the instructor assign the problem you will write up and initial your cover sheet.

2. A cover sheet for each problem must be placed on top of each problem report handed in to the instructor. A cover sheet can be found at the end of every lab. It gives you a general outline of what to include in a report.

3. A problem report is due **within two days of the end of the lab**.

4. **A problem report should be an organized, coherent display of your thoughts, work, and accomplishments**. It should be written *neatly* (word processor recommended) in English that is *clear*, *concise*, and *correct*. It may help you to imagine that hundreds of people will read your report and judge you by it. **Communication is the goal of the report.** In many cases, communication can be aided greatly by use of tables and graphs.

5. Sample reports are included in *Appendix E*. Listed below are the major headings which most laboratory reports use.

MAJOR PARTS OF A LABORATORY REPORT:

COVER SHEET

See the end of this introduction for a sample cover sheet.

TITLE

Write a descriptive title with your name, name of partners, date performed, and TA name.

STATEMENT OF THE PROBLEM

State the problem you were trying to solve and how you went about it. Describe the general type of physical behavior explored and provide a short summary of the experiment.

PREDICTION

This is a part of the lab where you try to predict the outcome of the experiment based on the general knowledge of Physics. Generally, you start from fundamental laws or principles and derive the theoretical expression for the measured quantity. Later you are going to use your prediction to compare with experimental results.

EXPERIMENT AND RESULTS

Following the Prediction is an Experiment and Results section, containing a detailed description of how you made your measurements and what results you obtained. This usually involves an organized and coherent display of labeled diagrams, tables of measurements, tables of calculated quantities, and graphs. Explanations of all results must occur in correct grammatical English that would allow a reader to repeat your procedure. Also, include all information necessary to repeat your experiment.

Mathematical calculations connecting fundamental physics relationships to the quantities measured should be given. Any interesting behavior should be explained. Difficulties performing the experiment should be described as well as any subtleties in the analysis.

All data presented must be clearly identified and labeled. Calculated results should be clearly identified. Anybody should be able to distinguish between quantities you measured, those you calculated, and those you included from other sources. Clearly assign uncertainties to **ALL** measured values -- **without uncertainties, the data is nearly meaningless.**

CONCLUSIONS

The Conclusions section should include your answers to the following questions: What generalized behavior did you observe? Was it different from what you expected? Why? (e.g. What were the possible sources of uncertainties? Did you have any major experimental difficulties?) How do your results compare with the theory presented in your textbook or during lectures? Can you think of any other ways to check your theory with your data?

SAMPLE COVER SHEET

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 <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.

INTRODUCTORY LABORATORY 0:
DETERMINING AN EQUATION FROM A GRAPH

Throughout this course, you will use computer programs to graph physical quantities. Before measuring, you enter equations to represent predictions for the quantities to be measured. After measuring, you determine the equations that best represent (*fit*) the measured data, and compare the resulting Fit Equations with your Prediction Equations. This activity will familiarize you with the procedure for fitting equations to measured data.

EXPLORATION

Log on to the computer. Open the *PracticeFit* program by double-clicking its icon on the desktop. The "Instruction" box provides instructions that change as you progress. Holding the mouse over a button or the graph also provides some help.

You will try to fit equations to data generated by a Mystery Function. There are several sets of "Mystery Functions" to choose from; ranging from simpler (1) to more varied and complicated (10). The parameters, and in some cases the function types, are randomly chosen; you can try each Mystery Function several times until you are comfortable with it.

Follow the instructions on the screen until you are asked to select a "Fit Function" to approximate the Mystery Function data graphed on the screen. (You may need to change the graph's axis limits to locate the Mystery Function data!) The curve graphed for the Fit Function will change to match parameters you select; try to find the equation that gives the best possible fit to the Mystery Function data. The Method Questions below are designed to help. Once you are satisfied with an equation, press "Accept Fit Function" to reveal the equation of the Mystery Function.

WARM-UP

The following questions should help you determine the equation that best matches the curve:

1. Determine the type of Fit Function that can best approximate the Mystery Function data. Examine the data's graph. Is it a straight line? If the graph bends, does it have a parabolic shape, an exponential shape, or a repeating pattern? Use your knowledge of functions to select the best equation type from the choices offered by *PracticeFit*.

2. Next you need to determine the constants in the equation. Examine the graph where the horizontal coordinate is zero:

- At this point, what is the *value* of the vertical coordinate of the graph? What constant in the Fit Function equation is represented by this vertical coordinate?

- At this same point, what is the *slope* of the graph, and what constant does it represent? (If you have taken some calculus, you will know that the derivative of a function represents the slope of its graph.)

If there are more constant parameters to determine for the Fit Function, you must look at other points on the graph; your knowledge of functions and calculus will help. You might examine points on the horizontal axis, points with zero slope, and/or the graph's asymptotic behavior. It may also be useful to consider the derivative of the Fit Function.

During the rest of this physics course, you will deal with real physical situations. You can usually determine the form of the best Fit Function and estimate its constant parameters based on your physics knowledge and what you observe in the laboratory; this can greatly simplify the fitting process.

CONCLUSION

How close was your equation to the Mystery Function used to generate the each curve? If your equation was not exactly the same as the actual equation, how would you determine what would be an acceptable degree of difference?

If the horizontal axis represents time and the vertical axis represents position, what type of motion might this curve represent?

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.

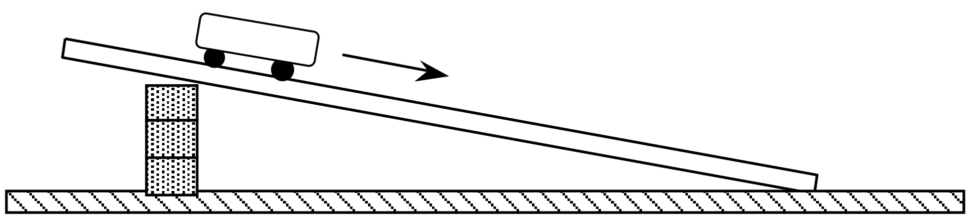
In VideoTOOL and "Lab1Sim", how do you think the computer generates data for a velocity graph? How is this related to the effect of measurement uncertainty on velocity (compared to position) graphs? Why is there one less data point in a *velocity vs. time* graph than in the corresponding *position vs.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

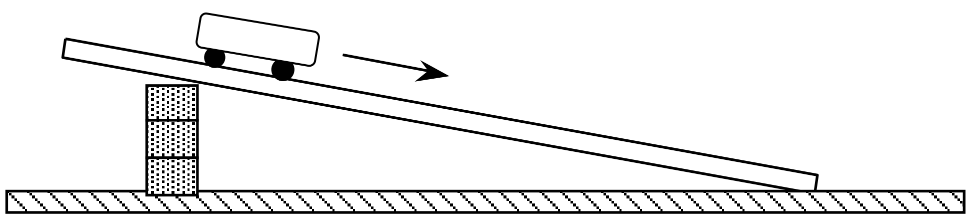
PROBLEM #5:
MASS AND MOTION DOWN AN INCLINE

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

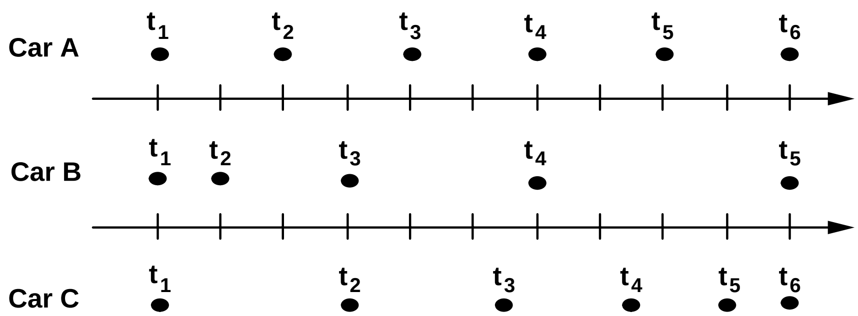
How will you respond to your friend? Does the *acceleration* down a nearly frictionless roller coaster depend on the mass of the people in the coaster? Does the *velocity* of the coaster depend on its mass? (Will the roller coaster be just as fast with fewer people?) State your result in the most general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

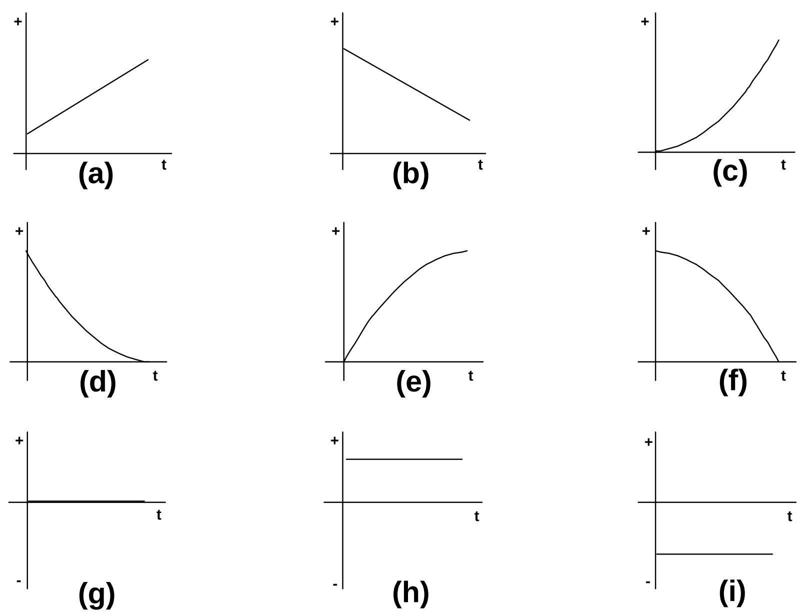
b. At approximately what clock reading (or readings) does one car pass another car? In each instance you cite, indicate which car, A, B or C, is doing the overtaking. Explain your reasoning.

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.

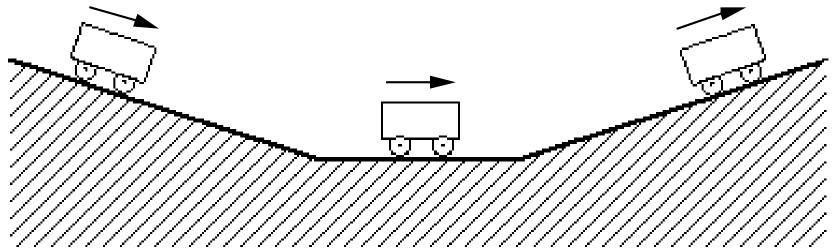
d. Which graph below best represents the position-versus-time graph of Car A? Of Car B? Of car C? Explain your reasoning.

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.



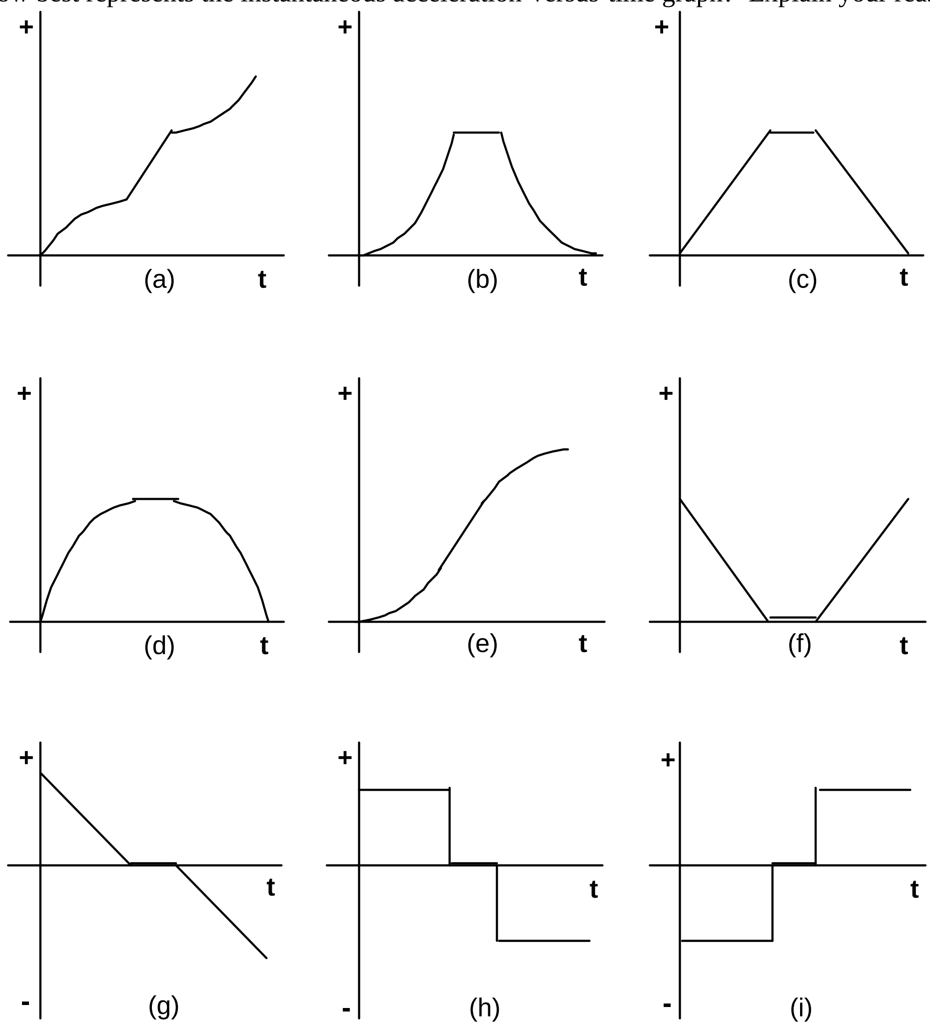
2. A mining cart starts from rest at the top of a hill, rolls down the hill, over a short flat section, then back up another hill, as shown in the diagram above. Assume that the friction between the wheels and the rails is negligible.



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 <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.

LABORATORY II
DESCRIPTION OF MOTION IN TWO DIMENSIONS

In this laboratory you continue the study of accelerated motion in more situations. The carts you used in Laboratory I moved in only one dimension. However, as you know, objects don't *always* move in a straight line! However, motion in two and three dimensions can be decomposed into one-dimensional motions; what you learned in the first lab can be applied to this lab.

You will study the motions of an object in free fall and an object tossed into the air. In these labs, you will need to consider the effects of *air resistance* on the motion of the objects. Can it always be neglected? As always, if you have any questions, talk with your fellow students or your instructor.

OBJECTIVES:

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

- Determine the motion of an object in free-fall by considering what quantities and initial conditions affect the motion.
- Determine the motion of a projectile from its horizontal and vertical components by considering what quantities and initial conditions affect the motion.

PREPARATION:

Read Serway & Vuille Chapter 2 section 2.6 and Chapter 3. Review your results and procedures from Laboratory I. Before coming to the lab you should be able to:

- Determine instantaneous and average velocities and accelerations from video images.
- Analyze a vector in terms of its components along a set of perpendicular axes.
- Add and subtract vectors.

PROBLEM #1:
MASS AND THE ACCELERATION OF A FALLING BALL

The local fire station in California has enlisted your help in studying the dropping of balls of chemicals from helicopters to extinguish forest fires. The amount of chemicals in one of these balls is varied depending on the size of the fire. As a first step to your study, you assume the helicopters are stationary, hovering over a fire. You are to determine if balls of the same size with different amounts of chemicals will fall differently.

EQUIPMENT

For this problem you will have a collection of balls each with approximately the same diameter but different masses. 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).

PREDICTION

Sketch how you expect the *acceleration vs. mass graph* to look for balls dropped from rest with the same size and shape, but having different masses.

Do you think the free-fall acceleration **increases**, **decreases**, or **stays the same** as the mass of the object increases? Explain your reasoning. (Remember that the shape of the ball does not change.)

WARM-UP

Read: Serway & Vuille Chapter 2 Section 2.6

1. Sketch a graph of *instantaneous acceleration vs. time* for a falling ball. Next to this graph sketch a graph of *instantaneous acceleration vs. time* for a heavier falling ball that has the same size and shape. 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 a light and heavy ball 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. How could you determine the acceleration of a falling ball from video data (graphs and equations for position and velocity)? Write down an outline for how to do this, based on your experiences in Lab I.

5. Do you expect that a heavier ball will have a higher, lower, or equal acceleration as a lighter ball of the same size? Is the relationship linear, or curved? Use this to predict a graph of *acceleration vs. mass* for falling balls.

6. Use the simulation "Lab2Sim" (See Appendix F for a brief explanation of how to use the simulations) to explore the approximate the conditions of your experiment. Look at the graphs produced through simulated freefall. (The initial position of the ball should be well off the table, and the initial speed should be zero. Note that the initial position and velocity parameters in Lab2Sim are specified as vectors of the form <x0, y0, z0> and <vx0, vy0, vz0>. The x-axis is along the Right/Left direction, the y-axis is Up/Down, and the z-axis is Front/Back.) If you believe air resistance may affect your results, explore the effects with the simulation. Check the graphs of position and velocity with various values for air resistance. Test the effects of a large air resistance on the ball's velocity and acceleration. 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 effect on the position vs. time graph and the velocity vs. time graph.

EXPLORATION

Review your lab journal from the problems in Lab 1. Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice dropping one of the balls until you can get its motion to fill the least distorted part of the screen. Determine how much time it takes for the ball to fall and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position and screen size to give you enough data points. You should be able to reproduce the conditions described in the Predictions.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might hold an object of known length *in the plane of motion* of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object in the video image? The best place to put the reference object to determine the distance scale is at the position of the falling ball.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame. Write down your measurement plan.

MEASUREMENT

Measure the mass of the ball and make a video of its fall according to the plan you devised in the exploration section. Make sure you can see the ball in every frame of the video.

Digitize the position of the ball in enough frames to accomplish your analysis. 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 ball travels and total time to determine the maximum and minimum value for each axis before taking data.

Complete your data analysis as you go along (before making the next video), so you can determine how many different videos you need to make and what the object's mass should be for each video. Don't waste time collecting data you don't need or, even worse, incorrect data. Repeat this procedure for more balls with different masses. Collect enough data to convince yourself and others of your conclusion.

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 each 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 of the ball for different masses. Is the average acceleration different for the beginning of the video (when the object is moving slowly) and the end of the video (when the object is moving fast)?

Determine the average acceleration of the object in free fall for each value of its mass and use this to make a graph of the acceleration vs. mass. Is the average acceleration of the ball equal to its instantaneous acceleration in this case? Do you have enough data to convince others of your conclusions about your predictions? If the accelerations turn out to be dependent on mass, what might be the reason for the difference?

CONCLUSION

How does the acceleration of a freely falling object depend on its mass? Did the data from the video images support your predicted relationship between acceleration and mass? (Make sure you carefully review *Appendix C* to determine if your data really supports this relationship.) If your data did not support your prediction, were your predictions wrong or were your results unreliable? Explain your reasoning.

How does the acceleration you found compare to the gravitational acceleration? Can you explain any differences? What are the limitations on the accuracy of your measurements and analysis?

If your results did not completely match your expectations, you should use the simulation "Lab2Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore what might have happened.

PROBLEM #2:
ACCELERATION OF A BALL
WITH AN INITIAL VELOCITY

You have designed an apparatus to measure air quality in your city. To quickly force air through the apparatus, you will launch it straight downward from the top of a tall building. A very large acceleration may destroy sensitive components in the device; the launch system's design ensures that the apparatus is protected during its launch. You wonder what the acceleration of the apparatus will be once it exits the launcher. Does the object's acceleration after it has left the launcher depend on its velocity when it leaves the launcher? You decide to model the situation by throwing balls straight down. The "launcher" is your hand.

EQUIPMENT

You will have a ball, a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL applications).

PREDICTION

Sketch a graph of a ball's acceleration as a function of time after it is launched downward with an initial velocity. State how your graph will change if the object's initial velocity increases or decreases.

Do you think that the acceleration **increases**, **decreases**, or **stays the same** as the initial velocity of the object increases? Make your best guess and explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 2, Section 2.6

1. Sketch a graph of *acceleration vs. time* for a ball dropped from rest (refer to the Warm-up questions from the previous lab problem). Next to this graph, sketch the *acceleration vs. time* for a ball launched downward with an initial velocity. How are these graphs similar or different? Explain your reasoning. 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 graph?
2. Write down the relationships between the acceleration and the velocity and the velocity and the position of the ball. Use these relationships to construct the graphs for *velocity vs. time* and *position vs. time* just below each acceleration graph from question 1. Use the same scale for each time axis. Write down the equation that best represents each graph. If there are constants in your equations, what kinematic quantities do they represent? How would you determine these constants from your graphs? Can any of the constants be determined from the equations representing the acceleration graphs?

3. How will you determine the acceleration of a falling ball from video data (graphs and equations for position and velocity)? Write down an outline for how to do this, based on your experiences in previous labs.
4. Explain how you expect the initial launch velocity to affect the acceleration of the ball.
5. Use the simulation "Lab2Sim" to approximate the conditions of your experiment. (See Appendix F for a brief explanation of how to use the simulations.) Do multiple runs of the simulations with various initial velocities and compare graphs. (The initial position of the ball should be well off the table, and the initial speed should be downward. Note that the initial position and velocity parameters in Lab2Sim are specified as vectors of the form <x0, y0, z0> and <vx0, vy0, vz0>. The x-axis is along the Right/Left direction, the y-axis is Up/Down, and the z-axis is Front/Back.) If you believe air resistance may have affected your results, explore the effects of each with the simulation. If you believe that uncertainty in position measurements may have affected your results, use the simulation to compare the results with and without error. Compare the effect of error in the position vs. time graph with the velocity vs. time graph.

EXPLORATION

Review your lab journal from Lab 1. Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice throwing the ball straight downward until you can get the ball's motion to fill most of the video screen **after** it leaves your hand. Determine how much time it takes for the ball to fall and estimate the number of video points you will get in that time. Is it sufficient to make the measurement? Adjust the camera position to get enough data points.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might hold an object of known length *in the plane of motion* of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object in the video image? The best place to put the reference object to determine the distance scale is at the position of the falling ball.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame.

Write down your measurement plan.

MEASUREMENT

Make a video of the ball being tossed downwards according to your measurement plan from the Exploration secton.

Digitize the position of the ball in enough frames of the video so that you have sufficient data to accomplish your analysis. 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 ball travels and total time to determine the maximum and minimum value for each axis before taking data.

Graph your data as you go along (before making the next video), so you can determine how many different videos you need to make and how you should change the ball's initial velocity for each video. Don’t waste time collecting data you don't need or, even worse, incorrect data. Collect enough data to convince yourself and others of your conclusion.

Repeat this procedure (with the same ball) for different launch velocities.

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 each 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 launch velocity of the ball from this graph. Is this value reasonable?

From the velocity vs. time graph(s) determine the acceleration of the ball. Use the function representing the velocity vs. time graph to calculate the acceleration of the ball as a function of time. Is the average acceleration different for the beginning of the video (just after launch) and the end of the video?

If you cannot get one function to describe your velocity graph in a consistent way, you can try using one function for the first half of the motion and another for the last half. To do this you must go through the video analysis process twice and record your results each time. (How can you avoid repeating some work with the “Save Session” and “Open Session” commands?)

Determine the acceleration of the ball just after launch and at the end of the video. How do they compare with the gravitational acceleration? Do you have enough data to convince others of your conclusions about your predictions?

Repeat the analysis for another launch velocity and compare the results.

CONCLUSION

Did the data support your predicted relationship between acceleration and initial velocity? (Make sure you carefully review *Appendix C* to determine if your data really supports this relationship.) If not, what assumptions did you make that were incorrect. Explain your reasoning.

What are the limitations on the accuracy of your measurements and analysis?

Will the survival of your apparatus depend on its launch velocity? State your results in the most general terms supported by your analysis.

SIMULATION

If your results did not completely match your expectations, you may use the simulation “Lab2Sim” (See Appendix F for a brief explanation of how to use the simulations) to explore what might have happened.

PROBLEM #3:
PROJECTILE MOTION AND VELOCITY

In medieval warfare, probably the greatest technological advancement was the trebuchet, which slings rocks into castles. You are asked to study the motion of such a projectile for a group of local enthusiast planning a war reenactment. Unfortunately an actual trebuchet had not been built yet, so you decide to first look at the motion of a thrown ball as a model of rocks thrown by a trebuchet. Specifically, you are interested in how the horizontal and the vertical components of the velocity for a thrown object change with time.

EQUIPMENT

For this problem you will have a ball, a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

1. Make a rough sketch of how you expect the graph of the *horizontal velocity vs. time* to look for the thrown object. Do you think the horizontal component of the object's velocity **changes** during its flight? If so, how does it change? Or do you think it **is constant**? Explain your reasoning.

2. Make a rough sketch of how you expect the graph of the *vertical velocity vs. time* to look for the object. Do you think the vertical component of the object's velocity **changes** during its flight? If so, how does it change? Or do you think it **is constant**? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 3, Sections 3.1 to 3.4

1. Make a large (about one-half page) rough sketch of the trajectory of the ball after it has been thrown. Draw the ball in at least five different positions; two when the ball is going up, two when it is going down, and one at its maximum height. Label the horizontal and vertical axes of your coordinate system.

2. On your sketch, draw and label the expected acceleration vectors of the ball (relative sizes and directions) for the five different positions. Decompose each acceleration vector into its vertical and horizontal components.

3. On your sketch, draw and label the velocity vectors of the object at the same positions you chose to draw your acceleration vectors. Decomposes each velocity vector into its vertical and horizontal components. Check to see that the changes in the velocity vector are consistent with the acceleration vectors.

4. Looking at your sketch, how do you expect the ball's *horizontal acceleration* to change with time? Write an equation giving the ball's horizontal acceleration as a function of time.

Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

5. Looking at your sketch, how do you expect the ball's *horizontal velocity* to change with time? Is it consistent with your statements about the ball's acceleration from the previous question? Write an equation for the ball's horizontal velocity as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

6. Write an equation for the ball's *horizontal position* as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph? Are any of these constants related to the equations for horizontal velocity or acceleration?

7. Repeat Warm-up questions 4-6 for the *vertical* component of the acceleration, velocity, and position. How are the constants for the acceleration, velocity and position equations related?

8. Use the simulation "Lab2Sim" to simulate the projectile motion in this problem. Note that in this case the initial velocity should have non-zero horizontal and vertical components.

EXPLORATION

Review your lab journal from the problems in Lab 1.

Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice throwing the ball until you can get the ball's motion to fill the video screen (or at least the undistorted part of the video screen) **after** it leaves your hand. Determine how much time it takes for the ball to travel and estimate the number of video points you will get in that time. Is that enough points to make the measurement? Adjust the camera position to give you enough data points.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might need to place an object of known length in the plane of motion of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object? Determine the best place to put the reference object for calibration.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image of the ball due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame.

Write down your measurement plan.

MEASUREMENT

Measure the total distance the ball travels and total time to determine the maximum and minimum value for each position axis before taking data with the computer.

Make a video of the ball being tossed. Make sure you can see the ball in every frame of the video.

Digitize the position of the ball in enough frames of the video so that you have sufficient data to accomplish your analysis. Set the scale for the axes of your graph so that you can see the data points as you take them.

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 each 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. How can you calculate the values of the constants of these functions from the functions representing the position vs. time graphs? You can also estimate the value of the constants from the graph. What kinematics quantities do these constants represent?

From the velocity vs. time graph(s) determine the acceleration of the ball independently for each component of the motion as a function of time. What is the acceleration of the ball just after it is thrown, and just before it is caught? What is the magnitude of the ball's acceleration at its highest point? Is this value reasonable?

Determine the launch velocity of the ball from the velocity vs. time graphs in the x and y directions. Is this value reasonable? Determine the velocity of the ball at its highest point. Is this value reasonable?

CONCLUSION

Did your measurements agree with your initial predictions? Why or why not? If they do not agree, are there any assumptions that you have made, that might not be correct?   What are the limitations on the accuracy of your measurements and analysis?

How does the horizontal velocity component of a launched rock depend on time? How does the vertical velocity component of depend on time? State your results in the most general terms supported by your analysis. At what position does the ball have the minimum velocity? Maximum velocity?

If your results did not completely match your expectations, you shoud go back and use the simulation "Lab2Sim" again.

PROBLEM #4:
PROJECTILE MOTION AND MASS

We now extend the study started in Problem #3. Understandably, it was hard to find rocks of the same mass to launch using a trebuchet during medieval times. The second part of your study requires you to determine if the mass of an object would affect your conclusions in Problem #3. Specifically, you want to determine how the horizontal and vertical components of the velocity of a thrown object depend on its mass.

EQUIPMENT

For this problem you will have a collection of balls each with approximately the same diameter but different masses. 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).

PREDICTIONS

1. Make a rough sketch of how you expect the graph of the <u>horizontal</u> component of *acceleration vs. mass* to look for the object in projectile motion. Do you think the horizontal component of an object's acceleration will **increase**, **decrease**, or **stay the same** as the mass of that object increases? Explain your reasoning.

2. Make a rough sketch of how you expect the graph of the <u>vertical</u> component of *acceleration vs. mass* to look for the object in projectile motion. Do you think the vertical component of an object's acceleration will **increase**, **decrease**, or **stay the same** as the mass of that object increases? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 3, Sections 3.1 to 3.4

If you have done Problem #3, skip Questions 1 – 7 and review your notes from that problem.

1. Make a large (about one-half page) rough sketch of the trajectory of the ball after it has been thrown. Draw the ball in at least five different positions; two when the ball is going up, two when it is going down, and one at its maximum height. Label the horizontal and vertical axes of your coordinate system.

2. On your sketch, draw and label the expected acceleration vectors of the ball (relative sizes and directions) for the five different positions. Decompose each acceleration vector into its vertical and horizontal components.

3. On your sketch, draw and label the velocity vectors of the object at the same positions you chose to draw your acceleration vectors. Decomposes each velocity vector into its vertical and horizontal components. Check to see that the changes in the velocity vector are consistent with the acceleration vectors.

4. Looking at your sketch, how do you expect the ball's *horizontal acceleration* to change with time? Write an equation giving the ball's horizontal acceleration as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

5. Looking at your sketch, how do you expect the ball's *horizontal velocity* to change with time? Is it consistent with your statements about the ball's acceleration from the previous question? Write an equation for the ball's horizontal velocity as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph?

6. Write an equation for the ball's *horizontal position* as a function of time. Graph this equation. If there are constants in your equation, what kinematic quantities do they represent? How would you determine these constants from your graph? Are any of these constants related to the equations for horizontal velocity or acceleration?

7. Repeat Warm-up questions 4-6 for the *vertical* component of the acceleration, velocity, and position. How are the constants for the acceleration, velocity and position equations related?

8. How are the components of the acceleration of a projectile related to the mass of the object? How are the components of the velocity related to mass?

EXPLORATION

If you have done Problem #3, the following is a review -- you need only do what you feel is necessary.

Position the camera and adjust it for optimal performance. *Make sure everyone in your group gets the chance to operate the camera and the computer.*

Practice throwing the ball until you can get the ball's motion to fill the video screen (or at least the undistorted part of the video screen) **after** it leaves your hand. Determine how much time it takes for the ball to travel and estimate the number of video points you will get in that time. Is that enough points to make the measurement? Adjust the camera position to give you enough data points.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. Instead, you might need to place an object of known length in the plane of motion of the ball, near the center of the ball's trajectory, for calibration purposes. Where you place your reference object does make a difference in your results. Check your video image when you put the reference object close to the camera and then further away. What do you notice about the size of the reference object? Determine the best place to put the reference object for calibration.

Step through the video and determine which part of the ball is easiest to consistently determine. When the ball moves rapidly you may see a blurred image of the ball due to the camera's finite shutter speed. If you cannot make the shutter speed faster, devise a plan to measure the position of the same part of the "blur" in each video frame.

Write down your measurement plan.

MEASUREMENT

If you have done Problem #3, the following is a review.

A way to save time in this lab is for each group in your class to determine the horizontal and vertical acceleration for **a different** mass and report their findings to the class. You should be able to draw a sketch of the horizontal and vertical components of the acceleration vs. mass of the object from the data collected by the class.

If you are not using data from other groups analyzing different balls, you yourself will have to use several different balls of different masses. Use your experience from Problem #1 to determine which balls and how many are needed.

Measure the total distance the ball travels and total time to determine the maximum and minimum value for each position axis before taking data with the computer. Make a video of the ball being tossed. Make sure you can see the ball in every frame of the video.

Digitize the position of the ball in enough frames of the video so that you have sufficient data to accomplish your analysis. Set the scale for the axes of your graph so that you can see the data points as you take them.

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 each 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. How can you calculate the values of the constants of these functions from the functions representing the position vs. time graphs? You can also estimate the value of the constants from the graph. What kinematics quantities do these constants represent?

From the velocity vs. time graph(s) determine the acceleration of the ball independently for each component of the motion as a function of time. What is the acceleration of the ball just after it is thrown, and just before it is caught? What is the magnitude of the ball's acceleration at its highest point? Is this value reasonable?

Determine the launch velocity of the ball from the velocity vs. time graphs in the x and y directions. Is this value reasonable? Determine the velocity of the ball at its highest point. Is this value reasonable?

Report the value of your object's mass (with uncertainty) and its horizontal and vertical accelerations as a function of time to the class. Also report the object's average acceleration for each component (with uncertainties) to the class and record the values from other groups. Make graphs of horizontal and vertical acceleration vs. mass.

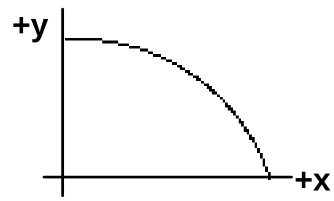
CONCLUSION

How does the horizontal component of a projectile's acceleration depend on its mass? How does the vertical component of the acceleration depend on mass? State your result in the most general terms supported by your analysis. Did your measurements agree with your initial predictions? Why or why not?

How does your conclusion tie together with your results from previous problems? What are the limitations on the accuracy of your measurements and analysis?

☑ CHECK YOUR UNDERSTANDING:

1. A baseball is hit horizontally with an initial velocity v_o at time $t_o = 0$ and follows the parabolic arc shown at right.



a. Which graph below best represents its horizontal position (x) versus time graph? Explain your reasoning.

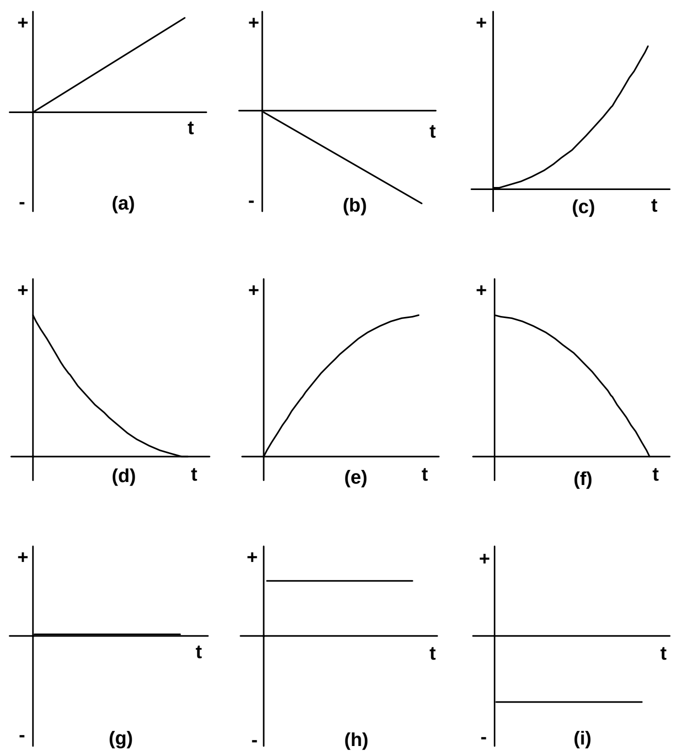
b. Which graph below best represents the horizontal velocity (v_x) versus time graph? Explain your reasoning.

c. Which graph below best represents the horizontal acceleration (a_x) versus time graph? Explain your reasoning.

d. Which graph below best represents the vertical position (y) versus time graph? Explain your reasoning.

e. Which graph below best represents the vertical velocity (v_y) versus time graph? Explain your reasoning.

f. Which graph below best represents the vertical acceleration (a_y) versus time graph? Explain your reasoning.



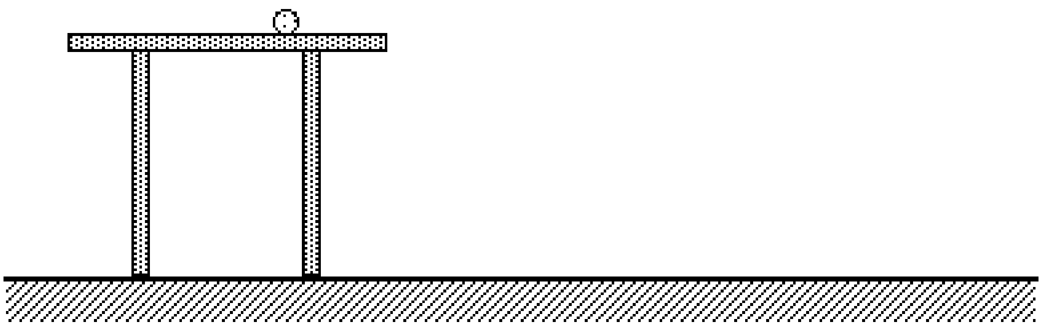
2. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two-story building at the same instant of time. Which ball will reach the ground first, or will they reach the ground at the same time? Explain your reasoning.

3. Suppose you throw a ball vertically up into the air with an initial velocity v_o.

   a. What is the acceleration of the ball at its maximum height? Explain your reasoning.

   b. What would the acceleration-versus-time graph look like from the moment the ball leaves your hand to the moment before it returns to your hand?

4. A ball slides off the edge of a table with a horizontal velocity v_x and lands on the floor.



   a. On the diagram above, sketch a possible trajectory (the path followed by the ball) from the edge of the table to the floor.

   b. On the same diagram sketch another trajectory, that of another ball having a very much larger mass than that of the first ball, but exactly the same initial velocity v_x. Explain your reasoning.

TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory II

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.

LABORATORY III
FORCES

The problems in this laboratory will help you investigate the effect of forces on the motion of objects. In the first problem, you will investigate the effects of forces on a sliding object. In the second problem, you will apply the force concept and the vector nature of forces to a situation in which nothing moves. The third and fourth problems investigate the behavior of the frictional forces.

OBJECTIVES:

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

- Make and test quantitative predictions about the relationship of forces on objects and the motion of those objects for real systems.
- Use forces as vector quantities.
- Characterize the behavior of the frictional force.
- Improve your problem solving skills.

PREPARATION:

Read Serway & Vuille Chapter 4. Review Sections 3.1 and 3.2 regarding the properties of vectors. Review your lab journal notes about the behavior of an object sliding down an inclined track.

Before coming to lab you should be able to:

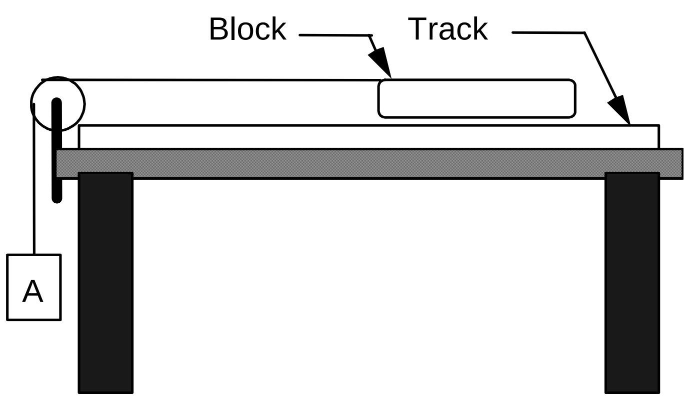
- Define and use sine, cosine and tangent for a right triangle.
- Recognize the difference between mass and weight.
- Determine the net force on an object from its acceleration.
- Draw and use free-body diagrams.
- Resolve force vectors into components and determine the total force from the components.
- Explain what is meant by saying a system is in "equilibrium."
- Write down the force law for a frictional force.

PROBLEM #1:
HOW SURFACES AFFECT
THE KINETIC FRICTIONAL FORCE

You are helping a friend design a new game to use on the Midway at the Minnesota State Fair. The game is similar to shuffleboard -- players use a short stick to push a puck just hard enough so that it will travel along a level surface and fall into one of several holes. To construct the pucks your friend wants to use either natural wood, or felt covered wood. He has decided that the sliding surface will be aluminum. He needs to know which block surface (felt or wood) to use for the game. If there is too much friction, no one will ever get the puck into the holes. If there is too little friction, then the game will be too easy. He knows you are taking a physics course, so he asks you to help. To solve this problem, you devise an experiment to measure the kinetic frictional force between the block and the board.

EQUIPMENT

A block is pulled along a level track as shown below.



For this lab you will have a block that has both a wood side and a felt side. You will also have a stopwatch, meter stick, string, pulley, aluminum track, mass hanger with a set of masses (for object A), a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

Write an expression for the frictional force on the sliding block as a function of the mass hanging on the string (object A), the mass of the block, and the acceleration of the block.

WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.6

1. Make a sketch the problem situation that is similar to the picture in the Equipment section. Draw and label vectors to indicate the direction of the velocity and the direction of the acceleration for both the hanging object A and the block. Also assign symbols to the "known" quantities in the problem: the mass of object A and the mass of the block.

2. Write down the principles of Physics that you will use to solve the problem. (Hint: Think about Newton's laws of motion!) Will you need any of the principles of kinematics? Write down any assumptions you have made that are necessary to solve the problem and are justified by the physical situation. What quantities can you measure using the video analysis software?

3. Draw separate free-body diagrams of the forces on the block and the forces on object A after they start accelerating. Assign symbols to all of the forces, and define what they represent next to your diagram. For easy reference, it is useful to draw the acceleration vector for the object next to its free-body diagram. It is also useful to put the force vectors on a separate coordinate system for each object (force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system.

4. For *each* force diagram (one for the block and another one for object A), write down Newton's 2nd law in both the x and y directions. It is important to make sure that all of your signs are correct. For example, if the acceleration of the block is in the positive direction, is the acceleration of object A positive or negative? Your answer will depend on how you define your coordinate system.

5. What special condition connects the acceleration of the block and object A? Relate the force of the string pulling on the block to the force of the string pulling on object A (assuming a "massless" string and "frictionless" pulley).

6. Write down an equation, from those you have collected in steps 4 and 5 above, which relates what you want to know (the kinetic frictional force on the block) to a quantity you either know or can find out (the acceleration of the block).

7. Now you have a new unknown (the force of the string on the block). Write down a new equation for this unknown which relates the force of the string on the block to the force of the string on object A. Again you have a new unknown (the force of the string on object A). Write down a new equation for this unknown which relates it to the acceleration of object A.

8. Write down a new equation that relates the acceleration of object A to the acceleration of the block. If you have generated no additional unknowns, you should have as many equations as unknowns.

9. Combine your equations from step 6 with algebra to write an expression for the kinetic frictional force on the block in terms of the mass of object A, the mass of the block, and the acceleration of the block.

EXPLORATION

For both surfaces in question (felt and wood), slide the block along the track. Make sure it slides smoothly. If it does not, try cleaning the surfaces.

Determine the length of string you should use to connect the block to the mass hanger holding masses (object A). Remember that you will want to take a video of the system while both objects are accelerating (before object A hits the floor). Decide on a position where you will release the block that fits in the frame of the camera, and will give you enough data points for the motion.

Find a range of masses for object A that allows the block to accelerate smoothly across the track. Explore the different accelerations using a large range of masses. Try these masses for the two contact surfaces to be sure the block accelerates uniformly in both cases. Choose a range of masses that will give a smooth acceleration. You should use the same range of block masses for each surface.

Practice releasing the block from the position you determined and one of your chosen masses for object A. Determine how much time it takes for object A to hit the floor and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position, mass range of object A, or the release position/length of the string to give you enough data points. Be sure to check this for both surfaces of the block.

Write down a plan of how you will take your measurements. What will you use for a reference object to calibrate your video? Make sure that the plan will adequately check your prediction.

MEASUREMENT

Carry out the measurement plan you determined in the Exploration section. You can change the mass of the block, the mass of object A, or the surfaces and determine if the frictional force behaves as you predict.

Make sure you measure and record the mass of the block and object A (with uncertainties). Repeat the necessary measurements using a different block surface.

Complete the entire analysis of one case before making videos and measurements of the next case. *Make sure each person in your group gets a chance to operate the computer.*

ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the position vs. time graphs for the sliding block in the x and y directions. How can you estimate the values of the constants of each 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.

From each video, determine the acceleration of the sliding block (with uncertainty). Is the average acceleration different for the beginning of the video (when the object is moving slowly) and the end of the video (when the object is moving fast)? Before you begin any time consuming analysis, determine if the acceleration of the block is constant. If it is, you can use kinematic relationships to simplify your task. Decide on the minimum number of data points that you need to analyze in order to determine the acceleration accurately and reliably. Remember that it is not the purpose of this problem to find accelerations!

For each contact surface, use your predicted expression from the Warm-up and Prediction to calculate the kinetic frictional force with the appropriate units. Have you measured all of the quantities that you need for this expression? If not, make sure you measure them before you leave the lab.

CONCLUSION

What does your data show about the effect of the contact surfaces on the kinetic frictional force? Did you results agree with your initial prediction? Why or why not?

Which surface (wood or felt) will you recommend to your friend? Why? Will one surface be more useful to the game at the State Fair? What are the limitations on the accuracy of your measurements and analysis?

PROBLEM #2:
FORCES IN EQUILIBRIUM

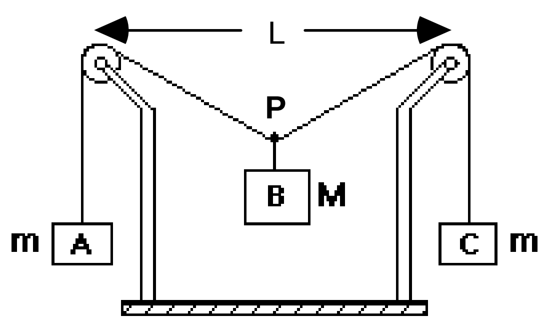
You have a summer job with a research group studying the ecology of a rain forest in South America. To avoid walking on the delicate rain forest floor, the team members walk along a rope walkway that the local inhabitants have strung from tree to tree through the forest canopy. Your supervisor is concerned about the maximum amount of equipment each team member should carry to safely walk from tree to tree. If the walkway sags too much, the team member could be in danger, not to mention possible damage to the rain forest floor! You are assigned to set the load standards.

Each end of the rope supporting the walkway goes over a branch and then is attached to a large weight hanging down. When the team member is at the center of the walkway between two trees, you need to determine how the sag of the walkway is related to the mass of the counterweights and the total mass of the team member with their equipment. To check your calculation, you decide to model the situation using the equipment shown below.

EQUIPMENT

The system consists of a central object B (mass M), suspended halfway between two pulleys by a string. The picture below is similar to the situation with which you will work. The objects A and C, which have the same mass (m), allow you to determine the force exerted on the central object by the string.

You do need to make some assumptions about what you can neglect. For this investigation, you will also have a meter stick, two pulleys with two pulley clamps, three mass hangers, and a mass set to vary the mass of object B.



PREDICTION

Write an equation for the change in the vertical displacement of the central object B in terms of the horizontal distance between the two pulleys (L), the mass of object B (M), and the mass (m) of objects A and C.

Use your equation to sketch the expected graph of the vertical displacement of object B versus its mass (M). When you are making your graph, consider what happens when $M = 2m$, and when $M > 2m$.

WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.4. Review Chapter 3 Sections 3.1 and 3.2

1. Draw a picture of the setup similar to the one in the Equipment section (be sure to include the symbols for the horizontal distance L, and the masses m and M.) Label the angle that the string sags below the horizontal as theta (θ) and the displacement of point P as "d". Use trigonometry to show how the vertical displacement (d) of object B is related to the angle theta and the horizontal distance L.

2. Draw separate free-body diagrams of the forces on objects A, B, C, and at point P. Assign symbols to all of the forces, and define what they represent next to your diagram. Check to see if any of these forces are related by Newton's 3rd Law (Third Law Pairs). It is also useful to put the force vectors on a separate coordinate system for each object (force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system.

3. Write down the acceleration for each object. For *each* force diagram resolve all forces into their x and y components and write down Newton's 2nd law along each coordinate axis.

4. Solve your equations for the vertical displacement (d) of object B in terms of the mass (M) of object B, the mass (m) of objects A and C, and the horizontal distance (L) between the pulleys. Your final equation **should not** depend on angles. *Hint: Use definitions of trig functions (sine, cosine, and tangent) for a right triangle, and the Pythagorean Theorem for additional relationships.*

5. Use your equation to sketch the shape of the graph of the vertical displacement versus mass of object B.

EXPLORATION

Build the system of pulleys and masses without the central object so that the string looks horizontal. Make sure to use an appropriate length of string; if it is too short, the mass hangers from objects A and C will interfere with the pulleys when object B is lowered. Attach a central object and observe how the string sags. Decide on the origin from which you will measure the vertical position of object B.

Try changing the mass of objects A and C (keep them equal for the measurements, but you will want to explore the case where they are not equal). Are you able to create a stable system with unequal masses for A and C? Choose a set of masses for A and C that will allow you to get enough data to determine the vertical displacement as it depends on the mass of object B.

For the entire range of weights you will use, determine if the pulleys turn freely. How can you determine if the assumption that these pulleys are frictionless is good?

With the system in equilibrium, move the pulleys closer to one another and observe what happens to the vertical displacement of object B. Does the result make sense? Observe what happens when you move the pulleys farther apart. Decide on a separation distance between the two pulleys for your measurements.

Determine the range of masses for object B so that your system can be in equilibrium. Decide on the number of measurements that you will need to determine if your prediction agrees with the results. You may need to refer to your prediction to determine the proper range of masses.

MEASUREMENT

Using your plan from the exploration section, measure the vertical position of the central object as you increase its mass. Make a table and record your measurements. Also record the masses of objects A and C, and the horizontal separation of the pulleys. What units should you use? Don't forget to record your uncertainties.

ANALYSIS

Make a graph of the *measured* vertical displacement of the central object as a function of its mass based on your data. On the same graph, plot your *predicted* equation for vertical displacement versus mass of the central object.

Where do the two curves match? Where do the two curves start to diverge from one another? What does this tell you about the system?

CONCLUSION

What will you report to your supervisor? How does the vertical displacement of this object depend on its mass? Did your measurements of the vertical displacement of object B agree with your initial predictions? If not, why? What are the limits on the accuracy of your measurements and analysis?

What information would you need to apply your calculation to the walkway through the rain forest?

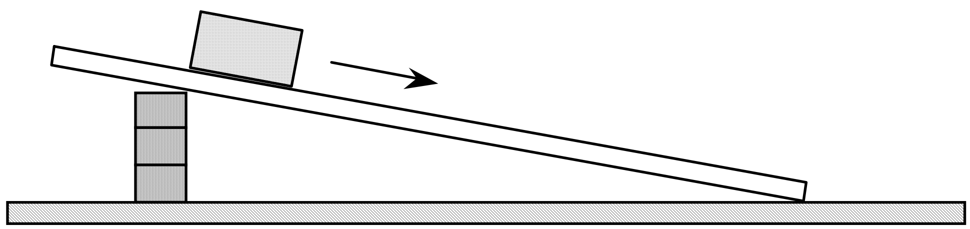
Estimate reasonable values for the information you need, and solve the problem for the walkway over the rain forest.

PROBLEM #3:
NORMAL FORCE AND THE
KINETIC FRICTIONAL FORCE (PART A)

You have taken a job with a theater company and you are in charge of setting up the props. The props are transported in crates by a truck. The crates are unloaded by pushing them down a ramp. You realize that the frictional force is making your job difficult, so you decide to investigate how to reduce the frictional force. At your disposal are a small ramp and a wooden block. You are interested in determining how the kinetic frictional force depends on the normal force acting on an object. *As a firt step, you decide to vary the normal force by changing the angle of the ramp.*

EQUIPMENT

A wooden block slides down a ramp, as shown below.



For this lab you will have wooden blocks, an aluminum track, a meter stick, a stopwatch, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTIONS

Sketch a graph of the magnitude of the kinetic frictional force on the sliding block as a function of the magnitude of the normal force.

Does the kinetic frictional force on the block **increase**, **decrease**, or **stay the same** as the normal force on the block increases? Is the relationship linear, or curved? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.6

1. Make a sketch of the wood block sliding down the inclined track. Draw and label vectors to indicate the direction of the velocity and the direction of the acceleration. Also assign a symbol to the mass of the block and label it on the drawing.
2. Draw a free-body diagram of the forces on the block as it slides down the ramp. Draw the acceleration vector for the block near the free-body diagram. Choose a coordinate

system, and draw the force vectors on your coordinate system (a force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the ramp and the table? Determine all of the angles between the force vectors and the coordinate axes.

3. Write down Newton's 2nd law in both the x and y directions. For any forces that are at an angle to your coordinate system, be sure to consider the *components* along the x and y axes. It is also important to make sure that all of your signs are correct. For example, is the acceleration of the block positive or negative? You answer will depend on how you define your coordinate system.

4. Using the equations in step 3, determine an equation for the *normal force* in terms of quantities you know or can measure (the mass of the block, the angle of the track, and *g*).

5. Using the equations in step 3, determine an equation for the magnitude of the *kinetic frictional force* on the block in terms of quantities you know or can measure (the mass of the block, the angle of the track, *g*, and the acceleration of the block). How will you obtain the value of the acceleration from the video analysis software?

6. In this problem, you will change the normal force on the block by <u>changing the angle of the track</u> (keeping the mass of the block constant). If you increase the angle of the track, does the normal force on the block increase or decrease? Use your equation for the normal force from question 4 to explain your reasoning. What happens to the kinetic frictional force?

7. The normal force and the kinetic frictional force can also be related using a coefficient of kinetic friction, μ_k. What is this relationship? Use the equation to sketch a graph of the magnitude of the kinetic frictional force on the block as a function of the magnitude of the normal force. How could you determine the value of μ_k from this graph?

8. Use the simulation "Lab1Sim" (See Appendix F for a brief explanation of how to use the simulations) to simulate the effects of a wide range of friction coefficients, block masses, initial speeds, and track angles.

EXPLORATION

Find an angle where the block accelerates smoothly down the ramp. Try this when the block has different masses on top of it. If the block sticks, try using more mass or tilting your ramp from table to floor instead of just using the wooden blocks. Find a mass that allows the block to accelerate smoothly down the track for a range of angles. What measurements could you make with a meter stick to determine the angle of incline?

Decide on a position where you will release the block that fits in the frame of the camera, and will give you enough data points for the motion. Practice releasing the block from this position with your chosen mass for the block. Determine how much time it takes for the block to slide down the track and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position, mass of the block, or the release position to give you enough data points. What will you use for a calibration object in your video?

Select a series of angles and a block mass that will make your measurements most reliable.

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan from the Exploration section to select a block mass and series of angles that will make your measurements the most reliable. 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!*

Take a video of the block's motion for one angle. *Make sure you measure and record the angle of the track with uncertainty.* Analyze your data as you go along (before making the next video) so you can determine how many videos you need to make, and what the angle should be for each video.

Repeat this procedure with the same mass but for different angles. Make sure each new angle allows the block to move freely down the incline. Be sure to measure and record your angles with the uncertainty. Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the block depends on the normal force on the block.

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?

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 block slides down the track for a given angle. From your answers to the Warm-up questions, calculate the magnitude of the kinetic frictional force and the normal force on the block.

Graph the magnitude of the kinetic frictional force versus the magnitude of the normal force for <u>one block mass and the different angles you used</u>. On the same graph, show your predicted relationship. What physical quantity does the slope of the line represent?

What are the limitations on the accuracy of your measurements and analysis? Over what range of values does the measured graph best match the predicted graph? Do the two curves ever start to diverge from one another? What does this tell you about the system and the limitations on its accuracy?

CONCLUSION

How does the magnitude of the kinetic frictional force on an object depend on the normal force on the object? Did your measurements agree with your initial prediction? If they did not, explain why.

From your graph, determine the value of the coefficient of kinetic friction. Compare your value (with uncertainty) with values obtained by the other teams. Are they consistent? How does your value compare to the values in the table on page 16?

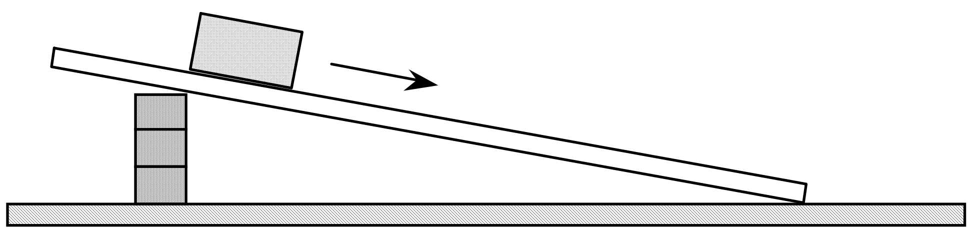
What role does the kinetic frictional force play as the crates go sliding down the ramp? How could you change the angle of the ramp to your advantage as you unload the props?

PROBLEM #4:
NORMAL FORCE AND THE
KINETIC FRICTIONAL FORCE (PART B)

You have taken a job with a theater company and you are in charge of setting up the props. The props are transported in crates by a truck. They are unloaded by pushing them down a ramp. You realize that the frictional force is making your job difficult, so you decide to investigate how to reduce the frictional force. At your disposal are a small ramp and a felt block. You are interested in determining how the kinetic frictional force depends on the normal force acting on an object. As a first step (Part A), you varied the normal force by changing the angle of the ramp. *As a second step, you decide to vary the normal force by changing the mass of the object.*

EQUIPMENT

A wooden block slides down a ramp, as shown below.



The tilt (angle) of the ramp with respect to the horizontal can be adjusted, and you can change the mass of the block by attaching weights to it. For this lab you will also have a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

Sketch a graph of the magnitude of the kinetic frictional force on the sliding block as a function of the magnitude of the normal force.

Do you expect the kinetic frictional force on the disk to **increase**, **decrease**, or **stay the same** as the normal force on the block increases? Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.6

Note: If you have completed Problem #3, refer to your previous answers to the Warm-up for questions 1-5 and question 7.

1. Make a sketch of the wood block sliding down the inclined track. Draw and label vectors to indicate the direction of the velocity and the direction of the acceleration. Also assign a symbol to the mass of the block and label it on the drawing.
2. Draw a free-body diagram of the forces on the block as it slides down the ramp. Draw the acceleration vector for the block near the free-body diagram. Choose a coordinate system, and draw the force vectors on your coordinate system (a force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the ramp and the table? Determine all of the angles between the force vectors and the coordinate axes.
3. Write down Newton's 2nd law in both the x and y directions. For any forces that are at an angle to your coordinate system, be sure to consider the *components* along the x and y axes. It is also important to make sure that all of your signs are correct. For example, is the acceleration of the block positive or negative? You answer will depend on how you define your coordinate system.
4. Using the equations in step 3, determine an equation for the *normal force* in terms of quantities you know or can measure (the mass of the block, the angle of the track, and *g*).
5. Using the equations in step 3, determine an equation for the magnitude of the *kinetic frictional force* on the block in terms of quantities you know or can measure (the mass of the block, the angle of the track, *g*, and the acceleration of the block). How will you obtain the value of the acceleration from the video analysis software?
6. In this problem, you will change the normal force on the block by <u>changing the mass of the block</u> (keeping the angle of the track constant). If you increase the mass of the block, does the normal force on the block increase or decrease? Use your equation for the normal force from question 4 to explain your reasoning. What happens to the kinetic frictional force?
7. The normal force and the kinetic frictional force can also be related using a coefficient of kinetic friction, μ_k. What is this relationship? Use the equation to sketch a graph of the magnitude of the kinetic frictional force on the block as a function of the magnitude of the normal force. How could you determine the value of μ_k from this graph?
8. Use the simulation "Lab1Sim" (See Appendix F for a brief explanation of how to use the simulations) to simulate the effects of a wide range of friction coefficients, block masses, initial speeds, and track angles.

EXPLORATION

Find an angle where the block accelerates smoothly down the ramp. Try this when the block has different masses on top of it. If the block sticks, try using more mass or tilting your ramp from table to floor instead of just using the wooden blocks. Find an angle that allows the block to accelerate smoothly down the track for a range of masses. What measurements could you make with a meter stick to determine the angle of incline?

Decide on a position where you will release the block that fits in the frame of the camera, and will give you enough data points for the motion. Practice releasing the block from this position with your chosen angle for the track. Determine how much time it takes for the block to slide down the track and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position, angle of the track, or the release position to give you enough data points. What will you use for a calibration object in your video?

Select a series of block masses and a track angle that will make your measurements most reliable.

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan from the Exploration section to select a track angle and series of block masses that will make your measurements the most reliable. 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!*

Take a video of the block's motion for one block mass. *Make sure you measure and record the angle of the track and the block mass with uncertainty.* Analyze your data as you go along (before making the next video) so you can determine how many videos you need to make, and what the block mass should be for each video.

Repeat this procedure with the same mass but for different angles. Make sure each new angle allows the block to move freely down the incline. Be sure to measure and record your angles with the uncertainty. Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the block depends on the normal force on the block.

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?

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 block slides down the track for a given angle. From your answers to the Warm-up questions, calculate the magnitude of the kinetic frictional force and the normal force on the block.

Graph the magnitude of the kinetic frictional force versus the magnitude of the normal force for <u>one track angle and the different block masses you used</u>. On the same graph, show your predicted relationship. What physical quantity does the slope of the line represent?

What are the limitations on the accuracy of your measurements and analysis? Over what range of values does the measured graph best match the predicted graph? Do the two curves ever start to diverge from one another? What does this tell you about the system and the limitations on its accuracy?

CONCLUSION

Explain how the magnitude of the kinetic frictional force on an object depends on the normal force on the object. Did your measurements agree with your initial prediction? If not, explain why .
From your graph, determine the value of the coefficient of kinetic friction. Compare your value (with uncertainty) with values obtained by the other teams. Are they consistent? How does your value compare to the values in the table on page 16?

What role does the kinetic frictional force play as the crates go sliding down the ramp? How could you change the angle of the ramp to your advantage as you unload the props?

If you also did Problem #3, compare the results from Part A and Part B. Do you think it is better to vary the normal force by changing the angle or by changing the mass of the object? Why?

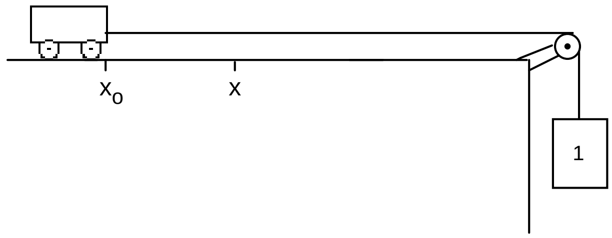
Table of Coefficients of Friction*

Surfaces	μ_s	μ_k
steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
copper on steel	0.53	0.36
steel on lead	0.9	0.9
copper on cast iron	1.1	0.3
copper on glass	0.7	0.5
wood on wood	0.25 - 0.5	0.2
glass on glass	0.94	0.4
metal on metal (lubricated)	0.15	0.07
Teflon on Teflon	0.04	0.04
rubber on concrete	1.0	0.8
ice on ice	0.1	0.03

* All values are approximate.

☑ CHECK YOUR UNDERSTANDING

1. A cart and Block 1 are connected by a massless string that passes over a frictionless pulley, as shown in the diagram below.



When Block 1 is released, the string pulls the cart toward the right along a horizontal table. For each question below, explain the reason for your choice.

a. The *speed* of the cart is:

(a) constant.
(b) continuously increasing.
(c) continuously decreasing.
(d) increasing for a while, and constant thereafter.
(e) constant for a while, and decreasing thereafter.

b. The *force* of the string on Block 1 is

(a) zero.
(b) greater than zero but less than the weight of Block 1.
(c) equal to the weight of Block 1.
(d) greater than the weight of Block 1.
(e) It is impossible to tell without knowing the mass of Block 1.

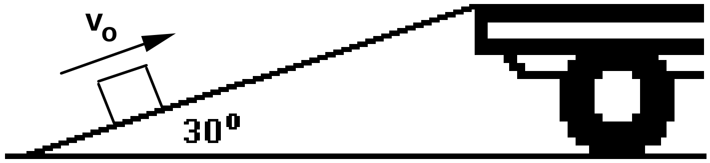
c. When the cart traveling on the table reaches position x, the string breaks. The cart then

(a) moves on at a constant speed.
(b) speeds up.
(c) slows down.
(d) speeds up, then slows down.
(e) stops at x.

d. Block 1 is now replaced by a larger block (Block 2) that exerts *twice the pull* as was exerted previously. The cart is again reset at starting position x_o and released. The string again breaks at position x. Now, what is the *speed* of the cart at position x *compared to* its speed at that point when pulled by the smaller Block 1?

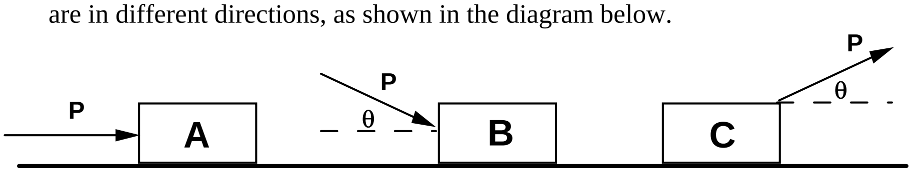
(a) Half the speed it reached before.
(b) Smaller than the speed it reached before, but not half of it.
(c) Equal to the speed it reached before.
(d) Double the speed it reached before.
(e) Greater than the speed it reached before, but not twice as great.

2. A crate is given an initial push up the ramp of a truck. It starts sliding up the ramp with an initial velocity v_o, as shown in the diagram below. The coefficient of kinetic friction between the box and the ramp is μ_k.



Will the magnitude of the acceleration of the sliding crate be greater on the way up or on the way back down the ramp? Or will the accelerations be the same? Explain using appropriate free-body diagrams.

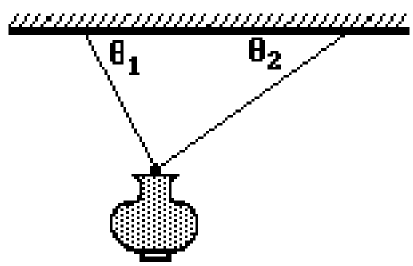
3. The same constant force (P) is applied to three identical boxes that are sliding across the floor. The forces are in different directions, as shown in the diagram below.



On which of the three boxes is the frictional force the largest? The smallest? Or is the frictional force on each box the same? Explain using appropriate free-body diagrams and Newton's second law.

4. A lamp is hanging from two light cords. The cords make unequal angles with the ceiling, as shown in the diagram at right.

a. Draw the free-body diagram of the *lamp*. Clearly describe each force drawn.



b. Is the horizontal component of the pull of the left cord on the lamp greater than, less than, or equal to the horizontal component of the pull of the right cord on the lamp? Explain your reasoning.

c. Is the vertical component of the pull of the left cord on the lamp greater than, less than, or equal to the vertical component of the pull of the right cord on the lamp? Explain your reasoning.

d. Is the vertical component of the pull of the left cord on the lamp greater than, less than, or equal to half the weight of the lamp? Explain your reasoning.

TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory III

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.

LABORATORY IV
CIRCULAR MOTION

The problems in this laboratory will help you investigate objects moving in uniform circular motion. This is the same motion that describes satellites in orbit around the earth, or objects whirled around on a rope.

Circular motion can be explained with the same concepts as those used in explaining projectile motion: position, velocity, acceleration, and time. Unlike projectile motion, however, the acceleration of an object undergoing circular motion is *not* constant!

In problems one and two, you will determine the magnitude and direction of acceleration for a rotating platform with uniform circular motion. In problems three and four, you will use acceleration and net force required for circular motion to determine the period of an object whirled horizontally by a rope.

OBJECTIVES:

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

- Determine the acceleration of an object undergoing uniform circular motion.
- Use position, velocity, acceleration, and force as vector quantities.
- Use forces to make quantitative predictions for objects in circular motion

PREPARATION:

Read Serway & Vuille Chapter 7 Sections 7.1 to 7.4. Review your results and procedures from Laboratories I, II, and III. Before coming to the lab you should be able to:

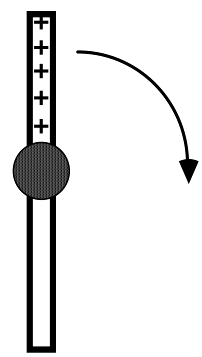
- Determine an object's instantaneous and average velocity and acceleration from video images.
- Analyze a vector in terms of its components.
- Add and subtract vectors graphically.

PROBLEM #1:
CIRCULAR MOTION AND ACCELERATION (PART A)

You have been appointed to an amusement ride safety committee for the Mall of America's Camp Snoopy, which is reviewing the safety of a ride that consists of seats mounted on each end of a steel beam. For most of the ride, the beam rotates about its center in a horizontal circle at a constant speed. One committee member insists that a person moving in a circle at constant speed is not accelerating, so there is no need to be concerned about the ride's safety. Another thinks that the person has a constant acceleration when moving at a constant speed. Yet a third argues that the person's acceleration depends on the rate of change of their velocity, not their speed. Since each component of the person's velocity changes with time, their acceleration must change with time. You decide to settle the issue by making a model of the ride and measuring the **magnitude** of the acceleration of different positions on the model when it spins at a constant speed.

EQUIPMENT

For this lab you will have a rotating platform on an A-frame base (top view is shown on the right.) You will also have a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoTOOL and VideoRECORDER).



PREDICTION

Does an object moving in a circle accelerate? If so, does the *magnitude* of the acceleration change with time? Explain your reasoning. Use the acceleration equation you derived in the Warm-up to support your claim.

WARM-UP

Read: Serway & Vuille Chapter 7, Section 7.1 to 7.4

1. Make a drawing of the path of an object in circular motion at constant speed. On that path, use a dot to represent the object's position at time t_1. Label this point as O, and draw a vector at O to represent the magnitude and direction of the object's velocity at time t_1. Draw another dot to represent the object's position at a later time t_2, shortly after t_1, and label this point P. Draw a vector at P to show the magnitude and direction of the object's velocity at time t_2.

2. Redraw the velocity vectors with the tail of one vector (point P) at the tail of the other vector (point O). Keep the same size and direction as in the previous drawing. To find the acceleration of the object, you are interested in the change in velocity (Δv). The change Δv is the increment that must be added to the velocity at time t_1 so that the resultant velocity has the new direction after the elapsed time $\Delta t = t_2 - t_1$. Add the change in velocity Δv to your drawing of the velocity vectors; it should be a straight line connecting the heads of the vectors.

3. On your drawing from question 1, label the distance r from the center of the circle to points O and P. In the limit that the time interval is very small, the arc length distance traveled by the object can be approximated as a straight line. Use this approximation to label the distance traveled by the object along the circle from point O to P in terms of the object's velocity and the elapsed time.

4. The triangle drawn in question 2 (with v and Δv) is similar to the triangle drawn in question 3 (with r and the straight line distance traveled by the object) because they have the same apex angle. Use the relationship of similar triangles to write an equation that connects the sides and the bases of the two triangles.

5. Solve your equation for $\Delta v/\Delta t$ to get an expression for the acceleration in terms of the object's uniform velocity and the distance r.

6. From your equation, is the acceleration of an object in circular motion ever zero? Does the magnitude of the acceleration change with time?

EXPLORATION

Attach the metal platform to the A-frame base and practice spinning it at different speeds. How many rotations does the platform make before it slows down appreciably? Use the stopwatch to measure the total time. Determine which spin gives the closest approximation to constant speed. At that speed, how many video frames will you get for one rotation? Will this be enough to calculate the acceleration as a function of time?

Check to see if the rotating platform is level. Place the apparatus on the floor and adjust the camera tripod so that the camera is directly above the center of the rotating platform.

Practice taking some videos. Choose a position on the platform to represent a person on the spinning ride. How will you make sure that you always click on this same position on the platform when acquiring data?

Decide how to calibrate your video. Where would you put your origin?

MEASUREMENT

Obtain position and velocity data for a specific point on the platform as it spins. Your video should consist of more than two complete rotations. Does the initial position of the rotating platform in your video affect your data? Measure the distance from the center of the platform to rider position with a ruler.

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 the total distance the object travels and the total time to determine the maximum and minimum values for each axis.

ANALYSIS

Choose a function to represent the graph of horizontal position versus time and another for the graph of vertical position versus time. Can you determine any of the constants from your graph? You can waste a lot of time if you just try to guess the constants in your equations. How can you tell when a complete rotation occurred from each graph? *Hint: Think about what functions might match the general shape of your graph. Are the data linear, or curved? Try some of the menu options. If you still have trouble choosing a function, ask your TA for more hints.*

Similarly, choose a function to represent the graph of horizontal velocity versus time and another for the graph of vertical velocity versus time.

Export your data to a spreadsheet.

The exported data should include horizontal and vertical positions you acquired, and the time stamp. What is a relationship between velocity and position? Make two new columns in your spreadsheet, and use this relationship to calculate the x and y components of the velocity for each pair of successive position measurements.

How can you determine the magnitude of the velocity from the x and y components of the velocity? Make a new column in your spreadsheet of the data that includes the magnitude of the velocity for each point.

Use your equation from the Warm-up to calculate the magnitude of the acceleration of the object in circular motion for each point. Include this in the data table. Is the acceleration zero, or nonzero? Do the values change with time, or remain relatively constant?

Make sure you save a copy of your data, because you might need it for your lab report or the next lab problem.

CONCLUSION

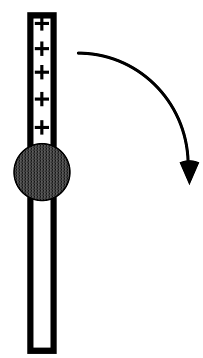
Does the magnitude of the acceleration agree with your prediction? Is it constant, or does it change with time? What will you tell the committee? State your result in the most general terms supported by your analysis. What are the limitations on the accuracy of your measurements and analysis?

PROBLEM #2:
CIRCULAR MOTION AND ACCELERATION (PART B)

You have finally convinced the safety committee that a person on the spinning ride at Camp Snoopy accelerates even though the ride moves at a constant speed. The next step for the Committee is to determine the **direction** of the acceleration and thus the direction of the net force on a person so that they can complete their safety proposal.

EQUIPMENT

For this lab you will have a rotating platform on an A-frame base (top view is shown on the right.) You will also have a stopwatch, a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoTOOL and VideoRECORDER).



PREDICTION

Determine the direction of the acceleration for an object rotating in a circle at a constant speed. Explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 7, Section 7.1 to 7.4

1. Make a drawing of the path of an object in circular motion at constant speed. On that path, use a dot to represent the object's position at time t_1. Label this point as O, and draw a vector at O to represent the magnitude and direction of the object's velocity at time t_1. Draw another dot to represent the object's position at a later time t_2, shortly after t_1, and label this point P. Draw a vector at P to show the magnitude and direction of the object's velocity at time t_2.

2. Redraw the velocity vectors with the tail of one vector (point P) at the tail of the other vector (point O). Keep the same size and direction as in the previous drawing. The change Δv is the increment that must be added to the velocity at time t_1 so that the resultant velocity has the new direction after the elapsed time $\Delta t = t_2 - t_1$. Add the change in velocity Δv to your drawing of the velocity vectors; it should be a straight line connecting the heads of the vectors.

3. Recalling the relationship between change in velocity and acceleration, construct a vector that represents the direction and magnitude of the *average acceleration* between the pair of velocities. Would the direction of the acceleration be different for very close points on the object's path?

4. Repeat steps 1-3 for two different neighboring positions on the object's circular path. Is the direction of the acceleration for this pair of velocities the same, or different as before? What can you conclude (in general) about the direction of acceleration?

EXPLORATION

If you have already done Problem #1, you can use that video and data and move on to the analysis. If not, do the exploration in Problem #1.

MEASUREMENT

If you have already done Problem #1, you can use those measurements and move on to the analysis. If not, do the measurement given in that Problem.

ANALYSIS

Use the spreadsheet data values you exported to determine the approximate velocity vector components at each position of the object's motion. Why are the velocity vectors approximate? Make a large drawing of the motion of the object, labeling the position and velocity components for a few of the consecutive values. Show the direction of the velocity at these points. You should use as many dots as needed to convince yourself and others of the direction of the velocity of the object.

Use the velocity vectors (and the change in the velocity vectors) to determine the approximate direction of the acceleration vectors at each position. Why are the acceleration vectors approximate? You should use as many dots as needed to convince yourself and others of the direction of the acceleration of the object.

CONCLUSION

What is the direction of the acceleration for an object rotating with a constant speed? What will you tell your committee members? How fast can the ride spin before harming the riders? Is this answer consistent with your prediction? Why or why not?

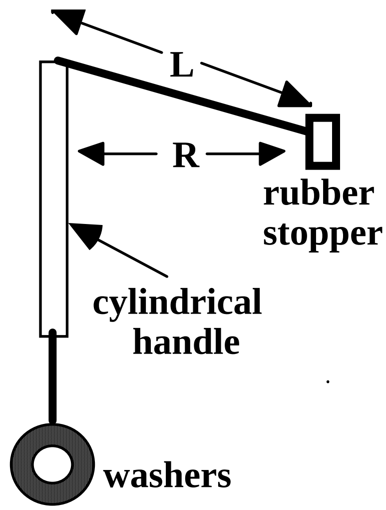
PROBLEM #3:
ROTATIONAL PERIOD AND FORCE (PART A)

Another popular amusement ride consists of seats attached to ropes which are then whirled in a circle. As a member of the safety committee you are asked to determine the relationship between the force exerted by the rope to keep the riders rotating approximately horizontal to the ground and the period of rotation. Specifically, you must determine how the force required to keep an object rotating at a constant speed changes depending on the object's rotational period. This is an essential study because it will help determine how fast the rotation can be without snapping the ropes.

EQUIPMENT

You will use a rubber stopper attached to one end of a string. The string is threaded through a cylindrical handle and a hanging washer is attached to the other end of the string. By gently rotating the vertical handle, you can make the rubber stopper move with a constant speed in a horizontal circle around the handle. You will also have a stopwatch, a meter stick, and a triple-beam balance.

In this lab problem you will have several washers available to vary the hanging mass on the string.



PREDICTION

Write an equation for the period of rotation for the stopper moving at a constant speed in a nearly horizontal circle. The equation should be in terms of the mass of the washer (M), mass of the stopper (m), and the length of the string from handle to stopper (L).

Determine how the force exerted on the string holding the stopper depends on the period of rotation. Use this equation to sketch a graph of the force on the string versus the period of rotation.

WARM-UP

Read: Serway & Vuille Chapter 7, Sections 7.1 to 7.4

1. Make a sketch of the problem situation similar to the one in the Equipment section. Indicate the path taken by the rubber stopper. In this case you may want to make two pictures: a top view and a side view.Label the length of the string between the top of the cylinder and the rotating stopper, the mass of the rubber stopper and hanging washer(s), and the velocity and acceleration vectors of the stopper.

2. Because gravity pulls downward on the stopper, the string slopes slightly downward in the picture. For simplicity, in this problem you can assume the string is approximately parallel to the ground. (The vertical forces on the stopper are small enough in comparison to the horizontal force(s) to be neglected.) Draw a new side view picture with the stopper moving purely horizontally.

3. Draw <u>separate</u> free-body diagrams of the forces on the stopper and the forces on the hanging washer(s) while the stopper is moving horizontally. What assumptions, if any, are you making? Assign symbols to all of the forces, and define what they represent next to your diagrams. For easy reference, it is useful to draw the acceleration vector for the object next to its free-body diagram. It is also useful to put the force vectors on a separate coordinate system for each object (force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system.

4. For *each* force diagram (one for the stopper and another one for the washers), write down Newton's 2nd law in both the x and y directions. What is the direction of the acceleration of the stopper? Your answer will depend on how you define your coordinate system.

5. Write down a relationship between the weight of the hanging washer(s) and the force acting on the stopper by the string. What is the force acting on the *string*?

6. How can you determine the stopper's centripetal acceleration from its speed? How can you determine the stopper's speed from its period? Combine these relationships with the ones in questions 4 and 5 to write an equation for the stopper's period in terms of the mass of the hanging washers (M), the mass of the stopper (m), and the length of the string from the handle to the stopper (L).

7. Use the relationship from question 5 to write an equation for the force on the *string* in terms of the stopper's period of rotation (T), the mass of the stopper (m), and the length L. Use this equation to sketch a graph of the force on the string versus the period of rotation.

EXPLORATION

TRY NOT TO HIT YOURSELF, YOUR CLASSMATES, OR YOUR LAB INSTRUCTOR!
The rubber stopper could give someone a serious injury. Wear the safety goggles provided to protect your eyes.

Assemble the apparatus as shown in the Equipment section. While rotating the rubber stopper, the length of the string between the top of the cylinder and the rotating stopper should be held constant. Mark the string with a pen or tape to ensure this.

Hang a different number of washers from the string to see how it feels when you rotate the rubber stopper. Decide on the range of washer masses that you need to use to determine the relationship between the period of rotation and the mass of hanging washers. You may need to refer to your predicted relationship to determine the range of masses to use.

Can you measure one period of rotation accurately with a stopwatch? If not, how many rotations are necessary to accurately measure the period? For very fast rotations, you might need to use many rotations to minimize uncertainty. Try it.

MEASUREMENT

Record the length of string between the top of the cylinder and the rotating stopper, and the mass of the rubber stopper. Include measurement uncertainties.

For a range of different hanging washers, measure the period of the rubber stopper with a stopwatch. Record your measurements of the period associated with each hanging mass in an organized way.

ANALYSIS

Using your prediction equation, calculate the predicted period for each hanging mass you used.

What is the relationship between the hanging washer mass and the tension force on the string? Calculate the force on the string for each of your measured periods.

Make a graph of the force on the string versus the *measured* period of rotation for your data. On the same graph, plot the force on the string versus the *predicted* period of rotation.

CONCLUSION

What are the limitations on the accuracy of your measurements?

How does the force required to keep an object rotating at a constant speed change depending on the object's rotational period? Explain your answer.

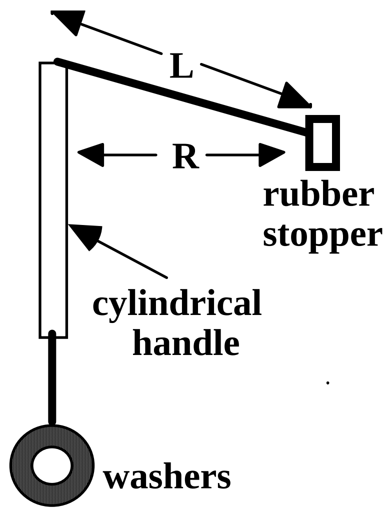
PROBLEM #4:
ROTATIONAL PERIOD AND FORCE (PART B)

As an extension of your study in Problem #3 you are now asked to determine how the period of rotation of a rider depends on the rider's mass when the radius of rotation is kept the same. This is important since obviously not all theme park visitors weigh the same.

EQUIPMENT

The apparatus you will use has a rubber stopper attached to one end of a string. The string is threaded through a cylindrical handle and a hanging washer is attached to the other end of the string. By gently rotating the vertical handle, you can make the rubber stopper move with a constant speed in a circle around the handle. You will also have a stopwatch, a meter stick, and a triple-beam balance.

In this lab problem you will have several rubber stoppers of different masses.



PREDICTION

Write an equation for the period (T) of rotation for the stopper moving at a constant speed in a nearly horizontal circle. The equation should be in terms of the mass of the washer (M), mass of the stopper (m), and the length of the string from handle to stopper (L).

Use this equation to sketch a graph of the period of rotation vs. mass of the stopper.

WARM-UP

Read: Serway & Vuille Chapter 7, Sections 7.1 to 7.4

If you have completed part A, refer to your answers to Warm-up questions 1 – 6 from problem #3.

1. Make a sketch of the problem situation similar to the one in the Equipment section. Indicate the path taken by the rubber stopper. In this case you may want to make two pictures: a top view and a side view. Label the length of the string between the top of the cylinder and the rotating stopper, the mass of the rubber stopper and hanging washer(s), and the velocity and acceleration vectors of the stopper.

2. Because gravity pulls downward on the stopper, the string slopes slightly downward in the picture. For simplicity, in this problem you can assume the string is approximately parallel to the ground. (The vertical forces on the stopper are small enough in comparison to the horizontal force(s) to be neglected.) Draw a new side view picture with the stopper moving purely horizontally.

3. Draw <u>separate</u> free-body diagrams of the forces on the stopper and the forces on the hanging washer(s) while the stopper is moving horizontally. What assumptions, if any, are you making? Assign symbols to all of the forces, and define what they represent next to your diagrams. For easy reference, it is useful to draw the acceleration vector for the object next to its free-body diagram. It is also useful to put the force vectors on a separate coordinate system for each object (force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system.

4. For *each* force diagram (one for the stopper and another one for the washers), write down Newton's 2nd law in both the x and y directions. What is the direction of the acceleration of the stopper? Your answer will depend on how you define your coordinate system.

5. Write down a relationship between the weight of the hanging washer(s) and the force acting on the stopper by the string. What is the force acting on the *string*?

6. How can you determine the stopper's centripetal acceleration from its speed? How can you determine the stopper's speed from its period? Combine these relationships with the ones in questions 4 and 5 to write an equation for the stopper's period in terms of the mass of the hanging washers (M), the mass of the stopper (m), and the length of the string from the handle to the stopper (L).

7. Use this equation to sketch a graph of the period of rotation versus the mass of the stopper.

EXPLORATION

TRY NOT TO HIT YOURSELF, YOUR CLASSMATES, OR YOUR LAB INSTRUCTOR!
The rubber stopper could give someone a serious injury. Where the safety goggles provided to protect your eyes.

Assemble the apparatus as shown in the Equipment section. While rotating the rubber stopper, the length of the string between the top of the cylinder and the rotating stopper should be held constant. Mark the string with a pen or tape to ensure this.

Decide how many washers you want to hang on the string. Make sure this number of washers enables you to produce good results for all of the different stopper masses that you will use.

Can you measure one period of rotation accurately with a stopwatch? If not, how many rotations are necessary to accurately measure the period? Try it.

MEASUREMENT

Record the length of string between the top of the cylinder and the rotating rubber stopper you will use, and the mass of the rubber stopper. Include uncertainties.

For a range of different masses of rubber stoppers, measure the period of the rubber stopper with a stopwatch. Record your measurements of the period associated with each stopper mass in an organized way.

ANALYSIS

Using your prediction equation from the Warm-up questions, calculate the *predicted* period for each stopper mass you used.

Make a graph of the *measured* period of the system vs. the mass of the rubber stopper. On the same graph, plot the *predicted* period vs. the mass of the rubber stopper.

CONCLUSION

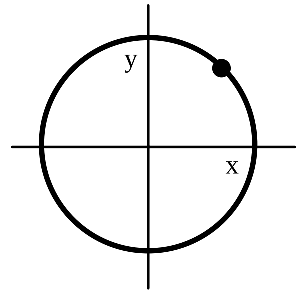
How does your predicted graph compare to the graph you found from your measurements? Explain any differences.

What is the limitation on the accuracy of your measurements? How does the period of rotation of the rubber stopper depend on its mass?

☑ CHECK YOUR UNDERSTANDING

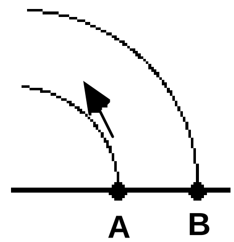
1. A ball on the end of a string travels in a clockwise circle at constant speed. On the figure at right, draw the vectors requested below, label them clearly, and explain your choices.

   a. The position vector for the ball.
   b. The velocity vector for the ball.
   c. The acceleration vector for the ball.



2. Two beads are fixed to a rod rotating at constant speed about a pivot at its left end, as shown in the drawing at right.

   a. Which bead has the greater speed? Explain your reasoning.

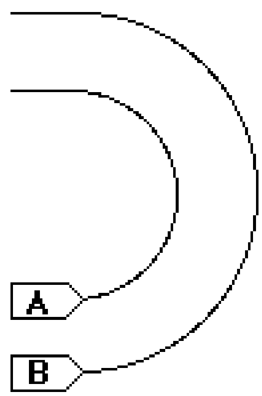


   b. Which bead has an acceleration of greater magnitude? Explain your reasoning.

3. Two racing boats go around a semicircular turn in a race course. The boats have the same speed, but boat A is on the inside while boat B is on the outside, as shown in the drawing.

   a. Which boat gets around the turn in less time? Explain your reasoning.

   b. Which boat undergoes the greater change in velocity while in the turn? Explain your reasoning.



   c. Based on the definition of acceleration, which boat has the greater acceleration while in the turn? Explain your reasoning.

   d. Based on the equation for centripetal acceleration, which boat has the greater acceleration while in the turn? Compare your answer to part c. Explain your reasoning.

4. A planet moves in a uniform circular orbit around the sun, which exerts a gravitational force F_G on the planet. What additional *force(s)* act on the planet?

   (a) A force of motion in the direction of the circular orbit.

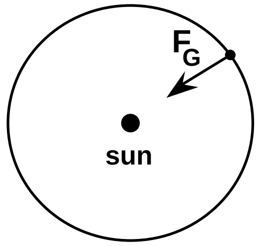
   (b) A centrifugal force acting outward (away from the sun).

   (c) A centripetal force acting inward (toward the sun).

   (d) A normal force.

   (e) The gravitational force (F_G) is the only force.

   Explain the reason for your choice.



5. Centripetal force is simply a special name that we give to the net force that produces a centripetal acceleration. In each case listed below, identify the force, force component, or combination of forces that provides the centripetal force. Draw a force diagram for each case and discuss it.

   a. A child on a swing travels in a circular arc. Analyze the situation at the bottom of the swing.

   b. A car travels around a circular, flat, horizontal curve.

   c. A person stands on the equator of the earth, traveling in an earth-sized circle as the earth rotates.

   d. A car travels in a circular curve that is banked inward.

   e. A ball rolls inside a circular hoop that is placed on a horizontal table.

   f. A car drives over the top of a circular hill.

   g. A tennis ball rolls without slipping over the top of a basketball

TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory IV

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.

LABORATORY V
ENERGY

In this lab, you will begin to use the principle of *conservation of energy* to determine the motion resulting from interactions that are difficult to analyze using force concepts alone. Keep in mind that **energy is always conserved**, it but it is sometimes difficult to calculate the value of all of the energy terms for an interaction.

Not all of the initial energy of a system ends up as visible energy of motion. Some energy is transferred into or out of the system, and some may be transformed to internal energy of the system. Since this energy is not observable in the macroscopic motion of objects, we sometimes say that the energy is "dissipated" in the interaction.

The first three problems explore the application of conservation of energy to collisions. The fourth problem deals with conservation of energy, power output, and the human body.

OBJECTIVES:

Successfully completing this laboratory should enable you to:

- Use the conservation of energy to predict the outcome of interactions between objects.
- Choose a useful system when using conservation of energy.
- Identify different types of energy when applying energy conservation to real systems.
- Decide when conservation of energy is not useful to predict the outcome of interactions between objects.

PREPARATION:

Read Serway & Vuille Chapter 5. You should also be able to:

- Analyze the motion of an object from videos.
- Calculate the kinetic energy of a moving object.
- Calculate the work done on a system by an external force.
- Calculate the gravitational potential energy of an object with respect to the earth.
- Calculate the total energy of a system of objects.
- Calculate the mechanical power output of a system.

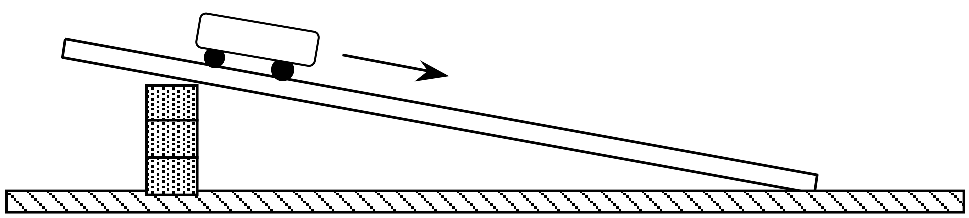
PROBLEM #1:
KINETIC ENERGY AND WORK

You have been hired as a technical adviser for an upcoming western film. In the script, a wagon containing boxes of gold has been cut loose from the horses by an outlaw. The wagon starts from rest near the top of a hill. The outlaw plans to have the wagon roll down the hill, across a flat section of ground, and over a cliff face into a canyon. The outlaw stations some of his gang in the canyon to collect the gold from the demolished wagon. Little do they know, the Lone Ranger sees the outlaw's action from his lookout post near the base of the hill, and quickly races on horseback to intercept the wagon before it plummets into the canyon. The Lone Ranger must match the speed of the wagon at the base of the hill to hook a strong cord onto the wagon, and then lasso the other end to a large rock.

The director asks you to determine how the velocity of the stagecoach near the bottom of the hill depends on its initial release height up the hill, to coordinate a reasonable required speed for the Lone Ranger's interception. You decide to model the situation using a cart released from rest on an inclined track.

EQUIPMENT

For this problem you will have a meter stick, a stopwatch, wood blocks, an aluminum track, a PASCO cart, a video camera, a triple-beam balance, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).



PREDICTION

For a cart rolling down an inclined track, write an expression for the final velocity in terms of the initial (vertical) release height. Does the final velocity depend on the steepness (angle) of the incline?

Use your expression to sketch a graph of the final velocity versus the initial release height.

WARM-UP

Read: Serway & Vuille Chapter 5, Sections 5.1 to 5.2

1. Draw two pictures, one showing the cart at rest at the top of the incline, and another when it is rolling at the bottom of the incline. Draw velocity vectors on your sketch. Define your system. Label the distances, mass of the cart, and the kinetic energy of all objects in your system for both pictures.

2. What is the work done by gravity on the cart from its initial position to when it reaches the bottom of the hill? Hint: remember that to calculate work, you need to multiply the magnitude of the force and the displacement *in the same direction* as the force. You can choose to use either the vertical displacement of the cart, or the distance traveled along the incline.

3. Use the work-kinetic energy theorem to write an equation that relates the work done by gravity on the cart to the change in kinetic energy between its initial release and when it reaches the base of the hill. Assume energy dissipation is small enough to be neglected. Solve your equation for the final velocity of the cart in terms of the vertical release height. (If your equation is in terms of the distance traveled along the incline, use trigonometry to relate this distance to the vertical height of the hill.) Does your equation depend on the steepness of the hill, as measured by the angle of the incline?

EXPLORATION

Practice releasing the cart from rest on the inclined aluminum track. Try a variety of different track angles, release heights, and cart masses. Record your observations of the cart's motion for each practice run. Do you observe a difference in the final velocity of the cart if you release it from the same height, but with a steeper incline? BE SURE TO CATCH THE CART AT THE BOTTOM OF THE TRACK!

Choose a single angle of incline for the aluminum track, the cart mass you will use, and several release heights for the cart. Set up the camera and tripod to give you the best video of the cart's motion down the incline. *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 will you use for a calibration object in your videos? What quantities in your prediction equation do you need to measure with the video analysis software, and what quantities can be measured without the video?

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan from the Exploration section. Record a video of the cart's motion down the incline for the first release height you have chosen. 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.

Open your video in VideoTOOL and follow the instructions to acquire data. As a lab group, decide how you will acquire the value for the final velocity of the cart when it is at the bottom of the hill.

Repeat the data acquisition and analysis for different cart release heights. How many different heights do you need to adequately verify your prediction?

If you have time, try acquiring data to compare two videos with the same vertical release height for the cart, but a steeper incline (different track angle).

ANALYSIS

Determine the fit functions that best represent the position vs. time graphs for the cart in the x and y directions. (If you are having trouble, review your notes from Lab I Problem 2: Motion Down an Incline.) How can you estimate the values of the constants of each 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? Be sure to record all of the fit equations into your lab journal in an organized manner.

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 quantity or quantities are you interested in acquiring from the graphs of position and velocity in VideoTOOL? Are the fit functions helpful in this case, or do you need to look at the raw data?

For each cart release height, use your predicted expression from the Warm-up and Prediction to calculate the predicted final velocity of the cart. Have you measured all of the quantities that you need for this expression? If not, be sure to take the measurements before you leave the lab. Make a data table in your lab journal that lists the predicted (calculated) final velocity and the measured final velocity from VideoTOOL for each release height.

Make a graph of the final velocity versus the release height for your predicted and measured data (plot the measured and predicted velocities on the same graph, but with different colors or symbols.)

CONCLUSION

How did your measurements compare to your prediction? What are the limitations on the accuracy of your measurements and analysis? What were the sources of your uncertainties?

For a cart rolling down an inclined track, how does the final velocity depend on the initial release height? Does the final velocity depend on the steepness (angle) of the incline? (If you did not try different angles for measurements or in the Exploration, compare notes with another lab group.)

PROBLEM #2:
ENERGY EFFICIENCY OF COLLISIONS

You are working at a company that designs pinball machines and have been asked to devise a test to determine the efficiency of some new magnetic bumpers. You know that when a normal pinball rebounds off traditional bumpers, some of the initial energy of motion is "dissipated" in the deformation of the ball and bumper, thus slowing the ball down. The lead engineer on the project assigns you to determine if the new magnetic bumpers are more efficient. The engineer tells you that the efficiency of a collision is the ratio of the final kinetic energy to the initial kinetic energy of the system.

Since you want to measure the efficiency of the bumper (not the ball), you decide to compare the collision efficiency of a cart with a magnet colliding with a magnetic bumper to the cart colliding with a nonmagnetic bumper.

EQUIPMENT

For this problem you will have a meter stick, a stopwatch, wood blocks, an aluminum track, a magnetic bumper (end stop), a PASCO cart, a video camera, a triple-beam balance, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

For a level track, write an expression for the energy efficiency of the collision between the cart and the bumper in terms of the least number of quantities that you can easily measure. Write an expression for the energy dissipated during the impact with the bumper in terms of measurable quantities.

Do you expect the cart's collision with a magnetic bumper to have a higher, lower, or equal efficiency to the cart's collision with a nonmagnetic bumper? Use your equations to explain your reasoning.

WARM-UP

Read: Serway & Vuille Chapter 5, Sections 5.2, 5.3, and 5.5

1. Draw two pictures, one showing the situation before the impact with the bumper and the other one after the impact. Draw velocity vectors on your sketch. Define your system. Label the kinetic energy of all objects in your system before and after the impact.

2. According to the engineer's information, what is the efficiency of the bumper in terms of the final and initial kinetic energies of the cart? Write an equation for the efficiency of the collision in terms of quantities you know or can measure. Does your equation depend on the cart mass?

3. Write down a conservation of energy equation for the collision with the bumper (remember to take into account the energy dissipated). Use this to write an expression for the energy dissipated during the impact with the bumper in terms of the cart mass and initial and final velocities. Does the energy dissipated depend on the mass of the cart?

EXPLORATION

Practice giving the cart an initial push along the level track to collide with the magnetic bumper. Repeat for several different initial velocities. How can you ensure that the bumper does not change position during the collision? Try adding more mass to the cart, and observe a collision. Do you notice any change in the cart's motion due to more mass?

Practice giving the cart an initial push along the level track to collide with a nonmagnetic bumper, such as a wood block or a nonmagnetic end stop. Repeat for several different initial velocities. How can you ensure that the bumper does not change position during the collision?

Find a range of initial velocities that do not collide too violently with the bumpers. Set up the camera and tripod to give you the best video of the collision immediately before and after the cart collides with the bumpers. Hint: For a clear comparison of the two bumpers, it is useful to use the same initial velocities for each kind of bumper.

What will you use for a calibration object in your videos? What quantities in your prediction equations do you need to measure with the video analysis software? Is it possible to obtain information before and after the collision with one video analysis, or will you need to analyze each video more than once?

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan from the Exploration section. Record a video of the cart's collision with a magnetic end stop and repeat (for the same initial velocity) with a nonmagnetic end stop, or a wood block. Use a stopwatch and the distance traveled by the cart before impact with the bumper to estimate the initial velocity of the cart for each trial.

Open one of your videos in VideoTOOL and follow the instructions to acquire data. As a lab group, decide how you will acquire data and analyze the collision. (Will you acquire data for the cart's motion before the impact and repeat the process for after the impact, or will you acquire data for the entire motion of the cart in a single analysis?)

If you have time, repeat the measurements for a different initial velocity. If there is not enough time, compare your data with another lab group that used a different initial velocity of the cart.

ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the position vs. time graphs for the cart in the x and y directions. If you acquired data separately for before and after the collision, you will have separate fit functions for each time you analyze the video. If you acquired data for the entire motion of the cart, look at the data and decide what fit function you think best matches the graphs. How can you estimate the values of the constants of each 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? Be sure to record all of the fit equations into your lab journal in an organized manner.

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

For each collision, use your predicted expressions from the Warm-up and Prediction to calculate the energy efficiency and energy dissipated with appropriate units. Have you measured all of the quantities that you need for these expressions? If not, make sure you measure them before you leave the lab.

CONCLUSION

What was the efficiency of each collision? How much energy was dissipated in the impact? What are the limitations on the accuracy of your measurements and analysis? What were the sources of your uncertainties?

Did a magnetic bumper have a higher, lower, or same efficiency as the nonmagnetic bumper? Did the efficiency of a bumper depend on the initial velocity you gave the cart?

PROBLEM #3:
ENERGY IN COLLISIONS WHEN OBJECTS STICK TOGETHER

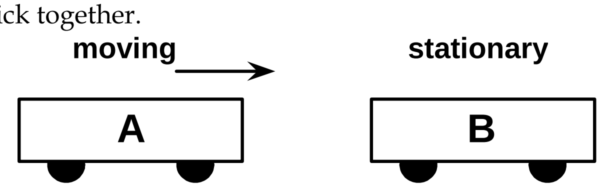
You have a summer job with the Minnesota Traffic Safety Board. You are helping to write a report about the damage done to vehicles in different kinds of traffic accidents. Your boss wants you to concentrate on the damage done when a moving vehicle hits a stationary vehicle and they stick together.

You know that in a traffic collision, as with any interaction, some of the initial energy of motion is transformed or "dissipated" in the deforming (damaging) of the vehicles. Your boss believes that the amount of damage done in such a collision depends only on the total combined mass of the two vehicles and the initial kinetic energy of the moving vehicle. Is your boss correct?

To resolve the issue, you decide to model the collision with carts of different masses and measure the energy efficiency of three different cart collisions: one in which the moving cart is more massive, one in which the stationary cart is more massive, and one in which the moving and stationary carts are equally massive. You define efficiency as the ratio of the final kinetic energy of the system to the initial kinetic energy.

EQUIPMENT

For this problem you will have several cart weights, a meter stick, a stopwatch, an aluminum track, two PASCO carts, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL). The carts have Velcro pads on one side, which will allow the carts to stick together.



PREDICTION

Consider the following three cases in which the total mass of the carts is the same ($m_A + m_B$ = constant), where m_A is the moving cart, and m_B is the stationary cart:

(a) $m_A = m_B$ (b) $m_A > m_B$ (c) $m_A < m_B$

Write an expression for the efficiency of the collision between moving cart A and stationary cart B. Rank the collision situations a, b, and c from most efficient to least efficient. (Make an educated guess and explain your reasoning.)

Write an expression for the energy dissipated in a collision in which the carts stick together, as a function of the mass of each cart, the initial kinetic energy of the system, and the energy efficiency of the collision. If you assume the kinetic energy of an incoming vehicle is the same in the three cases, which situation will cause the most damage?

WARM-UP

Read: Serway & Vuille Chapter 5, Sections 5.2, 5.3, and 5.5.

1. Draw two pictures, one showing the situation before the collision and the other one after the collision. Is it reasonable to neglect friction? Label the mass of each cart, and draw velocity vectors on each sketch. Define your system. If the carts stick together after the collision, what must be true about their final velocities? Write down expressions for the kinetic energy of the system before and after the collision.
2. Write down an energy conservation equation for this collision. (Remember to take into account the energy dissipated.)
3. Write an equation for the efficiency of the collision in terms of the final and initial kinetic energy of the carts, and then in terms of the cart masses and their initial and final speeds. How do you expect the final velocities to compare for situations a, b, and c? If the initial kinetic energy of cart A remains the same for all three situations, which situation is most efficient? Least efficient? Or do you expect them to be equally efficient? Explain your reasoning.
4. Solve your equation from question 2 for the energy dissipated in the collision. Solve your equation from question 3 for the final kinetic energy in terms of the efficiency and initial kinetic energy, and substitute this into the equation for energy dissipated. Your equation should now be only in terms of the efficiency and the initial kinetic energy of cart A.
5. How is the energy dissipated related to efficiency? For a constant initial kinetic energy, does a collision with a low efficiency have high or low energy dissipation? Based on your rankings of efficiency from question 3, which collision will cause the most damage (have the most energy dissipated)?
6. Use the simulation "Lab3Sim" (See Appendix F for a brief explanation of how to use the simulations) to explore the conditions of this problem. For this problem you will want to set the elasticity to zero.

EXPLORATION

Practice setting the cart into motion so the carts stick together with Velcro after the collision. Try various initial velocities and observe the motion of the carts.

Vary the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass the stationary cart while keeping the total mass of the carts the same. Be sure the carts still move freely over the track.

To keep the initial kinetic energy approximately the same for different masses of cart A, how should you change the initial velocity of the moving cart? Try it out.

Select the cart masses you will use for $m_A = m_B$, $m_A > m_B$, and $m_A < m_B$ for the same total mass. Determine an initial velocity for each case that will give you approximately the same initial kinetic energy for cart A. Use a stopwatch and meter stick to practice giving cart A these initial velocities.

Set up the camera and tripod to give you the best video of the collision immediately before and after the carts collide. What will you use for a calibration object in your videos? What quantities in your prediction equations do you need to measure with the video analysis software? Is it possible to obtain information before and after the collision with one video analysis, or will you need to analyze each video more than once?

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan from the Exploration section. Record a video of one collision situation. Use a stopwatch and the distance traveled by the cart before impact with the bumper to estimate the initial velocity of the cart.

Open one your video in VideoTOOL and follow the instructions to acquire data. As a lab group, decide how you will acquire data and analyze the collision. (Will you acquire data for the cart A's motion before the impact and repeat the process for cart A and B after the collision, or will you acquire data for the entire motion of the carts in a single analysis?) Repeat this process for the remaining two collision situations.

Measure and record the masses of the two carts for each situation. Analyze your data as you go along (before making the next video), so you can determine if your initial choice of masses and speeds is sufficient. Collect enough data to convince yourself and others of your conclusions about the efficiency of the collision.

Save all of your data and analysis. You can use it again for Laboratory VI.

ANALYSIS

From your videos, determine the velocities of the carts before and after the collision. Use your equations from the Warm-up and Prediction questions to calculate the initial and final kinetic energy, efficiency, and energy dissipated for each case.

Record the measured and calculated values in an organized data table in your lab journal.

CONCLUSION

Given the same initial energy, in which case(s) ($m_A = m_B$, $m_A > m_B$, or $m_A < m_B$) was the energy efficiency the largest? In which case was it the smallest?

Was a significant portion of the energy dissipated? Was it the same for each collision situation? Into what other forms of energy do you think the cart's initial kinetic energy is most likely to transform?

Was your boss right? Is the same amount of damage done to vehicles when (1) a car hits a stationary truck and they stick together as when (2) a truck hits the stationary car (given the same initial kinetic energies)? State your results that support this conclusion.

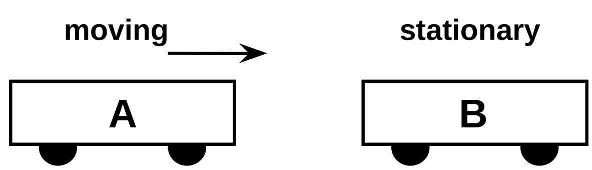
PROBLEM #4:
ENERGY IN COLLISIONS WHEN OBJECTS BOUNCE APART

You still have your summer job with the Minnesota Traffic Safety Board investigating the damage done to vehicles in different kinds of traffic accidents. Your boss now wants you to concentrate on the damage done in low speed collisions when a moving vehicle hits a stationary vehicle and they bounce apart. Even with new improved bumpers, your boss believes that, given the same initial energy, the damage to the vehicles in a collision when cars bounce apart will be less when the moving vehicle has a smaller mass than the stationary vehicle (e.g., a compact car hits a van) than for other situations.

To resolve the issue, you decide to model the collision with carts of different masses and measure the energy efficiency of three different cart collisions: one in which the moving cart is more massive, one in which the stationary cart is more massive, and one in which the moving and stationary carts are equally massive. You define efficiency as the ratio of the final kinetic energy of the system to the initial kinetic energy.

EQUIPMENT

For this problem you will have several cart weights, a meter stick, a stopwatch, an aluminum track, two PASCO carts, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL). The carts have magnets on one side which will allow them to repel each other.



PREDICTION

Consider the following three cases in which the total mass of the carts is the same ($m_A + m_B$ = constant), where m_A is the moving cart, and m_B is the stationary cart:

(a) $m_A = m_B$ (b) $m_A > m_B$ (c) $m_A < m_B$

Write an expression for the efficiency of the collision between moving cart A and stationary cart B. Rank the collision situations a, b, and c from most efficient to least efficient. (Make an educated guess and explain your reasoning.)

Write an expression for the energy dissipated in a collision in which the carts bounce apart, as a function of the mass of each cart, the initial kinetic energy of the system, and the energy efficiency of the collision. If you assume the kinetic energy of an incoming vehicle is the same in the three cases, which situation will cause the most damage?

WARM-UP

Read: Serway & Vuille Chapter 5, Sections 5.2, 5.3, and 5.5

1. Draw two pictures, one showing the situation before the collision and the other one after the collision. Is it reasonable to neglect friction? Label the mass of each cart, and draw velocity vectors on each sketch. Define your system. Write down expressions for the kinetic energy of the system before and after the collision.
2. Write down an energy conservation equation for this collision. (Remember to take into account the energy dissipated.)
3. Write an equation for the efficiency of the collision in terms of the final and initial kinetic energy of the carts, and then in terms of the cart masses and their initial and final speeds. How do you expect the final velocities for carts A and B to compare for situations a, b, and c? If the initial kinetic energy of cart A remains the same for all three situations, which situation is most efficient? Least efficient? Or do you expect them to be equally efficient? Explain your reasoning.
4. Solve your equation from question 2 for the energy dissipated in the collision. Solve your equation from question 3 for the final kinetic energy in terms of the efficiency and initial kinetic energy, and substitute this into the equation for energy dissipated. Your equation should now be only in terms of the efficiency and the initial kinetic energy of cart A.
5. How is the energy dissipated related to efficiency? For a constant initial kinetic energy, does a collision with a low efficiency have high or low energy dissipation? Based on your rankings of efficiency from question 3, which collision will cause the most damage (have the most energy dissipated)?
6. Use the simulation "Lab3Sim" (See Appendix F for a brief explanation of how to use the simulations) to explore the conditions of this problem. For this problem you will want to set the elasticity to something other than zero.

EXPLORATION

Practice setting the cart into motion so the carts bounce apart from the magnetic bumpers. Try various initial velocities and observe the motion of the carts.

Vary the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass the stationary cart while keeping the total mass of the carts the same. Be sure the carts still move freely over the track.

To keep the initial kinetic energy approximately the same for different masses of cart A, how should you change the initial velocity of the moving cart? Try it out.

Select the cart masses you will use for $m_A = m_B$, $m_A > m_B$, and $m_A < m_B$ for the same total mass. Determine an initial velocity for each case that will give you approximately the same initial kinetic energy for cart A. Use a stopwatch and meter stick to practice giving cart A these initial velocities.

Set up the camera and tripod to give you the best video of the collision immediately before and after the carts collide. What will you use for a calibration object in your videos? What quantities in your prediction equations do you need to measure with the video analysis software? Is it possible to obtain information before and after the collision with one video analysis, or will you need to analyze each video more than once? Write down your measurement plan.

MEASUREMENT

Follow your measurement plan from the Exploration section. Record a video of one collision situation. Use a stopwatch and the distance traveled by the cart before impact with the bumper to estimate the initial velocity of the cart.

Open one your video in VideoTOOL and follow the instructions to acquire data. As a lab group, decide how you will acquire data and analyze the collision. (Will you acquire data for the cart A's motion before the impact and repeat the process for cart A and B after the collision, or will you acquire data for the entire motion of the carts in a single analysis?) Change the masses of the carts and repeat this process for the remaining two collision situations.

Measure and record the masses of the two carts for each situation. Analyze your data as you go along (before making the next video), so you can determine if your initial choice of masses and speeds is sufficient. Collect enough data to convince yourself and others of your conclusions about the efficiency of the collision.

Save all of your data and analysis. You can use it again for Laboratory VI.

ANALYSIS

From your videos, determine the velocities of the carts before and after the collision. Use your equations from the Warm-up and Prediction questions to calculate the initial and final kinetic energy, efficiency, and energy dissipated for each case.

Record the measured and calculated values in an organized data table in your lab journal.

CONCLUSION

Given the same initial energy, in which case(s) ($m_A = m_B$, $m_A > m_B$, or $m_A < m_B$) was the energy efficiency the largest? The smallest? Was it ever the same? Could the collisions you measured be considered essentially elastic collisions? Why or why not? (The energy efficiency for an elastic collision is 1.)

Was a significant portion of the energy dissipated? Was it the same for each collision situation? How does it compare to the case where the carts stick together after the collision? Into what other forms of energy do you think the cart's initial kinetic energy is most likely to transform?

Was your boss right? Is the damage done to vehicles when a car hits a stationary truck and they bounce apart less than when a truck hits a stationary car (given the same initial kinetic energies)? State your results that support this conclusion.

PROBLEM #5:
POWER AND THE HUMAN BODY

You have a summer job in a laboratory investigating the factors that determine the maximum rate of energy output (power) from a human body. You realize that your body cannot convert all of its energy into mechanical energy - some of it goes into your body's responses such as sweating, increased heart action, and body temperature change. Most of these body responses seem to be linked to increased heart rate. You decide to determine if the usable mechanical power produced by humans is a function of a person's heart rate. The easiest change in energy of a system to measure is the change in gravitational potential energy. You will also determine the maximum human power output under this situation.

EQUIPMENT

You are the piece of equipment for this problem. You will be free to use the physics building and its surrounding area along with whatever is in the lab already. But, you must have your TA's approval before you begin! A stopwatch and a wide range of masses will be provided.

PREDICTIONS

Write down a relationship between power, energy, and time. Make an educated guess of the maximum useable power your body can produce.

Make a qualitative guess at the relationship between heart rate (pulse) and power output, and sketch a graph of your heart rate versus the usable mechanical power you are producing.

WARM-UP

Read: Serway & Vuille Chapter 5, Sections 5.2, 5.3, and 5.6.

1. Draw a picture that shows a situation in which you can easily measure the energy you transfer to do a specific task. Define the system transferring the energy and the system that the energy is transferred to. Write down the energy of each system before the transfer. Write down the energy of each system after the transfer.

2. Write down the energy conservation equation for this interaction process. Identify which terms in your equation represent the useful energy.

3. Identify the time interval in which you complete the energy transfer process.

4. Write an expression for the useful power transferred by your body, in terms of energy and time. How is heart rate related to power transferred by your body? Is there a reasonable limit to how high your heart rate can be?

EXPLORATION

Develop a simple way to determine your own useful power output. You must determine a way to measure your useful energy output over a period of time. Consider the ways that you know how to measure a change in energy - the easiest to measure is a change in potential energy. Determine whether you will use your arms or legs to transfer the energy.

Always stay in control while you are measuring your power output. Do not hurt yourself! **If you have special health concerns,** please consult your teaching assistant and/or have another member of your group try the method that you devised to determine the power output of a human.

Make a few test runs using the method that you have devised. What will affect your ability to measure your usable power output accurately? Consult your teaching assistant if you are having difficulties measuring your power output.

Try producing the largest range of useful power output possible. Find the smallest power output that gives a measurable effect and the largest power output that is comfortable for you. Qualitatively, what happens to your pulse rate? What are some other physical responses your body has? Will you need to rest in between each trial in order to get an accurate measure of your pulse rate for each independent trial?

What is the difference between peak power and average power? What should you use in your analysis? If you use average power, over what time interval will you take the average?

MEASUREMENT

As a group, decide who will produce the power for your measurements. Settle on a consistent method and make the necessary measurements to determine the power output. Produce a range of powers and measure your pulse rate for each case.

ANALYSIS

Create a graph of heart rate (pulse) versus power output. How does it compare to your prediction?

CONCLUSION

What are some of your body's responses to power production? Does the response depend on how much power is being produced? What happens to your heart rate (pulse) as you produce more power?

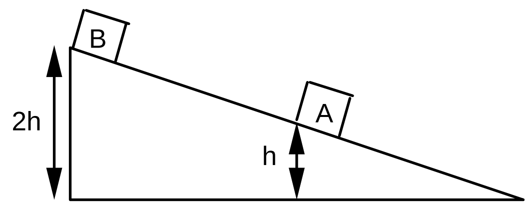
What was your largest power output? How long do you think that you could sustain your largest power output? What power output could you sustain for a long time?

☑ CHECK YOUR UNDERSTANDING

1. A 1-kg ball dropped from a height of 2 meters rebounds only 1.5 meters after hitting the floor. The amount of energy dissipated during the collision with the floor is

   (a) 5 joules.
   (b) 10 joules.
   (c) 15 joules.
   (d) 20 joules.
   (e) More than 20 joules.

2. Two boxes start from rest and slide down a *frictionless* ramp that makes an angle of 30^{o} to the horizontal. Block A starts at height h; while Block B starts at a height of 2h.



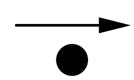
   a. Suppose the two boxes have the same mass. At the bottom of the ramp,

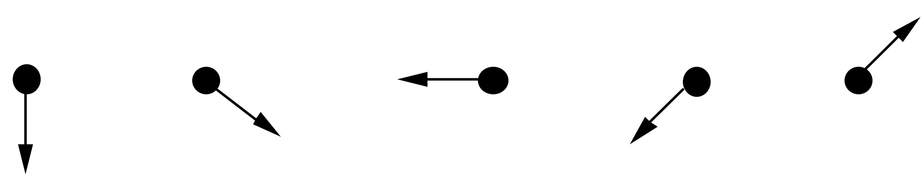
   (a) Box A is moving twice as fast as box B.
   (b) Box B is moving twice as fast as box A.
   (c) Box A is moving faster than box B, but not twice as fast.
   (d) Box B is moving faster than box A, but not twice as fast.
   (e) Box A has the same speed as box B.

   b. Suppose box B has a larger mass than box A. At the bottom of the ramp,

   (a) Box A is moving twice as fast as box B.
   (b) Box B is moving twice as fast as box A.
   (c) Box A is moving faster than box B, but not twice as fast.
   (d) Box B is moving faster than box A, but not twice as fast.
   (e) Box A has the same speed as box B.

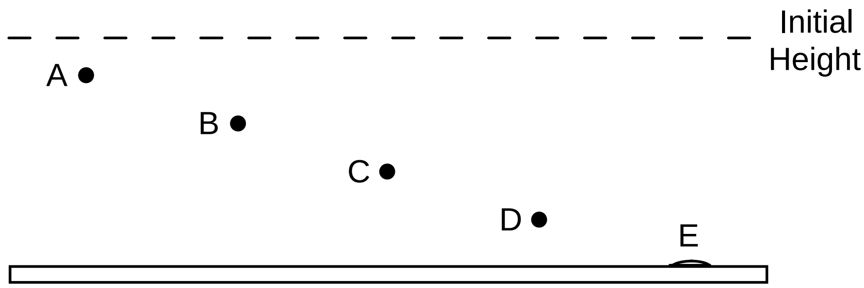
3. A hockey puck is moving at a constant velocity to the right, as shown in the diagram. Which of the following forces will do *positive* work on the puck (i.e., cause an *input* of energy)?





(a) **(b)** **(c)** **(d)** **(e)**

4. Five balls made of different substances are dropped from the same height onto a board. Four of the balls bounce up to the maximum height shown on the diagram below. Ball E sticks to the board.



a. For which ball was the most energy dissipated in the collision?

(a) Ball A
(b) Ball B
(c) Ball C
(d) Ball D
(e) Ball E

b. Which ball has the largest energy efficiency?

(a) Ball A
(b) Ball B
(c) Ball C
(d) Ball D
(e) Ball E

5. Two carts initially at rest on flat tracks are pushed by the same constant force. Cart 1 has twice the mass of cart 2. They are pushed through the same distance.
a. Which cart has the largest kinetic energy at the end and why?
b. Which cart takes the most time to travel the distance?

TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory V

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 <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.

LABORATORY VI
MOMENTUM

In this lab you will use *conservation of momentum to* predict the motion of objects motions resulting from collisions. It is often difficult or impossible to obtain enough information for a complete analysis of collisions in terms of forces. Conservation principles can be used to relate the motion of an object before a collision to the motion after a collision, without knowledge of the complicated details of the collision process itself, but conservation of energy alone is usually not enough to predict the outcome. To fully analyze a collision, one must often use both conservation of energy *and* conservation of momentum.

OBJECTIVES:

Successfully completing this laboratory should enable you to:

- Use conservation of momentum to predict the outcome of interactions between objects.
- Choose a useful system when using conservation of momentum.
- Identify momentum transfer (impulse) when applying energy conservation to real systems.
- Use the principles of conservation of energy and of momentum together as a means of describing the behavior of systems.

PREPARATION:

Read Serway & Vuille Chapter 6. You should also be able to:

- Analyze the motion of an object using video analysis tools.
- Calculate the kinetic energy of a moving object.
- Calculate the total energy and total momentum of a system of objects.

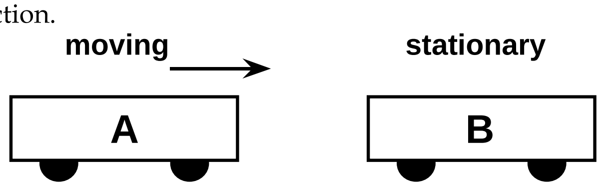
PROBLEM #1:
PERFECTLY INELASTIC COLLISIONS

You have a summer job at NASA with a group designing a docking mechanism that would allow two space shuttles to connect with each other. The mechanism is designed for one shuttle to move carefully into position and dock with a stationary shuttle. Since the shuttles may be carrying different payloads and have consumed different amounts of fuel, their masses may not be identical: the shuttles could be equally massive, the moving shuttle could be more massive, or the stationary shuttle could have a larger mass. Your supervisor wants you to calculate the magnitude and direction of the velocity of the pair of docked shuttles as a function of the initial velocity of the moving shuttle and the mass of each shuttle. You may assume that the total mass of the two shuttles is constant. You decide to model the problem in the lab using carts to check your predictions.

EQUIPMENT

For this problem you will have several cart weights, a meter stick, a stopwatch, an aluminum track, two PASCO carts, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL). The carts have Velcro pads on one side, which will allow the carts to stick together.

This is the same situation as Problem #3 in Lab V. If you completed that Problem, you can use that data to check your prediction.



PREDICTION

Write an equation for the final velocity of the stuck-together carts in terms of the cart masses and the initial velocity of cart A. What will be the direction of the final velocity?

Consider the following three cases in which the total mass of the carts is the same ($m_A + m_B$ = constant), where m_A is the moving cart, and m_B is the stationary cart:

(a) $m_A = m_B$ (b) $m_A > m_B$ (c) $m_A < m_B$

In which case will the final velocity of the carts be the largest? The smallest? Explain your reasoning. Does your answer depend on the initial velocity of cart A?

WARM-UP

Read: Serway & Vuille Chapter 6, Sections 6.1, 6.2, and 6.3.

1. Draw two pictures, one showing the situation before the collision and the other one after the collision. Is it reasonable to neglect friction? Label the mass of each cart, and draw velocity vectors on each sketch. Define your system. If the carts stick together after the collision, what must be true about their final velocities?

2. Write a momentum conservation equation for this situation and identify all of the terms in the equation. Are there any of these terms that you cannot measure with the equipment at hand?

3. Write down the total energy conservation equation for this situation and identify all the terms in the equation. Are there any of these terms that you cannot measure with the equipment at hand?

4. Which conservation principle should you use to predict the final velocity of the stuck-together carts, or do you need both equations? Explain your reasoning.

5. Solve one of your conservation equations for the magnitude of the final velocity of the carts in terms of the cart masses and the initial velocity of cart A. What direction is the final velocity of the carts when $m_A = m_B$? When $m_A > m_B$? When $m_A < m_B$?

6. Use the simulation "Lab3Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the conditions of this problem. For this problem you will want to set the elasticity to zero.

EXPLORATION

If you have done Problem 3 in Lab. V, you should be able to skip this part analyze the data you already have.

Practice setting the cart into motion so the carts stick together with Velcro after the collision. Try various initial velocities and observe the motion of the carts.

Vary the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass the stationary cart while keeping the total mass of the carts the same. Be sure the carts still move freely over the track.

Select the cart masses you will use for $m_A = m_B$, $m_A > m_B$, and $m_A < m_B$ for the same total mass. Determine what initial velocity you will give cart A for each case. Use a stopwatch and meter stick to practice giving cart A these initial velocities.

Set up the camera and tripod to give you the best video of the collision immediately before and after the carts collide. What will you use for a calibration object in your videos? What quantities in your prediction equations do you need to measure with the video analysis software? Is it possible to obtain information before and after the collision with one video analysis, or will you need to analyze each video more than once?

Write down your measurement plan.

MEASUREMENT

If you have done Problem 3 in Lab V, you should be able to skip this part and just use the data you have already taken. Otherwise make the measurements outlined below.

Follow your measurement plan from the Exploration section. Record a video of one collision situation. Use a stopwatch and the distance traveled by the cart before impact with the bumper to estimate the initial velocity of the cart.

Open one your video in VideoTOOL and follow the instructions to acquire data. As a lab group, decide how you will acquire data and analyze the collision. (Will you acquire data for the cart A's motion before the impact and repeat the process for cart A and B after the collision, or will you acquire data for the entire motion of the carts in a single analysis?) Repeat this process for the remaining two collision situations.

Measure and record the masses of the two carts for each situation. Analyze your data as you go along (before making the next video), so you can determine if your initial choice of masses and speeds is sufficient. Collect enough data to convince yourself and others of your conclusions about the efficiency of the collision.

ANALYSIS

From your videos, determine the velocities of the carts before and after the collision for each situation. Calculate the momentum of the carts before and after the collision. Use your equation from the Warm-up and Prediction questions to calculate the *predicted* final velocity of the stuck-together carts.

Record the measured and calculated values in an organized data table in your lab journal.

CONCLUSION

How do your measured and predicted values of the final velocities compare? Compare both magnitude and direction. What are the limitations on the accuracy of your measurements and analysis?

When a moving shuttle collides with a stationary shuttle and they dock (stick together), how does the final velocity depend on the initial velocity of the moving shuttle and the masses of the shuttles? State your results in the most general terms supported by the data.

A collision where kinetic energy is conserved is called "elastic." Any other kind of collision is "inelastic." How can you tell from your data if this collision was elastic, or inelastic?

What conditions must be met for a system's *total momentum* to be conserved? Describe how these conditions were or were not met for the system you defined in this experiment. What conditions must be met for a system's *total energy* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment.

PROBLEM #2:
ELASTIC COLLISIONS

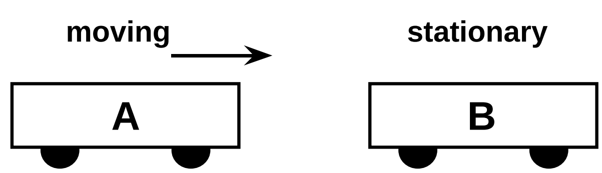
You are still working for NASA with a group designing a docking mechanism that would allow two space shuttles to connect with each other. The mechanism is designed for one shuttle to move carefully into position and dock with a stationary shuttle. Since the shuttles may be carrying different payloads and have consumed different amounts of fuel, their masses may be different when they dock: the shuttles could be equally massive, the moving shuttle could be more massive, or the stationary shuttle could have a larger mass.

Your supervisor wants you to consider another possible outcome of a shuttle docking. This scenario results in a "Houston we have a problem!" message from the astronauts, and you want to be prepared. In this case, either the pilot misses the docking mechanism or the mechanism fails to function. The shuttles then gently collide and bounce off each other. Your supervisor asks you to calculate the final velocity of each shuttle as a function of the initial velocity of the moving shuttle, the mass of each shuttle, and the fraction of the moving shuttle's initial kinetic energy that is *not dissipated* during the collision (the "energy efficiency"). You decide to check your calculations in the laboratory using the most efficient bumper you have, a magnetic bumper.

EQUIPMENT

This is exactly the same situation as for Problem 4 in Lab V. If you did that Problem, you can use that data to check your prediction.

For this problem you will have several cart weights, a meter stick, a stopwatch, an aluminum track, two PASCO carts, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL). The carts have magnets on one side which will allow them to repel each other.



PREDICTION

Write an equation for the final velocity of cart B as a function of the initial velocity of cart A and the masses of the two cart s for an elastic collision.

Consider the following three cases in which the total mass of the carts is the same ($m_A + m_B$ = constant), where m_A is the moving cart, and m_B is the stationary cart :

(a) $m_A = m_B$ (b) $m_A > m_B$ (c) $m_A < m_B$

What is the direction of each cart before Based on your measurement from Problem 4 in Lab V or your experience, what is the efficiency of the collision? What does this tell you about your assumption of an elastic collision?

WARM-UP

Read: Serway & Vuille Chapter 6, Sections 6.1, 6.2, and 6.3.

1. Draw two pictures, one showing the situation before the collision and the other one after the collision. Is it reasonable to neglect friction? Label the mass of each cart, and draw velocity vectors on each sketch. Define your system.
2. Write down the momentum of the system before and after the collision. Is the system's momentum conserved during the collision? Why or why not?
3. If momentum is conserved, write down a *momentum* conservation equation for the collision. Identify all of the terms in the equation. Is there any momentum transferred into or out of the system? Are you making any approximations?
4. Write down an *energy* conservation equation for this situation. Identify all the terms in the equation. Is any energy transferred into or out of the system? Are you making any approximations about the efficiency of the magnetic cart bumpers?
5. Use the equations you have written to solve for the final velocity of cart B. Your final velocity of cart B should *only* depend on the initial velocity of cart A and the masses of the two carts (assuming there is no energy dissipation). *Warning: the algebra may quickly become unpleasant! Stay organized.*
6. Use the energy conservation equation without any approximations (i.e. include actual efficiency of the bumpers) to calculate the energy dissipation for the collision. Write an expression for the energy dissipated in the collision in terms of the energy efficiency and the initial kinetic energy of the system (Refer back to Laboratory 5 problems 3 and 4.)
7. From your calculations determine the direction of cart A and B after the collision for the three different situations.
8. Use the simulation "Lab3Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the conditions of this problem. For this problem you will want to set the elasticity to something other than zero.

EXPLORATION

If you have done Problem 4 in Lab V under conditions of only a small amount of energy dissipation, you should be able to skip this part analyze the data you already have.

Practice setting the cart into motion so the carts bounce apart from the magnetic bumpers. Try various initial velocities and observe the motion of the carts.

Vary the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass the stationary cart while keeping the total mass of the carts the same. Be sure the carts still move freely over the track.

To keep the initial kinetic energy approximately the same for different masses of cart A, how should you change the initial velocity of the moving cart? Try it out.

Select the cart masses you will use for $m_A = m_B$, $m_A > m_B$, and $m_A < m_B$ for the same total mass. Determine an initial velocity for each case that will give you approximately the same initial kinetic energy for cart A. Use a stopwatch and meter stick to practice giving cart A these initial velocities.

Set up the camera and tripod to give you the best video of the collision immediately before and after the carts collide. What will you use for a calibration object in your videos? What quantities in your prediction equations do you need to measure with the video analysis software? Is it possible to obtain information before and after the collision with one video analysis, or will you need to analyze each video more than once?

Write down your measurement plan.

MEASUREMENT

If you have done Problem 4 in Lab V under conditions of only a small amount of energy dissipation, you should be able to skip this part and just use the data you have already taken. Otherwise make the measurements outlined below.

Follow your measurement plan from the Exploration section. Record a video of one collision situation. Use a stopwatch and the distance traveled by the cart before impact with the bumper to estimate the initial velocity of the cart.

Open one your video in VideoTOOL and follow the instructions to acquire data. As a lab group, decide how you will acquire data and analyze the collision. (Will you acquire data for the cart A's motion before the impact and repeat the process for cart A and B after the collision, or will you acquire data for the entire motion of the carts in a single analysis?) Change the masses of the carts and repeat this process for the remaining two collision situations.

Measure and record the masses of the two carts for each situation. Analyze your data as you go along (before making the next video), so you can determine if your initial choice of masses and speeds is sufficient. Collect enough data to convince yourself and others of your conclusions about the efficiency of the collision.

ANALYSIS

From your videos, determine the velocities of the carts before and after the collision. Use your equations from the Warm-up and Prediction questions to calculate the final velocity of cart B, the initial and final kinetic energies, and the momentum before and after the collision.

If you have the results from Lab V, Problem #4, use the appropriate energy efficiency you determined for the collision from that problem. If not, calculate the energy efficiency of each collision from the initial and final kinetic energy of the system. Can you make the approximation that no energy goes into internal energy of the system (energy efficiency = 1)?

Record the measured and calculated values in an organized data table in your lab journal.

CONCLUSION

How do your measured and predicted values of cart B's final velocity compare? What are the limitations on the accuracy of your measurements and analysis? Was the collision perfectly elastic in the three different cases?

Did the directions of the final velocities for cart A and cart B match your prediction? Why or why not? How does the efficiency of the collision affect the conclusion?

What conditions must be met for a system's *total momentum* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment. What conditions must be met for a system's *total energy* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment.

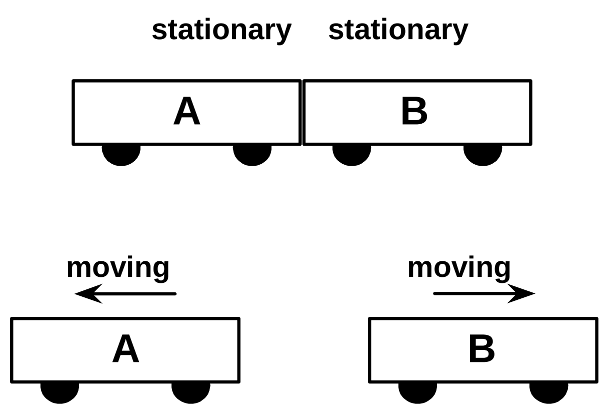
PROBLEM #3:
EXPLOSIONS

You have a summer job helping a local ice-dancing group prepare for their season. One routine begins with two skaters standing stationary next to each other. They push away from each other and glide to opposite ends of the ice rink. The choreographer wants them to reach the ends simultaneously. Your assignment is to determine where the couple should stand. To test your ideas you build a model of the situation. Your initial calculation assumes that the frictional force between the ice and the skates can be neglected so you decide to use a metal track and two carts of different masses to test it. Specifically, when the carts push each other apart, you want to find where they should start if they are to reach the ends of the track simultaneously.

EQUIPMENT

For this problem you will have a meter stick, a stopwatch, an aluminum track, end stops, PASCO carts, and a variety of masses to add to the carts..

A small tip button near one end of a cart releases a plastic arm that can provide the initial push between the two carts.



PREDICTION

Calculate a formula for the starting position of the two stationary carts as a function of their masses, and the total distance between the ends of the track if they are to reach the ends of the track simultaneously.

Hint: To make the math easier, you can treat the carts like point masses in your calculation. How does ignoring the cart length affect your result?

WARM-UP

Read: Serway & Vuille Chapter 6, Sections 6.1, 6.2, and 6.3. Also review motion in one dimension, sections 2.1 and 2.2

1. Draw a picture that shows the position of the carts when they are stationary. Label the cart masses, the cart lengths, the total length of the track between the end stops, and the distances that each cart must travel to hit the ends of the track from their starting position.

2. Draw another picture that shows the situation just after the carts have pushed off from one another. Label the velocities of the carts.

3. Define your system. Write down the conservation of energy equation for this situation. Identify all of the terms in the equation. (Where does the energy come from that creates the "explosion"?) Are there any terms that you do not know and cannot directly measure?

4. Write down the conservation of momentum equation for this situation. Identify all of the terms in the equation. Are there terms that you do not know and cannot directly measure?

5. Decide which conservation principle will be most useful in this situation. Write down your reason for this decision. Are both useful? Use your conservation equation(s) to determine the relationship between the speeds of the carts.

6. What is an equation that relates horizontal distance, velocity, and time? Write down an expression for the time cart A takes to reach the end of the track in terms of the distance it travels and its velocity. (*Hint: to make the calculation easier, you can treat the car as a point mass, ignoring the length of the cart*) Write down an expression for the time cart B takes to reach the end of the track in terms of the distance it travels and its velocity. What must be true of the time for cart A and cart B, if they reach the track ends simultaneously?

7. Write down a relationship between the distance traveled by cart A, the distance traveled by cart B, and the total length of the track.

8. Use your equations from questions 5, 6, and 7 to solve for the initial position of the carts before the explosion in terms of their masses and the total length of the track. How does neglecting the length of the carts affect your answer?

EXPLORATION

Position the carts next to each other on the track and let the side with the tip button of one cart close to the other cart, so that when the button is pushed, the pop up arm can provide the initial push for the two carts. Position the end stops on the aluminum track. How will you tell if the carts hit the end stops at the same time?

Practice pushing the tip button so that your finger will not prevent the cart with the button from moving freely right after you press the button. What is the best way to push the button? Will the contact between your finger and the button affect the motion of the carts? Try it. Make sure the carts move along the track smoothly after you push the button.

Try varying the masses of the carts while keeping the total mass of the carts the same. Be sure the carts still move freely over the track. What masses will you use in your final measurement? Determine a range of cart masses that will give you reliable results.

Write down your measurement plan.

MEASUREMENT

Position the carts on the track so that when the tip button on one cart is pushed, both carts hit the ends at the same time. Record this position and collect enough data so that you can convince yourself and others that you can predict where the carts should start for any reasonable set of masses.

ANALYSIS

Where did you need to place the carts so they hit the end at the same time for each case? What is the uncertainty in this measurement?

Use your equation from the Prediction and Warm-up questions to calculate the *predicted* starting position from the cart masses and the total distance between the end stops for each trial.

CONCLUSION

How did your measured starting position for the carts compare to your predicted position? What are the limitations on the accuracy of your measurement and analysis?

What will you tell the choreographer? Can you predict where the skaters should be standing for their push off? How does their starting position depend on the mass of the dancers and the length of the ice rink? Does it depend on how hard they push off? State your results in the most general terms supported by your data.

If you have time, modify your prediction equation to include the lengths of the carts. Recalculate the predicted starting position of the carts for each trial. Are the position values closer to your measured values than when you treated the carts like point masses?

☑ CHECK YOUR UNDERSTANDING

1. If a runner speeds up from 2 m/s to 8 m/s, the runner's *momentum* increases by a factor of

    (a) 64.
    (b) 16.
    (c) 8.
    (d) 4.
    (e) 2.

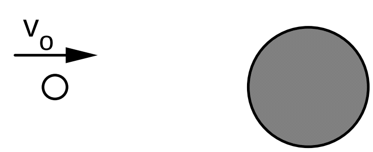
2. A piece of clay slams into and sticks to an identical piece of clay that is initially at rest. Ignoring friction, what percentage of the initial kinetic energy goes into changing the internal energy of the clay balls?

    (a) 0%
    (b) 25%
    (c) 50%
    (d) 75%
    (e) There is not enough information to tell.

3. A tennis ball and a lump of clay of equal mass are thrown with equal speeds directly against a brick wall. The lump of clay sticks to the wall and the tennis ball bounces back with one-half its original speed. Which of the following statements is (are) true about the collisions?

    (a) During the collision, the clay ball exerts a larger average force on the wall than the tennis ball.
    (b) The tennis ball experiences the largest change in momentum.
    (c) The clay ball experiences the largest change in momentum.
    (d) The tennis ball transfers the most energy to the wall.
    (e) The clay ball transfers the most energy to the wall.

4. A golf ball is thrown at a bowling ball so that it hits head on and bounces back. Ignore frictional effects.



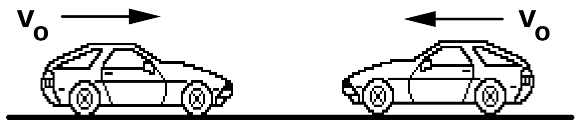
a. Just after the collision, which ball has the largest momentum, or are their momenta the same? Explain using vector diagrams of the momentum before and after the collisions.

b. Just after the collision, which ball has the largest kinetic energy, or are their kinetic energies the same? Explain your reasoning.

5. A 10 kg sled moves at 10 m/s. A 20 kg sled moving at 2.5 m/s has

    (a) 1/4 as much momentum.
    (b) 1/2 as much momentum.
    (c) twice as much momentum.
    (d) four times the momentum.
    (e) None of the above.

6. Two cars of equal mass travel in opposite directions with equal speeds on an icy patch of road. They lose control on the essentially frictionless surface, have a head-on collision, and bounce apart.



a. Just after the collision, the velocities of the cars are

(a) zero.
(b) equal to their original velocities.
(c) equal in magnitude and opposite in direction to their original velocities.
(d) less in magnitude and in the same direction as their original velocities.
(e) less in magnitude and opposite in direction to their original velocities.

b. In the type of collision described above, consider the system to consist of both cars. Which of the following can be said about the collision?

(a) The kinetic energy of the system does not change.
(b) The momentum of the system does not change.
(c) Both momentum and kinetic energy of the system do not change.
(d) Neither momentum nor kinetic energy of the system change.
(e) The extent to which momentum and kinetic energy of the system do not change depends on the coefficient of restitution.

7. Ignoring friction and other external forces, which of the following statements is (are) true just after an arrow is shot from a bow?

(a) The forward momentum of the arrow equals that backward momentum of the bow.
(b) The total momentum of the bow and arrow is zero.
(c) The forward speed of the arrow equals the backward speed of the bow.
(d) The total velocity of the bow and arrow is zero.
(e) The kinetic energy of the bow is the same as the kinetic energy of the arrow.

TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory VI

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ______________________________

Lab Partners' Names: ____

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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)	
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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)	

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LABORATORY VII
TORQUE AND EQUILIBRIUM

For most of this course you treated objects as points rather than as extended objects. This assumption is useful and sometimes sufficient. However, the approximation of objects as point particles gives an incomplete picture of the real world.

This laboratory introduces a more realistic description of the interactions of real objects that can *rotate* as well as move along trajectories. You already have a lot of experience with rotating objects: doors, wheels, and balls all rotate. Also, the earth rotates about its axis. Rotations are important to consider in all cases, whether you are discussing baseball, galaxies, or subatomic particles.

Describing rotations requires little more than the application of the physics concepts you have studied -- position, velocity, acceleration, force, mass, kinetic energy, and momentum. We apply these concepts to objects that have three-dimensional shape and exhibit rotational properties.

OBJECTIVES:

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

- Use the concept of torque in a system that is in static equilibrium.
- Determine the conditions under which an object is in equilibrium.

PREPARATION:

Read Serway & Vuille Chapter 8, sections 8.1 and 8.2.

Before coming to lab you should be able to:

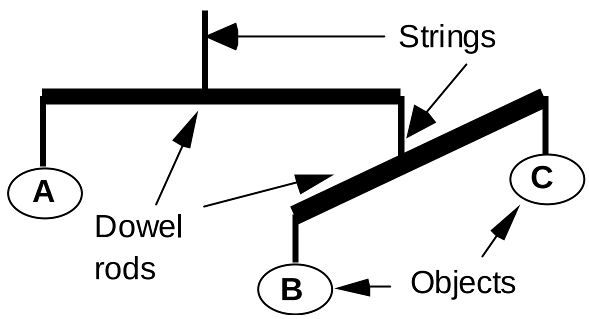
- Identify the forces acting on an object.
- Determine the net force on an object from its acceleration.
- Define the concept of torque, and determine the net torque on an object from its angular acceleration.
- Draw and use force and torque diagrams.
- Explain what is meant by a system in "equilibrium."

PROBLEM #1:
DESIGNING A MOBILE

A friend has asked you to help him make a mobile for his little sister's room. The project would be simple if your friend's sister knew what she wanted to hang from the mobile, but she cannot make up her mind. One day it is dinosaurs, another day it is planets, and another day it is famous women scientists. Frustrated, you decide to build a laboratory model to test the type of mobile you will build. Then, when she makes a decision, it can be easily assembled. To do this you must write an expression to calculate the position of the strings as a function of the masses of the objects and rods to balance a mobile consisting of two rods and three hanging objects, as shown below.

EQUIPMENT

To test your mobile design, you will have a meter stick, some string, two wooden dowel rods. One metal rod and one table clamp will be used to hang the mobile. You will also have 3 mass hangers and one mass set to create objects A, B, and C.



PREDICTION

Write a formula for the equilibrium position of each string that supports a dowel, in terms of equipment masses and distances.

WARM UP

Read: Serway & Vuille Chapter 8, Sections 8.1 and 8.2.

1. Draw a picture of the mobile similar to the one in the Equipment section. Select a coordinate system. Identify and label the quantities you can measure in this problem, such masses and lengths. The unknown quantities in the problem are the locations of the two strings that are attached to the rods.

2. On your picture, identify each force on your system. Then, draw a separate free-body diagram for each rod showing the location of the forces acting on the rods. Identify any forces related by Newton’s Third Law in the two diagrams. Label a point on each rod that you choose as the axis of rotation.

3. Write down Newton's second law for the forces on one rod. Next write down an expression for the net torque on that same rod. Repeat this procedure for the second rod. (Remember, your system will be in static equilibrium.) What are the total torque and the sum of the forces on an object when it is in equilibrium?

4. Solve these equations to find the equilibrium location of the two strings in terms of the masses and lengths along the rod. If there are more unknowns than equations, reexamine the previous steps to see if there is addional information about the situation that can be expressed in an equation. If not, see if one of the unknowns will cancel out.

EXPLORATION

Collect the necessary parts of your mobile. Find a convenient place to hang it.

Decide on the easiest way to determine the location of the center of mass of each rod. Do you think that the length of the strings for the hanging masses will affect the balance of the mobile? Why or why not? Try it. How close to the ends of the rods can you hang the masses? Where does the heaviest object go? The lightest?

Determine the location on the top rod from which you will hang it. Determine the location for the string connecting the second and third rods. Is there a configuration for these objects (the two rods) that results in a stable mobile?

Decide what measurements you need to make to check your prediction. If any major assumptions are used in your calculations, decide on the additional measurements that you need to make to justify them.

Outline your measurement plan.

MEASUREMENT

Measure and record the location of the center of mass of each rod, the mass of each rod, and the mass of the three hanging objects. Also, measure (a) the locations on the top rod where you will hang object A and the second rod, and (b) the locations on the bottom rod where you will hang objects B and C.

Note: Be sure to record your measurements with the appropriate number of significant figures and with your estimated uncertainty. Otherwise, the data are nearly meaningless. If you need a review, see Appendix B for how to determine significant figures and Appendix C for how to determine uncertainties.

ANALYSIS

Use your prediction equations to calculate the location (with uncertainties) of the two strings attached to the rods. using the values you measured.

To test your prediction, build your mobile and then hang it up. If your mobile did not balance, adjust the strings attached to the rods until it does and determine their new positions. Is there another configuration of these three objects that also results in a stable mobile? Try it!

Repeat this process, while hanging the masses in different places.

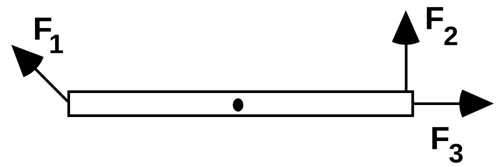
CONCLUSION

Did your mobile balance as designed? What corrections did you need to make to get it to balance? Were these corrections a result of some systematic error, or was there a mistake in your prediction? Justify your answer.

Was the length of each string important in your mobile design? Explain why or why not.

☑ CHECK YOUR UNDERSTANDING

1. A long stick is supported at its center and is acted on by three forces of *equal* magnitude, as shown at right. The stick is free to swing about its support. $\mathbf{F_2}$ is a vertical force and $\mathbf{F_3}$ is horizontal.



a. Rank the magnitudes of the torques exerted by the three forces about an axis perpendicular to the drawing at the *left* end of the stick. Explain your reasoning.

b. Rank the magnitudes of the torques about the *center* support. Explain your reasoning.

c. Rank the magnitudes of the torques about an axis perpendicular to the drawing at the *right* end of the stick. Explain your reasoning.

d. Can the stick be in translational equilibrium? Explain your reasoning.

e. Can the stick be in rotational equilibrium? Explain your reasoning.

TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory VII

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ______________________________

Lab Partners' Names: ____

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Problem # and Title: ____

Lab Instructor's Initials: __________

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LABORATORY VIII
MECHANICAL OSCILLATIONS

Most of the laboratory problems so far have involved objects moving with constant acceleration because the total force acting on those objects was constant. In this set of laboratory problems, the total force acting on an object, and thus its acceleration, will change with position. When the position and the acceleration of an object change in a periodic manner, we say that the object undergoes oscillations.

You are familiar with many objects that oscillate, such as pendula and the strings of a guitar. At the atomic level, atoms oscillate within molecules, and molecules oscillate within solids. This molecular oscillation gives an object the internal energy that defines its temperature. Springs are a common example of objects that exert the type of force that will cause oscillatory motion.

In this lab you will study oscillatory motion caused by springs exerting a changing force on an object. You will use different methods to determine the *strength* of the total force exerted by different spring configurations, and you will investigate what determines a system's oscillation *frequency*.

OBJECTIVES:

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

- Provide a qualitative explanation of the behavior of oscillating systems using the concepts of restoring force and equilibrium position.
- Identify the physical quantities that influence the period (or frequency) of the oscillatory motion and describe this influence quantitatively.
- Describe qualitatively the effect of additional forces on an oscillator's motion.

PREPARATION:

Read Serway & Vuille Chapter 13 sections 13.1, 13.2, and 13.3

Before coming to lab you should be able to:

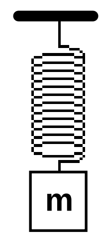
- Describe the similarities and differences in the behavior of the sine and cosine functions.
- Recognize the difference between amplitude, frequency, and period for repetitive motion.
- Determine the force on an object exerted by a spring using the concept of a spring constant.

PROBLEM #1:
MEASURING SPRING CONSTANTS

You are selecting springs for use in a large antique clock. In order to determine the force that they exert when stretched, you need to know their spring constants. One book recommends a **static approach**, in which objects of different weights hang from the spring and the displacement from equilibrium is measured. Another book suggests a **dynamic approach**, in which an object hanging from the end of a spring is set into motion and its oscillation frequency is measured. You wish to determine if these different approaches yield the same value for the spring constant. You decide to take both static and dynamic measurements and then compare.

EQUIPMENT

You will have a spring, a table clamp and metal rod, assorted masses, a mass hanger, a meter stick, a triple-beam balance, and a stopwatch.



PREDICTION

1. Write an expression for the relationship between the spring constant and the displacement of an object hanging from a spring.

2. Write an expression for the relationship between the spring constant and the period of oscillation of an object hanging from a spring.

WARM-UP

Read Serway & Vuille, Chapter 13, Sections 13.1 and 13.2

Method #1 (Static Approach)

1. Make two pictures of the situation, one before you attach an object to a spring, and one after an object is suspended from the spring and is at rest. Draw a coordinate system. On each picture, label the position where the spring is unstretched, the distance from the unstretched position to the stretched position, the mass of the object, and the spring constant.

2. Draw a force diagram for an object hanging from a spring at rest. Label the forces acting on the object. Use Newton's second law to write the equation of motion for the object.

3. Solve the equation of motion for the spring constant in terms of the other values in the equation. What does this tell you about the slope of a displacement (from the unstretched position) versus weight of the object graph?

Method #2 (Dynamic Approach): Suppose you hang an object from the spring, start it oscillating, and measure the *period* of oscillation.

1. Make three pictures of the oscillating system: (1) when the mass is at it maximum displacement *below* its equilibrium position, (2) after one half period, and (3) after one period. On each picture put arrows to represent the object's velocity and acceleration.
2. Write down an equation that is the relationship between the object's period, its mass, and the spring constant. Solve the equation for the spring constant in terms of the object's mass and period.

EXPLORATION

Method #1 - Static Approach:
Select a series of masses that give a usable range of displacements**.** The largest mass should not pull the spring past its elastic limit, for two reasons: (1) beyond the elastic limit there is no well-defined spring constant, and (2) a spring stretched beyond the elastic limit will be damaged.

Clamp the metal rod to the table, and hang the spring from the rod. Decide on a procedure that allows you to measure the distance a spring stretches when an object hangs from it in a consistent manner. Decide how many measurements you will need to make a reliable determination of the spring constant.

Method #2 - Dynamic Approach:
Secure the spring to the metal rod and select a mass that gives a regular oscillation without excessive wobbling. The largest mass you choose should not pull the spring past its elastic limit and the smallest mass should be much greater than the mass of the spring. Practice starting the mass in motion smoothly and consistently.

Decide how to measure the period of oscillation of the object-spring system most accurately. How can you minimize the uncertainty introduced by your reaction time in starting and stopping the stopwatch? How many times should you measure the period to get a reliable value? How will you determine the uncertainty in the period?

MEASUREMENT

For both methods, make the measurements that you need to determine the spring constant. **DO NOT STRETCH THE SPRINGS PAST THEIR ELASTIC LIMIT (ABOUT 60 CM) OR YOU WILL DAMAGE THEM.** Analyze your data as you go along so you can decide how many measurements you need to make to determine the spring constant accurately and reliably with each method.

ANALYSIS

Method #1: Graph displacement versus weight for the object-spring system. From the slope of this graph, calculate the value of the spring constant. Estimate the uncertainty in this measurement of the spring constant.

Method #2: Graph period versus mass for the object-spring system. If this graph is not a straight line, use *Appendix C: How do I linearize my data?* as a guide to linearize the graph. From the slope of the straight-line graph, calculate the value of the spring constant. Estimate the uncertainty in this measurement of the spring constant.

CONCLUSION

For each method, does the graph have the characteristics you predicted? How do the values of the spring constant compare between the two methods? Which method do you feel is the most reliable? Justify your answers.

PROBLEM #2:
EFFECTIVE SPRING CONSTANT

Your company has bought the prototype for a new flow regulator from a local inventor. Your job is to prepare the prototype for mass-production. While studying the prototype, you notice the inventor used some rather innovative spring configurations to supply the tension needed for the regulator valve. In one location the inventor had fastened two different springs side-by-side, as in Figure A below. In another location the inventor attached two different springs end-to-end, as in Figure B below.

To decrease the cost and increase the reliability of the flow regulator for mass production, you need to replace each spring configuration with a single spring. These replacement springs must exert the same forces when stretched the same amount as the original spring configurations.

EQUIPMENT

You have two different springs that have the same unstretched length, but different spring constants k_1 and k_2. These springs can be hung vertically side-by-side (Figure A) or end-to-end (Figure B).

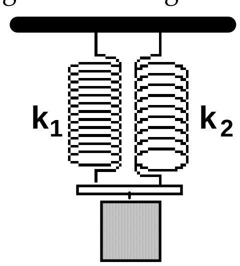


Figure A

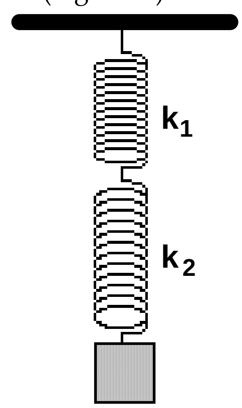


Figure B

As in Problem #1, you will have a table clamp and metal rod, a meter stick, a mass holder, assorted masses, a balance, and a stopwatch.

PREDICTIONS

The spring constant for a single spring that replaces a configuration of springs is called its *effective spring constant*.

1. Write an expression for the effective spring constant for a side-by-side spring configuration (Figure A) in terms of the two spring constants k_1 and k_2.
2. Write an expression for the effective spring constant for an end-to-end spring configuration (Figure B) in terms of the two spring constants k_1 and k_2.

Is the effective spring constant larger when the two springs are connected side-by-side or end-to-end? Explain your reasoning.

WARM-UP

Read Serway & Vuille, Chapter 13, Sections 13.1 and 13.2

Apply the following warm-up to the side-by-side configuration, and then repeat for the end-to-end configuration:

1. Make a picture of the spring configuration similar to each of the drawings in the Equipment section (Figure A and Figure B). Draw a coordinate system. Label the positions of each unstretched spring, the final stretched position of each spring, the two spring constants, and the mass of the object suspended. Put arrows on your picture to represent any forces on the object. Assume that the springs are massless.

For the side-by-side configuration, assume that the light bar attached to the springs remains horizontal (i.e. it does not twist).

For each two spring configurations make a second picture of a single (massless) spring with spring constant k' that has the same object suspended from it and the same total stretch as the combined springs. Be sure to label this picture in the same manner as the first.

2. Draw force diagrams of both spring systems and the equivalent single spring system. Label the forces. For the end-to-end configuration, draw an additional force diagram of a point at the connection of the two springs.

3. Apply Newton's laws to the object suspended from the combined springs and the object suspended from the single replacement spring. Consider carefully which forces and displacements will be equal to each other

For the end-to-end configuration: Draw an additional force diagram for the connection point between the springs. At the connection point, what is the force of the top spring on the bottom spring? What is the force of the bottom spring on the top spring?

4. Solve your equations for the effective spring constant (k') for the single replacement spring in terms of the two spring constants.

EXPLORATION

To test your predictions, you must decide how to measure each spring constant of the two springs and the effective spring constants of the side-by-side and end-to-end configurations.

From your results of Problem #1, select the best method for measuring spring constants (the static or dynamic method). Justify your choice.

Perform an exploration consistent with your selected method. If necessary, refer back to the appropriate Exploration section of Problem #1. Remember that the smallest mass must be much greater than the mass of the spring to fulfill the massless spring assumption. **DO NOT STRETCH THE SPRINGS PAST THEIR ELASTIC LIMIT (ABOUT 60 CM) OR YOU WILL DAMAGE THEM.**

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan to take the necessary data. If necessary, refer back to the appropriate Measurement section of Problem #1. What are the uncertainties in your measurements?

ANALYSIS

Determine the effective spring constants (with uncertainties) of the side-by-side spring configuration and the end-to-end spring configuration. If necessary, refer back to Problem #1 for the analysis technique consistent with your selected method.

Determine the spring constants of the two springs. Calculate the effective spring constants (with uncertainties) of the two configurations using your Prediction equations.

CONCLUSION

How do the measured values and predicted values of the effective spring constant for the configurations compare?

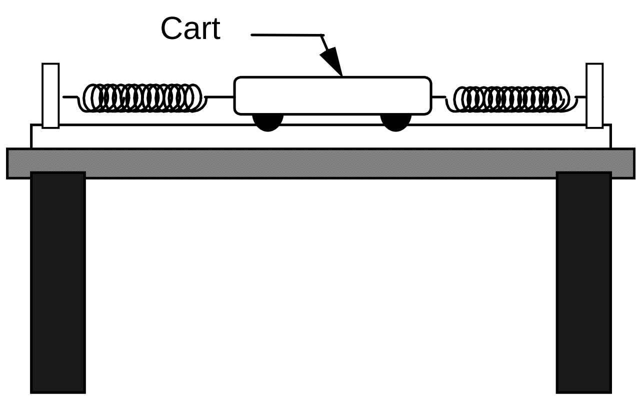
What are the effective spring constants of a side-by-side spring configuration and an end-to-end spring configuration? Which is larger? Did your measured values agree with your initial predictions? Why or why not? What are the limitations on the accuracy of your measurements and analysis? Can you apply what you learned to find the spring constant of a complex system of springs in the flow regulator?

PROBLEM #3:
OSCILLATION FREQUENCY WITH TWO SPRINGS

You have a summer job with a research group at the University. Because of your physics background, your supervisor asks you to design equipment to measure earthquake aftershocks. A calibration sensor needs to be isolated from the earth movements, yet it must be free to move. You decide to place the sensor on a low friction cart on a track and attach a spring to both sides of the cart. To make any quantitative measurements with the sensor you need to know the frequency of oscillation for the cart as a function of the spring constants and the mass of the cart.

EQUIPMENT

You will have an aluminum track, a PASCO cart, two adjustable end stops, two springs, a meter stick, and a stopwatch. You will also have a video camera and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).



PREDICTION

Write an expression for the frequency of the cart in terms of its mass and the two spring constants.

WARM-UP

Read Serway & Vuille, Chapter 13, Sections 13.1 and 13.2

1. Make two pictures of the oscillating cart (1) one at its equilibrium position and (2) one at some other position and time while it is oscillating. On your pictures, show the direction of the velocity and acceleration of the cart and the forces on the cart.

2. Draw a force diagram of the oscillating cart when it is at a position away from its equilibrium position. Label the forces.

3. Write down an equation for the total force on the cart in terms of the two spring constants and its displacement from the equilibrium position.

4. Now imagine that only one spring was attached to the cart, but it exerted the same force at the same displacement as the two-spring system. How would the motion of these two systems compare? What is the relationship between the spring constant of the single spring system and the two for the two-spring system?

5. Write down an equation for the frequency of the imaginary one spring system. How does it compare with the frequency of the two-spring system?

6. Use the simulation "LabSim5" (See *Appendix F* for a brief explanation of how to use the simulations) to approximate the conditions of this problem.

EXPLORATION

Decide the best method to determine the spring constants based on your results of Problem #1. **DO NOT STRETCH THE SPRINGS PAST THEIR ELASTIC LIMIT (ABOUT 60 CM) OR YOU WILL DAMAGE THEM.**

Find the best place for the adjustable end stop on the track. *Do not stretch the springs past 60 cm*, but stretch them enough so the cart oscillates smoothly. Find the most appropriate cart mass.

Practice releasing the cart smoothly. How long does it take for the oscillations to stop? What effect will this have on your measured values compared to your predicted values? How can you affect this time? What amplitude will you use to take your measurements? Between what positions should you measure a cycle? Over how many cycles should you measure to get a precise result?

MEASUREMENT

Determine the spring constants. Record these values. What is the uncertainty in these measurements?

Measure the period of oscillation of the cart. How many times should you take this measurement to be sure that it is reliable? What is the uncertainty in your measurement?

ANALYSIS

Analyze your video to find the period of oscillation. Calculate the frequency (with uncertainty) of the oscillations from your measured period. Calculate the frequency (with uncertainty) using your Prediction equation. How does your measured frequency compare with your predicted frequency?

CONCLUSION

What is the frequency of the oscillating cart? Did your measured frequency agree with your predicted frequency? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

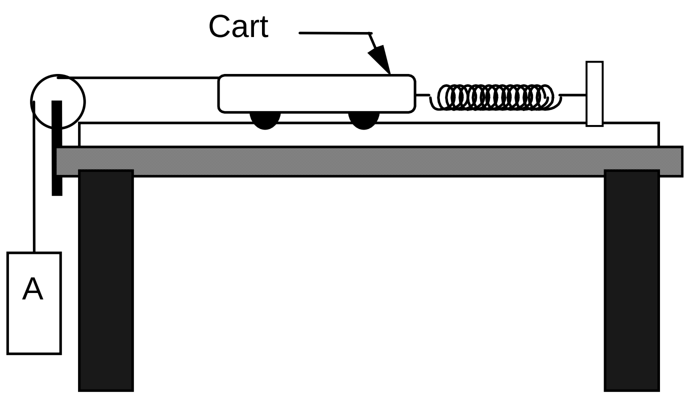
<u>If you completed Problem #2:</u> What is the effective spring constant of this configuration? How does it compare with the effective spring constants of the side-by-side and end-to-end configurations?

PROBLEM #4:
OSCILLATION FREQUENCY OF AN EXTENDED SYSTEM

You are the technical advisor for the next Bruce Willis action adventure movie, *Die Even Harder*, which is being filmed in Minnesota. The script calls for a spectacular stunt: Bruce Willis is dangling over a cliff from a long rope that is tied to the evil villain, who is on the ice-covered ledge of the cliff. The villain's *elastic* parachute line is tangled in a tree located several feet from the edge of the cliff. Bruce and the villain are in simple harmonic motion. At the top of his motion, Bruce unsuccessfully tries to grab for the cliff edge while the villain reaches for his boot knife. The script calls for the villain to cut the rope just as Bruce reaches the top of his motion again. It is expensive (and dangerous) to have Willis hanging from the rope while the crew films close-ups of the villain. However, the stunt-double weighs more than Bruce Willis. The director needs to know if the stunt double will have a different oscillatory motion than Bruce. You decide to solve this problem by modeling the situation with a cart on a track with a spring attached to one end and a hanging object attached to the other by a string. The track represents the ice-covered ledge of the cliff, the adjustable end-stop represents the tree, the spring represents the elastic parachute, the cart represents the villain, the string represents the rope, and the hanging object represents Bruce Willis or his stunt double in this problem.

EQUIPMENT

You have an aluminum track with an adjustable end-stop, a pulley that attaches to the end of the track, a spring, a PASCO cart, some string, a mass hanger, assorted masses, a meter stick, and a stopwatch.



PREDICTION

Write an expression for how the frequency of oscillation of the system depends on the mass of the object hanging over the table.

Use your equation to sketch the expected shape of a graph of oscillation frequency versus hanging mass. Will the frequency **increase**, **decrease** or **stay the same** as the hanging mass increases?

WARM-UP

Read Serway & Vuille, Chapter 13, Sections 13.1, 13.2 and 13.3

1. Make a picture of the situation when the cart and hanging object are at their equilibrium positions. Make another picture at some other time, while the system is oscillating. On your pictures, for the cart and the hanging object, show the directions of the acceleration and velocity. How are they related? Identify and label the known forces on the cart and on the hanging object.

2. Write down how to determine the frequency of a spring system's motion, if you know the relationship between the force on the object and the object's mass.

3. Draw separate force diagrams of the oscillating cart and hanging object when the system is not in its equilibrium position. Label the forces.

4. Independently apply Newton's laws to the cart and to the hanging object. Is the force of the string on the hanging mass constant?

5. Write down the equation that relates the acceleration of the cart to the forces on it. To determine the force of the string on the cart, use the same type of relationship for the hanging mass.

6. From the resulting equation that gives the acceleration of the cart in terms of the spring constant and masses, write down the frequency of oscillation of the cart. To determine the frequency, you should ignore any constant terms in this equation. Give an argument for doing this.

7. Use your equation to sketch the expected shape of the graph of oscillation frequency versus the hanging object's mass.

EXPLORATION

If you do not know the spring constant of your spring, you should decide the best way to determine the spring constant based on your results of Problem #1.

Find the best place for the adjustable end stop on the track. **DO NOT STRETCH THE SPRING PAST ITS ELASTIC LIMIT (ABOUT 60 CM) OR YOU WILL DAMAGE IT,** but stretch it enough so the cart and hanging mass oscillate smoothly.

Determine cart mass you will use for your measurements. Determine the best mass range for the hanging object.

Practice how you will release the cart-hanging mass system. How long does it take for the oscillations to stop? What effect will this have on your measured values compared to your predicted value? How can you affect this time? What amplitude will you use to take your measurements? Between what positions should you measure a cycle? Over how many cycles should you measure to get a precise result?

Write down your measurement plan.

MEASUREMENT

If necessary, determine the spring constant of your spring. What is the uncertainty in your measurement?

For each different hanging mass, measure the period of oscillation of the cart. How many times should you measure each period to be sure that it is reliable? What is the uncertainty of each measurement?

Analyze your data as you go along, so you can determine the size and number of different hanging masses you need to use.

Collect enough data to convince yourself and others of your conclusion about how the oscillation frequency depends on the hanging mass.

ANALYSIS

For each hanging mass, calculate the oscillation frequency (with uncertainty) from your measured period. Use your expression from the Prediction and Warm-up to calculate the *predicted* frequency for each mass.

Graph the frequency versus the hanging object's mass. On the same graph, show your predicted relationship.

What are the limitations on the accuracy of your measurements and analysis? Over what range of values does the measured graph match the predicted graph best? Do the two curves start to diverge from one another? If so, where? What does this tell you about the system?

CONCLUSION

Does the oscillation frequency increase, decrease, or stay the same as the hanging object's mass increases?

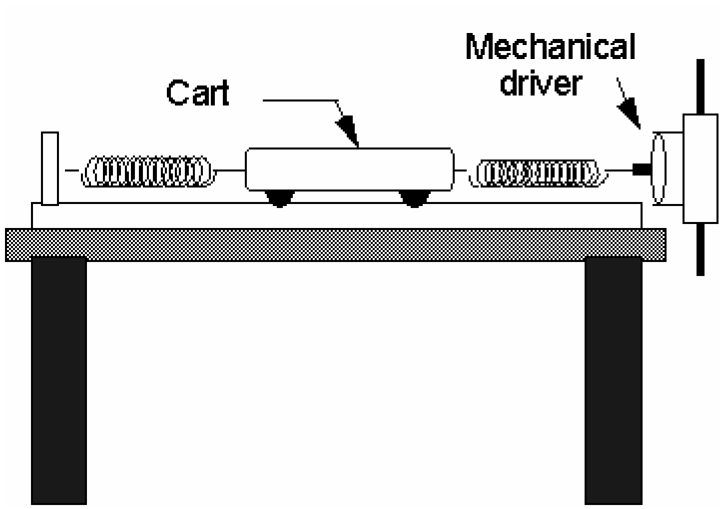
What will you tell the director? Do you think the motion of the actors in the stunt will change if the heavier stunt man is used instead of Bruce Willis? How much heavier than Bruce would the stunt man have to be to produce a noticeable difference in the oscillation frequency of the actors? Explain your reasoning in terms the director would understand.

EXPLORATORY PROBLEM #5:
DRIVEN OSCILLATIONS

You are now prepared to calibrate your seismic detector (from Problem #3). You need to determine how the amplitude of the oscillations of the detector will vary with the frequency of the earthquake aftershocks, so you replace the end stop on the track with a device that moves the end of the spring back and forth, simulating the earth moving beneath the track. The device, called a mechanical driver, is designed so you can change its frequency of oscillation.

EQUIPMENT

You will use a PASCO cart, two springs, an aluminum track, an adjustable end-stop, a signal generator, and a mechanical driver.



The mechanical driver is somewhat like a loudspeaker with one end of a metal rod attached to the center, and the other end of the rod is attached to one of the springs. The driver is connected to the signal generator that causes the rod to oscillate back and forth with adjustable frequencies that can be read off the display on the signal generator.

PREDICTION

Make your best-guess sketch of how you think a graph of the amplitude of the cart versus the frequency of the mechanical driver will look. Assume the driver has a constant amplitude of a few millimeters.

WARM-UP

Read Serway & Vuille, Chapter 13, Sections 13.1 and 13.2

Use the simulation "LabSim5" (See *Appendix F* for a brief explanation of how to use the simulations) to approximate the conditions of this problem.

EXPLORATION

Examine the mechanical driver. Mount it at the end of the track, using the clamp and metal rod so its shaft is aligned with the cart's motion. Connect it to the signal generator, using the output marked **Lo** (for ``low impedance''). Use the smallest amplitude that is sufficient to observe the oscillation of the cart at the lowest frequency possible.

Determine the accuracy of the digital display on the frequency generator by timing one of the lower frequencies.

Devise a scheme to accurately determine the amplitude of a cart on the track, and practice the technique. For each new frequency, should you restart the cart at rest?

When the driver is at or near the undriven frequency (natural frequency) of the cart-spring system, try to simultaneously observe the motion of the cart and the shaft of the driver. What is the relationship? What happens when the driver frequency is twice as large as that frequency?

MEASUREMENT

If you do not know the frequency of your system when it is not driven, determine it using the technique of Problem #3.

Collect enough cart amplitude and driver frequency data to test your prediction. Be sure to collect several data points near the undriven frequency of the system.

ANALYSIS

Make a graph the oscillation amplitude of the cart versus driver frequency.

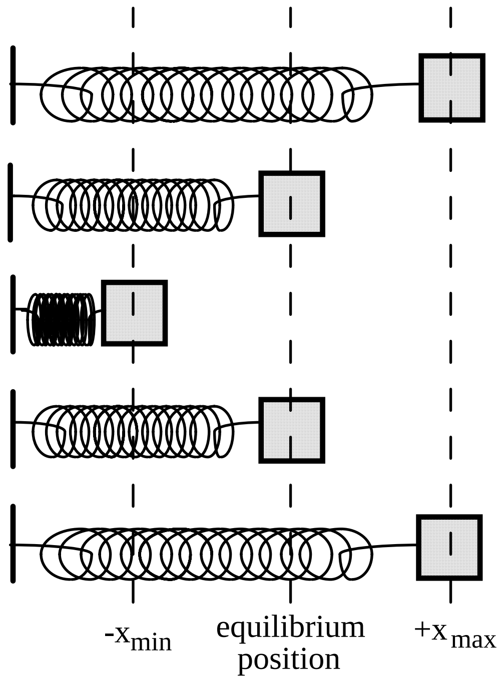
CONCLUSION

Is the graph what you had anticipated? Where is it different? Why? What are the limitations on the accuracy of your measurements and analysis?

Can you explain your results? Is energy conserved? What will you tell your boss about your design for a seismic detector?

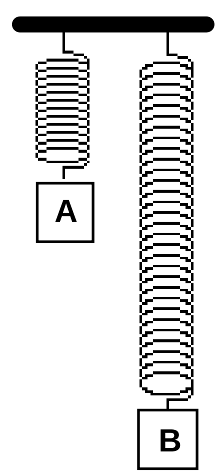
☑ CHECK YOUR UNDERSTANDING

1. The diagram below shows an oscillating mass/spring system at times 0, T/4, T/2, 3T/4, and T, where T is the period of oscillation. For each of these times, write an expression for the displacement (x), the velocity (v), the acceleration (a), the kinetic energy (KE), and the potential energy (PE) *in terms of the amplitude of the oscillations (A), the angular velocity (w), and the spring constant (k)*.



t	x	v	a	KE	PE
0					
$\frac{T}{4}$					
$\frac{T}{2}$					
$\frac{3T}{4}$					
T					

2. Identical masses are attached to identical springs that hang vertically. The masses are pulled down and released, but mass B is pulled further down than mass A, as shown at right.



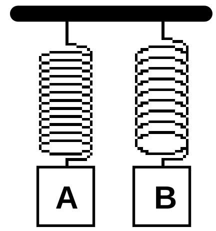
   a. Which mass will take a longer time to reach the equilibrium position? Explain.

   b. Which mass will have the greater acceleration at the instant of release, or will they have the same acceleration? Explain.

   c. Which mass will be going faster as it passes through equilibrium, or will they have the same speed? Explain.

   d. Which mass will have the greater acceleration at the equilibrium point, or will they have the same acceleration? Explain.

3. Two different masses are attached to different springs that hang vertically. Mass A is larger, but the period of simple harmonic motion is the same for both systems. They are pulled the same distance below their equilibrium positions and released from rest.



   a. Which spring has the greater spring constant? Explain.

   b. Which spring is stretched more at its equilibrium position? Explain.

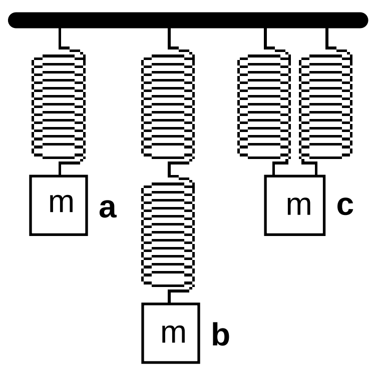
   c. The instant after release, which mass has the greater acceleration? Explain.

   d. If potential energy is defined to be zero at the equilibrium position for each mass, which system has the greater total energy of motion? Explain.

   e. Which mass will have the greater kinetic energy as it passes through its equilibrium position? Explain

   f. Which mass will have the greater speed as it passes through equilibrium? Explain.

4. Five identical springs and three identical masses are arranged as shown at right.



   a. Compare the stretches of the springs at equilibrium in the three cases. Explain.
   b. Which case, a, b, or c, has the greatest effective spring constant? The smallest effective spring constant? Explain.
   c. Which case would execute simple harmonic motion with the greatest period? With the least period? Explain.

   .

TA Name:______________________________

PHYSICS 1101 LABORATORY REPORT

Laboratory VIII

Name and ID#: ____

Date performed: _____________ Day/Time section meets: ________________________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: _________

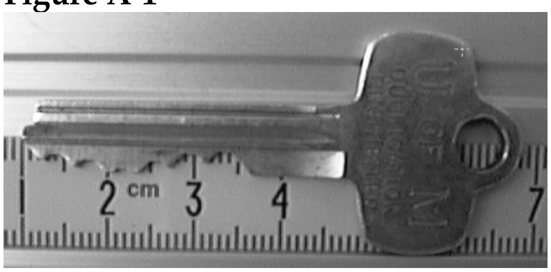
Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
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 <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.

Appendix A: Significant Figures

Calculators make it possible to get an answer with a huge number of figures. Unfortunately many of them are meaningless! For instance if you needed to split $1.00 among three people, you could never give them each exactly $0.333333… The same is true for measurements. If you use a meter stick with millimeter markings to measure the length of a key, as in figure B-1, you could not measure more precisely than a quarter or half or a third of a mm. Reporting a number like 5.8132712 cm would not only be meaningless, it would be misleading.

Figure A-1



In your measurement, you can precisely determine the distance down to the nearest millimeter and then improve your precision by estimating the next figure. It is always assumed that the last figure in the number recorded is uncertain. So, you would report the length of the key as 5.81 cm. Since you estimated the 1, it is the uncertain figure. If you don't like estimating, you might be tempted to just give the number that you know best, namely 5.8 cm, but it is clear that 5.81 cm is a better report of the measurement. An estimate is always necessary to report the most precise measurement. When you quote a measurement, the reader will always assume that the last figure is an estimate. Quantifying that estimate is known as **estimating uncertainties**. Appendix B will illustrate how you might use those estimates to determine the uncertainties in your measurements.

What are significant figures?

The number of significant figures tells the reader the precision of a measurement. Table A-1 gives some examples. One of the things that this table illustrates is that not all zeros are significant. For example, the zero in front of 0.45 is not significant, while the 0 in 1.50 is.

Table A-1

Length (centimeters)	Number of Significant Figures
12.74	4
11.5	3
1.50	3
1.5	2
12.25345	7
0.8	1
0.05	1

A good rule is to always express your values in scientific notation. If you say that your friend lives 143 m from you, you are saying that you are sure of that distance to within a few meters (3 significant figures). What if you really only know the distance to a few tens of meters (2 significant figures)? Then you need to express the distance in scientific notation 1.4×10^2 m.

Is it always better to have more figures?

Consider the measurement of the length of the key Figure A-1 if we used a scale with ten etchings to every millimeter. Then we could use a microscope to measure the spacing to the nearest tenth of a millimeter and guess at the one hundredth millimeter. Our measurement could be 5.174 cm with the uncertainty in the last figure, four significant figures instead of three. This is because our improved scale allowed our estimate to be more precise. This added precision is shown by more significant figures. The more significant figures a number has, the more precise it is.

How do I use significant figures in calculations?

When using significant figures in calculations, you need to keep track of how the uncertainty propagates. There are mathematical procedures for doing this estimate in the most precise manner. This type of estimate depends on knowing the statistical distribution of your measurements. With a lot less effort, you can do a cruder estimate of the uncertainties in a calculated result. This crude method gives an overestimate of the uncertainty but it is a good place to start. For this course this simplified uncertainty estimate (described in Appendix B and below) will be good enough.

Addition and subtraction

Doing addition and subtraction is straightforward. Your result should have the number of significant figures as the least precise measurement. Some examples are given below. The uncertain figure in each number is shown in **bold-faced** type.

addition	subtraction
6.24**2**	5.87**5**
+4.2**3**	-3.3**4**
+0.01**3**	2.5**35**
10.4**85**	
10.4**9**	2.5**4**

The examples above illustrate some rules of working with numbers. First, do all calculations with as many significant figures as you have. Then, at the end of the calculations, round the number off to the correct number of significant figures for the answer. Notice that we had to round the uncertain figure.

Multiplication and division

Multiplication and division are more complicated than addition. The common rule, keeping the same number of significant figures in your answer as in the starting number with the least significant figures, may not always work. As shown in the examples. However, this is the quickest and best rule to use. When in doubt, you can keep track of the significant figures in the calculation as is done in the examples.

multiplication

15.8**4**	17.2**7**
x 2.**5**	x 4.**0**
7920	69.**080**
316**8**	
3**9.600**	
4**0**	69.

division

1**17**	2**5**
2**3**)269**1**	7**5**)187**5**
2**3**	15**0**
39	3**75**
23	**375**
161	
161	
1.**2** x 10^2	2.**5** x 10^1

PRACTICE EXERCISES

1. Determine the number of significant figures in the following table.

Length (centimeters)	Number of Significant Figures
17.87	
0.4730	
17.9	
0.473	
18	
0.47	
1.34×10^{2}	
2.567×10^{5}	
2.0×10^{10}	
1.001	
1.000	
1	
1000	
1001	

2. Add: 121.3 to 6.7×10^{2}:

Answer: $121.3 + 6.7 \times 10^{2} = 7.9 \times 10^{2}$

3. Multiply: 34.2 and 1.5×10^{4}

Answers: $34.2 \times 1.5 \times 10^{4} = 5.1 \times 10^{5}$

Appendix B: Accuracy, Precision, and Uncertainty

How tall are you? How old are you? When you answered these everyday questions, you probably did it in round numbers such as "five foot, six inches" or "nineteen years, three months." But how true are these answers? Are you exactly 5' 6" tall? Probably not. You estimated your height at 5′ 6" and just reported two significant figures. Typically, you round your height to the nearest inch, so that your actual height falls somewhere between 5' 5.5" and 5' 6.5" tall, or 5' 6" ± 0.5". This ± 0.5" is the **uncertainty,** and it informs the reader of the precision of the **value** 5' 6".

What is uncertainty?

Whenever you measure something, there is always some uncertainty. There are two categories of uncertainty: **systematic** and **random**. Systematic uncertainties are those which consistently cause the value to be too large or too small. Systematic uncertainties include such things as reaction time, inaccurate meter sticks, optical parallax and miscalibrated balances. In principle, systematic uncertainties can be eliminated if you know they exist.

Random uncertainties are variations in the measurements which occur without a predictable pattern. If you make precise measurements, these uncertainties arise from the estimated part of the measurement. Random uncertainty can be reduced, but never eliminated. We need a technique to report the contribution of this uncertainty to the measured value.

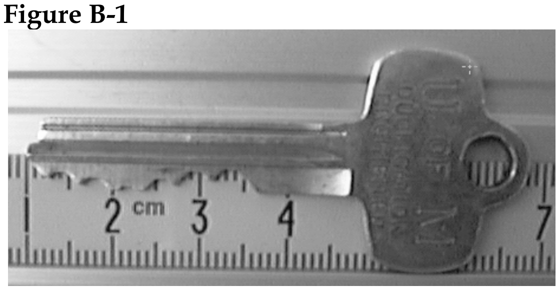
How do I determine the uncertainty?

This Appendix will discuss two basic techniques for determining the uncertainty: **estimating the uncertainty** and measuring the **average deviation.** Which one you choose will depend on your need for precision. If you need a precise determination of some value, the best technique is to measure that value several times and use the average deviation as the uncertainty. Examples of finding the average deviation are given below.

How do I estimate uncertainties?

If time or experimental constraints make repeated measurements impossible, then you will need to estimate the uncertainty. When you estimate uncertainties you are trying to account for anything that might cause the measured value to be different if you were to take the measurement again. For example, suppose you were trying to measure the length of a key, as in Figure B-1.

Figure B-1



If the true value was not as important as the magnitude of the value, you could say that the key’s length was 5 cm give or take 1 cm. This is a crude estimate, but it may be acceptable. A better estimate of the key’s length, as you saw in Appendix A, would be 5.81 cm. This tells us that the worst our measurement could be off is a fraction of a mm. To be more precise we estimate that fraction as about a third of a mm or that our value is 5.81 ±0.03 cm.

Another time you may need to estimate uncertainty is when you analyze video data. Figures B-2 and B-3 show a ball rolling off the edge of a table. These are two consecutive frames, separated in time by 1/30 of a second.

Figure B-2

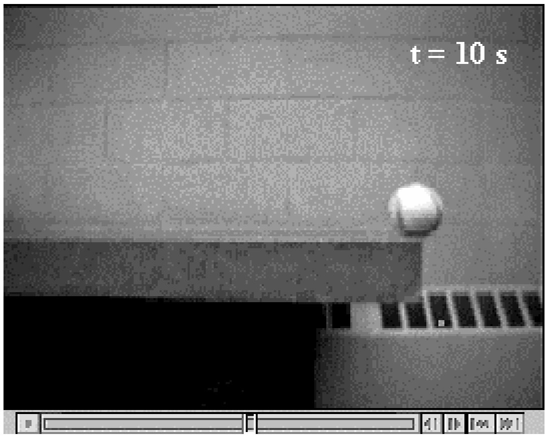
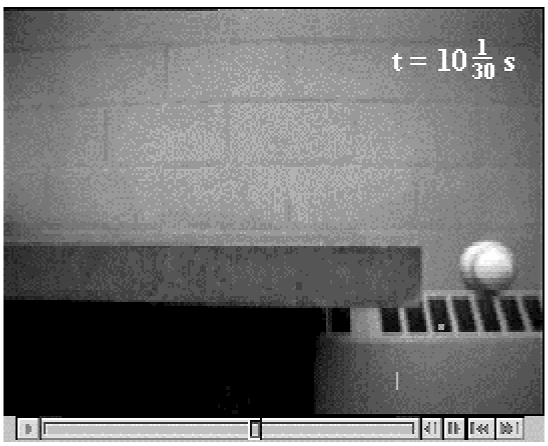


Figure B-3



The exact moment the ball left the table lies somewhere between these frames. We can estimate that this moment occurs midway between them ($t = 10\frac{1}{60}s$). Since it must occur at some point between them, the worst our estimate could be off by is $\frac{1}{60}s$. We can therefore say the time the ball leaves the table is $t = 10\frac{1}{60} \pm \frac{1}{60}s$.

How do I find the average deviation?

If estimating the uncertainty is not good enough for your situation, you can experimentally determine the uncertainty by making several measurements and calculating the average deviation of those measurements. To find the average deviation: (1) Find the average of all your measurements; (2) Find the absolute value of the difference of each measurement from the average (deviations); (3) Find the average of all the deviations by adding them up and dividing by the number of measurements. Of course you need to take enough measurements to get a distribution for which the average has some meaning. Here are two examples of finding the average deviation.

In example 1, a class of six students was asked to find the mass of the same penny using the same balance. In example 2, another class measured a different penny using six different balances. Their results are listed below:

Class 1
Penny A massed by six different students on the same balance.

Mass (grams)
3.110
3.125
3.120
3.126
3.122
3.120
3.121 average
The magnitude of the deviations are: 0.011g, 0.004g, 0.001g, 0.005g, 0.001g, 0.001g
Sum of deviations: 0.023 g
Average deviation: (0.023g)/6 = 0.004 g
Mass of penny A: 3.121 ± 0.004 g

Class 2
Penny B massed by six different students on six different balances

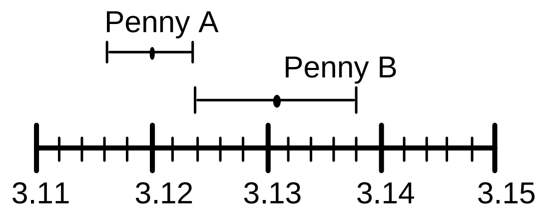
Mass (grams)
3.140
3.133
3.144
3.118
3.132
3.132
3.133 average
The magnitude of the deviations are: 0.007g, 0.000g, 0.011g, 0.015g, 0.001g, 0.001g
Sum of deviations: 0.037 g
Average deviation: (0.039g)/6= 0.006 g
Mass of penny B: 3.131 ± 0.007 g

However you choose to determine the uncertainty, you should always clearly state your method in your report. For the remainder of this appendix, we will use the results of these two examples.

How do I know if two values are the same?

If we compare only the average masses of the two pennies we see that they are different. But now include the uncertainty in the masses. For penny A, the most likely mass is somewhere between 3.116g and 3.124g. For penny B, the most likely mass is somewhere between 3.124g and 3.138g. If you compare the ranges of the masses for the two pennies, as shown in Figure B-4, they just overlap. Given the uncertainty in the masses, we are able to conclude that the masses of the two pennies could be the same. If the range of the masses did not overlap, then we ought to conclude that the masses are probably different.

Figure B-4



Mass of pennies (in grams) with uncertainties

Which result is more precise?

Using a meter stick, you might have an uncertainty of a fraction of a mm in measuring the length of a table or the width of a hair. Clearly, you are more certain about the length of the table than the width of the hair. Your measurement of the table is very precise and your measurement of the width of the hair is completely imprecise. To express this sense of precision, you need to calculate the percentage uncertainty. This is done by dividing the uncertainty by the value of the measurement and then multiplying by 100%. For example, class 1 and 2's precision can be calculated in the following way:

Precision of Class 1's value:
(0.004 g ÷ 3.120 g) x 100% = 0.1 %

Precision of Class 2's value:
(0.007 g ÷ 3.131 g) x 100% = 0.2 %

Class 1's results are more precise. This should not be surprising since class 2 introduced more uncertainty in their results by using six different balances instead of only one.

Which result is more accurate?

Accuracy is a measure of how your measured value compares with the real value. Imagine that class 2 made the measurement again using only one balance. Unfortunately, they chose a balance that was poorly calibrated. They analyzed their results and found the mass of penny B to be 3.556±0.004g. This number is more precise than their previous result since the uncertainty is smaller, but the new measured value of mass is very different from their previous value.

We might conclude that this new value for the mass of penny B is different since the range of the new value does not overlap the range of the previous value. However, that conclusion would be **wrong** since our uncertainty has not taken into account the inaccuracy of the balance. To determine the accuracy of the measurement, we should check by measuring something that is known. This procedure is called calibration, and it is absolutely necessary for making accurate measurements.

Be cautious. It is possible to make measurements that are extremely precise and, at the same time, grossly inaccurate.

How can I do calculations with values that have uncertainty?

When you do calculations with values that have uncertainties, you will need to estimate (by calculation) the uncertainty in the result. There are mathematical techniques for doing this, which depend on the statistical properties of your measurements. A very simple way to estimate uncertainties this is to find the *largest possible uncertainty* the calculation could yield. **This will always overestimate the uncertainty of your calculation**, but an overestimate is better than none at all. Examples of making calculations with uncertainties are shown below:

Addition:

3.120±0.004 g + 3.131±0.007 g =?

First find the sum of the values:

3.120 g + 3.131 g = 6.251 g

Next find the largest possible value:

3.124 g + 3.138 g = 6.262 g

The uncertainty is the difference between the two:

6.262 g - 6.251 g = 0.011 g

This is the same as just adding the uncertainties:

0.004 g+0.007 g = 0.011 g

Subtraction:

3.131±0.007 g - 3.120±0.004 g =?

First find the differences of the values:

3.131 g - 3.120 g = 0.011 g

Next find the largest possible uncertainty:

0.007 g+0.004 g = 0.011 g

So the result is 0.011±0.011 g.

Notice that zero is included in the range, so it is possible that there is no difference in the masses of the pennies, as we saw before.

Multiplication:

3.131±0.013 g x 6.1±0.2 cm = ?

First multiply the values:

3.131 g x 6.1 cm = 19.1 g-cm

Next find the maximum possible value (or the smallest):

3.144 g x 6.3 cm = 19.8 g-cm

And the difference gives the uncertainty:

19.8 g-cm - 19.1 g-cm = 0.7 g-cm

So the result is 19.1 ± 0.7 g-cm.

Division:

3.131±0.013 g ÷ 3.120±0.008 g = ?

First divide the values:

3.131÷3.120 = 1.0035

Next, find the maximum possible value (or the smallest):

3.144g ÷ 3.112g = 1.0103.

(Notice the largest possible value for the numerator and the smallest possible value for the denominator gives the largest result.)
And the deviation of this value:

$$1.0103 - 1.0035 = 0.0068$$

So the result is 1.004 ± 0.007

The same ideas can be carried out with more complicated calculations. Remember this will always give you an overestimate of your uncertainty. There are other calculational techniques which give better estimates for uncertainties. If you wish to use them, please discuss it with your instructor to see if they are appropriate.

These techniques help you estimate the random uncertainty that always occurs in measurements. They will not help account for mistakes or poor measurement procedures. There is no substitute for taking data with the utmost of care. A little forethought about the possible sources of uncertainty can go a long way in ensuring precise and accurate data.

PRACTICE EXERCISES:

B-1. Consider the following results for different experiments. Determine if they agree with the accepted result listed to the right. Also calculate the precision for each result.

a) $g = 10.4 \pm 1.1$ m/s^2 — $g = 9.8$ m/s^2

b) $T = 1.5 \pm 0.1$ sec — $T = 1.1$ sec

c) $k = 1368 \pm 45$ N/m — $k = 1300 \pm 50$ N/m

Answer: a) Yes, 11%; b) No, 7%; c) Yes, 3.3%

B-2. The area of a rectangular metal plate was found by measuring its length and its width. The length was found to be 5.37±0.05 cm. The width was found to be 3.42±0.02 cm. What is the area and the average deviation?

Answer: 18.4 ± 0.3 cm^2

B-3. Each member of your lab group weighs the cart and two mass sets twice. The following table shows this data. Calculate the total mass of the cart with each set of masses and for the two sets of masses combined.

Cart (grams)	**Mass set 1** (grams)	**Mass set 2** (grams)
201.3	98.7	95.6
201.5	98.8	95.3
202.3	96.9	96.4
202.1	97.1	96.2
199.8	98.4	95.8
200.0	98.6	95.6

Answer: Cart and set 1: 299.3 ± 2.2 g.
Cart and set 2: 297.0 ± 1.8 g.
Cart and both sets: 395.1 ± 2.8 g.

Appendix C: Graphing

The graph is one of the most powerful tools for data presentation and data analysis. When used properly, graphs become important guides that illustrate how an experiment was conducted. It is important to graph your data as you take it. Once you finish data taking, graphs are also the easiest way to make sense out of data.

LabVIEW™ will often provide you with a graph, but on occasion you will have to make your own. Good graphing practice, as outlined below, is a way to save time and effort while solving a problem in the laboratory.

How do I make a graph?

1. Graph paper was invented to make it easy to make graphs. Even if you are just making a quick sketch for yourself, it will save you time and effort to use graph paper. That is why your lab journal pages are graph paper. Make sure you graph your data as you take it.

2. Every graph should have a **title** so that later you recognize quickly what data it represents. In a stack of graphs, it is difficult to keep one graph distinct from another without a clear, concise title.

3. The axes of the graph should take up at least *half a page*. Give yourself plenty of space so that you can see the pattern of the data as it is developing. Both axes should be **labeled** so that later you will know what quantity was being measured and in what units it was measured without a lot of effort.

4. The scales on the graphs should be chosen so that the data occupies most of the space of your graph. "Fill up the graphs!" You do not need to include zero on your scales unless it is important to the interpretation of the graph.

5. If you have more than one set of data on a set of axes, be sure to label each set so you can't get confused later.

How do I plot data and its uncertainty?

Another tool that makes data analysis easier is a table to record all of your data. A useful data table starts with a title and column headings so that you will not forget what all the numbers mean. The column headings are usually the labels for the axes of your graph. As an example look at Table C-1 and Graph C-1 on the next page where a position-versus-time graph is drawn for a hypothetical situation.

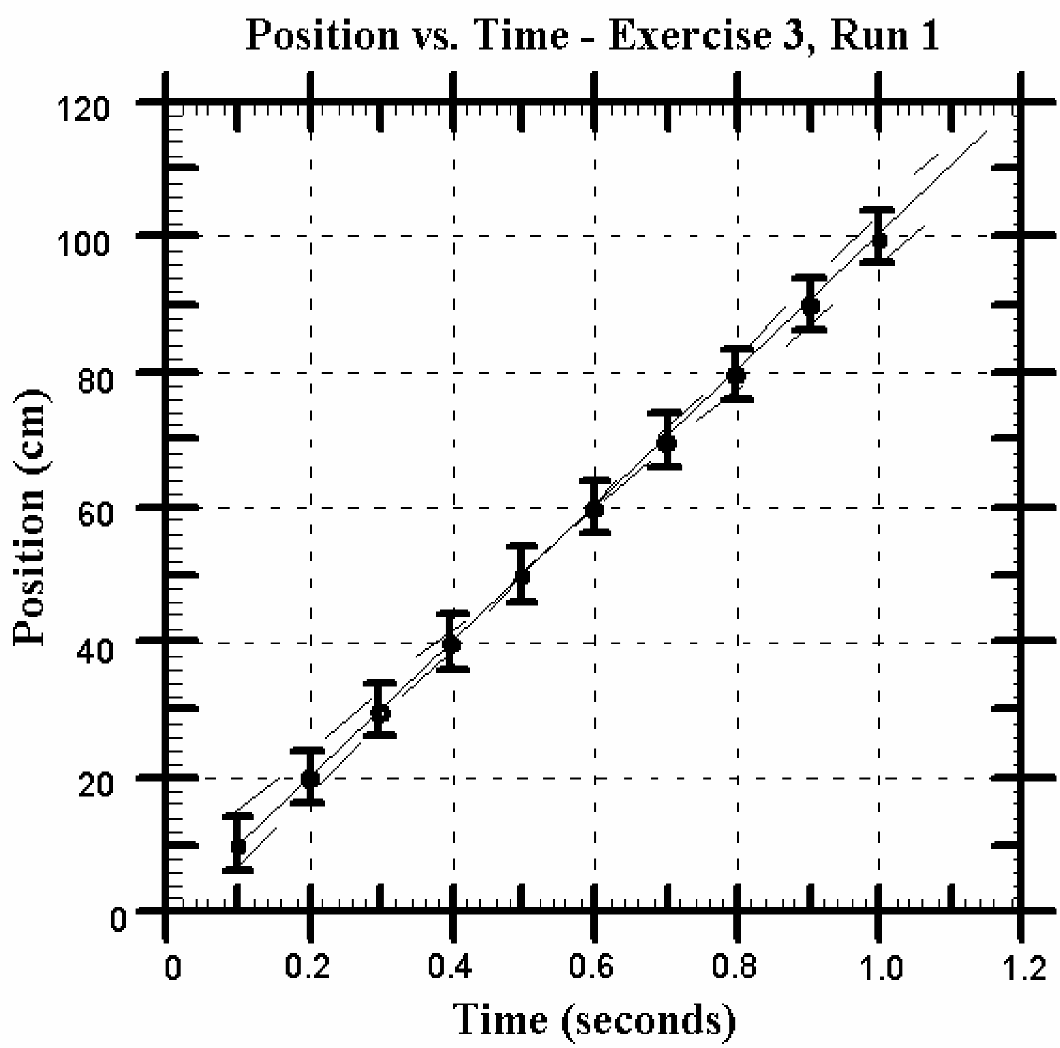
The uncertainty is shown on the graphs as a line representing a range of possible data with the principal value at the center. The lines are called **error bars**, and they are useful in determining if your data agrees with your prediction. Any curve (function) which represents your data should pass through your error bars not the data points.

Table C-1:

Position vs. Time: Exercise 3, Run 1

Time/sec	Position/cm
0.1	10 ± 5
0.2	20 ± 5
0.3	30 ± 5
0.4	39 ± 5
0.5	49 ± 5
0.6	59 ± 5
0.7	69 ± 5
0.8	79 ± 5
0.9	89 ± 5
1.0	98 ± 5

Graph C-1:



What is a best-fit straight line?

Whenever you have a graph of data, you are often asked to determine the relationship between two quantities that you measure (i.e. position and time). **Do not connect the dots** that are your data points; instead draw a smooth curve near all of the data, but within the error bars. If you expect it to be linear, then you should use a clear straight edge and try to draw the line. The line should pass through all of the error bars and have as many principal values beneath it as above it. The line does not, however, need to touch any of the data points.

When done correctly, this straight line represents the function that best fits your data. You can read from your graph the slope and intercept of the line. These quantities usually have some important physics interpretation. Some computer programs, like Excel or Cricket Graph, will determine the best straight line for your data and compute its slope, intercept, and their uncertainties. You should check with your lab instructor, before you use a graphing program to see if it is appropriate. As an example, look at Graph C-1. The dotted lines are possible linear fits, but the solid line is the best. Once you have found the best-fit line, you should determine the slope from the graph and record its value.

How do I find the slope of a line?

The slope of a line is defined to be the ratio of the change in a line's ordinate to the change in the abscissa, or the change in "rise" divided by the change in "run." Your text explains slope. For Graph C-1, the slope of the best-fit line will be the change in the position of the object divided by the time interval for that change in position.

To find the value of the slope, look carefully at your best fit line to find points along the line that have coordinates that you can identify. It is usually not a good idea to use your data points for these values, since your line might not pass through them exactly. For example, the best fit line on Graph C-1 passes through the points (0.15 sec, 15 cm) and (1.10 sec, 110 cm). This means the slope of the line is:

$$\text{slope} = \frac{\text{change in "rise"}}{\text{change in "run"}}$$

$$= \frac{110 \text{ cm} - 15 \text{ cm}}{1.10 \text{ sec} - 0.15 \text{ sec}}$$

$$= \frac{95 \text{ cm}}{0.95 \text{ sec}}$$

$$= 100 \, \frac{\text{cm}}{\text{sec}}$$

Note that the slope of a position-versus-time graph has the units of velocity.

How do I find the uncertainty in the slope of a line?

Look at the dotted lines in Graph C-1. These lines are the largest and smallest values of the slopes that can realistically fit the data. The lines run through the extremes in the uncertainties and they represent the *largest and smallest possible slopes* for lines that fit the data. You can extend these lines and compute their slopes. These are your uncertainties in the determination of the slope. In this case, it would be the uncertainty in the velocity.

How do I get the slope of a curve that is not a straight line?

The tangent to a point on a smooth curve is just the slope of the curve at that point. If the curve is not a straight line, the slope depends where on the curve you measure it.

To draw a tangent line at any point on a smooth curve, draw a straight line that only touches the curve at the point of interest, without going inside of the curve. What you are trying to do is get an equal amount of space between the curve and the tangent line on both sides of the point of interest.

The tangent line that you draw needs to be long enough to allow you to easily determine its slope. You will also need to determine the uncertainty in the slope of the tangent line by considering all other possible tangent lines and selecting the ones with the largest and smallest slopes. The slopes of these lines will give the uncertainty in the tangent line. Notice that this is exactly like finding the uncertainty of the slope of a straight line, but requires more imagination.

How do I "linearize" my data?

A straight-line graph is the easiest graph to interpret. By seeing if the slope is positive, negative, or zero you can quickly determine the relationship between two measurements. Unfortunately, not all the relationships in nature are straight lines. However, if we have a theory that predicts how one measured quantity (e.g. position) depends on another (e.g. time) for the experiment, we can make the graph be a straight line. To do this, you make a graph with the appropriate function of one quantity on one axis (e.g. time squared) and the other quantity (e.g. position) on the other axis. This is what is called "linearizing" the data.

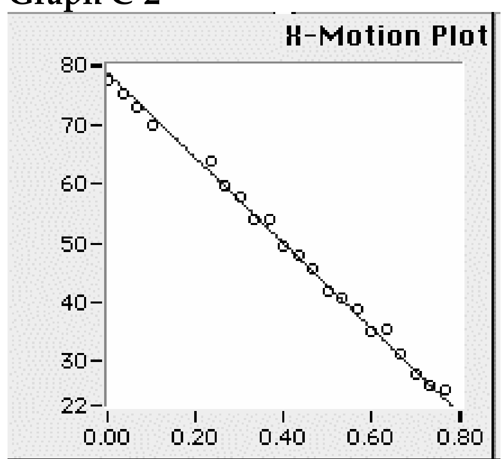
For example, if a rolling cart undergoes constant acceleration, the position-versus-time graph is a curve. In fact, our theory tells us that the curve should be a parabola. To be concrete we will assume that your data starts at a time when the initial velocity of the cart was zero. The theory predicts that the motion is described by $x = 0.5at^2$. To linearize this data, you square the time and plot position versus time *squared*. This graph should be a straight line with a slope of 0.5a. Notice that you can only linearize data if you know, or can guess, the relationship between the measured quantities involved.

How do I interpret graphs from LabVIEW™?

Graphs C-2 through C-4 were produced with LabVIEW™. They give the horizontal position as a function of time. Even though LabVIEW™ draws the graphs for you, it usually does not label the axes and never puts in the uncertainty. You must add these to the graphs yourself.

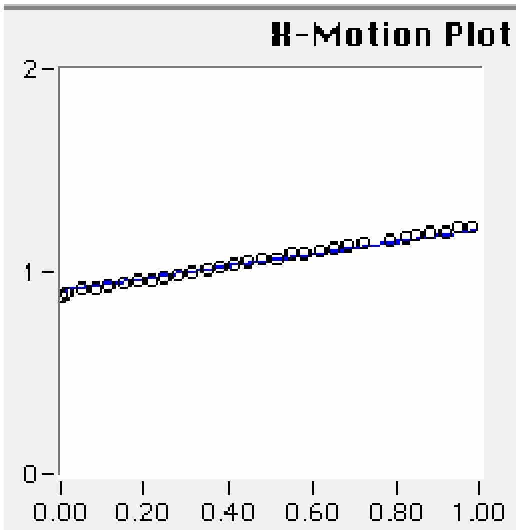
One way to estimate the uncertainty is to observe how much the data points are scattered from a smooth behavior. By estimating the average scatter, you have a fair estimate of the data's uncertainty. Graph C-2 shows position versus time for a moving cart. The vertical axis is position in cm and the horizontal axis is time in seconds. See if you can label the axes appropriately and estimate the uncertainty for the data.

Graph C-2

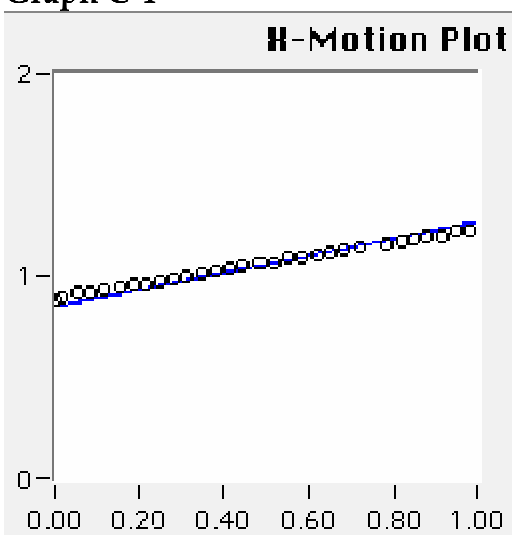


Finding the slope of any given curve with LabVIEW™ should be easy after you have chosen the mathematical equation of the best-fit curve. Graphs C-3 and C-4 each show one possible line to describe the same data. From looking at these graphs, the estimate of the data's uncertainty is less than the diameter of the circles representing that data.

Graph C-3



Graph C-4

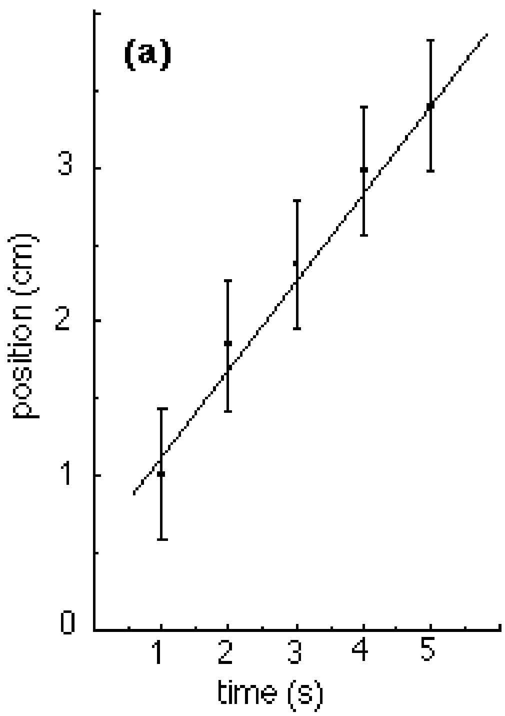


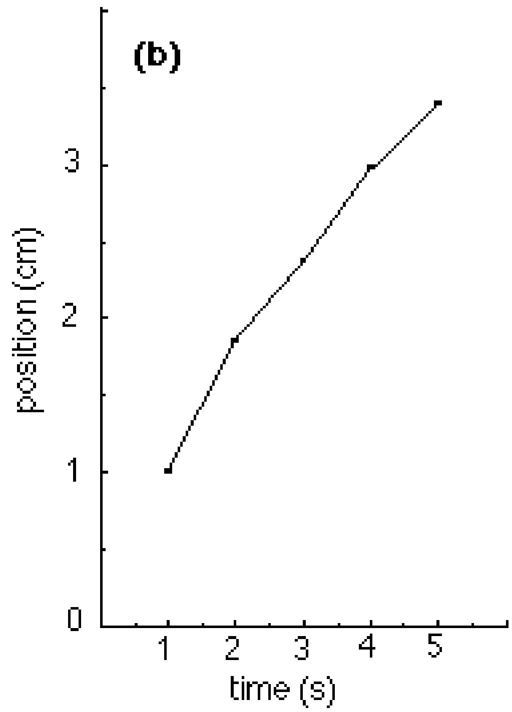
The line touching the data points in Graph C-3 has a slope of 0.38 m/sec. This is the **minimum** possible slope for a line that fits the given data.

The line touching the data points in Graph C-4 shows a slope of 0.44 m/sec. This is the **maximum** possible slope for a line that fits the given data.
You can estimate the uncertainty by calculating the average difference of these two slopes from that of the best-fit line. Therefore the uncertainty determined by graphs C-3 and C-4 is $\pm$ 0.03 m/sec.

PRACTICE EXERCISES:

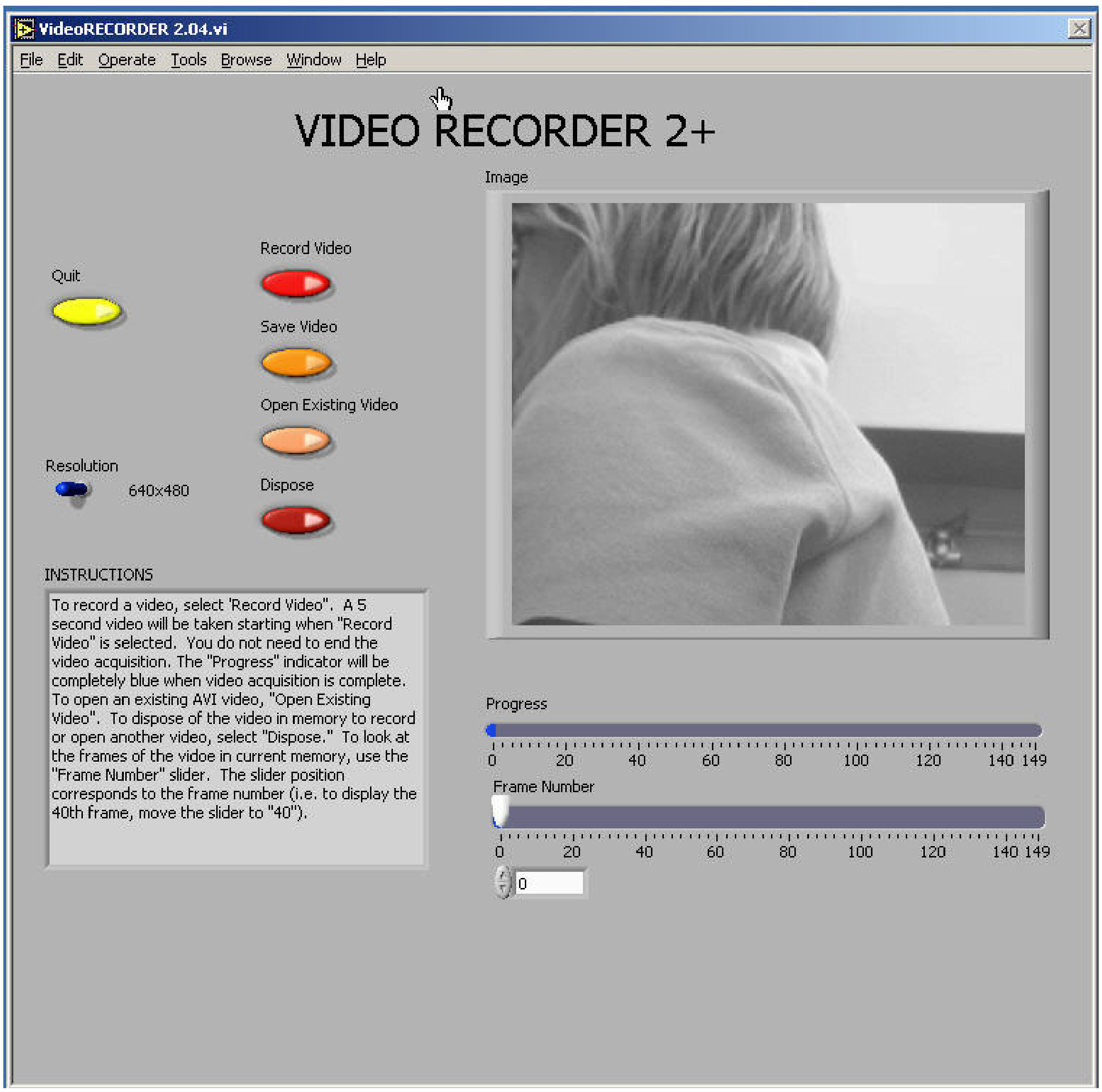
Explain what is wrong with each of the graphs below.





Appendix D: Video Analysis of Motion

Analyzing pictures (movies or videos) is a powerful tool for understanding how objects move. Like most forms of data, video is most easily analyzed using a computer and data acquisition software. This appendix will guide a person somewhat familiar with WindowsNT through the use of one such program: the video analysis application written in LabVIEW™. LabVIEW™ is a general-purpose data acquisition programming system. It is widely used in academic research and industry. We will also use LabVIEW™ to acquire data from other instruments throughout the year.



Using video to analyze motion is a two-step process. The first step is recording a video. This process uses the video software to record the images from the camera and compress the file. The second step is to analyze the video to get a kinematic description of the recorded motion.

(1) MAKING VIDEOS

After logging into the computer, open the video recording program by double clicking the icon on the desktop labeled *VideoRECORDER*. A window similar to the picture on the previous page should appear.

If the camera is working, you should see a "live" video image of whatever is in front of the camera. (See your instructor if your camera is not functioning and you are sure you turned it on.) By adjusting the lens on the video camera, you can alter both the magnification and the sharpness of the image until the picture quality is as good as possible.

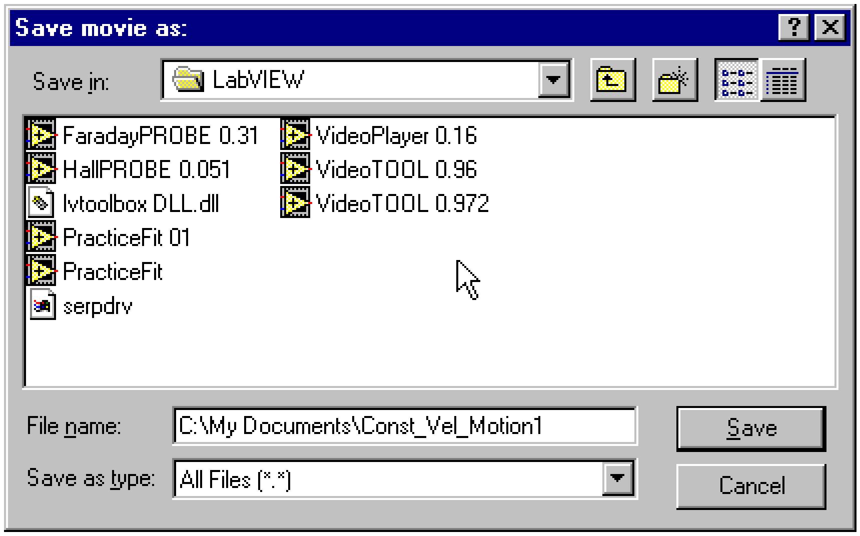
The controls are fairly self-explanatory; pressing the *Record Video* button begins the process of recording a 5-second video image. While the video is recording, the blue *Progress* bar beneath the video frame grows. Once you have finished recording, you can move through the video by dragging the *Frame Number* slider control. If you are not pleased with your video recording, delete it by pressing the *Dispose* button.

You may notice that the computer sometimes skips frames. You can identify the dropped frame by playing the video back frame by frame. If the recorded motion does not appear smooth or if the object moves irregularly from frame to frame, then frames are probably missing. If the computer is skipping frames, speak with your instructor.

While you are recording your video, you should try to estimate the kinematic variables you observe, such as the initial position, velocities, and acceleration. The time with the unit of second is shown in the *VideoRECORDER* window, in the box below the *Frame Number* slider. These values prove very useful for your prediction equations. Be sure to record your estimates in your journal.

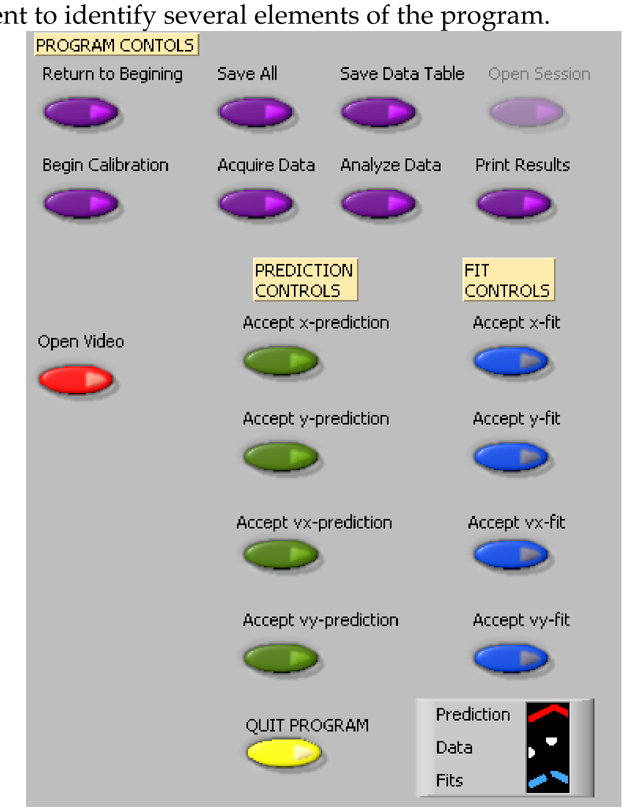
Once you have recorded a satisfactory video, save it by pressing the *Save Video* button. You will see a *Save* window, as shown on the next page.

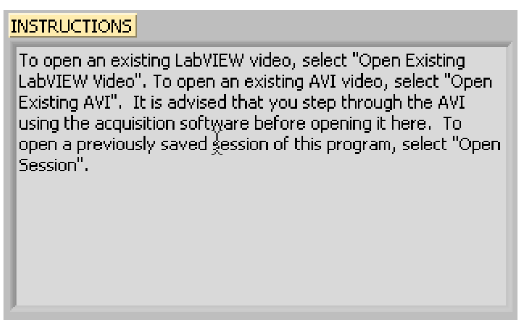
To avoid cluttering the computer, you will only be able to save your video to certain folders on the hard disk. One such folder is the *My Documents* folder located on the C drive. You should check with your lab instructor for the most suitable place to save your video. In the *File name* box, you should enter the location of the folder in which you wish to save your video followed by the name that you wish to give to your video. This name should be descriptive enough to be useful to you later (see the picture for an example).



(2) ANALYSIS BASICS

Open the video analysis application by clicking the icon labeled *VideoTOOL*, which is located on the desktop. You should now take a moment to identify several elements of the program. The two most important of these are the *Program Controls* panel shown to the right and the *Instructions* box shown below.





These two elements of the analysis program work in tandem. The *Instructions* box will give you directions and tasks to perform. It will also tell you when to select a control in the *Program Controls* panel. After you select a control, it will "gray out" and the next control will become available. If you make a mistake, you cannot go backwards!
You would have to quit your analysis and reopen the video to begin afresh.

You print and/or quit the video analysis from the *Program Controls* panel. You also have the option to save the data to continue later, or to save a data table.

Be careful not to quit without printing and saving your data! You will have to go back and analyze the data again if you fail to select *Print Results* before selecting *Quit Program* or *Return to Beginning*. Also be sure to save the data (*Save All*) and save the data table (*Save Data Table*).

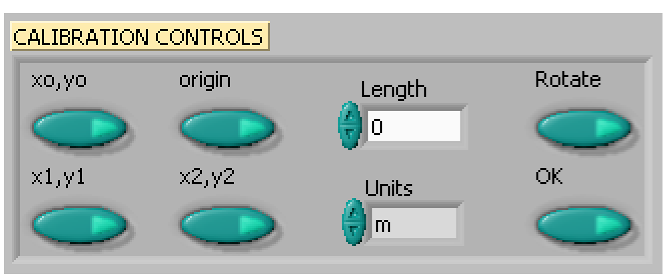
CALIBRATION

While the computer is a very handy tool, it is not smart enough to identify objects or the sizes of those objects in the videos that you take and analyze. For this reason, you will need to enter this information into the computer. If you are not careful in the calibration process, your analysis will not make any sense.

After you open the video that you wish to analyze and select *Begin Calibration* from the *Program Controls* panel you will be advised in the *Instructions* box "To begin Calibration, advance the video to a frame where the first data point will be taken. The time stamp of this frame will be used as the initial time." To advance the video to where you want time t=0 to be, you need to use the video control buttons, shown below. This action is equivalent to starting a stopwatch.

Practice with each button until you are proficient with its use. When you are ready to continue with the calibration, locate the object you wish to use to calibrate the size of the video. The best object to use is the object whose motion you are analyzing, but sometimes this is not easy. If you cannot use the object whose motion you are analyzing, you must do your best to use an object that is in the plane of motion of your object being analyzed.

Follow the direction in the *Instructions* box and define the length of an object that you have measured for the computer. Once this is completed, input the scale length with proper units in *Calibration Controls* box (shown below). Read the directions in the *Instructions* box carefully. Enter the scale length, and then use the arrows to select the units you are using.



Lastly, decide if you want to rotate your coordinate axes. If you choose not to rotate the axes, the computer will choose the lower left-hand corner of the video to be the origin with positive x to the right and positive y up. If you choose to rotate your axis, follow the directions in the *Instructions* box carefully. Your chosen axes will appear under the *Calibration Controls* box. This option may also be used to reposition the origin of the coordinate system, should you require it.

Once you have completed this process, select "OK" from the *Calibration Controls* box.

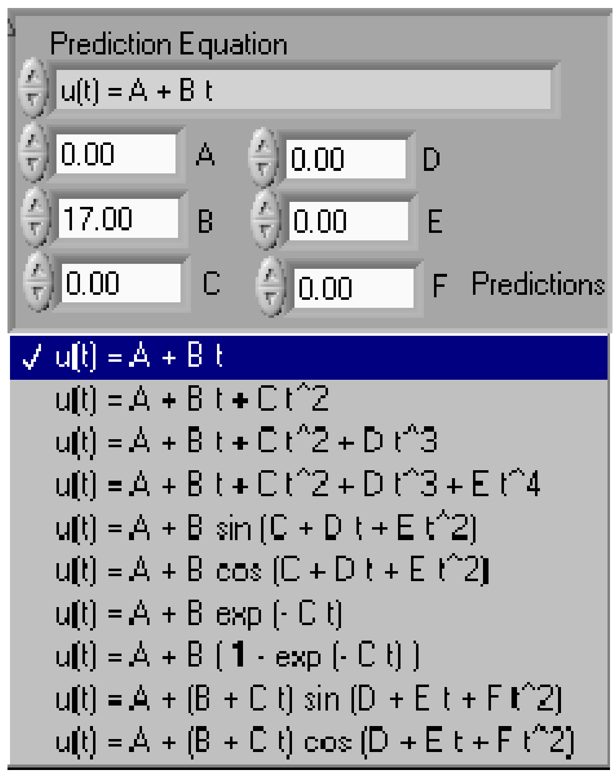
ANALYSIS PREDICTIONS

This video analysis relies on your graphical skills to interpret the data from the videos. Before doing your analysis, you should be familiar with both Appendix C: Graphing and Appendix B: Uncertainties.

Before analyzing the data, enter your prediction of how you expect the data to behave. This pattern of making predictions before obtaining results is the only reliable way to take data. How else can you know if something has gone wrong? This happens so often that it is given a name (Murphy's Law). It is also a good way to make sure you have learned something, but only if you stop to think about the discrepancies or similarities between your prediction and the results.

In order to enter your prediction into the computer, you first need to decide on your coordinate axes, origin, and scale (units) for your motion. Record these in your lab journal.

Next you will need to select the generic equation, u(t), which describes the graph you expect for the motion along your x-axis seen in your video. You must choose the appropriate function that matches the predicted curve. The analysis program is equipped with several equations, which are accessible using the pull-down menu on the equation line (shown to the right).



You can change the equation to one you would like to use by clicking on the arrows to the left of the equation in the *Prediction Equation* command box, shown to the right. Holding down the mouse button will give you the menu also shown to the right.

After selecting your generic equation, you next need to enter your best approximation for the parameters A and B and C and D where you need them. If you took good notes of these values during the filming of your video, inputting these values should be straightforward. You will also need to decide on the units for these constants at this time.

Once you are satisfied that the equation you selected for your motion and the values of the constants are correct, click "*Predictions*" in the *Prediction Equation* command box. Your prediction equation will then show up on the graph on the computer screen. If you wish to change your prediction simply repeat the above procedure. When you are satisfied, select the *Accept x- (or y-) prediction* option from the *Program Controls* panel. Once you have done this you cannot change your prediction except by starting over. Repeat this procedure for the Y direction.

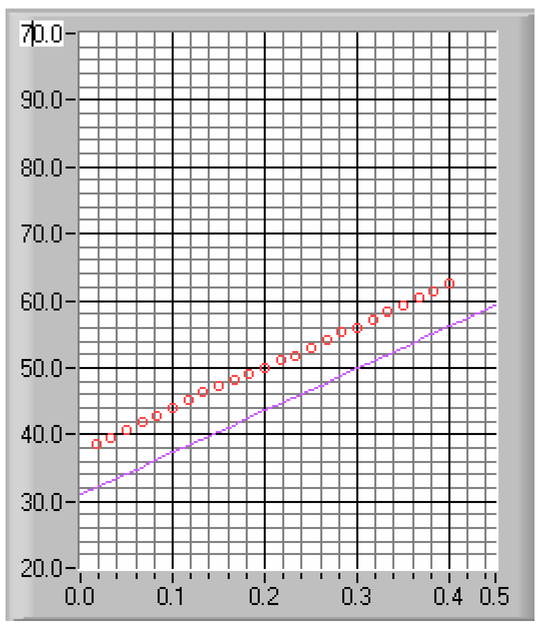
DATA COLLECTION

To collect data, you first need to identify a very specific point on the object whose motion you are analyzing. Next move the cursor over this point and click the green *Accept Data Point* button in *VideoPLAYER* window. The computer records this position and time. The computer will automatically advance the video to the next frame leaving a mark on the point you have just selected. Then move the cursor back to the same place on the object and click *Accept Data Point* button again. So long as you always use the same point on the object, you will get reliable data from your analysis. This process is not always so easy especially if the object is moving rapidly. Because the camera has an interlaced scan of the image, it actually gives you two images. For a rapidly moving object, these images split apart. You need to keep track of which image you are measuring for each picture frame. The data will automatically appear on the appropriate graph on your computer screen each time you accept a data point. If you don't see the data on the graph, you will need to change the scale of the axes. If you are satisfied with your data, choose *Analyze Data* from the *Program Controls* panel.

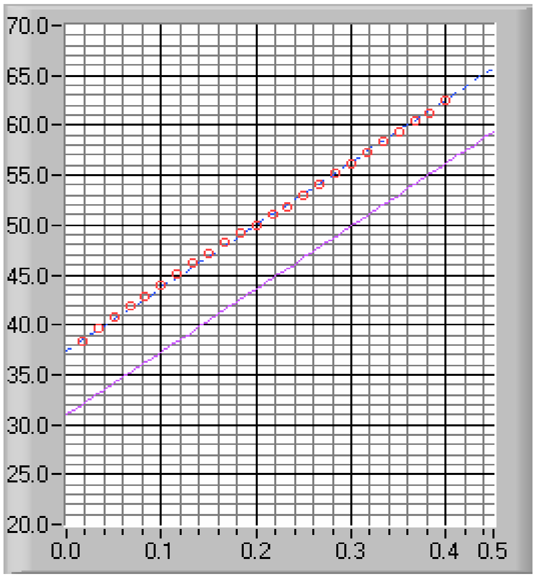
FITTING YOUR DATA

Deciding which equation best represents your data is the most important part of your data analysis. The actual mechanics of choosing the equation and constants is similar to what you did for your predictions.

First you must find your data on your graphs. Usually, you can find your full data set by adjusting the scales of your X-motion and Y-motion plots. This scaling is accomplished by entering the appropriate maximum and minimum values on the vertical axis (as shown to the right) as well as adjusting the time scale.

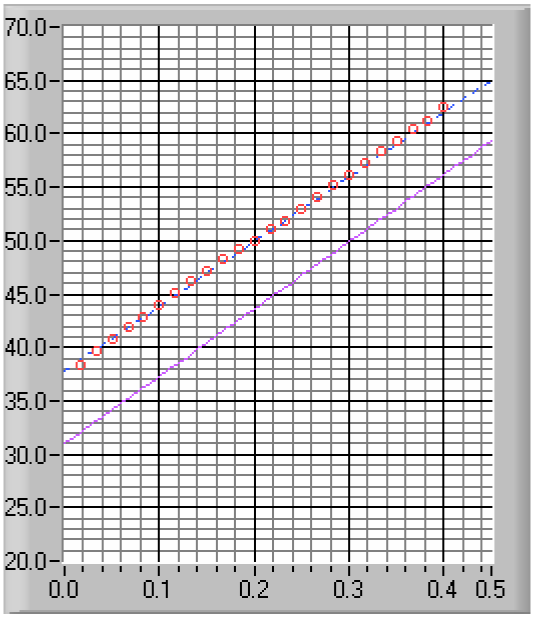


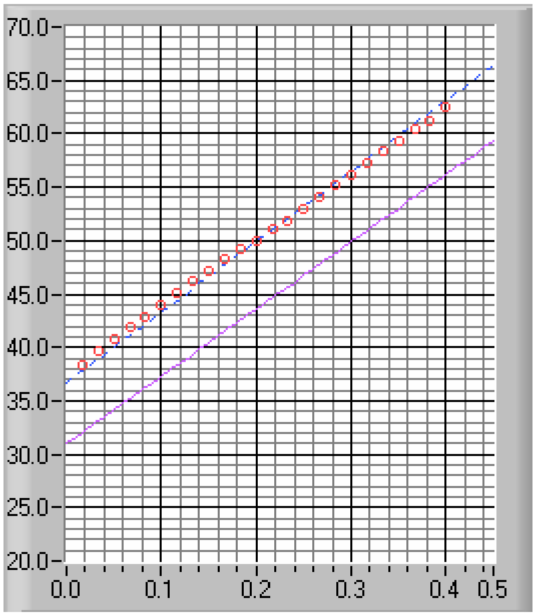
Secondly, after you find your data, you need to determine the best possible equation to describe this data. After you have decided on the appropriate equation, you need to determine the constants of this equation so that it best fits the data. Although this can be done by trial and error, it is much more efficient to think of how the behavior of the equation you have chosen depends on each parameter. Calculus can be a great help here.



As an example of a completed determination of the equation, the X-motion plot above shows both the predicted line (down) and the line that best fits the data (through the circles). Be sure to record the values of your parameters in your journal before you go on to the next stage.

Lastly, you need to estimate the uncertainty in your fit by deciding the range of other lines that *could* also fit your data. This method of estimating your uncertainty is described in Appendix C. Slightly changing the values for each constant in turn will allow you to do this quickly. For example, the X-motion plots below show both the predicted line (down) and two other lines that also fit the data (near the circles).





After you have found the uncertainties in your constants, return to your best-fit line and use it as your fit by selecting *Accept x- (or y-) fit* in the *Program Controls* panel.

LAST WORDS

These directions are not meant to be exhaustive. You will discover more features of the video analysis program as you use it. Be sure to record these features in your lab journal.

Appendix E: Sample Lab Report

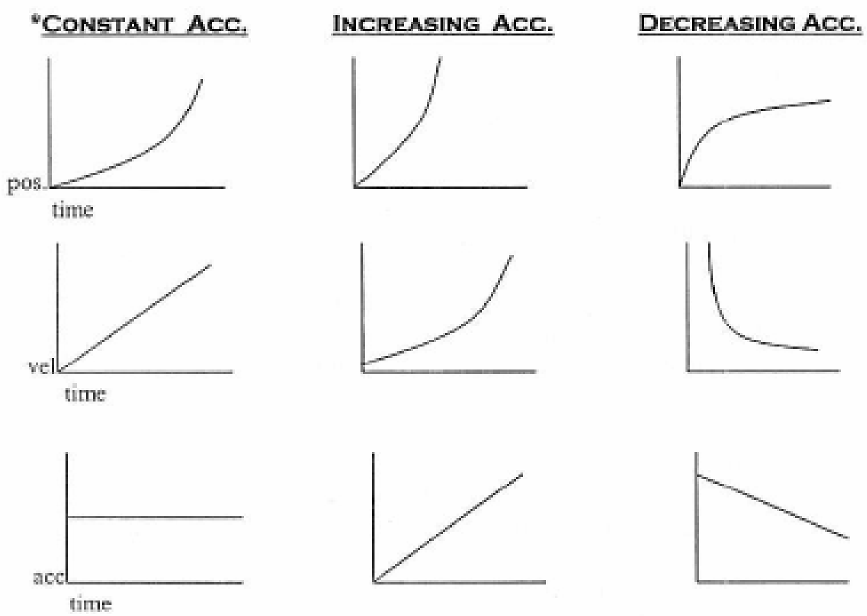
PROBLEM#2:
MOTION DOWN AN INCLINE

PROBLEM DESCRIPTION:

The state safety board is interested in determining how a car rolling down a hill accelerates so that they can better understand the dynamics of car accidents. This lab investigates the acceleration of a car rolling down a hill without any brakes. In lab, this problem was approached using a basic scientific method. First, predictions were made about the motion of the car. Second, the motion of the car was tested and recorded. Finally, the motion was analyzed using video analysis and conclusions were made. The experimental results of the lab where then compared to the theoretical results based upon vector and trigonometric reasoning. The lab required use of a stopwatch, cart, meter stick, end stop, as well as a video camera and the video analysis software, LabView.

PREDICTION:

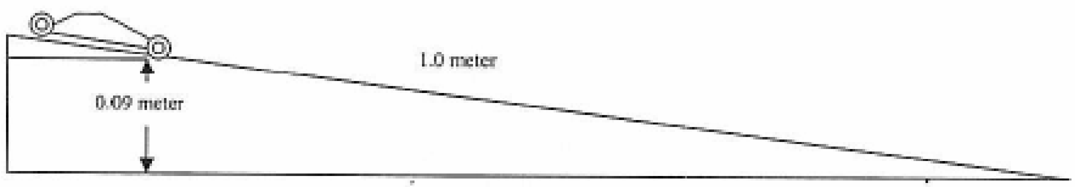
The essential question in this lab is whether the acceleration of the car down an incline is increasing, decreasing, or constant during its motion. This can be best examined by sketching position-versus-time, instantaneous velocity-versus-time, and acceleration-versus-time graphs for each of the possibilities.



From these graphs, it was predicted that **constant acceleration* best describes the motion of a car rolling down an incline. Velocity will increase during the motion, but acceleration will remain constant because it based entirely on the constant force of gravity (partial). Other than air resistance and friction, there should be no other forces acting upon the cart. The results of the lab will be able to approve or disprove this prediction because actual position vs. time and velocity vs. time data will be captured.

PROCEDURE:

The procedure involved three general steps; apparatus set-up, cart motion recording, and cart motion analysis. The set-up involved using a wooden block to prop up the track at a steady incline. A one-meter long section of the track was then measured and marked at 10 cm increments with white tape. Then, the height from the table-top to the top part of the measured section of the track was measured and recorded to be 0.09 (+/- 0.01) meters. The video camera was then positioned so that the entire one-meter section of track was clearly visible on the display screen. It was important that the camera was positioned parallel to the track so that there would be minimal error due to disparate distances from the camera to the two ends of the track. The cart was then placed at the top of the track, at the first tape mark, demarcating the initial position and start point of the motion. A simple illustration of the set-up can be seen below:



When the set-up was complete, it was time to release the car and record its motion using the video recorder program, LabView. The cart was released from position (0.00 m) and it traveled to the final position (1.0 +/- 0.01 m) near the end of the track. The time elapsed for the 1 meter displacement was also measured and recorded using a stopwatch.

The recorded video file was then opened using the Video Tool program. This program served as the major tool for analyzing the motion of the car. The coordinate system was calibrated and rotated so that the measurements were one-dimensional and approximately 1 meter in length. The program included predicting the equation of the position vs. time graph as well as the velocity vs. time graph. To make these predictions, it was important to first determine the general shape that the graph should be. Because position is exponentially related to acceleration, it was appropriate to predict that the general formula for the position vs. time graph should represent a parabolic shape. By changing the values of the variables in the general equation, a prediction was made based upon the known displacement and time of travel. The prediction was: $f(t) = 0 + 0t + 0.25^2$. In this equation f(t) means that the displacement is dependent on time. Second, the equation of the velocity vs. time graph was predicted using a linear formula. Acceleration and velocity are related by a single factor of time (m/s vs. m/s/s), therefore the graph of velocity vs. time with constant acceleration should be a straight, linear plot. Using the known values of displacement and time, the following prediction was made: $f(t) = 0 + 5t$. Following the predictions, the actual motion of the car was measured.

The motion was measured by marking the position of the car with data points at equally spaced time intervals. Approximately 12 data points were captured in the video. These data points were then plotted onto the same graph that displayed the predicted equations. A line was then fit to the actual data points, representing the actual equation for position vs. time and velocity vs. time for the moving cart.

DATA AND RESULTS:

Displacement = **1.0 (+/- 0.01) meter**
Height (starting point) = **0.09 (+/- 0.01) meter**
Time = **2.13 (+/- 0.1) seconds**

Position vs. Time:

Predicted Equation:
$f(t) = 0 + 0t + 0.25\ t^2$ {parabolic function}

*Actual Fit Equation:
$f(t) = 0 + 0t + 0.19\ t^2$ {parabolic function}

*When fitting the graph to the data points, the view was not zoomed in enough to provide the most accurate fit. This is a considerable source of error and could be easily avoided in future labs by simply making the values on the axis smaller.

It can be asserted that the predicted equation was accurate because of the similarity of the value of the 3rd term of the equation, $(0.25)^2$, to that of the actual equation, $(0.19)^2$. The similarity can be best understood by viewing the x-position vs. time graph on the next page.

Velocity vs. Time:

Predicted Equation:
$f(t) = 0 + 5(t)$ {linear function}

Actual Fit Equation:
$f(t) = 0 + 0.45(t)$ {linear function}

The predicted equation was relatively inaccurate compared to the actual fit equation. The predicted equation's slope was much too great and the line did not fit the data adequately. The x-velocity vs. time graph on the next page illustrates how the predicted equation had much too steep of a slope to fit the data points. The graph of this equation can be analyzed to determine if a cart moving down an incline has a constant, increasing, or decreasing acceleration.

ANALYSIS:

As evidenced by the velocity vs. time graph for the car's actual motion down an incline, *the acceleration is indeed constant.* This can be determined because the plot of the data points is linear and relatively straight. It resembles the graph illustrated in the initial prediction for constant acceleration. Using the function representing the velocity versus time graph, the acceleration of the cart as a function of time can be calculated.

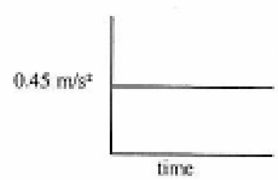
Velocity Function: f(t) = 0.45(t) {m/s}

Using the equation, $x = \frac{1}{2} a (t)^2 + v_0 (t) + x_0$, acceleration can solved for by substituting in values for the displacement (x), time (t), and initial position (x_0) variables.

1.0 m = $\frac{1}{2}$ a $(2.1s)^2 + 0 + 0$
1.0 m = $\frac{1}{2}$ a $(4.4s^2)$
1.0 m = $2.2s^2$ a
a = 0.45 m/s²

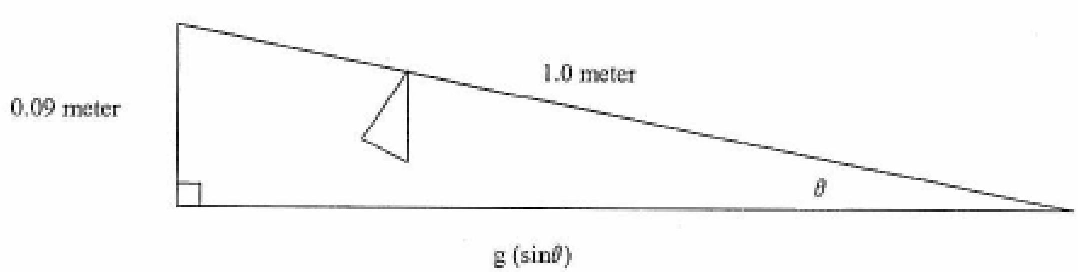
Acceleration Function: f(t) = 0.45 {m/s/s}

This can be graphed as follows:



The average acceleration of the cart is equal to its instantaneous acceleration in this particular case. The acceleration does not change throughout the motion of the car down the incline as shown by the graph above.

The average acceleration of the car using the stopwatch and meter stick measurements is calculated below. This is accomplished by utilizing vector quantities and trigonometric functions.



g = gravity constant = 9.8 m/s²

Using this information and the illustration, the angle θ was determined using the lengths of the opposite and hypotenuse sides in the sine function.

sin (θ) = opposite/hypotenuse
sin (θ) = 0.09 m / 1.0 m
sin (θ) = 0.09
(θ) = $\sin^{-1}$ (0.09)
(θ) = 5.2°

Using the angle measurement for θ and the magnitude of the acceleration for gravity, the acceleration can be determined using another sine function on the interior vectors of the illustration.

sin (θ) = opposite/hypotenuse
sin (5.2°) = x-acceleration / gravity acceleration
sin (5.2°) = x-acc. / 9.8 m/s²
0.09 = x-acc. / 9.8 m/s²
x-acc. = 0.09 x 9.8 m/s²
x-acc. = 0.88 m/s²

This theoretical acceleration value, **0.88m/s²**, is greater than the value derived from the video analysis, **0.45m/s²**. This can be explained by several factors which were omitted in this basic calculation. The first of which is friction, which opposes the acceleration vector of the car down the incline. The second is air resistance, which would also oppose the car's acceleration. These tangible forces were at work during the car's motion and were accounted for in the video analysis. However, in the hypothetical sense in which the theoretical acceleration was calculated, these factors were not taken into account. If these forces were considered, the theoretical value of acceleration would likely be lower, and much closer to the value derived from the video analysis.

There were also several other sources of error in this lab. There were many measurements taken throughout the lab and any of them were subject to human error. The stopwatch may not have been started at the instant the car was released or it may not have been stopped at the exact instant when the car reached the end-point. Also, because the track was marked with white tape, there could be discrepancies up to one centimeter in the measurements based on the position of the tape and how it was perceived during the trial. In addition, the relatively blurry display screen may have contributed to errors in video recording, calibration, and/or data point collection. Not having the green dot on the same exact position of the car during data point collection may also lead to inconsistencies in the results.

Conclusion:

After the various analyses, it can be concluded that a car has constant acceleration as it moves down an inclined ramp. The x-component of the acceleration was the focus of this study. Using vector diagrams, it was asserted that the x-acceleration of the car is indeed a small component of the downward force of gravity. Using video analysis and theoretical calculations, the x-acceleration was determined to be constant. This is supported by the fact that the velocity vs. time graph for the car's motion is a linear, upward sloping line indicating that velocity increased constantly. Therefore, as the definition of acceleration (the change in velocity over time) states, an object that has a constant velocity increase over time is accelerating at a constant rate. This conclusion agrees with the initial predictions set forth. Although there are several sources of error, the result of the investigation proved to be accurate and reliable. The investigation proved to be a useful application of the kinematics principles that have been discussed in both lecture and lab.

Appendix F: Simulation Programs (LabSims)

Note: Up-to-date information on using the LabSims can be found by pressing the "Sim Help" button at the lower left corner of a simulation window.

A LabSim program is a computer simulation of some of the situations you encounter in the lab. Simulations let you do things you can't do in the real world, in order to see what happens in those circumstances. That may sound silly (why would anyone *care* about what happens in an unreal world), but is actually very useful. If your data doesn't match your predictions, a simulation can help you find out what is causing the difference by letting you look at the consequences of different potential causes, and seeing what effects they make in isolation, without getting confused with something else.

The LabSims are meant to let you "explore the experiment", and to see the effects of different physical interactions. For example, suppose you thought your real experiment didn't match your predictions because of air resistance (which is present in the real world, but not in your predictions). A simulation lets you investigate the effects of air resistance by itself, without getting confused with other kinds of friction. Simulations also let you "turn up" air resistance to ridiculous levels, so you can see the form of its effects very clearly. If simulated air resistance <u>does reproduce</u> the problems you see in your data, then it might be the cause; if it <u>fails to reproduce</u> them, you should look elsewhere.

USING THE LABSIMS

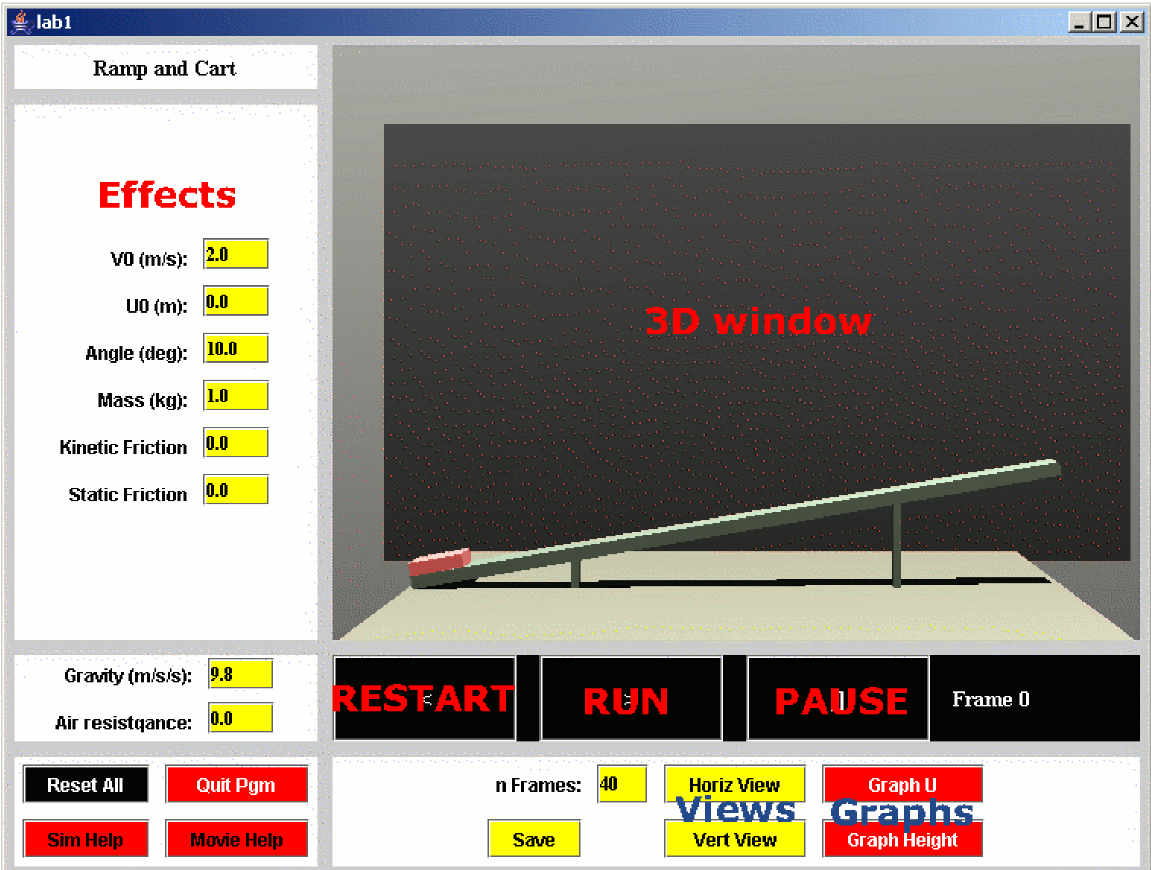
Once you get a LabSim program going, the easiest way to see what it does is to push the *Run* button, which is right under the 3D window (it's the black button with the ">" label). "Run" makes the LabSim go, using the *values in the yellow windows* to the left. You can change the length of a run by changing the *number of frames* (the current frame number is shown to the right of the run button). The "|<" button is a *"Rewind"*, which places all objects in their initial positions. The "||" button is "*Pause*", which stops everything. The buttons are meant to look like those on a DVD player or VCR.

3D NAVIGATION

You can "walk" around in the 3D window by using the *arrow keys* (but first you MUST put the mouse in the 3D window). The arrows move you around rather like in a video game, with which you may have experience. Holding down *ALT* while you push the arrows lets you move up and down or back and forth (gamers call it a "strafe" button) and *CTRL* lets you tip up and down. Experiment with these.

WHEN YOU GET LOST

If you get lost in the 3D space, click the "Horiz View", "Vert View" or "Reset All" buttons. *Horiz View* brings you back to your starting point, *Vert View* puts you over the table looking down, and *Reset All* resets everything to where it was when the program started.



PARAMETERS

The panel to the left of the 3D view has names and values of all the things you can vary in the experiment. For example, in the simulation pictured below you can adjust the cart's initial speed or position, change the ramp angle, change the cart's mass, or create friction,. You *change them by typing in new values*, then see what happens by pushing *Rewind* and then *Run*. If you change so many things you don't know where you are anymore, and you just want to get back to some reasonable defaults, click on "*Reset All*." in the lower left panel.

GRAPHS

A Powerful way to visualize motion using the LabSims is with real time **graphs**. If you *push one of the red graph buttons* at the bottom right, a separate window will pop up. The new window will be rather empty until you do a run in the 3D window, after which it will have graphs of position and speed. The top graph is the position, and the bottom one is speed (which component of position and speed depends on the button). You can change the limits on the graphs, redraw the plot and so on with the *boxes on the left side of the graph window*.

Sometimes a Graph window may appear to lose part of its information. Press the ***Redraw*** button to fix the problem.

Graphs are extremely useful for comparing different runs and checking for differences. Explore this by doing one run, then changing something and doing it again (*click on the new color button* after the first run).

Graphs also let you simulate the effects of **MEASUREMENT UNCERTAINTY**. You can never get perfect data in the laboratory. With the simulations you can see the difference between "perfect" data and what you get with imprecise "position clicks" in VideoTOOL. You may discover that it is worth your time to take VideoTOOL data very carefully.

To see the effect of measurement uncertainty, do a run. Then simulate uncertainty on the graph by pressing the "*Add error*" button in the graph window. This adds randomly distributed errors to the position measurements. Experiment with different measurement uncertainties by changing the "error" parameter in the pink box, or by adding error several times (just press *Add Error* several times). The velocity values are recalculated when you add error to the positions, so you can see what happens to velocity if position measurements are not made precisely.

To compare the effects of measurement uncertainty to other effects (air resistance, for example) go through the process of adding error to a clean run. *Change Color* on the graph, and then do another run with the other effect (air resistance, for example). Now you have two sets of graphs to compare.

MAKING MOVIES

Click the "Movie Help" button in any simulation for up-to-date information on this function.

Possibly the most useful, but currently the slowest, way to use the LabSims is to make a movie with them, and then to analyze the simulation movie in the same way you analyze real video data.

To make a movie, first you should clean out any old frames by clicking the "Cleanup" button on the computer desktop. Then you should play around with the LabSim until you have a run and a camera position you like. Click on the yellow "Save" button, which writes a little file to disk with the positions of the apparatus in every frame. Now click on the "Make Frames for Lab x" button on the desktop, which will start up a program called PoVRay. PoVRay makes high quality movie frames of the experiment (it will take a couple minutes). Finally you can turn the frames into a movie (which will be in c:\labSim\frames\simMovie.avi) by clicking on the "Make movie from frames" button. Then you can read the movie into VideoTOOL and analyze it with that.