TABLE OF CONTENTS

Acknowledgments

Much of the work to develop this problem solving laboratory was supported by the University of Minnesota and the National Science Foundation. We would like to thank all the people who have contributed directly to the development of this laboratory manual:

Heather Brown	Andy Ferstl	Tom Foster
Kaiyan Gao	Charles Henderson	Ted Hodapp
Andrew Kunz	Vince Kuo	Laura McCullough
Michael Myhrom	Jeremy Paschke	Leon Steed
Hao Wang	Paul Barsic	Yaroslav Lutsyshyn
Zhaoliang Pan	Yousi Ma	Rhonald Lua
Tom Thaden-Koch	Yves Adjallah	Matthew Fritts
Tao Hu	Maribel Núñez V.	Ivan Gordeli

And all of the faculty and graduate students who helped to find the 'bugs' in these instructions.

Kenneth & Patricia Heller

WELCOME TO THE PHYSICS LABORATORY!

Physics is the human attempt to explain our world. The success of that attempt is evident in the technology of our society. We are surrounded by the products resulting from the application of that understanding, technological inventions including clocks, medicine, and computers. You have already developed your own physical perception of the world around you. Some of those ideas are consistent with the accepted theories of physics while others are not. This laboratory is designed to focus your attention on your interactions with the world so that you can recognize where your ideas agree with those accepted by physics and where they do not.

You are presented with physics theories in lecture and in your textbook. The laboratory is where you apply those theories to problems in the real world. The laboratory setting is a good one to clarify your ideas through discussions with your classmates. You will also get to clarify these ideas through writing in a report so you can get feedback from your instructor. Each laboratory consists of 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 that the goal is not to make a lot of measurements. The goal is for you to examine your ideas about the real world. For that reason, you can never "finish" a lab. If you correctly complete a laboratory problem and its analysis to the satisfaction of your lab instructor, you will be given another problem to work on. Your goal in the lab is to spend as much time as possible examining your own ideas about physics in light of the ideas of the other members of your class, your instructor, the lectures, and the textbook. This is the time to reinforce your correct ideas by explaining them to others and modify your incorrect ideas by incorporating the ideas of others while focusing on the physics demonstrated by the equipment.

The three components of the course - lecture, discussion section, and laboratory - each serve a different purpose. The laboratory is where physics ideas, often expressed in mathematics, come to grips with the real world. Because different lab sections meet on different days of the week, sometimes you will deal with concepts in the lab before meeting them in lecture. In that case, the lab will serve as a good introduction to the lecture. In other cases, when the lecture about a topic precedes the lab, 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 you have understanding the material or applying your knowledge with your fellow students or the lab instructor.

WHAT TO DO TO BE SUCCESSFUL IN THIS LAB:

Safety always comes first in any laboratory.

If in doubt about any procedure, or if it seems unsafe to you, do not continue. 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. As such, your lab journal is a legal document; consequently you should **never** tear pages from it. For this reason, your lab journal **must** be bound, for example University of Minnesota 2077-S, and **not** of the varieties that allow pages to be easily removed, for example 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, you should carefully read the Introduction, Objectives and Preparation sections. Read the sections of the text specified in the *Preparation* section.

2. Each lab contains several different experimental problems. Before you come to a lab, be sure you have completed the assigned *Prediction* and *Warm-up Questions*. The Warm-up Questions will help you build a prediction for the given problem. It is usually helpful to answer the Warm-up Questions before making the prediction. **These individual predictions and warm-up questions will be checked (graded) by your lab instructor *before* 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 more dull or 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 not be happy if they must consistently carry the burden of someone who isn't doing their share.

C. Laboratory Problem 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 is not to be copied or fabricated. To do so constitutes Scientific Fraud. To make sure no one gets in that habit, such behavior will be treated in the same manner as cheating on a test: **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 semester at a 60% level or better will receive a semester 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. This is a writing intensive (WI) course so clear and logical written communication using correct English and correct physics is the most important goal of the laboratory report.

If you have made a good-faith attempt but your lab report has a few flaws, your instructor may allow you to rewrite those parts of the report. A rewrite must be handed in, 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 interacting 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 more 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 give your best prediction or explanation as you see it. Of course, there is always the possibility that you are wrong. 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.

Trying to convince others about 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 completely 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." Please clean up your area before you leave the lab. The equipment must be either returned to the lab instructor or left neatly at your station, depending on the circumstances. If you leave the lab neater than you found it, everyone will have a more productive experience.

   A note about Laboratory equipment:
   At times equipment in the lab may break or may be found to be broken. If this happens you should inform your TA and report the problem to the equipment specialist using the Problem Report Form found on the desktop. To use the Problem Report Form you will have to login using your University ID and password. Describe the problem, including any identifying aspects of the equipment, and be sure to include your lab room number.

   If equipment appears to be broken in such a way as to cause a danger do not use the equipment and inform your TA immediately.

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. Your instructor will assign you a problem to write up after you have complete all of the assigned problems for a lab.

2. A cover sheet for each problem must be placed on top of each 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 report is always due **within two days of being assigned**.

4. **A problem report must be an organized, coherent display of your thoughts, work, and accomplishments**. It should be written using a 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. A sample report is included in *Appendix E*. Listed below are the major parts of a laboratory report.

MAJOR PARTS OF A LABORATORY REPORT:

COVER SHEET

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

STATEMENT OF THE PROBLEM

State the problem you were trying to solve, and how you went about it. Describe the 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

Give 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 English that is clear enough to allow a reader to repeat your procedure.

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 meaningless.**

CONCLUSIONS

Here you should answer the following questions: What 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? Was your initial prediction based on incorrect physics that you now understand) How do your results compare with the physics presented in your textbook or during lectures? What assumptions did you make in your analysis and were they justified?

SAMPLE COVER SHEET

PHYSICS 1201 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 questions 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.

INTRODUCTORY LABORATORY 0: DETERMINING AN EQUATION FOR A FUNCTION FROM ITS 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 Warm-up 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 QUESTIONS

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
FORCES AND EQUILIBRIUM

In biological systems, most objects of interest are in or almost in equilibrium, either stationary or moving with a constant velocity. This important condition of equilibrium is the result of a balance among all of the different forces interacting with the object of interest. The development of problem solving skills to analyze forces under these situations is an important first step to understanding the interactions between the objects that make up any biological system.

OBJECTIVES:

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

- Determine the conditions under which an object is in equilibrium.
- Determine the interrelationships among forces that result in the equilibrium of an object or system of objects.

PREPARATION:

Read Serway & Jewett: Chapter 1 (sections 1-10), chapter 4 (sections 1, 2, 5- 7), the paragraph at equation 6-13, chapter 10 (sections 5 and 6), and chapter 15 (section 4). It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. So, it is very important that you read the text before coming to lab.

Before coming to lab you should be able to:

- Identify the forces acting on an object.
- Write down the conditions satisfied by the forces acting on an object or a system of objects in equilibrium.
- Depict forces as vectors and break these vectors into components.
- Define the concept of torque and incorporate this concept into conditions satisfied by objects in equilibrium.
- Write down the relationship between the force exerted by a spring and its elongation.

PROBLEM #1:
SPRINGS AND EQUILIBRIUM I

These laboratory instructions may be unlike any you have seen before. You will not find worksheets or step-by-step instructions. Instead, each laboratory consists of a set of problems that you solve **before coming to the laboratory** by making an organized set of decisions (problem solving) based on your initial knowledge. The instructions 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 unless you take time to predict what will happen and know your reasons for that prediction before you do something. In particular, **before you come to the laboratory** it is important to do your best to answer the **Prediction** and **Warm-up Questions**. This will help tell you, the other members of your group, and your TA where you need to learn something.

While in the laboratory, work as rapidly as possible but take your time to explore both the behavior of the equipment and your own ideas. It is important to get a "feel" for how the lab equipment operates. This will help you develop the intuition about the physical world that is necessary to effectively solve problems. It is very important to use the equipment to answer the qualitative **Exploration** questions before you begin making measurements. Complete the entire laboratory problem, including all **Analysis** and **Conclusions**, before moving on to the next one. *Remember, there is no benefit in just doing the measurements for a lab problem. The benefit lies in examining your ideas and comparing them with how things behave in the real world. This is why the labs are a key to doing well in the entire course. If you don't see how the labs are connected to the material in the textbook, the lectures, the homework, or the exams, you are missing the point. Get help immediately***.**

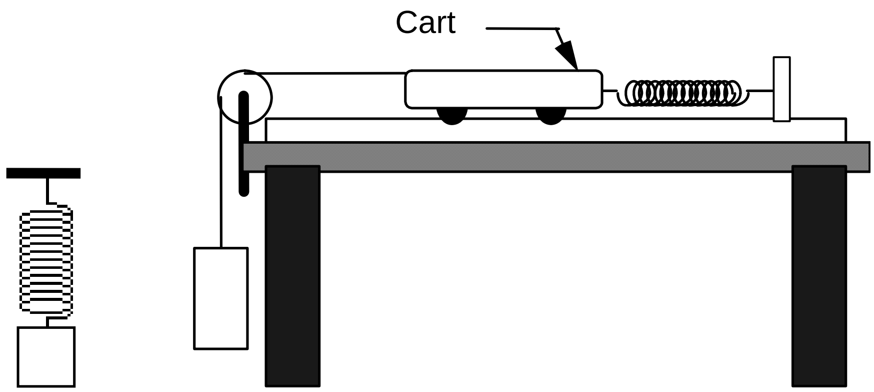
To help you become familiar with how to use the laboratory manual, this first problem contains both the instructions and an explanation of the various parts of the instructions. The explanation of the instructions is preceded by the double, vertical lines you see to the left of this paragraph. **Part of the design of these instructions is to make the laboratory problems easy to do if you understand what you are doing and very difficult to do if you do not**. If the laboratory manual is not clear to you then it is likely you do not understand some very important basic physics. That is your signal to learn what you need by reading the textbook (outside of lab), discussing your difficulties with your fellow students, and asking a TA or professor. If you ask your TA a question, it is likely that he or she will ask you questions in return to determine how you are thinking about the physics. Everyone has unique sets of experiences, learning styles, and ways of thinking. Your TA will try to help you develop yours. *Learning is not easy and no one can do it for you by just telling you the answer.*

The laboratory problem should allow you to answer the following questions that are important for meaningful learning. What is the point of doing this lab problem? How is it related to the real world? In the lab instructions, the first paragraphs describe a possible situation that raises the problem you are about to solve. This emphasizes the application of physics to situations that you might encounter.

You work for a biophysics research group studying the mechanics of DNA during cell division. One common technique involves securing one end of a DNA molecule to a surface and, with optical tweezers, measuring the force required to slightly straighten the DNA molecule from its normal coiled state. The optical tweezers exert a force on a tiny bead which has been attached to the free end of the DNA molecule. The group is concerned that the bead's mass could affect the DNA's response to the pulling force. The DNA molecules are expected to behave much like mechanical springs in this situation, so you decide to use a spring as a macroscopic model of DNA. You decide to calculate, and then measure, how much a spring stretches when it is subjected to external forces in two situations, which correspond to pulling on the DNA with and without a bead. In each situation, a force is exerted by a hanging object whose mass can be changed. In the first situation the object will hang directly from the spring, which will be suspended from a table. In the second situation the object will hang from a light string, which runs over a pulley and is attached to a medium-sized cart on a horizontal track. One end of the spring will be attached to the cart and the other end to an end-stop, itself attached to the track.

EQUIPMENT

To make a prediction about what you expect to happen, you need to have a general understanding of the apparatus you will use before you begin. This section contains a **brief** description of the apparatus and the kind of measurements you can make to solve the laboratory problem. The details should become clear to you as you use the equipment.



You will have a spring, a mass hanger and set of masses, a PASCO cart, cart weights, an aluminum track, an end-stop, a piece of string, and a meter stick.

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 purpose of the "Warm-up Questions" is to help you decide how to apply some important knowledge to build a prediction. If you cannot initially complete the prediction or are not sure if it is correct, the "Warm-up Questions" are designed to help. They should also be completed before you come to lab. **Try to answer the Prediction question first using your best understanding of the text reading. This first attempt tells you about your initial level of understanding of the material. Next answer the Warm-up Questions. These questions focus on some of the knowledge involved in making a correct prediction. After answering the Warm-up Questions, answer the Prediction question again. If you have changed your answer, determine what knowledge resulted in that change. If you cannot answer a Warm-up Question to your satisfaction, get help on that point from the textbook, lecture notes, fellow students, TAs, or the professor before going to lab.**

You will spend the first few minutes at the beginning of the lab session comparing your Prediction with those of your partners. Discuss the reasons for any differences in opinion. If you disagree, compare the answers to your Warm-up Questions. This might help pinpoint the difficulty. It is not necessary that your predictions are correct, but **it is necessary that you understand the basis of your prediction**. Your predictions represent your best determination of your own knowledge at the beginning of each lab session.

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. This equation will be a relationship between the extension of a spring (the distance it stretches) and the force exerted by an object to stretch the spring, in each situation described in the problem (when the system has reached equilibrium). Illustrate each relationship with a graph of the hanging object's *spring extension vs. weight*.

In this case, the prediction asks for a quantitative mathematical relationship. Occasionally, your prediction is a qualitative statement, drawing, or graph based on your current knowledge of the physical world. Even if no calculation is involved you still must carefully apply your knowledge and experience using systematic logical reasoning. For other problems, you will be asked to build on this knowledge of the concepts and principles of physics to calculate a mathematical relationship between quantities in the experimental problem. Always write down a logical procedure that goes from basic physics principles to your solution equation. Also make sure to write down any assumptions you need to make.

WARM-UP QUESTIONS

Warm-up Questions are intended to help you solve the experimental problem. They either help you make the prediction or help you plan how to analyze data. **The answers to the Warm-up Questions should be written in your lab journal and turned in *before* you come to lab.** If you completely understand the physics of these labs, you should find these questions simple and sometimes thought provoking. If you do not, they may appear incomprehensible. *If you get stuck or are not sure of an answer, get help. When you have finished the laboratory, **go back through the Warm-up Questions to see if they make more sense to you**. If not, get help.*

Read Serway & Jewett, sections 4.4 - 4.7 (through Quick Quiz 4.9), and the paragraph at equation 6-13 before attempting to answer these questions.

1. Draw a picture of a spring attached to a hanging object. On your picture, show and label the extension (distance stretched) of the spring.
2. Draw and label all the forces acting on the hanging object.
3. What condition must be satisfied by the forces acting on an object in equilibrium? Write the equation to express that for the hanging object. How do you know the object is in equilibrium?
4. Write an equation that relates the spring's stretch to the force it exerts. How does the force exerted by the spring on the hanging object relate to the force exerted by the hanging object on the spring? Use this equation and the result of the previous step to write down the relationship between the extension of the spring and the force exerted on the spring by the weight of the hanging object. Sketch a graph of *spring extension vs. weight*.
5. Draw a picture of a horizontal spring with one end connected to a cart and the other to a string which is in turn connected to a hanging object, as illustrated in the Equipment section. Identify all the forces acting on the hanging object; indicate them on the picture as vectors and label them. Repeat for the forces acting on the cart. What do you assume about the size of the force exerted by the string on the cart and the string on the hanging object? How do you justify this assumption?
6. Write an equation to express the equilibrium condition for the forces acting on (a) the hanging object and another equation for (b) the cart. Use these equations, together with the equation that gives the relationship between a spring's extension and the force it exerts, to write an equation for the relationship between the extension of the spring and the weight of the hanging object in the second situation. Sketch a graph of *spring extension vs. weight.* Is this graph the same, or different from the graph you drew in question 4?

EXPLORATION

This section is extremely important—many instructions will not make sense, or you may be led astray, if you do not take the time to carefully explore that your equipment actually works and to devise a plan for taking data before you actually take data.

In this section you practice with the equipment before you make time-consuming measurements that may not be valid. This is where you carefully observe the behavior of your physical system to see if it qualitatively matches your expectations. Remember to treat the equipment with **care and respect**. Your fellow students in the next lab section need to use the equipment after you are finished with it. If you are unsure about how anything works, ask your lab instructor.

Most equipment has a range in which its operation is simple and straightforward. This is its range of reliability. You can quickly determine the range of reliability by making **qualitative** observations at what you consider to be the extreme ranges of your measurements. Record your observations in your lab journal. If you observe that the equipment does not function as you expect for the range of quantities you were considering measuring, modify your experimental plan before you waste time taking an invalid set of measurements.

The result of the exploration should be a plan for doing the measurements that you need. **Record your measurement plan in your journal.**

Select spring(s) and a series of weights that give a usable range of displacements. The largest weight should not pull a spring past its elastic limit (about 60 cm for the large springs). Beyond that point the spring does not return to its original unstretched length is permanently damaged. Decide on a procedure to measure the extension of the spring in a consistent manner, and describe in your lab notebook why it is a reasonable procedure. Decide on how many measurements using different masses you will need to test your prediction.

MEASUREMENT

Now that you have predicted the result of your measurement and have explored how your equipment 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.

When the spring is vertical, make a series of measurements of the mass of the hanging object and the extension in the spring in a stationary state. Repeat for the case in which the spring is horizontal and connected to a cart. To see the effect of the cart's mass, make additional measurements with mass added to the cart. As a check, make measurements with the cart removed so the string that goes over the pulley is connected directly to one end of the horizontal spring.

Estimate the uncertainty in measuring the extensions. How does friction in the pulley and in the cart affect your measurement? Is it significant?

ANALYSIS

Data alone is of very limited use. Most interesting quantities are those *inferred* from the data, not direct measurements themselves. The Analysis is where you extract the essence of your data from the measurements. This analysis may be qualitative or quantitative. The analysis also includes your evaluation of the limitations of doing the best possible measurement with the equipment you have. (For example, can you tell if two measurements are really different quantities even if you measure different numbers for them?)

Always complete your analysis before you take your next set of data. If something is going wrong, this will prevent you from wasting time taking useless data. After analyzing the first collection of data, you may need to modify your measurement plan and re-do the measurements. If you do, be sure to **record how you changed your plan in your journal**.

From your measured values of the hanging object's mass, calculate its weight. Use a spreadsheet program (such as Excel on the computer at your lab workstation) to make a graph of the extension of the spring against the weight of the hanging object for the first situation (hanging mass only). Similarly, make a graph of the spring extension versus the weight of the hanging object for the situation with the cart, string, pulley, and hanging mass. Examine the shape of the graphs. If the points in a graph seem to fall on a line, estimate the slope of that line, with appropriate units. From your predicted equation, explain the physical significance of the slope. What is the slope if you reverse the axes and plot a graph of *weight vs spring extension*? Why don't all of the data points fall exactly on your line?

CONCLUSION

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.**

What can you say, based on your measurements, about the relationship between the extension of the spring and the weight of the hanging object each case? Compare the relationships for the two cases. Was the slope of your graphs the same for the situation without the cart and the situation with the cart? Did you find that the stretch of a horizontal spring is the same as a vertical spring? How did the mass of the cart affect the extension of the spring? Did your prediction agree with your measurements within the uncertainties of your measurement? If not, why?

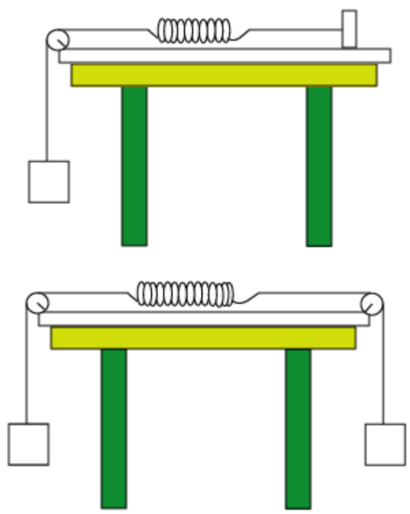
Was there a "minimum" force required to stretch your spring beyond its unstretched length? If so, write a brief justification for how you dealt with that in your measurements and analysis.

What conclusions can you draw about the corrections you will have to make for the bead's mass on the DNA measurement described in the original problem?

PROBLEM #2:
SPRINGS AND EQUILIBRIUM II

You are a cellular biologist investigating treatments for genetic diseases weakening the fibrous connective tissue that forms tendons. The cells act something like little springs, and to test their strength you are designing an experiment in which individual cells are attached to a fixed surface while a force is applied to the other end. By measuring how much the cell stretches in response to a force of a certain size you can get a measure of its elastic strength. You worry that your experiment is different what happens in the body, where a cell experiences forces exerted by neighboring cells at each end. You need to decide if a cell pulled at one end would stretch only half as much as one pulled at both ends, if all the pulling forces are equal. For that reason, you model the two possibilities using a spring in place of the cell and hanging objects to exert the pulling forces.

EQUIPMENT



You will have a spring, two mass hangers and masses, an aluminum track, two pulleys, an end-stop, string, and a meter stick.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.   What will you compare in the two situations?

WARM-UP QUESTIONS

Read Serway & Jewett, sections 4.4 - 4.7 (through Quick Quiz 4.9), and the paragraph at equation 6-13 before answering these questions.

1. Draw a picture of a spring attached to a hanging object by a string over a pulley on one end and an end stop on the other. On your picture, show and label the extension of the spring.
2. Draw and label all the forces acting on the hanging object, the spring, and the string.
3. What condition must be satisfied by the forces acting on an object in equilibrium? Write the equation to express that condition for the hanging object, another equation for the spring, and a third equation for the string.
4. Use Newton's third law to identify pairs of forces, ACTING ON DIFFERENT OBJECTS, that must have equal magnitudes.
5. Write an equation that relates the extension of a spring to the force it exerts. Use this equation and the result of the previous steps to write down the relationship between the extension of the spring and the weight of the hanging object. Sketch a graph of *spring extension vs. weight*.
6. Draw a picture of a spring connected over pulleys to two hanging objects of equal weight, as in the second illustration in the Equipment section. Repeat the above steps, this time for *both* hanging objects and strings. Write a relationship between the extension of the spring and the weight of **one** of the hanging objects in this situation, and briefly describe your reasoning. Sketch a graph of *spring extension vs. weight* for this situation. How is the displacement of each hanging mass related to the spring extension?

EXPLORATION

Select springs and a series of weights that give a usable range of displacements. The largest weight should not pull a spring past its elastic limit (about 60 cm for the large springs). Beyond that point the spring will be permanently damaged. Decide on a procedure to measure the extension of the spring in a consistent manner. Decide how many measurements using different masses and corresponding extensions you need to test your prediction. Decide how many different masses you should use in order to make a reasonable graph of the extension of the spring versus weight of the hanging object.

MEASUREMENT

For the two cases, make measurements of the weights of the hanging object(s) and the extension in the spring.

Estimate the uncertainty in measuring the spring extension. How significant is friction in the pulley?

ANALYSIS

For each case, make a graph of the extension of the spring against the weight of the hanging object. Examine the shape of each graph. If the points seem to follow a line, estimate the slope of the line. Clearly indicate the units of this slope. How is this slope related to an important property of a spring? Compare the slope for the different cases.

CONCLUSION

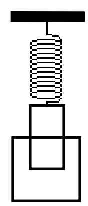
By how much does the spring in the first case stretch compared to the spring in the second case with equal weight hanging objects? Did your measurements agree with your predictions? If the measurement disagreed with your prediction, re-examine the steps that led to your prediction as well as to the analysis of your data.

How many forces acted on the spring in the first case; how many in the second case? How much a cell will stretch if only one force is acting on it?

PROBLEM #3:
FORCES AND LIQUIDS

While working with a sports medicine group, you are investigating the use of swimming pools for physical therapy. Being underwater gives a sense of "reduced weight", which can be useful for injured athletes who exercise in the pool as part of their rehabilitation. You know that the gravitational force on a person doesn't change as you stay on the surface of the earth, so the sense of reduced weight must result from a force exerted by the water. One of your co-workers believes that this force depends on the amount of a person's mass that is submerged while another claims that only the person's submerged volume is important. This is important because you need to know if the effect is the same for different people. To resolve this dispute, you calculate the size of this force as a function of the amount of the person's body that is underwater. Your next step is to test your calculation in the laboratory. You decide to use a small object hanging on a spring and measure the extension of the spring when different fractions of the object are submerged in water. To see if the effect is due to volume or mass, you repeat the measurements using a second object of the same size but different mass.

EQUIPMENT



You will have a container of water and several cylinders that are the same size but different masses. You will also have a spring, string, meter sticks, calipers, a triple-beam balance, and a stand.

PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. This equation will be a relationship between the force of the water on the object, the spring's equilibrium extension, and the object's weight. Write another relationship that shows how that force depends on the submerged volume of the object.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 4.4 - 4.7 (through Quick Quiz 4.9), the paragraph at equation 6-13, and 15.4.

1. Draw a picture of the object hanging on a spring with no water involved. Indicate all the forces acting on the object. Write down the condition satisfied by the forces acting on the object. Write a relationship between the weight of the object and the extension of the spring in equilibrium.
2. Draw a picture of the object hanging on a spring, with a portion of the object submerged in water. Label all the forces acting on the object.
3. Calculate the force exerted by the water on the partially submerged object. To do so, it may help to imagine replacing the underwater volume of the object with water at equilibrium. What force must the rest of the water exert on this volume of water to maintain equilibrium? How is that related to the force exerted by the water on the submerged object?
4. Write down the conditions satisfied by the forces acting on the object immersed in water. What is the relationship between (a) the volume of the submerged portion of the object and (b) the extension of the spring?

EXPLORATION

Select a spring and a series of objects that give a usable range of displacements. The largest mass should not pull a spring past its elastic limit (about 60cm for the large springs). Beyond that point the spring is damaged permanently. Decide on a procedure to measure the extension of the spring in a consistent manner.

Decide on a procedure to change the submerged volume of the object in a measurable way. Decide on how many measurements using different masses and submerged volumes you will need to test your prediction. Decide how you will measure the spring constant for the spring that you use.

MEASUREMENT

Determine the spring's spring constant by taking new measurements or using the value you found in a previous lab problem with the same spring.

Make measurements of the masses of the object, the volume of the submerged portion, and the induced extension in the spring. Repeat for enough volumes (and masses) to convince others of your results.

ANALYSIS

Graph the extension of the spring versus the mass of hanging object with no water involved. For each object, graph the extension of the spring versus volume submerged. Repeat for the extension of the spring versus the submerged mass. If the graphs resemble lines, estimate their slopes and determine their physical significance, using your prediction equation as a guide. Be sure to estimate uncertainty.

CONCLUSION

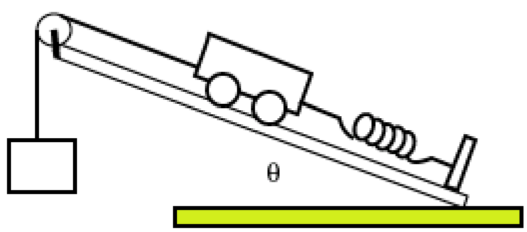
What do your measurements reveal about the relationship between volume submerged and the extension of the spring? Do your measurements agree with your predictions?

How is the stretch of the spring related to an athlete's "perceived weight"? If you wished to reduce an athlete's "perceived weight" by a particular amount, what would you need to know in order to determine the appropriate depth of the pool for that person? Explain.

PROBLEM #4:
LEG ELEVATOR

You are a consultant to a medical technology company evaluating an inexpensive traction system for exerting a predictable force at the location of a patient's leg injury. The device consists of a foot-strap connected to a weight by a rope that goes over a pulley. You are worried that the force exerted on the injury will change when the angle of the leg changes. As a first step in understanding the situation, you decide to model the portion of the patient's leg below the injury with a cart on an inclined track. You attach the cart to the bottom of the track with a spring so you can determine the force on the cart. The traction device is simply a string attached to the cart which goes over a pulley at the end of the track where it is attached to an object hanging straight down. You have been asked to calculate the force that the spring exerts and to predict how it will depend on the angle of the track. You will then test your calculation in the lab, by building the model.

EQUIPMENT



You will have a mass hanger and masses, a cart and cart masses, string, springs, an end stop, a cart track, blocks for varying the track angle, and a meter stick.

PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant?

WARM-UP QUESTIONS

Read Serway & Jewett, 1.7, 1.10, 4.4 - 4.7 (through Quick Quiz 4.9), the paragraph at equation 6-13

1. Draw a picture of the cart, spring, hanging weight and inclined track arranged as in the figure. Draw a convenient coordinate system to serve as a reference for the orientation of forces.
2. Draw and label the forces acting on the cart. Draw and label the forces acting on the hanging object (counterweight). How does the force exerted on the string by the hanging object relate to the force exerted on the cart by the string?

3. Draw a free-body diagram of the cart. Check to see that it is possible that the cart is in equilibrium. Transfer the force vectors to a coordinate system so that you can easily find the components of the forces.
4. Write down the equations that give the condition of equilibrium of the cart and the counterweight. Remember to write a separate equation for force components along each axis of your coordinate system.
5. Calculate the magnitude of the force exerted by the spring on the cart, as a function of the mass of the hanging object, the mass of the cart, and the angle of the track. For data analysis, it will be useful to calculate the amount the spring stretches, rather than the force exerted on the spring, so write an equation for the spring stretch as well.
6. Sketch a graph of *spring stretch vs. track angle*, for constant masses. Does the stretch ever equal zero? If so, under what conditions?

EXPLORATION

Select a spring and a series of weights that give a usable range of displacements. The largest weight should not pull a spring past its elastic limit (about 60cm for the large springs). Beyond that point the spring will be permanently damaged. Check the effect of removing the cart and connecting the spring directly to the hanging object via the string.

Decide which quantities you should change to test your prediction, and make a plan to change them systematically, so that you can observe the effect of changing one while the others remain constant.

Decide on a procedure to measure the extension of the spring in a consistent manner. Decide on a procedure to measure the angle or slope of the inclined track. Decide on how many measurements using different inclinations or masses you will need to test your prediction.

Decide how you will measure the spring constant.

MEASUREMENT

Make measurements of the equilibrium extension in the spring when the slope or angle of the incline is varied. Measure the effects of adding weight to the cart and to the hanging object. Don't forget to measure your spring constant.

ANALYSIS

Graph the measured extension of the spring versus the angle of the incline. On the same graph, plot the predicted relationship for the same cart and hanging object. Repeat this for the extension vs. other quantities that you systematically changed.

CONCLUSION

How does the extension of the spring vary with the angle of the track? How does the extension of the spring vary with the mass of the cart? How does the extension of the spring vary with the mass of the hanging object? How well did your prediction agree with your measurements?

In which case will a change in the leg's elevation have a greater effect on the force exerted on a patient's injury site by this device – when the injury is very near the foot, or when the injury is near the hip? In which case will the mass of the patient's leg be most important? Explain, in terms of physics and the analysis of your experiment.

PROBLEM #5:
EQUILIBRIUM ON A WALKWAY

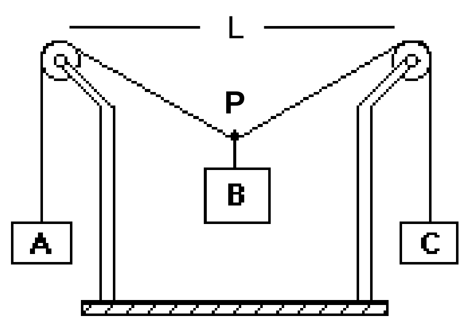
You have job with a research group studying the ecology of a rain forest in South America. To avoid walking on the delicate rain forest floor, the team members walk along a rope walkway that the local inhabitants have strung from tree to tree through the forest canopy. Your supervisor is concerned about the maximum amount of equipment each team member may 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. You need to determine how the sag of the walkway is related to the mass of a team member plus equipment when they are at the center of the walkway between two trees. You know the distance between the two trees. To check your calculation, you decide to model the situation in the lab using the equipment shown below.

EQUIPMENT

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

For this investigation, you will need a meter stick, two pulley clamps, three mass hangers, string, and a mass set to vary the mass of objects.



PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant? Illustrate your calculation by graphing *distance sagged vs. the mass of the central object*, assuming other quantities remain constant.

WARM-UP QUESTIONS

Read Serway & Jewett, 1.7, 1.10, 4.5-4.7(through Quick Quiz 4.9), and the paragraph at equation 6-13.

1. Draw a free-body diagram of forces acting on object B. Do the same for objects A, C and point P. Point P may be treated as an object of zero mass.
2. Establish a coordinate system that you will use to break the forces into their components. Draw the forces on that coordinate system for object B.
3. From your force diagrams, write down the equations that describe the conditions for equilibrium of each object. Remember the components of vectors along each coordinate axis have their own equation.
4. How are the angles used in getting your force components related to the distance of sag which you want to find out and the distance between the pulleys which you know?
5. Check that the expression you obtained is reasonable by determining the largest possible value for the mass of object B. What happens if this mass is greater than or equal to that value?

EXPLORATION

Start with the string suspended between the pulleys (no central object), so that the string looks horizontal. Attach a central object and observe how the string sags. Decide how you will measure the vertical position of the object.

Try changing the mass of objects A and C (keep them equal for the measurements, but *explore* the case where they are not equal).

Do the pulleys behave in a frictionless way for the entire range of mass that you will use? How can you determine if the assumption of frictionless pulleys is a good one?

Add mass to the central object to decide what increments of mass will give a good range of values for the measurement. Decide how many measurements you will need to make.

MEASUREMENT

Measure the vertical position of the central object as you increase its mass. Record the uncertainty for each measurement. Determine what happens when object B is has its maximum mass.

ANALYSIS

Make a graph of the vertical displacement of the central object as a function of its mass, based on your measurements. On the same graph, plot the predicted relationship.

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

CONCLUSION

What will you report to your supervisor? How does the vertical displacement of an object suspended on a string between two pulleys depend on the mass of that object? Did your measurements of the vertical displacement of object B agree with your initial predictions? Explain any discrepancies. State your result in the most general terms supported by your analysis.

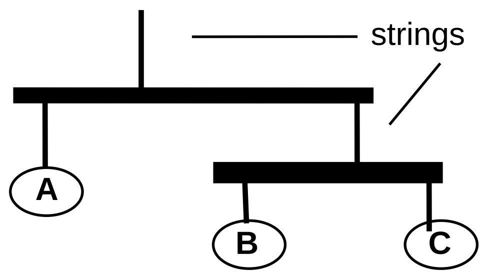
What information would you need to apply your calculation to the walkway through the rain forest?

PROBLEM #6:
DESIGNING A MOBILE

While volunteering at a hospital you are asked to design a mobile for the hospital nursery. Your design includes 5 pieces of string, two identical rods, and three objects with unknown masses. The first rod hangs from the ceiling. One object hangs from a string attached to one end of the rod; the second rod hangs from a string attached to its other end. An object hangs from a string at each end of the second rod. Your instructions are to balance the rods, but selecting the three objects is up to you. You know that the pivot point from which each rod hangs will depend on the hanging objects, and decide to prepare yourself for anything by writing an equation that relates the position of the pivot points to the masses of the rods, the length of the rods, and the masses of the three objects.

EQUIPMENT

You will have two wooden rods, some string, and three objects (A, B, and C) of different masses. Your mobile should use all these parts.



One metal rod and one table clamp will be used to hang the mobile. You will also have three mass hangers and one mass set.

PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant?

WARM-UP QUESTIONS

Read Serway & Jewett sections 10.5 and 10.6

1. Draw a mobile similar to the one in the Equipment section. Establish your coordinate system. Identify and label the masses and lengths relevant to this problem. Draw and label all the relevant forces.
2. Draw a 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. Choose the axis of rotation for each rod (your pivot point). Identify any torques on each rod.

3. What is the net torque on an object when it is in equilibrium? What is the sum of the forces acting on an object when it is in equilibrium? For each free-body diagram, write down the conditions for equilibrium in terms of the specific quantities you have defined.

4. Identify the target quantities you wish to determine. Use the equations collected in step 3 to plan a solution for the target. If there are more unknowns than equations, reexamine the previous steps to see if there is additional information about the situation that can be expressed in an additional 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 position of the center of mass of each rod.

Will the length of the strings for the hanging objects affect the balance of the mobile? Test and explain the result. Where will you put the heaviest object? The lightest?

Decide what measurements are needed to check your prediction. If any assumptions are used in your calculations, decide on the additional measurements needed to justify them. Outline your measurement plan.

MEASUREMENT

Measure and record the location of the center of mass of each rod. Also, measure and record the mass of each rod and the mass of the three hanging objects. Use your prediction to assemble the mobile, and adjust if necessary so the mobile balances. Measure (with uncertainties) the locations of the strings holding up the rods.

Is there another configuration of the three objects that also results in a stable mobile?

ANALYSIS

Calculate the differences between your measured results and the predictions. Are those differences probably due to measurement uncertainty, or are they due to some systematic error?

CONCLUSION

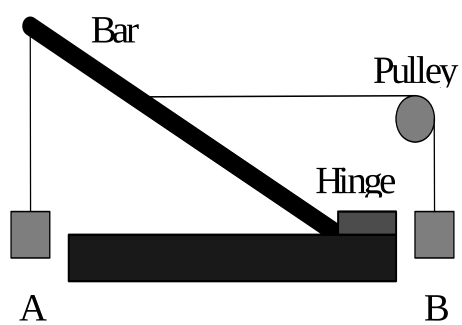
Did your mobile balance as designed? What corrections did you make to get it to balance? Were these corrections a result of measurement uncertainty, or was there a difficulty with your prediction or your measurement plan? Explain why the lengths of the strings were or were not important to the mobile design. Did your prediction work for just one design, for more than one design, or for zero designs?

PROBLEM #7:
MECHANICAL ARM

You have been hired as part of a team to design a mechanical arm as a model for future prosthetics. To begin the project you evaluate several simple designs that test specific features needed in the final device. The first is designed for lifting small objects. The arm is a steel bar of uniform thickness with one end attached to the base by a hinge (elbow) that allows it to rotate in the vertical plane. Near the other end of the arm is a cable that supports a small weight. The arm is supported at an angle to the horizontal by another cable, intended to mimic a bicep muscle. One end of the support cable is attached to the arm and the other end goes over a pulley. That other end is attached to a counterweight that hangs straight down. The pulley is supported by a mechanism that adjusts its height so the support cable is always horizontal. Your task is to determine how the angle of the arm to the horizontal changes as a function of the weight of the object being lifted. The mass of the arm, the mass of the counterweight, the attachment point of the support cable and the attachment point of the lifting cable have all been specified for your model. You will test your calculations in the laboratory, with the equipment shown below.

EQUIPMENT

You will have an aluminum bar, a pulley, a pulley clamp, two mass hangers, a mass set, and some strings.



PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. What quantities must you calculate? What quantities will you measure? Which ones might you adjust in the lab? What quantities will remain constant? Illustrate your calculation with a graph.

WARM-UP QUESTIONS

Read Serway & Jewett sections 10.5 and 10.6

1. Draw an arm similar to the one in the Equipment section. Establish your coordinate system. Identify and label the masses and lengths relevant to this problem. Draw and label all the relevant forces.

2. Draw a free-body diagram for the bar showing the location of the forces acting on it. Label these forces. Choose the axis of rotation. Identify any torques on the rod.

3. Write down the conditions for equilibrium (rotational and translational) using specific variables you have defined.

4. Identify the target quantities you wish to determine. Use the equations collected in step 3 to plan a solution to obtaining the target(s). If there are more unknowns than equations, reexamine the previous steps to see if there is additional information about the situation that can be expressed in an additional equation. If not, see if one of the unknowns will cancel out.

5. Use your equation to sketch a graph of the arm angle vs. the weight being lifted assuming all other quantities are constant. Is this what you expect? (If you add more weight to be lifted by the arm, do you need to increase or decrease the angle to maintain equilibrium?)

EXPLORATION

Build your device. Pay attention to the adjustments that make it stable or unstable. Decide on the easiest way to determine where the center of mass is located on the bar. How will you measure the angle?

Determine where to attach the lifting cable and the support cable so that the arm is in equilibrium for the weights you want to hang. Try several possibilities. If the bar tends to lean to one side or the other, try putting a vertical rod near the end of the bar to keep it from moving in that direction. If you do this, what effect will this vertical rod have on your calculations?

Does the length of the strings for the hanging weights affect the balance of the bar? Why or why not? Outline your measurement plan.

MEASUREMENT

Make all necessary measurements of the configuration when it is in equilibrium. Vary the mass of object A and determine the angle of the bar when the system is in equilibrium. Remember to adjust the height of the pulley to keep the support string that hangs object B horizontal for each case. Is there another configuration of the three objects that also results in a stable configuration?

ANALYSIS

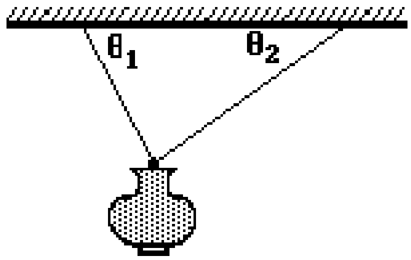
Make a graph of the bar's angle as a function of the weight of object A. What happens to that graph if you change the mass of object B? The position of the attachment of the support cable to the bar?

CONCLUSION

Did your arm balance as designed? What corrections did you need to make to get it to balance? Were these corrections a result of some measurement error, or was there a mistake in your prediction? Explain why the string lengths were (or were not) important for this experiment.

☑ CHECK YOUR UNDERSTANDING

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



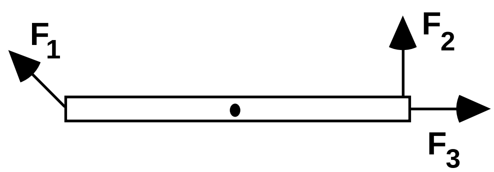
a. Draw the force diagram of the *lamp*. Clearly describe each force drawn.

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.

2. 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 1201 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 questions 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 II
FORCE AND CONSERVATION OF ENERGY

After studying forces and material bodies in equilibrium, it is natural to examine how forces may affect bodies when they move. We will also explore the relationship between forces and energy conservation. Energy and forces, together, support an extremely versatile and powerful set of tools for solving physics problems.

OBJECTIVES:

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

- Use the concept of energy to solve problems.
- Make quantitative predictions about the relationship of forces on objects and the motion of those objects and test these predictions for real systems.

PREPARATION:

Read Serway & Jewett chapter 2 (sections 1-3), and chapter 6. It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. It is very important that you read the text before coming to lab.

Before coming to lab you should be able to:

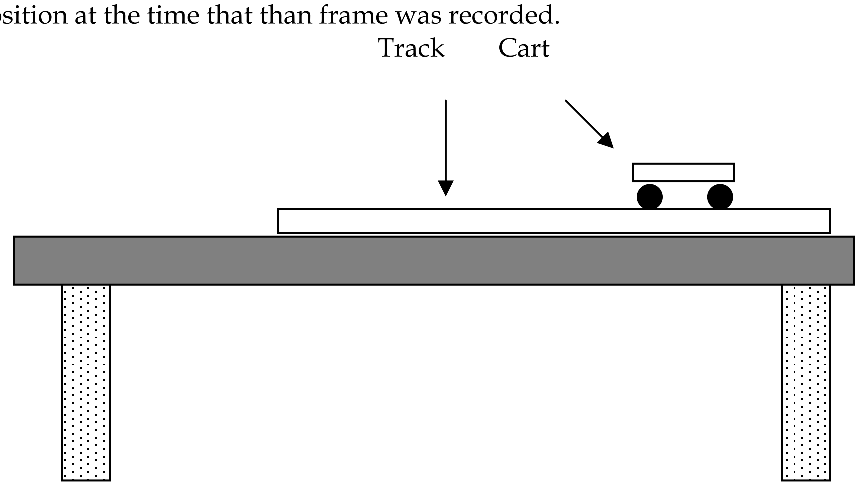
- State the principle of conservation of energy; state the relationship between the work done on an object and its kinetic energy.
- Define and use sine, cosine and tangent for a right triangle.
- Recognize the difference between mass and weight.
- Define, use, and know the difference between average velocity and velocity.
- Draw and use force diagrams.
- Write down the empirical force law for a frictional force.

PROBLEM #1:
CONSTANT VELOCITY MOTION

You are working in a research lab that uses gel phase electrophoresis for separating protein molecules by mass. In this process the molecules move slowly across the substrate. You have been asked to measure their velocity. One technique to get the velocity is to measure the time the protein takes to travel a measured distance. To determine if this is valid, you decide to videotape the protein motion and analyze the video. You will then compare the video analysis to the distance and time measurement. To develop your technique, you decide to practice using a cart as the moving object. You decide to give the cart a push so that it moves down a horizontal track and make a video of its motion. You then compare your video analysis for velocity to a distance and time measurement using a stopwatch and a meter stick. Your video analysis can generate position-vs.-time from them velocity-vs.-time graphs. Before you do your first video you predict the result by sketching a graph of what you think the position-vs-time graph will be for the cart and then use that graph to make a velocity-vs-time graph. Show how your graphical results would compare to a velocity calculated by using the total distance and total time from the first graph.

EQUIPMENT

For this problem, you will use a PASCO cart and 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*). Each frame of the video shows you the object's position at the time that than frame was recorded.



PREDICTION

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

What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

To make your prediction, 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 and Jewett Chapter 2 sections 1, 2, and 3

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? How does each quantity in your equation show up on your graph?
2. How would you expect a *position vs. time* graph to look for an object moving with constant velocity? Make a rough sketch and explain your reasoning. What is the relationship between this graph and the instantaneous velocity versus time graph? Write down an equation that describes this graph. What is the meaning of each quantity in your equation? How does each quantity in your equation show up on your graph? In terms of the quantities in your equation, what is the velocity?
3. Repeat the first two steps if the cart is slowing down slightly as it moves down the track.
4. Repeat the first two steps if the cart is speeding up slightly as it moves down the track.
5. Use the simulation "Lab1Sim" to model constant velocity motion of the protein molecule or the cart you will be using instead of the molecule. You will need to experiment with the settings to find conditions that will produce a 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. You should note that the graphs aren't labeled. 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

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

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

Do you need to focus the camera to get a clean image? How do the room lights affect the image? Which controls help sharpen the image? Record your camera adjustments in your lab journal.

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

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

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

What would happen if you click on a different part of the moving object to get your different data points?

MEASUREMENT

Record the time the cart takes to travel a known distance. Estimate the uncertainty in time and distance measurements. Take a good video of the cart's motion. Analyze the video with VideoTOOL to predict and fit functions for *position vs. time* and *velocity vs. time*.

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 information you should read *Appendix D*).

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

1. To open your video click 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 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 of the object to change with time. Notice that the symbols used by the equations in the program are *general letters*, which means that you have to identify those with the quantities involved in your prediction. In order to make 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 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. If you do not see your data point on the graph, change the scale of the graph axes. Again drag 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 parameters are the best approximations for your data and accept your "x-fit" and "y-fit". To do this you will probably have to adjust the scale of your axes so that you can see the behavior of the data. If the scale is too large, you will not be able to see important changes in behavior. If the scale is too small the data will be so "jumpy" that you will not be able to see the overall behavior.

7. Next the program will ask you to enter your prediction for velocity in the x- and y-direction. Choose the appropriate equations and give your best approximations for the parameters. The parameters for the position equations will help you determine these parameters. Accept your v_x- and v_y-predictions and you will see the data on the last two graphs. Again you will probably need to adjust the scale of each axis.

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.

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

Note: Be sure to record your measurements with the appropriate number of significant figures and with your estimated uncertainty (see Appendix B).

ANALYSIS

Calculate the average speed of the cart from your stopwatch and meter stick measurements. Can you determine the instantaneous speed of your cart as a function of time from these measurements? If so how?

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

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

CONCLUSION

Compare the cart's speed measured with video analysis to the measurement using a stopwatch. How do they compare? Did your measurements and graphs agree with your answers to the Warm-up

Questions? If not, why? What are the limitations on the accuracy of your measurements and analysis? Are the techniques used in this lab problem applicable to analyzing the motion of protein molecules moving through gel? How is the motion of protein molecules similar to the motion of the cart? How would it differ?

SIMULATION

Compare the simulated graphs to your graphs of the car's motion. 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. Can you more easily see the effect in the *position vs. time* graph or in the *velocity vs. time* graph?

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?

A computer simulation of the motion will also let you determine how parts of the experiment outside your control in the real world could affect your results. For example, you can adjust friction or air resistance to see what role they play in the results.

PROBLEM #2:
FALLING

While watching a cat you wonder about its biomechanics. It seems that a cat lands easily after jumping from heights that would injure a human. This puzzles you because you know that a human has much stronger bones and muscles than a cat. On of your friends believes that the answer is simple, humans are heavier than cats and therefore fall faster. When a human and a cat fall from the same height, the human hits the ground going much faster and sustains more injury. You are not so sure that this is the explanation so you calculate the speed that an object hits the ground as a function of its height and its mass using conservation of energy. Because both the human subjects committee and animal rights groups would object if you tested this idea by pushing your friend and a cat off a building, you decide to measure the speed of falling balls with different masses dropped from the same height in the laboratory.

EQUIPMENT

For this problem, you will have a collection of balls with approximately the same size 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

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. From your equation, draw a velocity-vs-time graph and a position-vs-time graph. Explain how these graphs resulted from your equation.

What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

Read Serway & Jewett: sections 2.2, 4.5, 6.1, 6.2, 6.5, and 6.6.

1. Draw a diagram of a ball in midair and establish a convenient coordinate system. Identify all the forces acting on the ball. State any simplifying assumptions you make.
2. Does the ball fall with a constant speed or is it speeding up or slowing down? Sketch a graph of how you think the ball's *velocity* changes with *time*. What is the shape of the graph and what features of that shape correspond to physical quantities that you know? How does the speed of the ball just after you release it show up on the graph? Make a *position vs. time* graph based on your *velocity vs. time* graph? How do the features of the *velocity vs time* graph show up on the *position vs. time* graph? Calculus is very useful for this discussion

3. Write an equation for the ball's kinetic energy in terms of its velocity. Identify all forces on the ball that cause either an energy input to the ball or an energy output from the ball. Write an equation that relates this energy transfer to these forces. Use conservation of energy to relate the kinetic energy of a ball to this energy transfer. Use this result to get an equation for velocity in terms of the forces acting on the ball. How does it depend on mass? Is this solution consistent with your qualitative solution?

4. Use your conservation of energy equation and calculus to write an expression for the ball's position as a function of time. Make a graph of this equation and compare it to the graph you sketched in 2.

5. Use your equation for position as a function of time and calculus to write an equation for the ball's velocity as a function of time. Make a graph of this equation and compare it to the graph you sketched in 2.

6. Use the simulation "Lab2Sim" to explore the approximate the conditions of your experiment. (See Appendix F for a brief explanation of how to use the simulations.) 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. Take note of the effect of error on the various graphs. Remember to check for the effects of measurement uncertainty in your VideoTOOL measurements later in lab.

EXPLORATION

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 the ball's motion to fill 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. Take a test video and step through it to determine its quality.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. If your image is not sharp or not bright enough to determine the edges of the ball, ask your instructor to adjust its shutter speed or sensitivity. If this adjustment cannot be made, and you cannot clearly determine the edges of your ball in the first frame of the video you want to use, you can 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.

Step through the video and determine which part of the ball is easiest to consistently mark. When the ball moves rapidly the image may blur because of the shutter speed of the camera. It is also possible that the image is too dark or too light to see a good edge.

Measure the distance the ball travels with a meter stick and the time for the fall to determine the maximum value for each axis (as well as to check that the numbers the computer will give you make sense) before taking data. Try balls of different mass.

Does the size of the ball really make a difference? If they are available, try balls of different size. What origin of the coordinate system will you use for the graph? Check whether up or down is positive. If the camera is slightly tilted, how will that affect your measurement? Write down your measurement plan.

MEASUREMENT

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

Measure 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.

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. (Refer to the Exploration section in Problem 1 for instructions on using the software, and Appendix D "Video Analysis of Motion" as necessary.) Don't waste time in collecting data you don't need or, even worse, collecting incorrect data. Collect enough data to convince yourself and others of your conclusion.

Repeat this procedure for different balls.

ANALYSIS

Choose a function to represent the *position vs. time graph*. Estimate the values of the parameters of the function from the points on the graph. Use the concepts of calculus. You can waste a lot of time if you just try to guess the constants. What kinematics quantities do these parameters represent?

Choose a function to represent the *velocity vs.time* graph. Calculate the values of the parameters of this function from the function representing the *position vs. time* graph using calculus. Check how well this works. You can also estimate the values of the parameters from the graph itself. Just trying to guess the constants can waste a lot of your time. What kinematics quantities do these parameters represent?

Use the fit equations for *position vs. time* and *velocity vs. time* to determine a single equation for *velocity* as a function of *position*.

Compare the information contained in the graphs of balls with different masses.

CONCLUSION

What do your measurements say about the variation of the velocity of a free-falling object with time? What do your measurements say about the variation of velocity with the height at which the object is dropped? Did the data support your predictions? If not, what assumptions did you make that were incorrect? Explain your reasoning.

Does the ball's velocity change more or less in the first centimeter of falling or the last centimeter? Support your answer with your data, and with physics reasoning.

Do your results hold regardless of the mass of the ball? Would the character of the motion of a falling Styrofoam ball be the same as that of a falling baseball? Do the size and shape of the object matter? Is air resistance significant?

Will the velocity of a falling cat be larger or smaller than that of a person who has fallen the same distance? State your results in the most general terms supported by your analysis. Compare the kinetic energy of a cat and that of a person just before each strikes the ground. What is the effect of this energy when each makes a hard landing?

SIMULATION

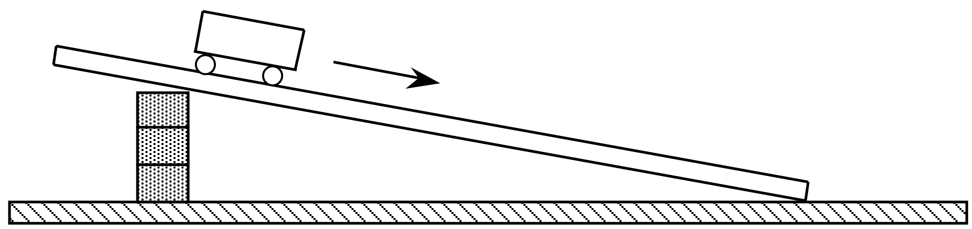
Compare the simulated graphs to your graphs of the falling objects. If your results did not completely match your expectations, use the simulation "Lab2Sim" to explore what might have happened (See *Appendix F* for a brief explanation of how to use the simulations). First, set the simulation to approximate the conditions of your experiment. Can you get the behavior, and the graphs of position and velocity, that you expect?

Discuss the graphs produced by the simulation and verify that they meet your expectations. Use the simulation controls to vary the amount of air resistance and the mass of the object. Can you more easily see the effects in the *position vs. time* graph or in the *velocity vs. time* graph? Use the simulation to determine how your uncertainties affect your measurements.

PROBLEM #3:
MOTION DOWN AN INCLINE

You are part of a group concerned about injuries to children. One common injury is the result of skateboard accidents. Skateboarders typically pick up speed by going down some kind of ramp. The faster the skateboard goes, the more serious the potential injury. To study different safety devices, you first need to determine how the speed of a skateboard depends on the characteristics of a ramp. For this reason you decide to calculate the final speed of a skateboard coming off a ramp as a function of the properties of the ramp and the mass of the skateboard. You will then test your calculation in the laboratory using a cart going down a sloped track.

EQUIPMENT



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

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

Read Serway & Jewett: sections 1.10, 2.2, 4.5, 4.6, 6.1, 6.2, 6.5, and 6.6.

1. Draw a picture of the situation labeling all of the relevant forces, distances, and angles. Decide on a useful coordinate system and explain why you chose it. Draw a free-body diagram of the cart as it moves down the track. Show all forces acting on the cart. Describe which forces you can neglect and explain why.

2. Draw your coordinate system and put the forces on the cart on it. Is there a component of the cart's motion that can be considered as in equilibrium in your coordinate system?

3. Write down the forces or force components that transfer energy to or from the cart. If any angles are involved, write down how they are related to the angle of the track.

4. Calculate the energy transferred to the cart and the energy transferred from the cart. Relate this energy transfer to the change of the kinetic energy of the cart.

5. From this conservation of energy equation use calculus to get an equation describing how the position of the cart changes with time. Use this equation and calculus to get another equation describing how the velocity of the cart changes with time.

6. Use the simulation "Lab1Sim" to explore the approximate the conditions of your experiment. (See Appendix F for a brief explanation of how to use the simulations.) 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. Take note of the effect of error on the various graphs. 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 incline in a reproducible way? How can you use trigonometry to measure this angle with respect to the table?

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. Explore a range of angles and roughly measure the time it takes to get to the bottom. **BE SURE TO CATCH THE CART BEFORE IT HITS THE END STOP!** If the time is too short, you may not get enough video frames, and thus enough position and time measurements. If the time is too long, you may not be able to neglect certain forces. Select the best angle for this measurement.

Where is the best place to put the camera? Which part of the motion do you wish to capture? Explore different camera positions. Should you rotate your coordinates? If so how? What will you use as your calibration object?

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 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.

See qualitatively how the motion changes when you change the mass of the cart by the maximum amount. How many different cart masses to you need to determine the effect of the mass of the cart on the final velocity?

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

Write down your measurement plan.

MEASUREMENT

Follow the measurement plan you wrote down.

When you have finished making measurements, you should e-mail PDF files of the position and velocity graphs to each group member. Sketch the graphs in your lab journal, and check that you have kept good records of your determination of the incline angle, the time it takes the cart to roll a known distance down the incline starting from rest, the length of the cart, the length of the track, and prediction and fit equations for position and velocity. All of the preceding measurements should include your estimate of the measurement uncertainties.

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

ANALYSIS

Choose a function to represent the *position vs. time* graph. Write down the physical meaning of each parameter in the equation. Use your knowledge of functions and calculus to estimate the values of the constants of the function from the graph itself and the measurements you made in the exploration section. You can waste a lot of time if you just try to guess the constants.

Choose a function to represent the *velocity vs. time* graph. 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 itself. Just trying to guess the constants can waste a lot of your time. What kinematics quantities do these constants represent?

Combine your equation for position as a function of time and your equation of velocity as a function of time to arrive at an equation of velocity as a function of position.

For each different angle, you should do the above analysis once.

CONCLUSION

How do the graphs of your measurements compare to your predictions? How does velocity vary with the distance the cart travels and the angle of the incline? In what sense is the motion similar to freefall? In what sense is it different? Extrapolate your results to the case of a vertically inclined track and compare with that of freefall.

In what direction is the cart accelerating? How does the downward component of that acceleration compare with the gravitational acceleration of the cart if you dropped it?

SIMULATION

If your results did not completely match your expectations, you may use the simulation "Lab1Sim" to explore what might have happened (See *Appendix F* for a brief explanation of how to use the simulations). First, set the simulation to approximate the conditions of your experiment. Can you get the behavior, and the graphs of position and velocity, that you expect?

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?

Investigate the effect of friction or air resistance by changing these settings in the simulation. How does increasing the friction affect the *velocity vs. time* graph? Can you tell the difference between this effect and the effect due to uncertainty? Do you see a friction effect in your data?

Examine the effect of changing the gravitational acceleration in the simulation.

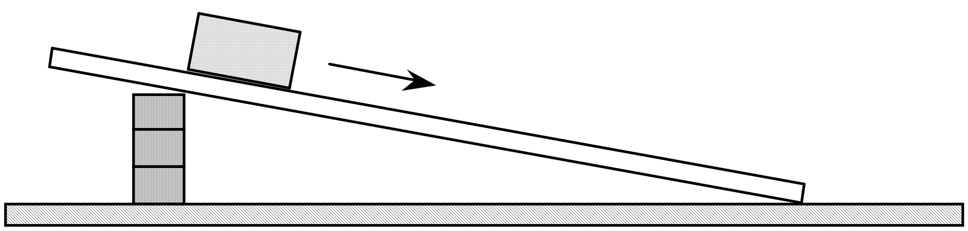
PROBLEM #4: NORMAL FORCE AND FRICTIONAL FORCE

You are working in a biotech company investigating substances that organisms produce to cope with their environment. Some of these substances could be synthesized and be useful to humans. For example, some fish have a substance on their scales that reduces the friction between them and the water. This substance might be a replacement for oil based lubricants in some types of machinery. To test the effectiveness of such substances, you decide to measure its coefficient of kinetic friction when used between an object moving down a ramp and the ramp.

First you need to determine how well the approximate expression relating the frictional force to the normal force and the coefficient of kinetic friction works under laboratory conditions. To perform this check you decide to calculate the frictional force when a block of wood slides down an aluminum ramp using conservation of energy. Then you calculate the normal force using Newton's second law. Assuming the usual expression for the frictional force is approximately correct in this situation you make a sketch of the graph that should result from plotting frictional force determined by conservation of energy versus normal force determined by Newton's second law. This is what you will test in the laboratory.

EQUIPMENT

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



PREDICTIONS

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get the two equations that each give one of the forces you need to solve the problem. Make sure that you state any approximations or assumptions that you are making. Make sure that in each case the force is given in terms of quantities you know or can measure. Write down the approximate expression for friction that you are testing and sketch a graph of frictional force as a function of normal force for that equation.

What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

Read Serway & Jewett: sections 1.10, 2.2, 4.5, 4.6, 5.1, 6.1, 6.2, 6.5, and 6.6.

1. Make a drawing of the problem situation including labeled vectors to represent the motion of the block as well as the forces on it. What measurements can you make with a meter stick to determine the angle of the incline?
2. Draw a free-body diagram of the block as it slides down the track. Choose a coordinate system that will make calculations of energy transfer to and from the block easiest. What is your reason for choosing that coordinate system?
3. Transfer the force vectors to your coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the track and the table?
4. In the coordinate system you have chosen, is there a component of the block's motion that can be considered as in equilibrium? Use Newton's second law in that direction to get an equation for the normal force in terms of quantities you know or can measure. Does the normal force increase, decrease, or stay the same as the ramp angle increases?
5. Write down the energy transfer to or from the block caused by each of the forces acting on the block when the block has slid some distance. Which forces give an energy input and which an output? Write down an equation that expresses conservation of energy for this situation. Solve this equation for the kinetic frictional force.
6. Sketch a graph of the frictional force as a function of the normal force if the approximate relationship between them is good in this situation. How would you determine the coefficient of kinetic friction from this graph?

EXPLORATION

The frictional force is usually very complicated but you need to find a range of situations where its behavior is simple. To do this, try different angles until you find one for which the wooden block slides smoothly down the aluminum track every time you try it. Make sure this is also true for the range of weights you will add to the wooden block.

You can change the normal force on the block either by changing the weight of the block and keeping the angle of the track the same or by changing the angle of the track and keeping the weight of the block the same.

Select an angle and determine a series of masses that always give you smooth sliding. Select a block mass and determine a series of track angles that always give you smooth sliding. Determine which procedure will give you the largest range of normal forces for your measurement.

Write down your measurement plan.

MEASUREMENT

Follow your measurement plan. *Make sure you measure and record the angles and weights that you use.*

Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the wooden block depends on the normal force on the wooden block.

ANALYSIS

From your video analysis and other measurements, calculate the magnitude of the kinetic frictional force. Also determine the normal force on the block.

Graph the magnitude of the kinetic frictional force against the magnitude of the normal force. On the same graph, show the relationship predicted by the approximation for kinetic friction.

CONCLUSION

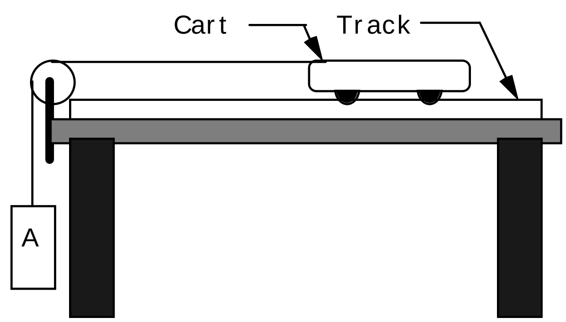
Is the approximation that kinetic frictional force is proportional to the normal force useful for the situation you measured? Justify your conclusion. What is the coefficient of kinetic friction for wood on aluminum? How does this compare to values you can look up in a table such as the one is given at the end of this lab?

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

PROBLEM #5:
VELOCITY AND FORCE

You are in a research group investigating whether birds are the direct descendants of dinosaurs. Of particular interest are the most primitive gliding dinosaurs. Your team will build models of these animals with different wing shapes to study the difficulties in becoming airborne. You are assigned to design a simple launch mechanism that will provide a reproducible launch velocity. In your design, the dinosaur model will ride on a cart that moves along a horizontal track. The cart begins its motion when the hanging object attached to it by rope going over a pulley is allowed to fall. You need to calculate the speed of the cart as a function of the mass of the hanging object, the mass of the cart, and the distance that the hanging object falls. You will then test your calculations in the laboratory. One of your colleagues claims that the calculation is easy because the force of the string on the cart is just the weight of the hanging object. Another colleague claims that the calculation is even easier if you calculate the velocity of the cart as a function of time. Then the velocity of the cart that you want is just the distance the hanging object falls divided by the time it takes it to fall. Still another colleague claims they are both obviously wrong. Who is correct?

EQUIPMENT



For this problem you will have an aluminum track, a PASCO cart, a stopwatch, a meter stick, a balance, weights, a pulley, a pulley clamp, one piece of string, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the velocity you need and another equation that expresses the force of the string on the cart. Make sure that you state any approximations or assumptions that you are making.

Sketch a graph of what you expect to see for the cart's velocity as a function of time, and position as a function of time, from the time of release until just before the hanging object hits the ground. What assumptions are you making to solve this problem?

WARM-UP QUESTIONS

Read Serway & Jewett: sections 2.1-2.3, 4.4-4.6, 6.1, 6.5, and 6.6.

1. There are two important time intervals for this problem. The first is from the time the cart is released until the hanging object hits the floor. The second is from the time the hanging object hits the floor until the cart hits the end of the track. Make a drawing of the problem situation for each time interval. Draw and label vectors that describe the motion of the cart and hanging object during each interval. Label quantities in your picture you know or can measure.
2. Draw vectors to represent the forces acting on the cart before the hanging mass hits the floor. Draw force vectors for the hanging object while it is in motion. If forces are larger or smaller, be sure to indicate this with the length of the vector arrow you draw. Are the forces on the hanging object equal, or not? How do you know? Before the hanging object hits the ground, describe the motion of the cart (speeding up, slowing down, or staying constant).
3. If two quantities have the same magnitude, use the same symbol *and* write down your justification for doing so. Define a convenient coordinate system.
4. Draw vectors to represent the forces acting on the cart after the hanging mass hits the floor. Draw force vectors for the hanging object while it is touching the floor. If forces are larger or smaller, be sure to indicate this with the length of the vector arrow you draw. After the hanging object hits the ground, describe the motion of the cart (speeding up, slowing down, or staying constant). In each time interval, what quantities are constant and what quantities are changing?
5. To use conservation of energy, you must first define your system. For the time interval from when the hanging object is released until it hits the ground, define the system that you want to use. Write down conservation of energy for that system. Check that any energy transferred to or from your system is caused by forces from objects that are not in your system.
6. If your conservation of energy equation has the final velocity of the cart as a function of quantities that you know or can measure, you can go to the next part of the problem. If there is an unknown in your equation, define a different system where that unknown will also occur and write the conservation of energy for that system. Then use this to eliminate the unknown.
7. If you used systems in which the force of the string on the cart occurs in the conservation of energy equation, you can solve those equations for that force as a function of the mass of the hanging object and the mass of the cart. If the conservation of energy equation for your system did not include the force of the string on the cart, select another system in which it does occur. Now, solve your equations for the force of the string on the cart as a function of the mass of the hanging object and the mass of the cart. In either case compare this force to the weight of the hanging object. Are they equal? Why or why not?
8. Use the simulation "Lab4Sim" to explore the effects of a very wide range of masses for the hanging object and the cart. (See *Appendix F* for a brief explanation of how to use the simulations.) From the simulation try to address those questions. When the hanging object is *much more massive* than the cart, does the system have the final velocity you would expect? When the

hanging object is *much less massive* than the cart, does the system have the final velocity you would expect? Explain your reasoning.

EXPLORATION

Adjust the length of the string such that object A hits the floor well before the cart runs out of track. You will be analyzing a video of the cart both *before* and *after* object A has hit the floor. Is it possible to analyze both intervals at the same time, or do you need to analyze the video twice? Adjust the string length to give you a video that is long enough to allow you to analyze enough frames of motion.

Choose a mass for the cart and find a range of masses for object A that allows the cart to achieve a reliably measurable velocity before object A hits the floor. Make sure you include masses of object A that range from at least 1/2 that of the cart to masses that are a small fraction of the cart. Practice catching the cart before it hits the end stop on the track.

Make sure that the assumptions for your prediction apply to the situation in which you are making the measurement. For example, if you are neglecting friction, make sure that the cart's wheels turn freely. Also check that the pulley wheel turns freely.

Write down your measurement plan.

MEASUREMENT

Carry out your measurement plan.

Complete the entire analysis of one case before making videos and measurements of the next case. *A different person should operate the computer for each case.*

Make sure you measure and record the mass of the cart and object A. Record the height through which object A falls and the time this takes to occur.

Take a video that will allow you to analyze the data during both time intervals. Make measurements for at least two different heights of release.

ANALYSIS

Determine the velocities of the cart just before the hanging object hits the floor and just before the cart hits the end-stop. Examine the dependence of these velocities on the masses and the height of release.

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

CONCLUSION

How does the velocity of the cart depend on the masses and the distance traveled just before the hanging object strikes the floor? What is the relationship between the velocity of the cart just before the hanging object hits the floor and the velocity just before the cart hits the end-stop? Did your measurements agree with your initial prediction? If not, why?

Which colleague was correct? Is the force of the string on the cart equal to the weight of the hanging object? Greater than that weight? Less than that weight? Explain your reasoning.

What is the total force on the hanging object? Is the force of the string on the hanging object greater than, less than, or equal to the gravitational pull of the earth on the hanging object? Explain.

Is the final velocity of the cart equal to the distance it goes divided by the time it takes to go that distance? Greater than that velocity? Less than that velocity? Explain your reasoning.

To launch a 3.5 kg model of a gliding dinosaur at a speed of 5.0 m/s, what should be the mass of the hanging object, assuming that it falls a distance of 1.5 m?

SIMULATION

If your data did not match your expectations, you should use the simulation to explore what could have happened.

If that is the case set the simulation to approximate the conditions of your experiment. Do you get the behavior, and the graphs of position and velocity, that you expect?

If you believe friction may have affected your results, explore its effects with the simulation. Does it affect the behavior, and the graphs of position and velocity, in the ways you expect?

If you believe that your prediction was incorrect because it did not take into account the effects of the mass of the string or the mass of the pulley, explore their effects with the simulation. Do they affect the behavior, and the graphs of position and velocity, in the ways you expect? Explain.

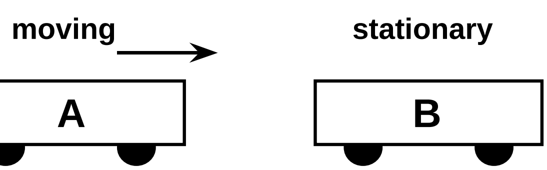
If you believe uncertainty in position measurements may have affected your results, use the simulation to compare the results with and without error. Can you more easily see the effect in the position vs. time graph or in the velocity vs. time graph? Did you see the effects of measurement uncertainty in your VideoTOOL measurements?

PROBLEM #6: COLLISIONS

You are on a research team investigating the interactions of molecules that drive biological processes. Within a biological system, these molecules move at random until one collides with another. At that point they might stick together as when an active site of an enzyme attaches to a substrate. It is also possible that they will bounce apart. In both cases it is interesting to determine what happens to the kinetic energy of the molecules since this affects their mobility. Your assignment is to investigate the velocity of the resulting molecules after a collision. You decide to use conservation of energy to determine the speeds of the two molecules in the two cases of when they stick together or when they bounce apart. You know that molecules have structure so that some of the initial kinetic energy of the molecules can be transferred into internal energy of the molecule, molecular excitation. To simplify the possible situations, you take two simple cases. In both cases the molecules will have equal mass and one will initially be stationary and the other will be moving. In the first case the molecules will stick together and in the second case they will bounce apart. First you calculate the speed of each molecule after the collision ignoring any internal energy change. In each case what fraction of the initial energy do you think will be converted into internal energy? Then you write down the conservation of energy equation allowing for internal energy change and use you guess to calculate the final speed of each molecule. To test your results, you decide build a laboratory model using low friction carts and measure the amount of internal energy change when the carts stick together and when the bounce apart.

EQUIPMENT

You will have a meter stick, a stopwatch, two PASCO carts with Velcro and magnetic bumpers, an aluminum track, cart masses, wooden blocks, a camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem for each case. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett: sections 6.1, 6.6, and 6.7.

1. Make two drawings. One that shows the situation before the collision and one after the collision for the case of a moving cart bouncing off of a stationary cart of the same mass.

Label the velocity vectors and masses for every object in both drawings. Define the most convenient system to use for conservation of energy.

2. Write down the energy conservation equation for this situation and identify all of the terms in the equation. Identify any energy transferred to or from your system by interactions with objects that are not in your system. Include a change in the system's internal energy that is some unknown fraction of the initial energy. Calculate this fraction as a function of quantities you know or can measure.
3. Repeat 1 and 2 for the situation where the carts stick together.

EXPLORATION

Practice setting the cart into motion so that the Velcro ends of the carts stick together after the collision. Also, after the collision carefully observe the carts to determine whether or not either cart leaves the grooves in the track. Adjust your procedure to minimize this effect so that your results are reliable. Be sure the carts still move freely over the track.

Try giving the moving cart various initial velocities over the range that will give reliable results. Note how fast the carts are moving after the collision. Does this agree qualitatively with your prediction? Keep in mind also that you want to choose an initial velocity that gives you a good video.

For collisions in which you want the objects to bounce off elastically instead of sticking together, experiment use the magnetic bumpers and repeat the procedures above.

Write down your measurement plan.

MEASUREMENT

Make all measurements necessary to check your predictions.

Analyze your data as you go along (before making the next video), so you can determine how many different videos you need to make, and what the carts' masses should be for each video. Collect enough data to convince yourself and others of your conclusion the fraction of the initial energy of the system that goes into internal energy. Also make sure that your data covers a range of initial velocities from very small to the largest possible without causing the carts to visibly vibrate on the track or move the track.

ANALYSIS

Determine the velocities of the carts (with uncertainty) before and after each collision from your video. Calculate the change in internal energy for each case. Compare with your prediction.

CONCLUSION

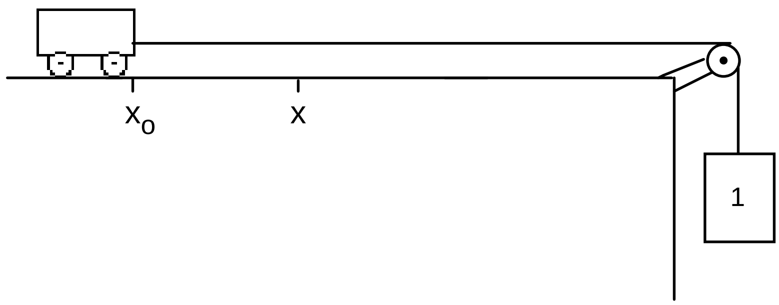
How do your measured and predicted values of internal energy change compare? What are the limitations on the accuracy of your measurements and analysis? In which case is there the most change in the system's internal energy. What is the change in internal energy? Could you ignore this change for either case as an approximation?

Surfaces	static	kinetic
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
Wood on Aluminum		0.25-0.3

* 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.

TA Name:______________________________

PHYSICS 1201 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 questions 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
POTENTIAL ENERGY

In previous problems, you have been introduced to the concepts of kinetic energy, which is associated with the motion of an object, and internal energy, which is associated with the internal structure of a system. In this section, you work with another form of energy, called potential energy, which is associated with the configuration of a system of two or more interacting objects or particles.

OBJECTIVES:

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

- Incorporate the concept of potential energy within the framework of the conservation of energy.
- Apply the concept of potential energy in problem solving.

PREPARATION:

Read Serway & Jewett chapter 7 (sections 1-4). It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. It is very important that you read the text before coming to lab.

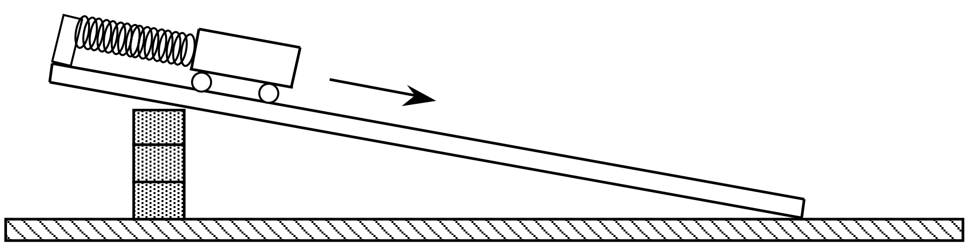
Before coming to lab you should be able to:

- Write down the conservation of energy equation for any system of one object.
- Understand the difference between energy transfer terms and the energy of the system.
- Be able to use forces and draw a free-body diagram for any system.
- Be able to determine the components of forces.
- Know which components of forces contribute to energy transfer.
- Write down the potential energy for a spring.
- Write down the gravitational potential energy for a system of two objects.
- Use the concept of velocity.

PROBLEM #1:
ELASTIC AND GRAVITATIONAL POTENTIAL ENERGY

You are working in a research group investigating the structure of coiled proteins. These proteins behave to some extent like a spring. Your group intends to fasten one end of the protein to a stationary base while it attaches an electrically charged bead to the other end. The bead will be attracted by an electrostatic force. From the motion of the bead under the influence of this electrostatic force, your group will determine the mechanical properties of the protein. Before setting up this experiment, you decide to test the ideas using a physical model in the lab. You decide to model you system using a cart attached by a spring to the top of an inclined track. Instead of an electrostatic force, you will use the gravitational force. You can't change the gravitational force but you can change its effect on the cart by changing the angle of the track. You intend to release the cart from the top of the track where the spring is unstretched and measure its motion. To characterize the motion, you have been asked to calculate what will be the maximum extension of the spring and where the cart will have its maximum speed as a function of the properties of the cart and the spring and the angle of the track.

EQUIPMENT



For this problem you will have an aluminum track, a cart, weights, springs, a balance, a meter stick, a video camera and a computer with a video analysis application written in LabVIEW™.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get the two equations that give the solutions to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett: sections 7.1-7.3.

1. Draw a picture of the situation at each of the three different times described in the problem. Label all relevant quantities on the diagram for each time.

2. Define a system you will use. Does the spring transfer energy into or out of your system? Write an expression for the energy transferred by the spring while the cart is moving down the ramp. This is also called the "elastic potential energy" of the spring. Does the force of gravity transfer energy into or out of your system? Write an expression for the energy transferred by gravity while the cart is in motion. . This is also called the change in "gravitational potential energy" for the system. Express this energy in terms of the distance traveled along the ramp, rather than the vertical height. Use these terms to write a energy conservation equation for the system that relates its initial energy to its energy when the cart's speed is maximum.
3. Solve your conservation of energy equation for the velocity of the cart. When the cart has reached its maximum position (maximum spring stretch), what is its velocity? Use this information to solve for the maximum extension of the spring.
4. What is the position of the cart when the velocity is at a maximum? Write down a calculus expression that you can use to find the cart displacement when the velocity is maximum. Use this calculus expression with your equation for the velocity of the cart to solve for the position when velocity is maximum. Make a graph of velocity as a function of position and verify that your calculus does give you the maximum.
5. How does the position of the cart at maximum velocity compare to the cart's position when the spring is at its maximum extension?
6. What is the maximum velocity of the cart, in terms of its mass, the angle of the incline, and the spring constant?

EXPLORATION

Choose an angle of incline for the track and a range of weights to place on the cart such that the elongations of the spring are distinct, significant and do not exceed the elastic limit of the spring which is about 60 cm. Try different track angles to get a good range of motion for the video.

Use a meter stick to get approximate values for the maximum displacement and the position when the velocity is maximum.

Decide how you will measure the spring constant and the angle of the track. Decide how you will measure the cart's maximum speed and displacement from each video, and how you will adjust the camera for maximum convenience and accuracy. Decide on how many angles and cart weights you will need to test your equations. Write down a measurement plan.

MEASUREMENT

Carry out your measurement plan. Remember to measure the dimensions necessary to determine the slope or angle of the inclined track, and the spring constant.

ANALYSIS

Analyze the video for the position and velocity of the cart as a function of time. Use both graphs to determine the position of the cart when it has maximum velocity. Also indicate how you would determine the position of maximum velocity from the just the graph of position vs. time.

CONCLUSION

Do your measurements match your predictions? Why or why not?

PROBLEM #2:
USING POTENTIAL ENERGY

Redo the calculations for one of the problems from Lab 2 problems 1 – 5 by re-defining your system so that you can use potential energy. Use the data you have already recorded in your lab journal to test your calculations.

Read Serway & Jewett: sections 7.1-7.3.

PROBLEM #3:
PENDULUM

You work in a research group trying to understand the migration patterns of mammals. One element in this investigation is the maximum speed with which different mammals can walk. One theory is that this speed is determined primarily by the length of the animal's leg. In this theory, the leg is essentially a pendulum pivoted at the hip. Then the maximum speed of the leg is related to the maximum angle that the leg can be displaced from the vertical as well as other properties of the leg. You have been asked to calculate this relationship and then test your calculation by using a model of this motion in the laboratory. As a first step, you calculate the maximum speed of the end of a pendulum as a function of the maximum angle that the pendulum is displaced from the vertical as well as the other properties of the pendulum for a model in which all of the mass is concentrated at the end of the pendulum instead of being continuously distributed as with a real leg.

EQUIPMENT

For this problem you will have a stopwatch, a protractor, string, weights, a meter stick, rods and clamp, a video camera and a computer with a video analysis application written in LabVIEW™.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett: sections 7.1-7.3.

1. Draw a picture of the pendulum at an initial time, with the string at an angle and an initial speed of zero. Draw a second picture to represent the time when the speed of the object at the end of the string, called the pendulum bob, is maximum. On each picture, draw and label the quantities necessary to describe the energy of your system.
2. Write down a relationship between the height of the bob and the angle of the pendulum. Label any other quantities of interest in each picture.
2. Define your system for this situation so that you can use gravitational potential energy. Are there any external forces on your system? Determine if they transfer any energy to or from your system and explain why.
3. Write the conservation of energy equation to relate the system's energy at the initial time to its energy when the bob has its maximum velocity. If energy is transferred into or out of the system, be sure to include it in your equation. State and justify any approximations or assumptions you make.

4. Solve your equation to give the maximum speed of the pendulum bob in terms of its initial angle and properties of the pendulum. At what angle does the speed reach a maximum? Sketch a graph of *maximum speed vs. release angle*. How does this maximum speed depend on the mass of the pendulum bob?

EXPLORATION

Choose a convenient length of string. Test the effects of using different pendulum bob masses when they are released from the same height. Explore a useful set of heights at which the pendulum may be released. Can you neglect air resistance?

Decide how you will determine the pendulum's maximum speed from video measurements of its horizontal and vertical velocity components. Decide how you will determine the pendulum's initial angle from video measurements of its horizontal and vertical position.

Decide how many different pendulum masses and lengths you need to use in your measurement to convince yourself and others that you calculation is correct.

Write down your measurement plan.

MEASUREMENT

Measure the length of the pendulum string. Record the necessary video for several release heights, lengths of string, and pendulum masses. Be sure to measure each initial angle and bob height with a meter stick for comparison with your video measurements.

ANALYSIS

Analyze each video to determine the pendulum bob's initial angle and maximum speed. Check to see that the maximum speed occurs at the expected position.

Make a graph of the measured *maximum speed vs. release angle* data, with estimated uncertainties. On the same graph, plot the predicted relationship. Also graph the *maximum speed vs pendulum mass* and *maximum speed vs pendulum length* for the initial release angle.

CONCLUSION

Were your predictions consistent with your measurements? Why or why not?

How would doubling the pendulum bob's mass affect its maximum speed? How would doubling the pendulum's initial height affect its maximum speed?

TA Name:______________________________

PHYSICS 1201 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 questions 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
OSCILLATIONS

You are familiar with many objects that oscillate -- a tuning fork, a pendulum, the strings of a guitar, or the beating of a heart. At the microscopic level, you have probably observed the flagellum of microbes. Even at the nanoscopic level, molecules oscillate, as do their constituent atoms. All of these objects are subjected to forces that change with position. Springs are a common example of objects that exert this type of force.

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

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.
- Demonstrate a working knowledge of the mathematical description of an oscillator's motion.
- Describe qualitatively the effect of additional forces on an oscillator's motion.

PREPARATION:

Read Serway and Jewett chapter 2 (section 4), chapter 4, chapter 12 (sections 1-4 and 6-8). It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. It is very important that you read the text before coming to lab.

Before coming to lab you should be able to:

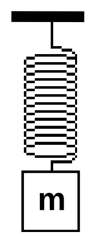
- Describe the similarities and differences in the behavior of the sine and cosine functions.
- Recognized the difference between amplitude, frequency, and period for repetitive motion.
- Determine the force on an object exerted by a spring.
- Be able to use Newton's second law for accelerating objects.

PROBLEM #1: MEASURING SPRING CONSTANTS

Your research group is studying the properties of a virus that attaches to the outside of a healthy cell and injects its RNA into that cell. The injection process relies on a single large molecule in the virus that provides the force for the injection process. This biopolymer is coiled up like a spring and pushes the RNA through the cell wall. Your group needs to determine the maximum force the molecule can exert when it uncoils like a spring. You know you can determine the "spring constant" of the polymer by measuring its extension in response to a known force. However, it is much easier to disturb the molecule and observe its oscillation. This should give you the result you need since the oscillation period of a system also depends on the spring constant. To compare the two methods of determining the spring constant, you decide to try them both in the lab. First you need to calculate the spring constant as a function of the forces on the system and the properties of the system that you can measure using each method.

EQUIPMENT

You will have a spring, clamps, a vertical support, a meter stick, a stopwatch, a balance, a set of weights, and a computer with a video analysis application written in LabVIEW™.



PREDICTIONS

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem for each method. Make sure that you state any approximations or assumptions that you are making. Do you expect the two methods to yield similar results?

WARM-UP QUESTIONS

Read Serway & Jewett: section 2.4, Chapter 4, sections 12.1 and 12.2.

Method #1:

1. Make a sketch of an object suspended from a spring, as shown in the equipment section. Draw and label the forces acting on the object when it is in equilibrium. Use Newton's second law to write an equation that relates the forces acting on the object. Solve your equation for the spring constant.
2. Sketch a graph of the weight of the object versus the extension of the spring. What does the slope of the graph tell you?

Method #2:

1. Draw a picture of the object hanging on the spring at a time when the object is **below** its equilibrium position. Identify and label this position on a coordinate axis with an origin at the equilibrium position of the object.
2. Label the forces acting on the object at this position Next to the diagram draw a vector representing the acceleration of the object.
3. Write down an equation relating the forces on the object to its acceleration. Write down an equation that relates the force exerted by the spring on the object to the displacement of the object from its equilibrium position.
4. Solve your equation for the acceleration of the object as a function of the mass of the suspended object, the spring constant, and the displacement of the object from its equilibrium position.
5. Write down the definition of the acceleration of an object, in terms of the rate of change of its position using calculus notation. Re-write your equation from the previous question, so that position including its derivatives is the only variable.
6. Solve that equation for the position as a function of time by guessing a reasonable solution and trying it. How do you justify your guess? Determine the values of constants necessary to satisfy the equation. Which of these constants is related to the period of the system? Why? Show how the period depends on the spring constant.

EXPLORATION

Method #1: Select a series of masses that give a usable range of displacements**. The largest mass should not pull the spring past its elastic limit (about 60 cm). Beyond that point you will damage the spring**. Decide on a procedure that allows you to measure the extension of the spring in a consistent manner. Decide how many masses ou will need to use to make a reliable measurement of the spring constant.

Method #2: Select a range of object masses that give a regular oscillation without excessive wobbling to the hanging end of the spring. Make sure that the largest mass does not pull the spring past its elastic limit while oscillating. Practice starting the mass so that it oscillates vertically in a smooth and consistent manner. Using a stopwatch, decide whether or not the oscillation amplitude affects its period, for a particular mass.

Practice making a video to record the motion of the object. Decide how to measure the period of oscillation of the spring-object system both by video and by using a stopwatch. 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?

Write down your measurement plan.

MEASUREMENT

Method #1: Make the measurements necessary to determine the equilibrium spring extension for different masses.

Method #2: Make a video of the motion of the hanging object to find its oscillation period. Compare the stopwatch measurements with the video measurements. Repeat for objects with different masses.

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.

ANALYSIS

Method #1: Make a graph of the weight of the hanging object as a function of spring extension. From the slope of this graph, calculate the value of the spring constant, including the measurement uncertainty.

Method #2: Determine the period of the motion of the object from the graph of position as a function of time. Make a graph of the period of the oscillation as a function of mass for the object. If this graph is not a straight line, make another graph with the period as a function of mass raised to some power such that the graph is a straight line. From the slope of the straight-line graph, calculate the value of the spring constant, including the uncertainty.

CONCLUSION

How do the two values of the spring constant compare? Which method of measuring the spring constant is more efficient? Which method do you feel is the most reliable? Justify your answers.

Does the oscillation period depend on the oscillation amplitude? Defend your response with data from the exploration, and with arguments based on the prediction equation.

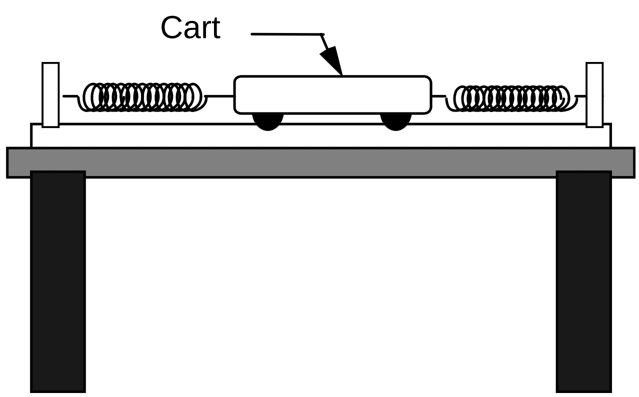
What is the spring constant of a polymer extended to 2 nanometers with a force of 0.2×10^{-12} Newton? What would be its oscillation period?

PROBLEM #2:
OSCILLATION FREQUENCY WITH TWO SPRINGS

You have a job with a group practicing industrial medicine. Your group is advising employees on how to avoid repetitive stress syndrome. As part of a demonstration, you have been asked to build a simple mechanical system that repeats its motion. You decide to place a low friction cart between two springs. To be able to adjust the period in a predictable manner, you calculate the oscillation period of the system as a function of the cart mass and the two spring constants. You then decide to check your calculation in the lab.

EQUIPMENT

You will have an aluminum track, two adjustable end stops, two springs, a meter stick, a stopwatch, a cart, cart masses, and the video analysis equipment.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making. Make a graph of period of the system as a function of the cart's mass for a given set of springs.

WARM-UP QUESTIONS

Read Serway & Jewett: section 2.4, Chapter 4, sections 12.1 and 12.2.

1. Make two pictures of the oscillating cart, one at its equilibrium position, and one at some other position and time while it is oscillating. On each of your sketches, show the direction of the velocity and acceleration of the cart. Identify and label the relevant forces and positions.

2. Decide on a coordinate system and draw a free-body diagram of the cart at a position other than its equilibrium position. Label the forces and define the symbols you are using. Draw the acceleration vector near the diagram.
3. Write down the equation relating the forces on the cart to its acceleration. Write down an equation that relates the force exerted by each spring on the object to the displacement of the object from its equilibrium position.
4. Solve your equation for the acceleration of the cart as a function of its mass, the spring constants, and the displacement of the cart from its equilibrium position.
5. Write down the definition of the acceleration of the cart, in terms of the rate of change of its position using calculus notation. Re-write your equation from the previous question, so that position including its derivatives is the only variable.
6. Solve that equation for the position as a function of time by guessing a reasonable solution and trying it. How do you justify your guess? Determine the values of constants necessary to satisfy the equation. Which of these constants is related to the period of the system? Why? Show how the period depends on the spring constants and the mass of the cart.

EXPLORATION

Decide on the best method to determine each spring constant based on the results of a previous lab problem. **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 they oscillate the cart smoothly. Practice releasing the cart smoothly. Use a stopwatch to roughly determine the period of oscillation. Use this to set up the time axis in LabVIEW. Determine if the period depends appreciably on the starting amplitude of the oscillation. Decide on the best starting amplitude to use for your measurements.

You will notice that the amplitude of the oscillation decreases as time goes by. What causes it? Check if this seems to affect the period of oscillation.

Try changing the mass of the cart and observe how that qualitatively changes its period of oscillation. How much of a mass change is too little to see an effect? How much of a mass change is too much? Write down your measurement plan.

MEASUREMENT

Determine the spring constant for each spring. Record these values. What is the uncertainty in these measurements?

Use the video equipment to record the motion of the cart. Record a sufficient number of complete cycles to reliably measure the oscillation period and to determine how it changes with amplitude. Repeat for different cart masses.

Analyze your data as you go along in order to determine the magnitude and number of different cart masses you need to use. Collect enough data to convince yourself and others of your conclusions.

ANALYSIS

Analyze your video to find the period of oscillation. Make a graph of *period vs. cart mass*, showing the estimated uncertainty.

Using your prediction, calculate the predicted period for these springs and each cart mass you used. Record these points on your graph, with estimated uncertainty.

CONCLUSION

Did your measurements agree with your predictions? Explain any discrepancies. What are the limitations on the accuracy of your measurements and analysis?

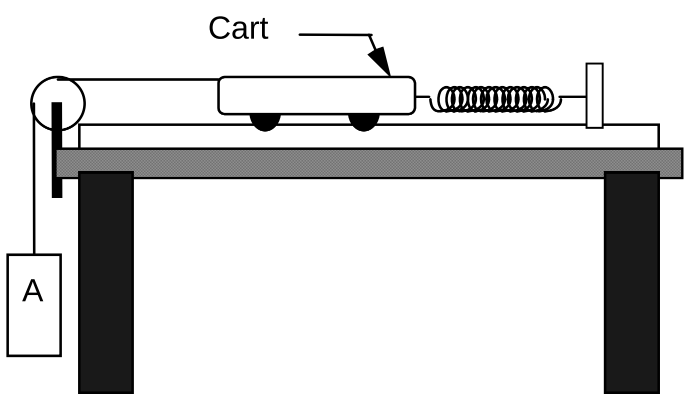
If you decided that your first attempt produced an oscillation frequency too fast for effective demonstration, what kinds of changes could you make to increase the period?

PROBLEM #3:
OSCILLATION FREQUENCY OF AN EXTENDED SYSTEM

A male cricket produces sound by oscillating its wings. This sound has a specific frequency distribution that attracts females of the same species. You are interested in the sensitivity of the females – will they respond to slightly different frequencies? The frequency of the sound is the same as the frequency of the oscillating wing. To change the frequency you will add a very small mass to the males' wings. To model this, you decide to attach one end of a low friction cart to a spring. The other end you attach to a string that goes over a pulley and is connected to an object hanging straight down. As the cart moves back and forth, it raises and lowers the object. First you need to be able to calculate how the frequency of the system depends on the amount of mass hanging from the string. After that, you will check your calculations in the lab.

EQUIPMENT

You have an aluminum track with an adjustable end stop, a pulley, a pulley clamp, a spring, a cart, some strings, a mass hanger, a mass set, cart masses, a meter stick, a stopwatch and the video analysis equipment.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

Make a graph of frequency of the system as a function of mass of the hanging object for a given cart mass and spring constant. Will the frequency **increase**, **decrease** or **stay the same** as the hanging mass increases?

WARM-UP QUESTIONS

Read Serway & Jewett: section 2.4, Chapter 4, sections 12.1 and 12.2.

1. Make two pictures, one when the cart and hanging object are at their equilibrium position and one at some other position. On your pictures, show the direction of the acceleration of the cart and hanging object. Identify and label the known (measurable) and unknown quantities.
2. Decide on a coordinate system and draw separate force diagrams of the cart and the hanging object. Label the forces acting on each object. Draw the appropriate acceleration vector next to each force diagram.
3. Independently apply Newton's laws to the cart and to the hanging object. Is the magnitude of the acceleration of the cart always equal to that of the hanging object? Is the force the string exerts on the cart always equal to the weight of the hanging object? Explain.
4. Solve your equations for the acceleration of the cart in terms of quantities you know or can measure. Write the acceleration as the second derivative of position with respect to time.
5. Solve that equation for the position as a function of time by guessing a reasonable solution and trying it. How do you justify your guess? Determine the values of constants necessary to satisfy the equation. Which of these constants is related to the period of the system? Why? Show how the frequency depends on the spring constant and the masses of the cart and the hanging object. Sketch a graph of *frequency vs. mass of hanging object* for constant cart mass and spring constant.

EXPLORATION

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

Determine the best range of masses for the hanging object. Use a stopwatch to roughly determine the period of oscillation. Use this to set up the time axis in LabVIEW. Determine if the period depends appreciably on the starting amplitude of the oscillation. Decide on the best starting amplitude to use for your measurements. Try adding some mass to the cart to see how it affects the motion.

Practice releasing the cart and hanging object smoothly and consistently. You want to make sure that the hanging object moves straight up and down and does not swing from side to side. You may notice the amplitude of oscillation decreases. Explain the cause. Does this affect the period of oscillation?

MEASUREMENT

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

Use the video to record the motion of the cart. Record a sufficient number of complete cycles to reliably measure the oscillation period and to determine how it changes with amplitude. Repeat for enough different hanging object masses to make a graph of frequency as a function of mass. Analyze your data as you go in order to determine the magnitude and number of different hanging masses you need to use.

Collect enough data to convince yourself and others of your conclusion regarding the dependence of the oscillation frequency on the mass of the hanging object.

ANALYSIS

Analyze your video to find the period of oscillation. Calculate the frequency (with uncertainty) of the oscillations from your measured period. Make a graph of frequency as a function of hanging object mass.

Calculate your predicted frequency for each value of the hanging object's mass and plot those predicted values on your graph.

CONCLUSION

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?

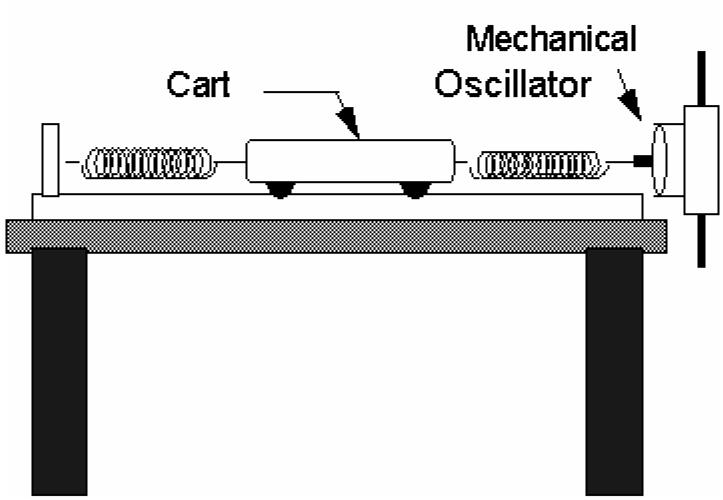
If you were to use this device on the surface of the moon, where the gravitational field is much weaker than on the earth's surface, would you expect the frequency to be any different? Use physics arguments and your prediction equation to justify your explanation.

PROBLEM #4:
DRIVEN OSCILLATIONS

You are working a consultant to a medical school that wants to introduce future doctors to Magnetic Resonance Imaging (MRI) machines. You are asked to design a device that illustrates the principle of resonance. You decide to use a low friction cart connected between two springs. One spring is connected to a device that mechanically pulses the spring at a frequency which can be varied while the other spring is connected to an end stop. The amplitude of the mechanical oscillator's movement is only a few millimeters. Make an educated guess, justified by your experience, about what frequency of the mechanical oscillator will cause the maximum oscillation of the cart. How big do you think the amplitude of this oscillation will be?

EQUIPMENT

You will have an aluminum track, an adjustable end stop, two springs, a clamp, a meter stick, a stopwatch, a cart, a mechanical oscillator, two cables with banana plugs, and a function generator. The mechanical oscillator has a rod that goes back and forth with an adjustable frequency that can be read out from a display on the function generator.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Calculate the oscillation frequency of the cart when the mechanical oscillator is *turned off*. This is called the system's natural frequency.

Sketch a graph illustrating, qualitatively, how you expect the amplitude of the cart's oscillation to vary with the frequency of the mechanical oscillator. Will the maximum amplitude occur at a frequency less than, equal to, or greater than the natural frequency of the cart and the springs?

WARM-UP QUESTIONS

Read Serway & Jewett: sections 12.1 and 12.2

1. If you have not already calculated the oscillation frequency of the cart and two springs without the mechanical oscillator, follow the Warm-up Questions of problem 2.
2. To qualitatively decide on the behavior of the system with the mechanical oscillator attached and turned on, think about an experience you have had putting energy into an oscillating system. For example, think about pushing someone on a swing. When is the best time to push to get the maximum height for the person on the swing? How does the frequency of your push compare to the natural frequency of the person on the swing? How does the maximum height of the swinger compare to the size of your push?

EXPLORATION

Examine the mechanical oscillator. Mount it at the end of the aluminum track, using the clamp and metal rod so its shaft is aligned with the cart's motion. Connect it to the function generator, using the output marked **Lo** (for "low impedance"). Use between middle and maximum amplitude to observe the oscillation of the cart at the lowest frequency possible.

Determine the accuracy of the digital display on the frequency generator by using the stopwatch to measure one of the lower frequencies.

Devise a scheme to accurately determine the amplitude of a cart on the track, and practice the technique.

What happens to the cart when you change frequencies? Determine how long you should stay at one frequency in order to determine an effect. Try changing frequencies. For each new frequency you try, does it matter whether or not you restart the cart from rest?

Try setting the driver frequency to the natural frequency of the cart-spring system. Determine the response sensitivity by making very small changes in the frequency and watching the result. Plan a strategy to find the frequency for maximum amplitude oscillation.

If you guessed that some other pushing frequencies would be effective, try them to see their effect.

MEASUREMENT

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

When the mechanical oscillator is at or near the natural frequency of the cart-spring system, try to simultaneously observe the motion of the cart and the shaft of the mechanical oscillator. Describe what you see. What happens when the oscillator's frequency is twice as large as the natural frequency?

ANALYSIS

Make a graph of the oscillation amplitude of the cart as a function of the oscillator frequency.

CONCLUSION

Was your prediction correct? How does it differ from the results? Explain. What is the limitation on the accuracy of your measurements and analysis?

How does the maximum kinetic energy of the cart compare with the energy input to the system by each stroke of the mechanical oscillator? Describe, qualitatively, how conservation of energy can be applied to this system.

PROBLEM #5:
SIMPLE PENDULUM

You work for a NASA team investigating the effects of a reduced gravity environment, such as in a space station or the Martian surface, on human biological cycles. One theory is that the body has many mechanical oscillators within it and it is the effect of the gravitational force on these oscillators that changes biological cycles. Although you do not believe this theory, you decide to test it. As a first step, you decide to study a simple cyclical physical system that you know depends on the gravitational force, the pendulum. First you calculate an expression relating the period of the pendulum to the gravitational acceleration and properties of the pendulum. To make your calculation easier, you only consider small oscillations. You will then test your calculations in the laboratory.

EQUIPMENT

The pendulum consists of a small object, called a bob, connected to one end of a string which is suspended by the other end. You will also have a meter stick, a stopwatch, a set of different mass bobs, and a stand from which to hang the pendulum.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett: section 12.4

There are two ways to solve this problem, one using forces and acceleration and the other using conservation of energy. The main features of both are given below. After trying both, decide which you like better. Both should give the same answer.

Method #1 (Force and acceleration)

1. Draw a picture of the pendulum at some typical time in its swing. Label all the forces acting on the bob, all relevant lengths, and the angle of the pendulum. Draw a free-body diagram of the forces on the bob.
2. Choose a coordinate system with one axis along the direction of the bob's motion. Transfer your forces to that coordinate system and relate any angles to the pendulum angle. Write down Newton's second law to express the component of acceleration in the direction the bob moves. The bob moves on the circumference of a circle. What is the radius of that circle?

3. How is the distance that the pendulum bob swings along that circle (its arclength) related to the pendulum angle measured in radians? The acceleration of the bob along its path is the time derivative of how that distance changes with time. Use the arclength relationship to write down the acceleration of the bob along its circular path in terms of the pendulum angle and the length of the pendulum. Use this acceleration in the Newton's law equation from 2.
4. Use the small angle approximation, that the sine of an angle is approximately equal to the angle in radians, to modify your equation so that the only variable is the angle.
5. Solve that equation for the angle of the pendulum as a function of time by guessing a reasonable solution and trying it. How do you justify your guess? Determine the values of constants necessary to satisfy the equation. Which of these constants is related to the period of the system? Why? Show how the period depends on the gravitational acceleration and the length of the pendulum. Sketch a graph of *period vs. gravitational acceleration* for a constant length pendulum**.**

Method #2 (Conservation of energy)

1. Define your system. Be sure to indicate all external forces that can transfer energy to or from the system. Write an energy conservation equation for the system.
2. Use geometry to change terms that involve the height of the pendulum bob into terms involving the pendulum angle.
3. Use the definition of the angle in radians to write the velocity of the pendulum bob in terms of a time derivative of the pendulum angle.
4. Take the time derivative of the resulting conservation of energy equation. Don't forget the Chain Rule. Then use the small angle approximation, that the sine of an angle is approximately equal to the angle in radians, to modify your equation so that the only variable is the angle.
5. Solve that equation for the angle of the pendulum as a function of time by guessing a reasonable solution and trying it. How do you justify your guess? Determine the values of constants necessary to satisfy the equation. Which of these constants is related to the period of the system? Why? Show how the period depends on the gravitational acceleration and the length of the pendulum. Sketch a graph of *period vs. gravitational acceleration* for a constant length pendulum**.**

EXPLORATION

Try different masses for the pendulum bob. According to your prediction, should this change the oscillation frequency? Does it?

Try releasing the pendulum bob at different heights. Does the period vary when the pendulum is released at different heights? What range of angles appears to be *small enough* for the small angle approximation to be good?

Try different lengths for the pendulum. Determine a range of lengths for which you can reliably measure the oscillation frequency, and for which the frequency will vary enough to test your prediction.

Determine an efficient way to vary the length of the pendulum, to measure that length, and to measure the oscillation frequency. Write down your measurement plan.

MEASUREMENT

Follow your measurement plan. Be sure to take more than one measurement for each length, and to estimate the uncertainties in the measurements.

ANALYSIS

As you take each measurement, create a graph of the oscillation period versus the length of the pendulum (with uncertainties). Is the relationship linear? Did you predict a linear relationship? Plot the prediction equation on the same graph as the data.

Use your prediction to decide on a set of axes that will linearize the data (give a linear relationship). Graph your prediction equation and your measurements on these axes.

As a check of your data, use the slope of the line to determine the gravitational acceleration. Compare it to the expected value.

CONCLUSION

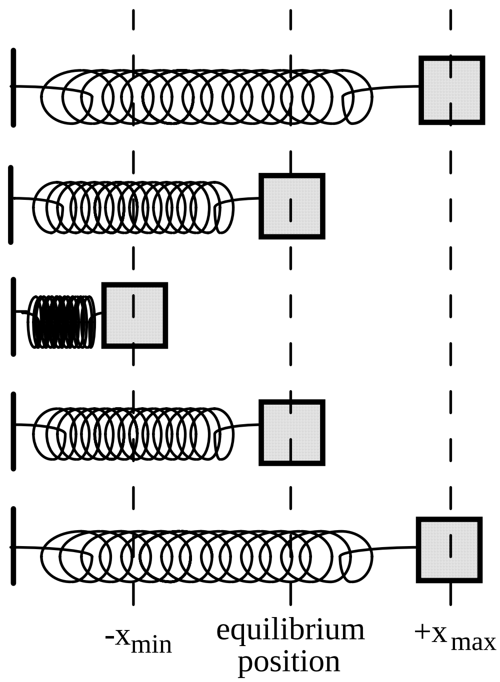
Did the measured period follow your predictions? If not, explain why.

How close is your calculated value for the gravitational acceleration to the accepted value? Based on the uncertainties of your measurements, how close should it be? If it is not close enough, explain why.

If the pendulum were moved from the earth's surface to the surface of the moon, where the gravitational acceleration is approximately one-sixth the value we are accustomed to, what effect should that have on the pendulum's period?

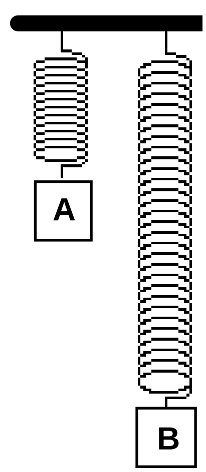
☑ CHECK YOUR UNDERSTANDING

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 frequency (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 which hang vertically. The masses are pulled down and released, but mass B is pulled further down than mass A, as shown at right.



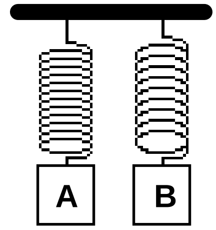
   a. Which mass will take a longer time to reach the equilibrium position? Explain.

   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 which 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.

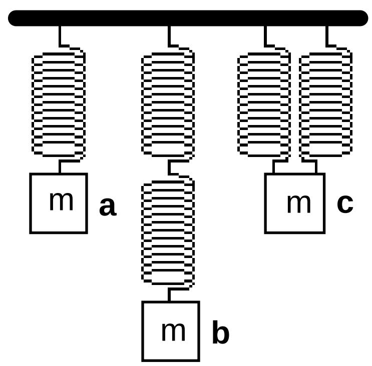
c. The instant after release, which mass has the greater acceleration? Explain.

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 would execute simple harmonic motion with the greatest period? With the least period? Explain.

TA Name:______________________________

PHYSICS 1201 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 questions 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
PREDICTING NON-REPETITIVE MOTION

In this section, you will continue working on problems in dynamics, the relationship of force and acceleration especially in complex situations that occur in biological systems. Of particular interest are problems involving dynamic equilibrium (e.g. terminal velocity), and the motion of an object that takes place in two dimensions.

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.
- Improve your problem solving skills.

PREPARATION:

Read Serway & Jewett, chapter 2, chapter 3 (sections 1-4), chapter 4 (sections 1-7), chapter 5 (sections 1-4), chapter 10 (section 1), chapter 15 (section 4). It is likely that you will be doing some of these laboratory problems before your lecturer addresses this material. It is very important that you read the text before coming to lab.

Before coming to lab you should be able to:

- Determine the components of forces.
- Add forces by adding their components.
- Use Newton's second law to relate force to acceleration.
- Draw and use free-body diagrams.
- Use calculus to relate position, velocity, and acceleration.
- Write down the form of the retarding or drag force against an object moving through a liquid.

PROBLEM #1:
MOTION IN A FLUID

You are studying bacteria as migrate through the body. You know that when single-cell organisms such as bacteria move, the medium through which they move plays a dominant role. The fluid surrounding the organism exerts a force which depends on the organism's size and velocity. When it begins to move, the tiny organism quickly reaches a terminal velocity, after which it must constantly expend energy to continue at the same velocity. Your have been asked to investigate that stage in a microorganism's motion. As a first step to understanding the approach to terminal velocity, you decide to model the organism as a spherical bead falling through a liquid. You calculate the velocity of a bead as a function of time, the properties of the bead, and the properties of the fluid. You then check your calculation in the lab.

EQUIPMENT

For this problem you will have small spheres or beads of different sizes, water to serve as a viscous fluid, beakers, a stopwatch, a meter stick, a balance, magnets, a video camera and a computer with a video analysis application written in LabVIEW™.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, section 5.4, example 5.10, and section 15.4.

1. Draw a picture of a bead, immersed in fluid, dropping with some velocity along the vertical direction. In this picture, draw and label all the forces acting on the bead.
2. Write down an expression for the buoyant force acting on the bead. What is the direction of this force?
3. Write down an expression for the drag force encountered by the bead as it moves through the fluid. Explain why this force is proportional to the velocity of the bead. What is the direction of this force relative to the velocity? How does this force depend on the properties of the bead and the fluid?
4. Write down Newton's second law for the bead, putting in all the forces you identified in the previous steps. What is the value of the bead's acceleration after it has reached terminal velocity?

5. Solve for the velocity of the bead as a function of time and find the terminal velocity. How does the terminal velocity depend on the properties of the bead and the viscosity of the fluid?

EXPLORATION

Choose an appropriate container for the fluid. Determine the amount of fluid and the range of distances the bead falls through that would suffice to measure the approach to terminal velocity accurately. Use a stopwatch to estimate the terminal velocity. Check if the height at which the bead is dropped affects the velocity. Check if dropping the bead near the walls of the container affects the measurement. Decide on the best position of the camera. Determine the range of mass and size of the beads available. How many different beads will you need for your measurement?

Write down your measurement plan.

MEASUREMENT

Measure the relevant properties of each bead. Measure the density of the fluid.

Drop a bead and video its descent. While analyzing the video, make sure you set the scale for the axes of your graph so that you can see the data points as you take them. Determine the velocity from both the plot of position versus time and the plot of velocity versus time. Which one do you think is more reliable?

Repeat the procedure for beads of different sizes.

ANALYSIS

Make a graph of the terminal velocity as a function of the diameter of the bead and compare it to your prediction. Calculate the viscosity of the fluid from the measured relationship between velocity and bead diameter. Does the computed value seem reasonable?

CONCLUSION

Do your measurements agree with your predictions? If not, explain why not.

How fast does the bead reach terminal velocity? How does this depend on the properties of the bead?

PROBLEM #2:
MOTION UP AND DOWN AN INCLINE

You are a safety consultant for the Valley Fair amusement park. They have asked you to examine the safety of a proposed ride. The ride launches a roller coaster car up an inclined track. Near the top of the track, the cart reverses its direction and rolls backward. The regulations set the maximum acceleration that is safe for most people. The launcher and catching mechanism at the beginning and end of the ride have already been shown to be safe. However, your employers are worried about the acceleration as the car goes up and down the track, especially at the top where the car reverses direction. To address the issue, you calculate the car's position and velocity up and down the track as a function of time, the properties of the track, and the properties of the car. From these graphs you determine the car acceleration paying particular attention to its acceleration at the top of the track? You decide to test your calculation in the lab.

EQUIPMENT

For this problem you will have a stopwatch, a meter stick, an end stop, wood block, a video camera and a computer with a video analysis application written in LabVIEW™. You will also have a cart and a track.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equations that give a solution to the problem. Make sure that you state any approximations or assumptions that you are making.

What is the acceleration (direction and magnitude) of the cart when it reaches its highest point on the inclined track? What is its acceleration (direction and magnitude) as it moves up to that point? As it moves down from that point?

WARM-UP QUESTIONS

Read Serway & Jewett chapter 2 and chapter 4.

1. Draw a picture of a cart moving up an inclined track. Label all forces acting on the cart. Are there any forces that can be neglected? Indicate the direction of acceleration.
2. Choose a coordinate system and draw it next to your diagram.
3. For the coordinate system you have chosen, use Newton's Second Law to write equations for each axis separately. Check that the sign of each term in your equations matches your coordinate system. Write an expression for the acceleration (magnitude and direction) in terms of other quantities that you know or can measure.

4. Repeat steps 1-3 for the cart moving down the incline.

5. Repeat steps 1-3 for the cart at its highest point. Is it possible that the acceleration of the cart at the top of the track is zero? What would that imply about the forces on the cart at the top of the ramp? Is this realistic? Explain.

6. Compare the three expressions for the acceleration obtained from questions 3, 4, and 5 in both magnitude and direction. How does the acceleration change during the motion up and down the ramp?

7. Use calculus to write an equation for the cart's velocity as a function of time from its acceleration. Is there any time at which the velocity of the cart is zero? From your equation, what is the cart's acceleration at that time?

8. Use calculus to write an equation for the cart's position as a function of time from its velocity. From this equation, is there a time at which the position of the cart is a maximum? From your equation, write an equation for the velocity of the cart at that time. From your equation, determine the acceleration of the cart at that time.

9. Use the simulation "Lab1Sim" to explore the approximate the conditions of your experiment. Produce graphs *position vs. time* and *velocity vs. time* graphs of simulated motion up and down a ramp. You will likely need to select more frames than previous simulations to get the correct motion. 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

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. Is it speeding up or slowing down? What is the direction of its acceleration? When the cart reaches its highest point, what is its velocity? Just before it reached that point was it speeding up or slowing down? What was the direction of its acceleration? Observe the cart as it moves down the inclined track. Just after it reached its highest point was it speeding up or slowing down? What was the direction of its acceleration? Do your observations agree with your prediction? If not, this is a good time to change your prediction.

Where is the best place to put the camera? Which part of the motion do you wish to capture? Is there any advantage to rotating the angle of the camera? What is your calibration object?

Try several different angles. **Be sure to catch the cart before it collides with the end stop at the bottom of the track.** If the angle is too large, the cart may not go up very far and 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.

Choose the angle that gives you the best video record.

What is the total distance through which the cart rolls? How much time does it take? Use these measurements to determine the scales for the axes of the graphs for your computer data acquisition.

Determine how you will measure the angle, the distance rolled, the cart's acceleration and its velocity. Write down your measurement plan.

MEASUREMENT

Using the plan you devised in the exploration section, make a video of the cart moving up and 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).*

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

ANALYSIS

Choose a function to represent the *position vs. time* graph. How can you estimate the values of the parameters of the function? You may waste a lot of time if you just try to guess the constants. What kinematics quantities do these constants represent? Can you tell from your graph where the cart reaches its highest point?

Choose a function to represent the *velocity vs. time* graph. How can you calculate the values of the constants of this function from the function representing the *position vs. time* graph? Check how well this works. What kinematics quantities do these constants represent? Can you tell from your graph where the cart reaches its highest point?

From the *velocity vs. time* graph determine if the acceleration changes as the cart goes up and then down the ramp. Use the functions representing the *velocity vs. time* graph and the *position vs. time* graph to calculate the acceleration of the cart as a function of time. Do the two calculations agree? Make a graph of *acceleration vs. time*. Can you tell from your *acceleration vs. time* graph where the cart reaches its highest point?

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

CONCLUSION

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

Does the cart have the same acceleration throughout its motion? Does the acceleration change direction? Is the acceleration zero at the top of its motion, or nonzero? Describe the acceleration of the cart through its entire motion **after** the initial push. Justify your answer. What are the limitations on the accuracy of your measurements and analysis?

How does the direction of the acceleration of the cart going down a track correspond to the direction of the total force on the cart as it goes down that track? Up the track? When the cart reaches its highest point, what is the total force on the cart? How does this total force correspond to the cart's acceleration?

SIMULATION

If your data did not match your expectations, you should go back and use the simulation to explore what could have happened.

A computer simulation of the motion, "Lab1Sim", will let you determine how parts of the experiment outside your control in the real world could affect your results. See *Appendix F* for an introduction to the Simulation Programs.

Adjust the simulation settings to find conditions that will produce motion similar to the cart in this problem. For example, you can adjust friction or air resistance to see what role they play in the results. Produce simulated *position vs. time* and *velocity vs. time* graphs of constant velocity motion, and verify that they meet your expectations.

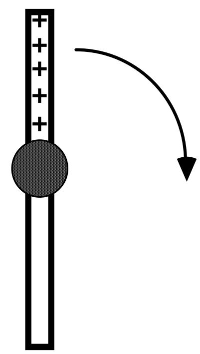
Now produce graphs that more closely match the motion you measured. Add the amount of uncertainty that you estimated for your measurement to the position measurements by pressing "Add Error" in the "Graph frame." Can you more easily see the effect in the *position vs. time* graph or in the *velocity vs. time* graph? Compare the simulated graphs to your graphs of the car's motion.

PROBLEM #3:
CIRCULAR MOTION

You have been asked to help evaluate a new ultracentrifuge for the microbiology laboratory. The device consists of hole in a steel beam, which is pivoted about its center, to insert test tubes. For most of the process, the beam rotates about its center in a horizontal circle at a constant speed. Your task is to calculate the acceleration of each test tube as a function of its speed and position. To check your calculation in the laboratory, you also calculate the perpendicular components of each test tube's velocity as a function of time and use those equations to calculate the magnitude of the acceleration as a function of time. Then you go to test your calculations using a laboratory model of a centrifuge that operates at lower speeds.

EQUIPMENT

You will be using a rotational apparatus that spins a horizontal beam on a stand. A top view of the device is shown to the right. You will have a stopwatch, a meter stick and the video analysis equipment.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

Make a graph of *position vs. time* and *velocity vs. time* for one position on your rotating beam.

WARM-UP QUESTIONS

Read Serway & Jewett sections 3.4, 5.3, and 10.1.

1. Draw the trajectory of an object moving in a horizontal circle with a constant speed. Choose a convenient origin and coordinate axes. Draw the vector that represents the position of the object at some time when it is not along an axis.

2. Write down an equation for one component of the position vector as a function of the radius of the circle and the angle the vector makes with one axis of your coordinate system. Sketch a graph of x-*position vs. time* and *y-position vs. time*.

3. Use calculus (and the Chain Rule) to write an equation for each component of the velocity. For this motion, the rate that the angle changes with time, called the angular speed, is constant.

4. Using your equations for the components of the velocity of the object as a function of time, write an equation for the speed of the object. Is the speed a function of time or is it constant? Use this equation to express the angular speed in terms of the speed of the object.

5. Since angular speed is constant, use calculus to write down an equation for the angle as a function of time. Substitute this into your equations for position and velocity and sketch a graph for each component as a function of time.

6. Use the calculus relationship between velocity and acceleration to write down the equation for each component of the acceleration of the object. Sketch a graph for each component of the acceleration as a function of time.

7. Using your equations for the components of the acceleration of the object as a function of time, write an equation for the magnitude of the acceleration of the object. Is the magnitude of acceleration a function of time or is it constant?

EXPLORATION

Practice spinning the beam at different speeds. How many rotations does the beam make before it slows down appreciably? Use the stopwatch to decide which spin gives the closest approximation to constant speed. At that speed, make sure you will get enough video frames for each rotation to make your measurement.

Check to see that the spinning beam is level.

Move the apparatus to the floor and adjust the camera tripod so that the camera is directly above the middle of the spinning beam. Practice taking some videos. How will you make sure that you always click on the same position on the beam?

Decide how to calibrate your video. Decide how many different positions on the beam you need to measure and write down your measurement plan.

MEASUREMENT

Use the video software to acquire data for the position of a fixed point on the beam in enough frames of the video so that you have the sufficient data to accomplish your analysis. Your video should consist of more than two complete rotations. 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 object travels and total time to determine the maximum and minimum value for each axis before taking data.

Measure as many different positions as called for by your plan.

ANALYSIS

Analyze the motion for both of the components that you chose. How can you tell from each graph when a complete rotation occurred?

Compare the speed that you obtain from your graphs with your measurements using a stopwatch and meter stick.

CONCLUSION

How do your graphs compare to your predictions and warm-up questions? What are the limitations on the accuracy of your measurements and analysis?

Is it true that the velocity of the object changes with time while the speed remains constant?

Is the instantaneous speed of the object that you calculate from your measurements the same as its average speed that you measure with a stopwatch and meter stick?

Have you shown that an object moving in a circle with a constant speed is always accelerating? Explain.

Compare the magnitude of the acceleration of the object that you calculate from your measurements to the "centripetal acceleration" that you can calculate from the speed and the radius of the object.

PROBLEM #4:
TWO-DIMENSIONAL MOTION

You are investigating the integration of the nervous system, and how the brain processes sensory input to guide the body's movements. While a subject performs a task, the subject's brain activation and neural response are mapped. You decide to investigate the common but complex activity of catching a ball. One goal of the investigation is to determine if the brain's activity when perceiving an object moving in two dimensions is qualitatively different from its activity when the object moves in only one dimension. Before study begins, you have been assigned to calculate the position, velocity, and acceleration for a ball tossed through the air, as functions of time and make graphs of those functions. They will later be checked against the observer's brain activity. The next step is to check your calculations in the lab.

EQUIPMENT

For this problem, you will have a ball, a stopwatch, a meter stick, a video camera and a computer with a video analysis application written in LabVIEW™.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett section 3.3 and examples 3.2, 3.3 and 3.4.

1. Draw a picture of the path of motion for the tossed ball. Draw the ball at several points along the trajectory. At each of those positions draw and label the forces on the ball as well as the velocity and acceleration vectors that describe the motion of the ball. If any angles are involved, label them as well.
2. Are there any forces you assume are so small they can be neglected? Do the forces on the ball change or remain constant as it moves? Is the acceleration indicated in your drawing constant or does it change with time?
3. Draw a convenient coordinate system. For each position of the ball that you drew on its trajectory, draw the x and y components of the velocity and acceleration of the ball. Check to see that the change of each component of the velocity vector is consistent with that component of the acceleration vector. Also check that the vector sum of the x-velocity and y-velocity you have drawn matches the magnitude and direction of the velocity vector you have drawn at that position. Explain your reasoning.
4. Write down an equation for horizontal acceleration as a function of time. What causes this acceleration? Is this acceleration changing with time or is it constant? Use the relationship between velocity and acceleration to write an equation for horizontal velocity

as a function of time for this situation. Use calculus and the relationship between position and velocity to write an equation for the horizontal position as a function of time.

5. Repeat Question 4 for the vertical direction.

6. Use the simulation “Lab2Sim” to simulate the situation in this problem. Note that in this case the initial velocity should have non-zero horizontal and vertical components.

EXPLORATION

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 **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. Are there enough points to make the measurement? Adjust the camera position to give you enough data points. You should be able to reproduce the conditions described in the predictions.

Measure the distance that the ball goes. The distance and time you measure here will be useful to set the scales of the graphs in your video analysis.

Although the ball is the best item to use to calibrate the video, the image quality due to its motion might make this difficult. 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. Take a test video to determine if you need a separate calibration object and where it is best to place it if needed.

Quickly step through the video and determine which part of the ball is easiest to consistently locate. You should use the same part of the ball for each measurement.

Write down your measurement plan.

MEASUREMENT

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

Use the video software to acquire data for the position of the ball in enough frames of the video so that you have the sufficient data to accomplish your analysis. Make sure you set the scale for the axes of your graphs so that you can see the data points as you take them. Use your measurements of total distance the ball travels and total time from the exploration section to determine the maximum and minimum value for each axis before taking data.

ANALYSIS

Choose a function to represent the horizontal position versus time graph and another for the vertical position graph. How can you estimate the values of the constants of the functions from the graph and other information that you know? You can waste a lot of time if you just try to guess the constants. What kinematics quantities do these constants represent?

Choose a function to represent the *velocity vs. time* graph for each component of the velocity. What kinematics quantities do the constant parameters of the function represent? How can you calculate the values of the constants of these functions from the functions representing the position versus time graphs? Check how well this works. Determine the launch velocity of the ball from this graph. Is this value reasonable? Determine the velocity of the ball at its highest point. Is this value reasonable?

From the *velocity vs. time* graph determine the acceleration of the ball independently for each component of the motion. Determine the magnitude of the ball's acceleration at its highest point. Is this value reasonable?

CONCLUSION

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

What is the total vertical force on the ball? How does this explain the behavior of its vertical velocity? What is the total horizontal force on the ball? How does this explain the behavior of its horizontal velocity?

SIMULATION

If your results did not completely match your expectations, use the simulation "Lab2Sim" (*Appendix F*) to see the effects of air resistance.

Produce simulated *position vs. time* and *velocity vs. time* graphs, in both the horizontal and the vertical directions, for a ball tossed into the air and verify that they meet your expectations. Use the simulation controls to vary the amount of air resistance and the error. Can you more easily see the effects in the *position vs. time* graph or in the *velocity vs. time* graph? Compare the simulated graphs to your graphs of the ball's motion.

Add measurement uncertainty to the simulation to see if it agrees with your measurements.

PROBLEM #5:
BOUNCING

You are working for NASA to design a low cost landing system for a mission to look for life on Mars. The payload will be surrounded by a big padded ball and dropped onto the surface. When it reaches the surface, it will simply bounce. The height and the distance of the bounce will get smaller with each bounce so that it finally comes to rest on the surface. Your group needs to design the biological probes to survive the landing and subsequent bouncing. The group is also concerned with the distance that the bouncing might carry the probe away from the primary landing site. You have been assigned to determine how the ratio of the horizontal distance covered by two successive bounces depends on the ratio of the heights of each bounce and the ratio of the horizontal components of the velocity of each bounce. After making the calculation you decide to check it in your laboratory on Earth.

EQUIPMENT

For this problem, you will have a ball, a stopwatch, a meter stick, and a computer with a video camera and an analysis application written in LabVIEW™.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett section 3.3 and examples 3.2, 3.3 and 3.4.

1. Draw a picture of the situation including the velocity and acceleration vectors at all relevant times. Decide on a coordinate system to use. Is the acceleration of the ball during the bouncing constant or is it changing? Why? What is the relationship between the acceleration of the ball before and after a bounce? Are the time intervals for two successive bounces equal? Why or why not? Clearly label the horizontal distances and the heights for each of those time intervals. What reasonable assumptions will you probably need to make to solve this problem? How will you check these assumptions with your data?

2. For the time between successive bounces write down an equation that gives the horizontal distance traveled as a function of the time and the horizontal component of velocity. Is that component of velocity constant or changing in that time interval? Why? Write down another equation to solve for that time from the vertical motion.

3. Combining the previous steps gives you an equation for the horizontal distance of a bounce in terms of the ball's horizontal velocity, the height of the bounce, and the vertical acceleration of the ball.

4. Repeat the above process for the next bounce and take the ratio of horizontal distances.

5. Examine the forces on the ball during the bounce. Over that very short time interval, what is the direction of its acceleration? Does the horizontal component of the ball's velocity change or remain constant during the bouncing process? Explain.

EXPLORATION

Position the camera and adjust it for optimal performance.

Practice bouncing the ball without spin until you can get at least two full bounces to fill the video screen. Three is better so you can check your results. It will take practice and skill to get a good set of bounces. Everyone in the group should try to determine who is best at bouncing the ball.

Determine how much time it takes for the ball to have the number of bounces you will video and estimate the number of video points you will get in that time. Is that enough points to make the measurement?

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 to your results. 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. Write down your measurement plan.

MEASUREMENT

Make a video of the ball being bounced. 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 the sufficient data to accomplish your analysis and check to see if your assumptions about the motion are correct. Make sure you set the scale for the axes of your graph so that you can see the data points as you take them.

ANALYSIS

Analyze the video to get the horizontal distance of two successive bounces, the height of the two bounces, and the horizontal components of the ball's velocity for each bounce. The point where the bounce occurs will usually not correspond to a video frame taken by the camera so some estimation is necessary to determine this position. Can you tell where the bounce occurs in the vertical *position vs. time graph*? Can you tell where the bounce occurred in the horizontal *position vs. time* graph? How about the *velocity vs. time* graphs?

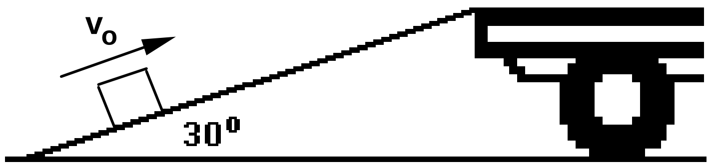
CONCLUSION

How do your graphs compare to your predictions and warm-up questions? What are the limitations on the accuracy of your measurements and analysis? Use your data to measure the gravitational acceleration to give you a measure of its accuracy.

Will the ratio you calculated be the same on Mars as on Earth? Why or why not?

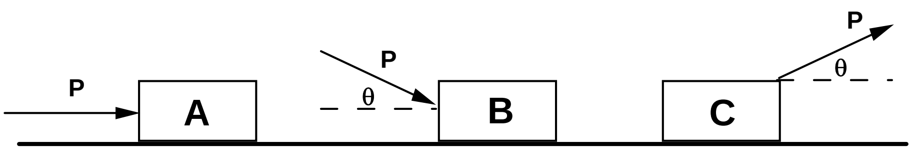
☑ CHECK YOUR UNDERSTANDING

1. A crate is given an initial push up the ramp of a large 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 floor is μ_k.



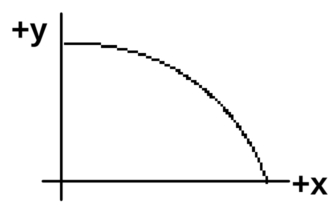
Will the magnitude of the acceleration of the sliding crate be greater on the way up or on the way back down the ramp? Or will the accelerations be the same? Explain using appropriate force diagrams.

2. 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 force diagrams and Newton's second law.

3. 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 the *horizontal position (x) versus time* graph? Explain your reasoning.

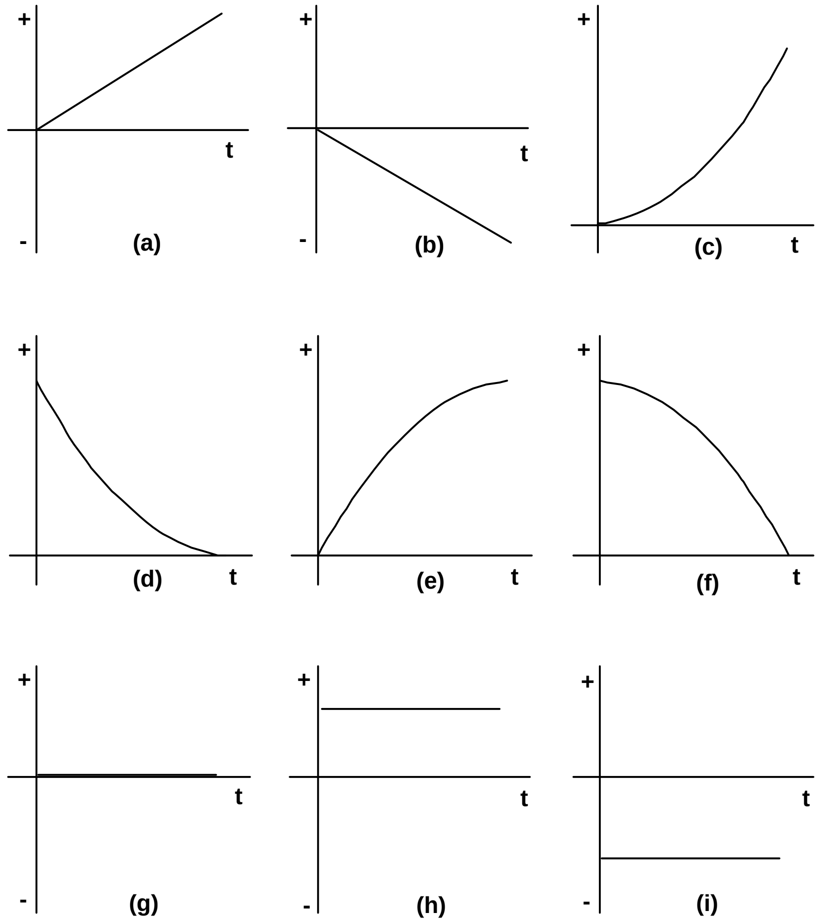
b. Which graph below best represents the *horizontal velocity (v_x) versus time* graph? Explain your reasoning.

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.

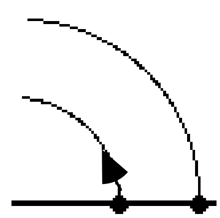


4. Suppose you throw a ball vertically up into the air with an initial velocity v_o.

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

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

5. 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 the greater acceleration? Explain your reasoning.

TA Name:______________________________

PHYSICS 1201 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 questions 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 VI
ENERGY AND THERMAL PROCESSES

The change of the internal energy of a system is often, but not always, signaled by a change in its temperature. This type of change is clearly very important for biological systems. After all one way to determine if you are ill is to measure your temperature. In this lab you will concentrate on quantifying the changes in internal energy within the framework of conservation of energy.

In the problems of this lab, you will master the relation of the temperature of objects to their internal energy and the notion of specific heat. Specific heat is a historical name for a quantity that isn't actually heat. You now know that energy can be transferred from one object to another by mechanical means. In this laboratory you will also explore the very common energy transfer from an object at higher temperature to an object of lower temperature. The energy transferred is called heat.

Many biological processes depend on energy cycles for their operation. One of the characteristics of a biological cycle is that energy is input and energy is output but the energy and state of the system itself does not change. In this laboratory you will investigate a system that undergoes a cycle: a heat engine.

OBJECTIVES:

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

- Use the principle of conservation of energy as a means of predicting the behavior of systems transferring energy by a variety of mechanisms such as mechanical, electrical, and heat.
- Calculate the change of internal energy of an object when its temperature changes.
- Use the concept of specific heat to calculate the energy change of an object.

PREPARATION:

Read Serway & Jewett, sections 6.8, 16.2, 16.4, 17.1, 17.2, 17.4 - 17.7, 18.1 - 18.3, and 25.1.

Before coming to lab you should be able to:

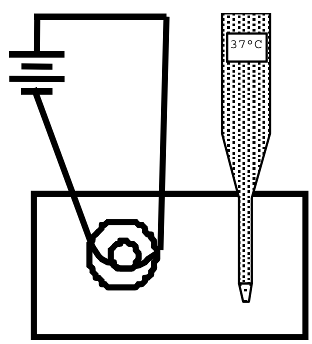
- Define and recognize the differences between these concepts:
  - heat and temperature
  - internal energy and energy transfer
  - heat and specific heat.
  - energy and power.
- Use the principle of conservation of energy and define a system for its use.
- Use the heat capacity to determine the change in internal energy of a system.
- Define what is meant by efficiency.

PROBLEM #1: POWER AND TEMPERATURE CHANGE

You have a position working with a group investigating biological mechanisms that determine a predisposition to obesity. Your assignment is to measure the rate that energy is output by certain types of cells when a nutrient is introduced. To begin this study, you have decided to use a calorimetric technique. A culture of cells with the appropriate nutrient is placed inside a closed container. That container is submerged in a water bath and you measure the rate that the temperature of the bath changes. To calibrate the apparatus, you decide to use a light bulb connected across a known voltage as a power source. You know that the power output by the bulb is just the current through the bulb times the voltage across the bulb. You then will compare that power to the rate that the internal energy of the water bath changes by measuring its temperature as a function of time. To accomplish this calibration, you calculate rate of temperature change as a function of the voltage across the bulb, the current through the bulb, the specific heat of the water, and the amount of the water. You know that even with good insulation, your apparatus will transfer some energy to the outside and your measurements will allow you to correct for this.

EQUIPMENT

You will have a constant voltage power supply, wires, a light bulb, digital multimeters (DMMs), a digital thermometer, a balance, water, and water containers.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 6.8, 16.2, 17.1, 17.2, and 25.1.

1. Make a sketch of the situation. Identify and label the quantities you can measure or look up. Write down the general conservation of energy equation and decide how it will apply to this situation.

2. Identify your system. Decide on the initial time for which you want to calculate the energy of your system and draw the system. Write down the expression for the energy of your system at that time. Decide on the final time for which you want to calculate the energy of your system and draw it. Write down the expression for the energy of your system at that time. Write down an expression for any energy transferred to or from your system. Identify the energy transfer on your drawing and whether the terms represent energy input or energy output for your system.
3. Write an equation that gives the rate that the energy of the liquid changes as its temperature changes. Write the equation that gives the rate that energy is output by the bulb.
4. Determine if any of the energy inputs into the system are small enough to be neglected. Determine if any of the energy outputs into the system are small enough to be neglected. Write down the conservation of energy equation specifically for this situation. Change this to a rate equation by using calculus.
5. Assuming that nothing but electricity transfers energy to or from your system, write an equation for the change in the temperature of the liquid as a function of time. Sketch a graph representing this function and write down how you can determine the power transferred from your system.

EXPLORATION

Assemble the circuit. Verify that you can measure current flowing in your circuit and voltage across the bulb. Determine if you need to do these measurements continuously or just once by making the measurements several times before putting the bulb in the liquid. See *Appendix A* for instructions about how to use the DMM to measure current and voltage. **BE SURE TO CONNECT THE DMM CORRECTLY FOR EACH MEASUREMENT!**

The submerged light bulb will heat the liquid in the bottle very slowly. Determine how much liquid should be used for the best result. Explain your reasoning. Try a short trial to see how much time it takes for the temperature of water to go up 1 degree. Try a few ideas to see if you can speed up the processes. Should you measure the temperature in Fahrenheit, or Celsius? Does it matter?

Determine how you can minimize any energy transfer that you cannot measure. Make some quick measurements to see how well they work.

Outline the measurement procedure you plan to use and conduct tests to estimate how long your measurement will last. The longer the measurement takes, the larger will be the affects of uncontrolled and unavoidable energy transfer. Write down your measurement plan.

MEASUREMENT

Using the procedure from your exploration, make the necessary measurements that will allow you to determine the power output of the light bulb from electrical measurements and also from the temperature increase of the water if other energy transfers were negligible.

ANALYSIS

From the data you collected, create a graph of the *temperature vs. time*. Use that graph to determine the power input to the water.

Compare the electrically measured power output of the light bulb to its power output calculated from the temperature of the water using the conservation of energy. From your results determine the size of the other sources of energy transfer.

CONCLUSION

Did your results match your prediction? Explain if it did not.

How do these two values of the bulb's power compare? Are they within the uncertainty of your measurement accuracy? How significant is the energy transferred to the surrounding air? What other form(s) of energy does a bulb generate?

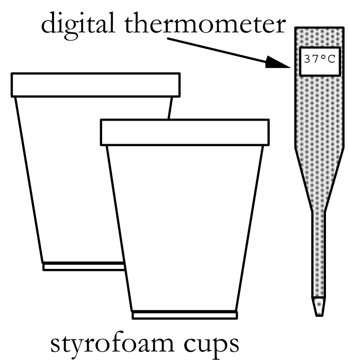
Can you use this type of apparatus to make your measurements of metabolic processes? What modifications might be necessary?

PROBLEM #2:
SPECIFIC HEAT OF SIMPLE OBJECTS

You are working in a research group investigating ways of transporting organs more effectively. Successful organ transplants require the organ be kept within a narrow range of temperatures during transportation from the donor to the recipient. The transportation device must be as small and compact as possible. In the procedure being tested, the organ is immersed in a liquid. You have been asked to calculate how the temperature of the organ responds to the temperature of its surrounding liquid and vice versa so you devise a procedure to measure its specific heat. An organ is very complex so you decide to test your method on metal objects of known specific heat. First you calculate the specific heat of an object as a function of the initial temperatures of both the metal and the liquid, and the final temperature after the metal and liquid reach equilibrium and the relevant properties of the metal and the liquid. Then you will check you calculation in the lab.

EQUIPMENT

You will have two different homogenous metal objects. Styrofoam cups, a digital thermometer, a balance, a stopwatch, a pair of scissors, and a ruler are also available.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 16.2, 17.1, and, 17.2.

1. Make two sketches of the situation: one just after the object is placed into the water and the other one after the object and water reach the same temperature. Label all of the quantities that you know or wish to know on both sketches.

2. Write down the general conservation of energy equation. To apply it to this situation, first decide on the system that you wish to consider. Write down a conservation of energy equation for this system and the initial and final time represented by your sketches in question 1.

3. Write down an equation that relates the initial internal energy of your system to its temperature or temperatures. Do the same for the final internal energy. Decide if you know the other quantities necessary to calculate the internal energy of your system from its temperature(s) or must calculate them from other information.
4. Determine if there is any energy transferred either to or from your system from another object between the initial time and the final time. Decide if this energy transfer is small enough to be neglected. If it is not, write down the source or receiver of this energy. Calculate this energy transfer by applying the conservation of energy equation to the source or receiver (i.e. taking the source/receiver as the system for another conservation of energy equation).
5. Write down a mathematical plan to solve your conservation of energy equation or equations for the specific heat of the object as a function of quantities you can measure.

EXPLORATION

WARNING: Be careful not to get scalded while handling heated water, as well as the hot plates.

Optimal use of the Styrofoam cups can minimize the energy transfer from the water to the environment. First you need to determine the approximately amount of time you will need to do your measurement. This tells you the time the energy transfer of your cup needs to be negligible. The shorter the time, the less energy will be transferred out of the cup. Try different amounts of water to determine how this time depends on the amount of water in the cup. Do you want to use a lot of water or a little?

Now that you have decided on the amount of water, put that amount of hot water in your cup and measure the temperature change for the time you will need. Is it negligible? If not, try different configurations of Styrofoam cups. Do two cups (one inside the other) work better? Three cups? Does covering the cup with a lid made from another cup help? After you have minimized the energy transfer from the cup and if it is still not negligible, measure that energy transfer as a function of time so that you can use it in your conservation of energy equation.

Determine which initial water temperature will minimize any unwanted energy transfers. Should it be colder than room temperature, equal to room temperature, or greater than room temperature?

You cannot measure the temperature of a metal object by sticking a thermometer in it or putting a thermometer on it. Discuss with your group to decide on a procedure for accurately measuring the initial and final temperature of your object using a thermometer.

The metal object is not the only thing in contact with the water during the measurement. The inside surface of the Styrofoam cup and the thermometer contact the water. Since both of those objects change their temperature to match that of the water, energy is transferred between them and water. Make a quick measurement to determine if this amount of energy is negligible for your purpose. If it is not, measure it and include this energy transfer in your conservation of energy equation.

Carefully examine the thermometer. You can tell if the scale is *Fahrenheit* or *Celsius* by measuring the room temperature. Does this thermometer have a switch to change temperature scales? If so set it to the one best suited for your calculations. Determine what part of the thermometer actually measures the temperature by holding your hand on different parts and seeing it the readings change. Make sure that the temperature measuring part is fully submerged in the water.

Decide if your measurement will be more accurate if you leave the thermometer in the water for the entire time or if you only insert the thermometer briefly when you want a temperature measurement.

What procedure should you use for putting the object into the cup? Should this be done fast or slow? Does water splash affect your measurement?

Write down a plan for giving you the most accurate results possible.

MEASUREMENTS

Follow the plan that you outlined in your Exploration.

Take temperature measurements for each object if the object starts out much colder than the water temperature and also if it starts out much warmer than room temperature.

ANALYSIS

Based on your temperature measurements, calculate the specific heat of the two homogeneous objects. What is the uncertainty in your measurement? Compare the specific heat for each object if it starts hot or starts cold. Compare this difference with your measurement uncertainty.

Use the chart at the end of this laboratory to look up the specific heat of your objects. What material are your objects made of?

CONCLUSION

Did your results agree with your prediction? Explain.

Does the specific heat of an object depend on whether it is hot or cold?

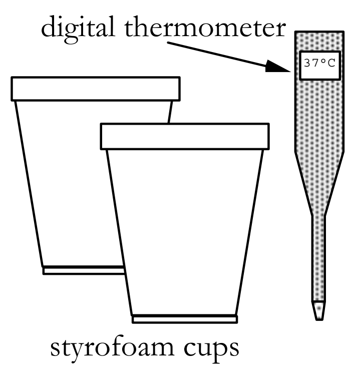
If you knew the specific heat of an organ and wished to cool it from body temperature to a certain final temperature by immersing it in a certain amount of liquid, what formula would you use to determine what the initial temperature of the liquid should be?

PROBLEM #3:
SPECIFIC HEAT OF COMPLEX OBJECTS

You are working in a research group investigating ways of transporting organs more effectively. Successful organ transplants require the organ be kept within a narrow range of temperatures during transportation from the donor to the recipient. The transportation device must be as small and compact as possible. In the procedure being tested, the organ is immersed in a liquid. You have been asked to calculate how the temperature of the organ responds to the temperature of its surrounding liquid and vice versa so you devise a procedure to measure its specific heat. Although an organ is very complex you have previously measured the specific heat of the types of tissue of which it is comprised. You also have a computer model of how each type of tissue is distributed in the organ. From this information, you believe you can calculate the specific heat of an organ but you need to check your calculation on a simple laboratory model. The model you decide to use an object consisting of two different kinds of metal that you will immerse in a liquid bath.   First you calculate the specific heat of an object as a function of the initial temperatures of both the metal and the liquid, and the final temperature after the metal and liquid reach equilibrium and the relevant properties of the metal and the liquid. Then you will check you calculation in the lab.

EQUIPMENT

You will have three different metal objects. Two of them will be the homogeneous metals making up a complex object. Styrofoam cups, a digital thermometer, a balance, a stopwatch, a pair of scissors, and a ruler are also available.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 16.2, 17.1, and, 17.2.

1. Make two sketches of the situation: one just after the object is placed into the water and the other one after the object and water reach the same temperature. Label all of the quantities that you wish to know on both sketches.

2. Write down the general conservation of energy equation. To apply it to this situation, first decide on the system that you wish to consider. Write down a conservation of energy equation for this system and the initial and final time represented by your sketches in question 1.
3. Write down an equation that relates the initial internal energy of your system to its temperature or temperatures. Do the same for the final internal energy. Decide if you know the other quantities necessary to calculate the internal energy of your system from its temperature(s) or must calculate them from other information.
4. Determine if there is any energy transferred either to or from your system from another object between the initial time and the final time. Decide if this energy transfer is small enough to be neglected. If it is not, write down the source or receiver of this energy. Calculate this energy transfer by applying the conservation of energy equation to the source or receiver (i.e. taking the source/receiver as the system for another conservation of energy equation).
5. Write down a mathematical plan to solve your conservation of energy equation or equations for the specific heat of the object as a function of quantities you can measure.
6. Write down an equation to calculate the specific heat of the complex object from the specific heat of each homogeneous object and the measured volume of each material making up the complex object.

EXPLORATION

WARNING: Be careful not to get scalded while handling heated water, as well as the hot plates.

Optimal use of the Styrofoam cups can minimize the energy transfer from the water. First you need to determine the approximately amount of time you will need to do your measurement. This tells you the time the energy transfer of your cup needs to be negligible. Try different amounts of water to determine how this time depends on the amount of water in the cup. Do you want to use a lot of water or a little?

Now that you have decided on the amount of water, put that amount of hot water in your cup and measure the temperature change for the time you will need. Is it negligible? If not, try different configurations of Styrofoam cups. Do two cups (one inside the other) work better? Three cups? Does covering the cup with a lid made from another cup help? After you have minimized the energy transfer from the cup and if it is still not negligible, measure that energy transfer as a function of time so that you can use it in your conservation of energy equation.

Determine which initial water temperature will minimize any unwanted energy transfers. Should it be colder than room temperature, equal to room temperature, or greater than room temperature?

You cannot measure the temperature of a metal object by sticking a thermometer in it or putting a thermometer on it. Discuss with your group to decide on a procedure for accurately measuring the initial and final temperature of your object using a thermometer.

The metal object is not the only thing in contact with the water during the measurement. The inside surface of the Styrofoam cup and the thermometer contact the water. Since both of those objects change their temperature to match that of the water, energy is transferred between them and water. Make a quick measurement to determine if this amount of energy is negligible for your purpose. If it is not, measure it and include this energy transfer in your conservation of energy equation.

Carefully examine the thermometer. You can tell if the scale is *Fahrenheit* or *Celsius* by measuring the room temperature. Does this thermometer have a switch to change temperature scales? If so set it to the one best suited for your calculations. Determine what part of the thermometer actually measures the temperature by holding your hand on different parts and seeing it the readings change. Make sure that the temperature measuring part is fully submerged in the water.

Decide if your measurement will be more accurate if you leave the thermometer in the water for the entire time or if you only insert the thermometer briefly when you want a temperature measurement. What procedure should you use for putting the object into the cup? Should this be done fast or slow? Does water splash affect your measurement? Write down a plan for giving you the most accurate results possible.

MEASUREMENTS

Follow the plan that you outlined in your Exploration.

To calculate the specific heat of the complex object, you will need to know the mass of each material that makes up the object. You cannot take the object apart and directly measure each mass. You can, however, measure the volume of each of the materials in the complex object. You can determine the density of each material by making measurements on the homogeneous objects.

ANALYSIS

Based on your temperature measurements, calculate the specific heat of the complex object. What is the uncertainty in your measurement? Compare the measured specific heat of the object for cases when it starts hot or cold. Compare this difference with your measurement uncertainty.

Based on your volume and mass measurements and the specific heats of the homogeneous objects, calculate the specific heat of the complex object. What is the uncertainty in your measurement? Compare this specific heat to that calculated from the temperature change.

CONCLUSION

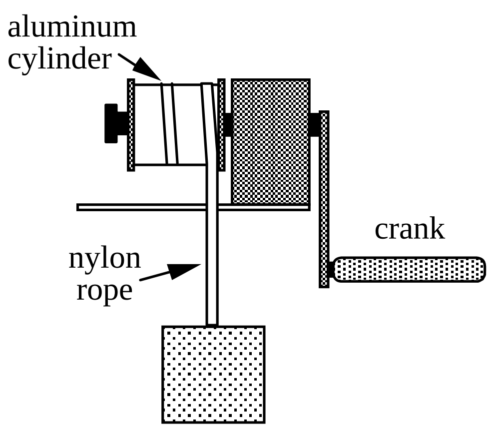
Did your results agree with your prediction? Explain. Does the specific heat of an object depend on whether it is hot or cold? Can you calculate the specific heat of a complex object if you know the specific heats of the materials that comprise it? Can the method be adapted to an object made of more than two different materials?

PROBLEM #4:
MECHANICAL ENERGY AND TEMPERATURE CHANGE

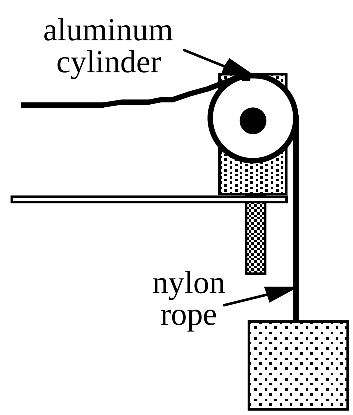
When running, you start thinking about the energy transformations of your body. You know that you are reducing your internal chemical energy stored in body fat. Since you are running at constant speed, your kinetic energy is not changing. Within your body, there are a lot of mechanical energy transformations such as your heart pumping and your muscles expanding and contracting. However, the effect of all of this internal body activity is that your body temperature increases. Your body then tries to maintain a constant temperature by sweating to cool down. Running seems to be the conversion of chemical energy to thermal energy. To test the idea that the primary effect of ordinary biological process is the conversion of chemical energy into thermal energy, you decide to make some measurements in the laboratory.

To make the biological process as simple as possible, you decide to convert your body's chemical energy into a mechanical energy that you can measure by exerting a force on an object for a distance. That mechanical energy is then converted into internal energy of an object and you measure the resulting temperature change. The device you decide to use is a cylinder with a handle that you can turn. The surface of the cylinder rubs against a rope wrapped loosely around it giving a frictional force. One end of that rope is attached to a heavy hanging block. The other end is free. You keep turning the cylinder so that hanging block is stationary. Then you know the frictional force. After a certain number of turns, you also measure the change of temperature of the cylinder. You then calculate that temperature change as a function of the mass of the hanging object, the radius of the cylinder, the number of turns of the cylinder, and the heat capacity of the cylinder. You check your calculation in the lab.

EQUIPMENT



Side view



Front view

Your device consists of an aluminum cylinder that can be turned with a crank. A rope is wrapped around the cylinder a few times so that, as the crank is turned, the friction between the rope and cylinder is just enough to support a heavy block hanging from one end of the rope. For safety, the other end of the rope is held loosely such that no force is exerted on that end of the rope.

An electronic thermometer is embedded in the cylinder. It is read out with a digital multimeter (DMM). The instructions for using the DMM are in *Appendix A*. A balance, a stopwatch, and ruler are also available.

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, Sections 17.1 and 17.5.

1. Draw a picture of the situation. On your picture, label all relevant quantities.
2. Write down the general conservation of energy equation. Decide on the most convenient system for this situation. Decide on your initial time. What energy being transferred to or from your system between the initial and final times?
3. Write down the initial energy of your system, the final energy of your system, and the energy transferred to or from your system. Put these terms into the general conservation of energy equation.
4. Write a relationship between the friction force between rope and the cylinder and the weight of the block. Explain why you believe this relationship is true.
5. What is the direction of the frictional force relative to the motion of the rim of the cylinder where it makes contact? Does all of the frictional force transfer energy to the cylinder? Is this energy transfer an input or an output? Explain.
6. Write down the distance that the frictional force of the rope is exerted on the cylinder when the cylinder makes one complete turn. What is this distance if the cylinder makes N turns?
7. Are any other forces exerted on the cylinder? Explain how they affect the energy of the cylinder. Write down any approximations that you think are justified.
8. Write down the relationship between the temperature change of the cylinder and its internal energy change. Look up the specific heat for aluminum. Use the previous steps to write down an equation for the temperature change as a function of the mass of the hanging object, the radius of the cylinder, the number of turns of the cylinder, and the heat capacity of the cylinder.

EXPLORATION

Switch the DMM to the Ohms (Ω) setting and connect it to the electronic thermometer (called a thermistor). Check that you get a numerical reading of *resistance*. Try different scales to determine which is most useful. See *Appendix A* for instructions about how to use the DMM to measure resistance. Touch the cylinder with your hand to make sure the reading responds to your body temperature.

The relationship between the temperature of the thermistor and its resistance is complex and may be different for different devices. Look at the table of *Temperature versus Resistance* that is attached to the base of the crank for yours. Make a graph of this table so that you can interpolate between temperature readings with sufficient accuracy. Estimate the current temperature of your cylinder and use your graph to see if the DMM reading is reasonable.

Try holding the block with your hand to give you a feeling for the amount of force necessary to hold the block steady. The block is heavy so **always make sure no one's foot is under it in case it drops!**

Practice rotating the aluminum cylinder uniformly so that the block hangs steady several centimeters from the floor. You may have to adjust the amount of rope you have wound around the cylinder. Try not to overlap the rope with itself since you want it to rub against the cylinder. Support the other end of the rope with your hand. Very little force (much less than the weight of the block) should be applied at this end while the crank is being turned.

Watch how the DMM reading changes when you rotate the cylinder to determine how many rotations you will have to make to get a significant temperature change.

Some energy is transferred from the cylinder into the air. This energy transfer is difficult to calculate but needs to be represented in your conservation of energy equation. Plan some way of estimating this. Write down your experimental plan.

MEASUREMENT

Using your plan, make the necessary measurements. Check your conservation of energy equation and all of the energy terms from the Warm-up Questions to make sure you have measured everything you need. Repeat your measurement enough times so that the average of all your measurements gives reliable results.

Make your measurement of the cylinder's energy transfer to the air for the amount of time this transfer actually takes place during your friction measurement. Since this energy transfer depends on the cylinder temperature, it is important to start the measurement at the right cylinder temperature. You can take apart the apparatus to measure the properties of the cylinder.

ANALYSIS

From your measurement results, determine the change in the cylinder's internal energy that you expect from mechanical energy transfer. Compare this to the change of the cylinder's internal energy directly determined from its temperature change.

Compare the size of the measured mechanical energy transferred to the cylinder by the frictional force to your separate measurement of the energy transferred from the cylinder to the air. Which is larger? Is the energy transfer to the air negligible? If not, include it in your conservation of energy equation.

Use your Prediction equation to calculate the *expected* temperature change.

CONCLUSION

Compare your predicted and measured temperature difference. Explain any difference. Estimate the amount of energy your body converted from chemical energy turning the cylinder.

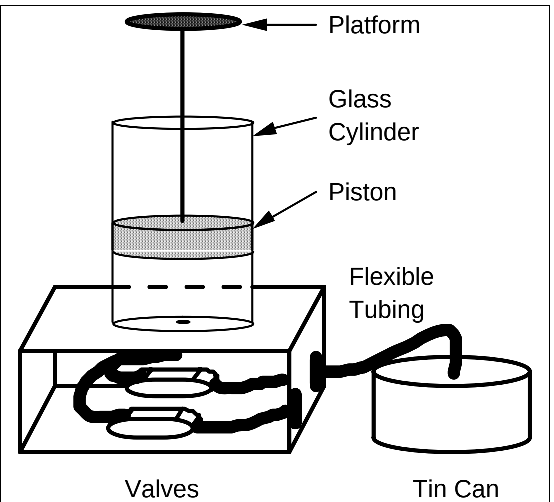
PROBLEM #5:
ENERGY CYCLES AND EFFICIENCY

You are trying to understand the efficiency of the complex energy cycles found everywhere in biological systems. For example, plants convert light energy into chemical energy stored in certain molecules (ATP) using intracellular organelles called chloroplasts. The energy is transported by these molecules to the parts of a cell that use it for growth, for moving water, or for moving leaves toward the sun. To test your understanding of energy conservation and the efficiency of cyclic processes, you decide to study a physical model that is simpler than a biological system.

The device that you decide to study uses thermal energy to lift objects. A piston that lifts the objects moves up and down inside of a cylinder filled with air. The air inside the cylinder is connected with a tube to a sealed metal can that can be heated and cooled by placing it in hot or cold water. A cycle starts with an object on top of the piston and the can immersed in cold water. The can is then immersed in hot water and the cylinder rises. At its highest point you remove the object and the piston rises some more. Next the can is placed into cold water. The piston descends to its lowest point and an object is put on it causing it to go lower. The system is now in its original state. Then the cycle is repeated. Even though the process is very simple, compared to a biological cycle, all of the heat from the water does not go into lifting the object. The system has an efficiency which you decide to calculate.

EQUIPMENT

A piston moves freely in the glass cylinder. The metal can is immersed in either cold or hot water to transfer heat to the air in the cylinder. Make sure that the can is tightly sealed. **NEVER IMMERSE THE CYLINDER IN WATER.** You will also have thermometers, weights, a balance, and a ruler.



PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, Sections 18.1-18.3.

1. Draw a picture of the system and label the relevant quantities. Using this sketch, describe how to measure the pressure in the cylinder. Assume that air is an ideal gas. Calculate the amount of air in the cylinder in terms of quantities you know or can measure.
2. Write down the general conservation of energy equation. Decide on the most convenient system for this situation. Decide on your initial time and choose your final time when the system returns to its initial state. Is any energy being transferred to or from your system between the initial and final times? The energy transfers may happen at different times in the cycle so write down a list of what the system is doing for each energy transfer.
3. Using your list, draw a pressure versus volume diagram for the cycle. Do this by first drawing axes to represent pressure and volume. Then:
    a. Start with the initial state and label that point. At that point also write the labels for the pressure, volume and, temperature of the system.
    b. Next draw a line or curve that represents the behavior of the system when the can is put into the hot water. During that time, does the pressure and/or volume of the system change? Does the temperature of the system change? Does the energy of the system change? Write equations for all of these changes in terms of quantities you know or can measure.
    c. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system.
    d. Next draw a line or curve that represents the behavior of the system when the object is removed. During that time, do the temperature, pressure, volume, and energy of the system change? Write equations for all of these changes in terms of quantities you know or can measure.
    e. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system.
    f. Next draw a line or curve that represents the behavior of the system when the can is put into the cold water. During that time, do the temperature, pressure, volume, and energy of the system change? Write equations for all of these changes as a function of quantities you know or can measure.
    g. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system.
    h. Next draw a line that represents the behavior of the system when the object is put on the platform. During that time, do the temperature, pressure, volume, and energy of the system change? Write equations for all of these changes as a function of quantities you know or can measure.
    i. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system. The system should now be in its original state and ready for the next cycle.

j. For every line on your plot, write symbols that indicate whether, during that time, there is work input or output and heat input or output.

4. Using your labeled P-V diagram, write down the conservation of energy equation for each line of your diagram.
5. Identify the terms you need to calculate the efficiency of the process. The efficiency is the ratio of the useful energy output to the energy input from the energy source. Write down the conservation of energy equation or equations containing those terms.

EXPLORATION

Familiarize yourself with the piston apparatus. Learn how the valves work. Does the piston move easily in the cylinder when the valves are open? When the valves are closed? When one is open and one is closed? All valves are likely to leak at some level. Check if your valves leak enough to seriously affect your measurement. Record how you made this determination.

The piston makes a seal with the cylinder but all such seals leak at some level. Check if your piston leaks enough to seriously affect your measurement. Record how you made this determination. Check to see if this leak depends on how much mass you put on the platform. This will tell you the maximum mass for which your results will be reliable.

How will you measure the height of the piston accurately and consistently? How large a mass will you need to give you a height change that you can measure accurately? This will tell you the minimum mass for which your results will be reliable.

Check that the can does not leak too much to affect the reliability of your measurements. If it does, check the stopper.

Run through the cyclic procedure several times without taking any measurements. Make sure you notice where the piston moves and where it stops when you do each operation. Note how long each motion takes to complete. These are the points you need to measure. When you move the can from one water bath to another, does the piston move as you expect?

Make a plan for moving through the cycle fast to minimize the effects of leaks. Practice your procedures so that you can make accurate measurements.

MEASUREMENT

Execute the measurement plan you created in the Exploration section to get the data you need. Run the cycle a few times for a given platform mass so that your average gives reliable results.

Measure the quantities necessary to determine the pressure in the cylinder at each stage.

Note the uncertainties of all of your measurements.

ANALYSIS

Create a P-V diagram based on your data. Using conservation of energy for the appropriate step(s) of the cycle, determine the efficiency for lifting the object. What is the uncertainty in this value?

CONCLUSION

Were you able to realize experimentally the predicted P-V diagram for the cycle? How much smaller (or larger) was the efficiency you calculated compared to the Carnot efficiency? Provide reasons for the discrepancies.

How could you relate this system's efficiency with a biological system you are interested in? Do you think that this is a reasonable model? Explain.

Thermal Properties of Certain Materials

Material	Specific Heat†	Density‡	Latent Heat of Fusion†
	J/g °C	g/cm^3	kJ/g
Aluminum	0.900	2.7	0.40
Chromium	0.460	7.14	0.33
Cobalt	0.419	8.71	0.28
Copper	0.39	8.92	0.20
Gold	0.13	19.3	0.063
Iron	0.452	7.86	0.27
Lead	0.13	11.34	0.023
Magnesium	1.02	1.75	0.37
Manganese	0.477	7.3	0.27
Mercury	0.14	13.59	0.011
Molybdenum	0.25	10.2	0.29
Nickel	0.444	8.9	0.30
Platinum	0.13	21.45	0.10
Potassium	0.754	.86	0.061
Silicon	0.71	2.33	1.80
Silver	0.24	10.5	0.11
Sodium	1.23	.97	0.11
Tin	0.23	5.75	0.059
Titanium	0.39	4.5	0.42
Zinc	0.093	7.04	0.11

Thermal Properties of Water and Alcohol

Substance	Specific Heat	Latent Heat of Fusion	Melting Temperature	Latent Heat of Vaporization	Boiling Temperature
	J/g °C	J/kg	°C	J/kg	°C
Water	4.19	3.35×10^5	0.00	2.256×10^6	100.00
Ice	2.09	3.35×10^5	0.00	n/a	n/a
Alcohol	2.48	10.42×10^5	-117.3	0.854×10^6	78.5

† Adapted from Handbook of Tables for Applied Engineering Science by R. E. Bolz & G. L. Tuve, The Chemical Rubber Co., 1970.

‡ Adapted From The Handbook of Chemistry and Physics, R. C. Weast, ed., The Chemical Rubber Co., 1970.

TA Name:______________________

PHYSICS 1201 LABORATORY REPORT

Laboratory VI

Name and ID#: ____

Date performed: ____________ Day/Time section meets: ______________________

Lab Partners' Names: ______________________________________

____

____

Problem # and Title: ____

Lab Instructor's Initials: ________

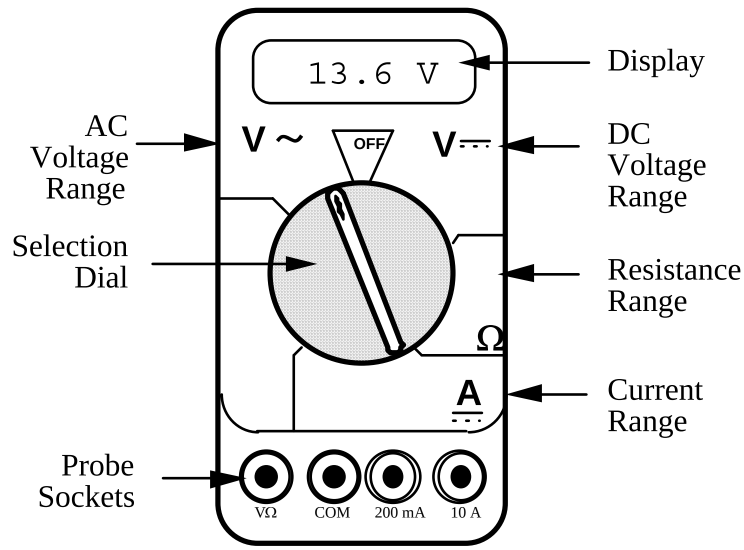
Grading Checklist	Points*
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up questions completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM 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.

Appendix A: Equipment

THE DIGITAL MULTIMETER (DMM)

The DMM is a common piece of lab equipment that can be used to measure various electrical quantities, most often current, resistance, and potential. The DMM's you will be using are capable of measuring both "direct current" (DC) and "alternating current" (AC) circuits. Be careful to know which type of measurement you need to make, then set your DMM accordingly. Some DMM's might be slightly different from the one pictured to the right.

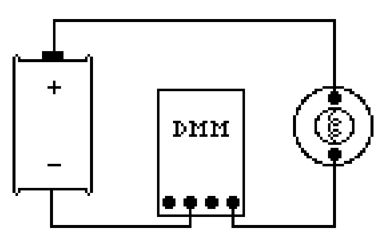


The DMM can measure currents anywhere from 10 amps to a microamp (10^{-6} amps). This versatility makes the DMM fragile. For example, measuring a 1 ampere current while the DMM is on the 2 milliamp scale will definitely blow a fuse! If this happens, your instructor can change the fuse. However, you can damage the DMM beyond repair, so follow the instructions below when you use it.

Measuring Current:

1. Set the selection dial of the DMM to the **highest** current measurement setting (10 amps). Insert one wire into the socket labeled '10A' and a second wire into the socket labeled 'COM'.

2. Attach the DMM into the circuit as shown below:



To measure current, the DMM must be placed in the circuit so that all the current you want to measure goes **through** the DMM.

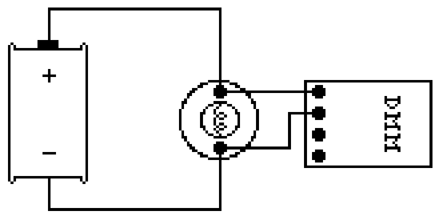
3. If no number appears while the DMM is at the 10A setting, move the wire from the 10A socket to the 200mA socket and then turn the selection dial to the 200 milliamp (200m) setting. If there is still no reading, change the dial to the 20 milliamp setting, etc.

4. When you have taken your measurement, return the DMM selection dial to the highest current setting (10 amps) and move the wire back to the 10A socket.

Measuring Voltage:

1. Set the DMM selection dial to read DC volts (V ⎓). Insert one wire into the socket labeled 'VΩ' and a second wire into the socket labeled 'COM'.

2. Set the selection dial of the DMM to the **highest** voltage measurement setting. Connect the two wires from the DMM to the two points between which you want to measure the voltage, as shown below.



   To measure voltage, the DMM must be placed in the circuit so that the voltage difference across the circuit element you want to measure is **across** the DMM.

3. If no number appears, try a different measurement scale. Start at the highest voltage scale and work your way down the scales until you get a satisfactory reading.

Measuring Resistance:

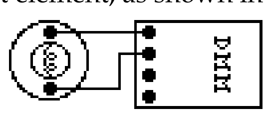
*The element whose resistance you are measuring **must** be free from all other currents (due to other batteries, power supplies, etc.) for the DMM to work*. That means you must **remove** it from a circuit.

To measure resistance:

1. Set the DMM selection dial to measure ohms (Ω). Insert one wire into the socket labeled 'VΩ' and a second wire into the socket labeled 'COM'.

2. *Make sure that the circuit element whose resistance you wish to measure is free of any currents*.

3. Attach the wires across the circuit element, as shown in the example below.

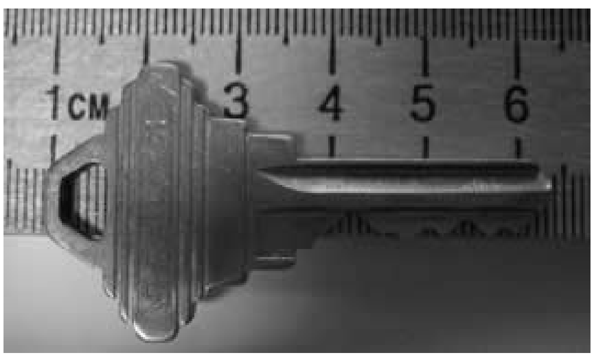


4. If no number appears, try a different measurement scale. Begin at the largest scale (20 MΩ) and work your way down.

Appendix B: 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 A-1, you could not measure more precisely than a quarter or half or a third of a mm. Reporting a number like 5.37142712 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 5.37 cm. Since you estimated the 7, 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 5.3 cm, but it is clear that 5.37 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.

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

One of the things that this table illustrates is that not all zeros are significant. For example, the zero in 0.8 is not significant, while the zero in 1.50 is significant. Only the zeros that appear after the first non-zero digit are significant.

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 shown in Figure A-1. If we have a scale with ten etchings to every millimeter, 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 5.814 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

When adding or subtracting numbers, the number of decimal places must be taken into account.

The result should be given to as many decimal places as the term in the sum that is given to the ***smallest*** *number of decimal places.*

Examples:

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 uncertain figures in each number are shown in **bold-faced** type.

Multiplication and division

When multiplying or dividing numbers, the number of significant figures must be taken into account.

The result should be given to as many significant figures as the term in the product that is given to the ***smallest*** *number of significant figures.*

The basis behind this rule is that the least accurately known term in the product will dominate the accuracy of the answer.

As shown in the examples, this does not always work, though it 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.

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

11**7**	2**5**
2**3**)269**1**	7**5**)187**5**
2**3**	15**0**
3**9**	37**5**
23	**375**
161	
161	
1.**2** x 10^2	2.**5** x 10^1

PRACTICE EXERCISES

1. Determine the number of significant figures of the quantities 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

[Answer: $34.2 \times 1.5 \times 10^4 = 5.1 \times 10^5$]

Appendix C: 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' 5½" and 5' 6½" tall, or 5' 6" ± ½". This ± ½" 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**.

(1) **Systematic uncertainties** are those that 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.

(2) **Random uncertainties** are variations in the measurements that 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.

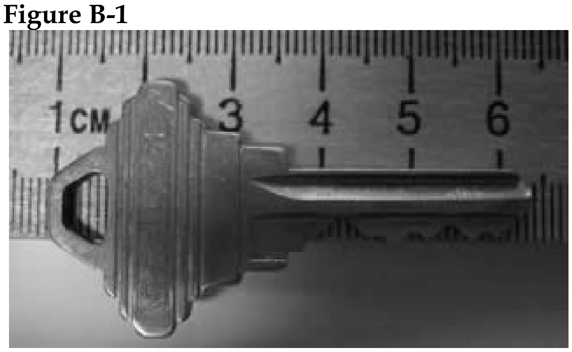
How do I determine the uncertainty?

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 were not as important as the magnitude of the value, you could say that the key's length was 5cm, give or take 1cm. 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 5.37cm. This tells us that the worst our measurement could be off is a fraction of a mm. To be more precise, we can estimate it to be about a third of a mm, so we can say that the length of the key is 5.37 ± 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

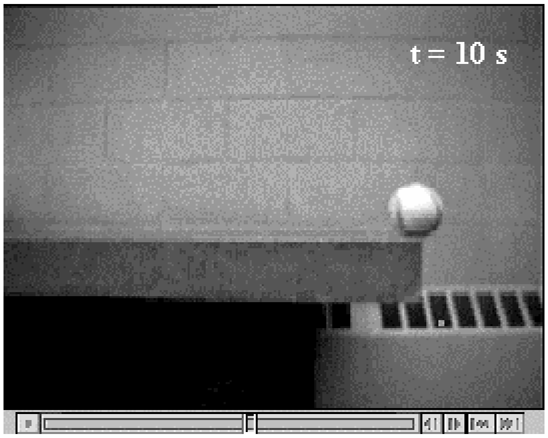
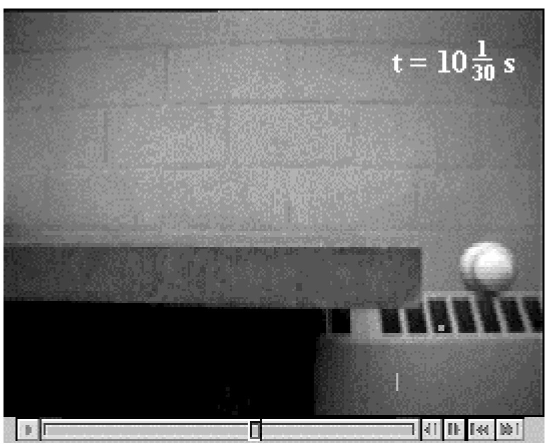


Figure B-3



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 un-certainty by making several measure-ments 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 (its deviation); (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 measure-ments to get a distribution for which the average has some meaning.

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 deviations are: 0.011g, 0.004g, 0.001g, 0.005g, 0.001g, 0.001g
Sum of deviations: 0.023g
Average deviation: (0.023g)/6 = 0.004g
Mass of penny A: 3.121 ± 0.004g

Class 2: Penny B massed by six different students on six different balances

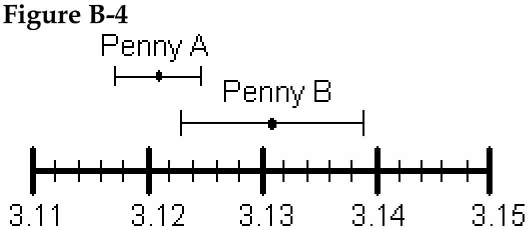
Mass (grams)
3.140
3.133
3.144
3.118
3.126
3.125
3.131 average
The deviations are: 0.009g, 0.002g, 0.013g, 0.013g, 0.005g, 0.006g
Sum of deviations: 0.048g
Average deviation: (0.048g)/6= 0.008g
Mass of penny B: 3.131 ± 0.008g

However you choose to determine the uncertainty, you should always state your method clearly 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 3.117g and 3.125g. For penny B, the most likely mass is somewhere between 3.123g and 3.139g. 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?

Suppose you use a meter stick to measure the length of a table and the width of a hair, each with an uncertainty of 1 mm. Clearly you know more about the length of the table than the width of the hair. Your measurement of the table is very precise but your measurement of the width of the hair is rather crude. To express this sense of precision, you need to calculate the percentage uncertainty. To do this, divide the uncertainty in the measurement by the value of the measurement itself, and then multiply by 100%. For example, we can calculate the precision in the measurements made by class 1 and class 2 as follows:

Precision of Class 1's value:
(0.004 g ÷ 3.121 g) x 100% = 0.1 %
Precision of Class 2's value:
(0.008 g ÷ 3.131 g) x 100% = 0.3 %

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 ± 0.004 g. 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 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 no estimate. The method for performing arithmetic operations on quantities with uncertainties is illustrated in the following examples:

Addition:

(3.131 ± 0.008 g) + (3.121 ± 0.004 g) = ?

First, find the sum of the values:

3.131 g + 3.121 g = 6.252 g

Next, find the largest possible value:

3.139 g + 3.125 g = 6.264 g

The uncertainty is the difference between the two:

6.264 g – 6.252 g = 0.012 g

Answer: 6.252 ± 0.012 g.

Note: This uncertainty can be found by simply adding the individual uncertainties:

0.004 g + 0.008 g = 0.012 g

Multiplication:

(3.131 ± 0.013 g) x (6.1 ± 0.2 cm) = ?

First, find the product of the values:

3.131 g x 6.1 cm = 19.1 g-cm

Next, find the largest possible value:

3.144 g x 6.3 cm = 19.8 g-cm

The uncertainty is the difference between the two:

19.8 g-cm - 19.1 g-cm = 0.7 g-cm

Answer: 19.1 ± 0.7g-cm.

Note: The percentage uncertainty in the answer is the sum of the individual percentage uncertainties:

$$\frac{0.013}{3.131}\times 100\% + \frac{0.2}{6.1}\times 100\% = \frac{0.7}{19.1}\times 100\%$$

Subtraction:

(3.131 ± 0.008 g) – (3.121 ± 0.004 g) = ?

First, find the difference of the values:

3.131 g - 3.121 g = 0.010 g

Next, find the largest possible difference:

3.139 g – 3.117 g = 0.022 g

The uncertainty is the difference between the two:

0.022 g – 0.010 g = 0.012 g

Answer: 0.010±0.012 g.

Note: This uncertainty can be found by simply adding the individual uncertainties:

0.004 g + 0.008 g = 0.012 g

Notice also, that zero is included in this range, so it is possible that there is no difference in the masses of the pennies, as we saw before.

Division:

(3.131 ± 0.008 g) ÷ (3.121 ± 0.004 g) = ?

First, divide the values:

3.131 g ÷ 3.121 g = 1.0032

Next, find the largest possible value:

3.139 g ÷ 3.117 g = 1.0071

The uncertainty is the difference between the two:

1.0071 - 1.0032 = 0.0039

Answer: 1.003 ± 0.004

Note: The percentage uncertainty in the answer is the sum of the individual percentage uncertainties:

$$\frac{0.008}{3.131}\times 100\% + \frac{0.004}{3.121}\times 100\% = \frac{0.0039}{1.0032}\times 100\%$$

Notice also, the largest possible value for the numerator and the smallest possible value for the denominator gives the largest result.

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 calculation 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

Answers: 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

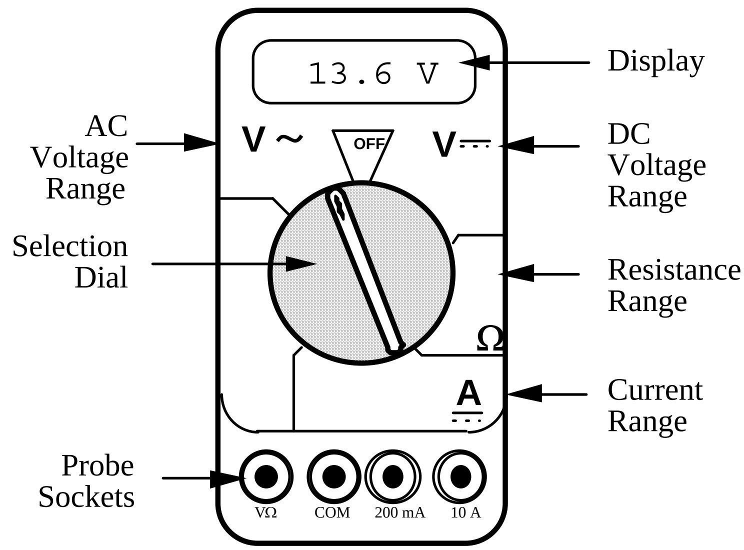
Answers:

Cart and set 1: 299.3±1.6 g.
Cart and set 2: 297.0±1.2 g.
Cart and both sets: 395.1±1.9 g.

Appendix C: Equipment

THE DIGITAL MULTIMETER (DMM)

The DMM is a common piece of lab equipment that can be used to measure various electrical quantities, most often current, resistance, and potential. The DMM’s you will be using are capable of measuring both “direct current” (DC) and “alternating current” (AC) circuits. Be careful to know which type of measurement you need to make, then set your DMM accordingly. Some DMM’s might be slightly different from the one pictured to the right.

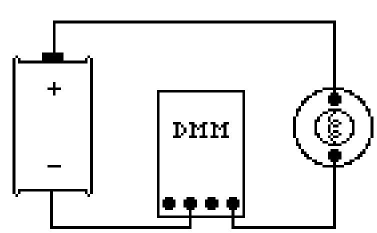


The DMM can measure currents anywhere from 10 amps to a microamp (10^{-6} amps). This versatility makes the DMM fragile. For example, measuring a 1 ampere current while the DMM is on the 2 milliamp scale will definitely blow a fuse! If this happens, your instructor can change the fuse. However, you can damage the DMM beyond repair, so follow the instructions below when you use it.

Measuring Current:

1. Set the selection dial of the DMM to the **highest** current measurement setting (10 amps). Insert one wire into the socket labeled '10A' and a second wire into the socket labeled 'COM'.

2. Attach the DMM into the circuit as shown below:



To measure current, the DMM must be placed in the circuit so that all the current you want to measure goes **through** the DMM.

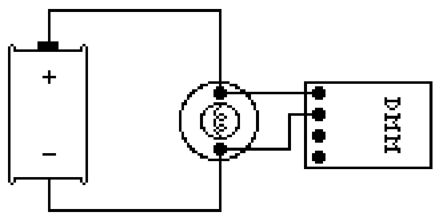
3. If no number appears while the DMM is at the 10A setting, move the wire from the 10A socket to the 200mA socket and then turn the selection dial to the 200 milliamp (200m) setting. If there is still no reading, change the dial to the 20 milliamp setting, etc.

4. When you have taken your measurement, return the DMM selection dial to the highest current setting (10 amps) and move the wire back to the 10A socket.

Measuring Voltage:

1. Set the DMM selection dial to read DC volts (V ⎓). Insert one wire into the socket labeled 'VΩ' and a second wire into the socket labeled 'COM'.

2. Set the selection dial of the DMM to the **highest** voltage measurement setting. Connect the two wires from the DMM to the two points between which you want to measure the voltage, as shown below.



   To measure voltage, the DMM must be placed in the circuit so that the voltage difference across the circuit element you want to measure is **across** the DMM.

3. If no number appears, try a different measurement scale. Start at the highest voltage scale and work your way down the scales until you get a satisfactory reading.

Measuring Resistance:

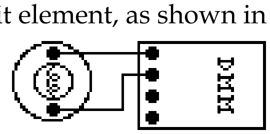
The element whose resistance you are measuring ***must*** *be free from all other currents (due to other batteries, power supplies, etc.) for the DMM to work*. That means you must **remove** it from a circuit.

To measure resistance:

1. Set the DMM selection dial to measure ohms (Ω). Insert one wire into the socket labeled 'VΩ' and a second wire into the socket labeled 'COM'.

2. *Make sure that the circuit element whose resistance you wish to measure is free of any currents*.

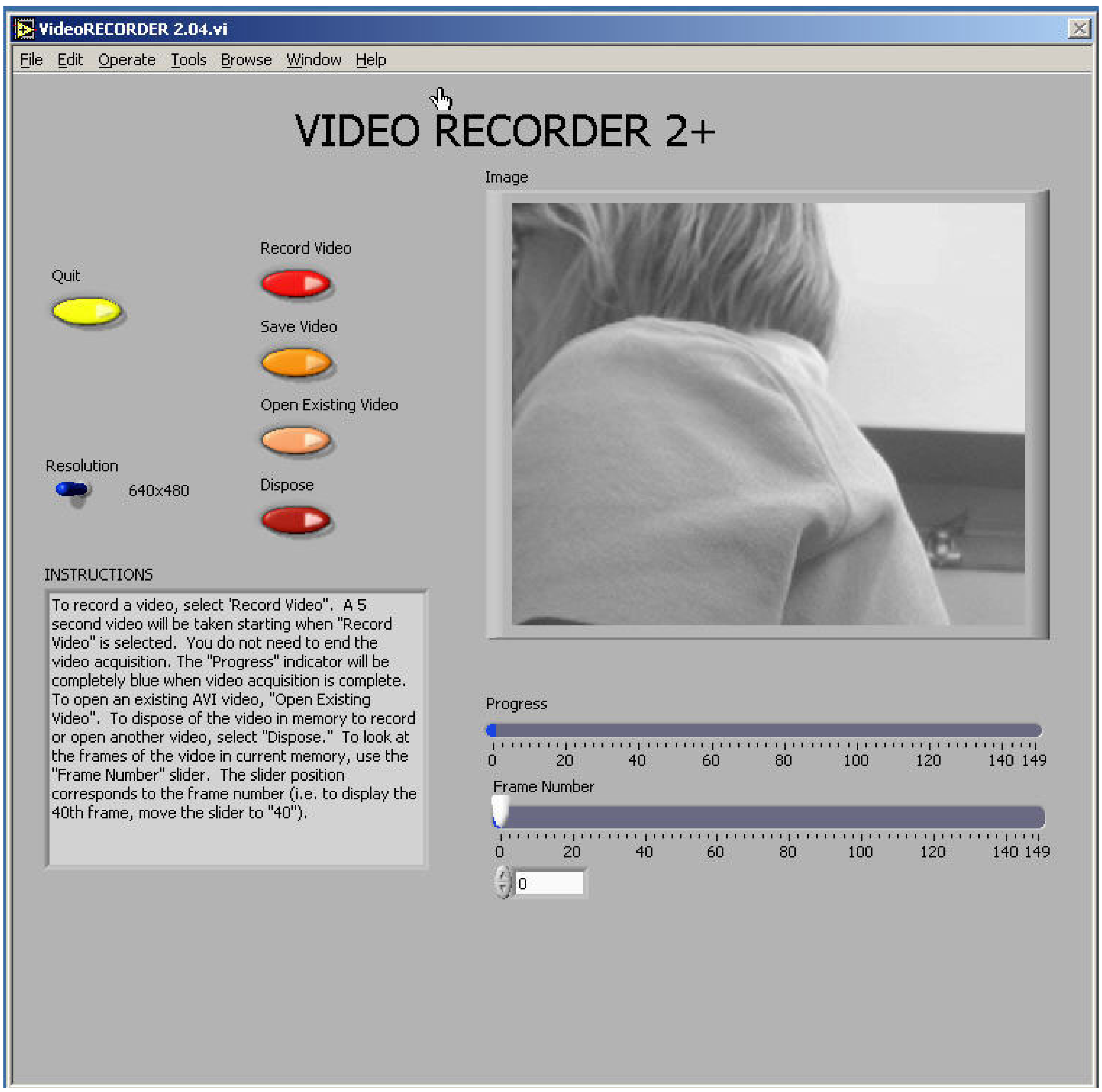
3. Attach the wires across the circuit element, as shown in the example below.



4. If no number appears, try a different measurement scale. Begin at the largest scale (20 MΩ) and work your way down.

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.

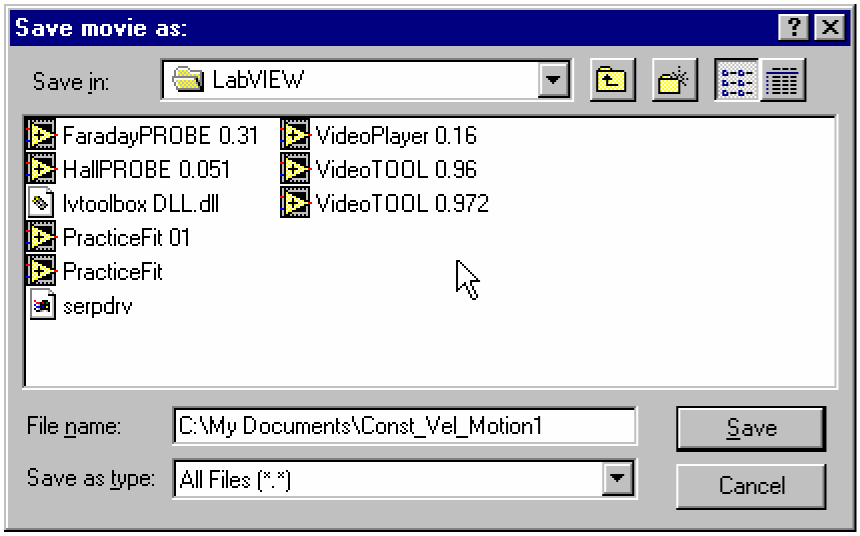
The controls are fairly self-explanatory; pressing the *Record Video* button begins the process of recording a 5-second video image. While the video is recording, the blue *Progress* bar beneath the video frame grows. Once you have finished recording, you can move through the video by dragging the *Frame 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.

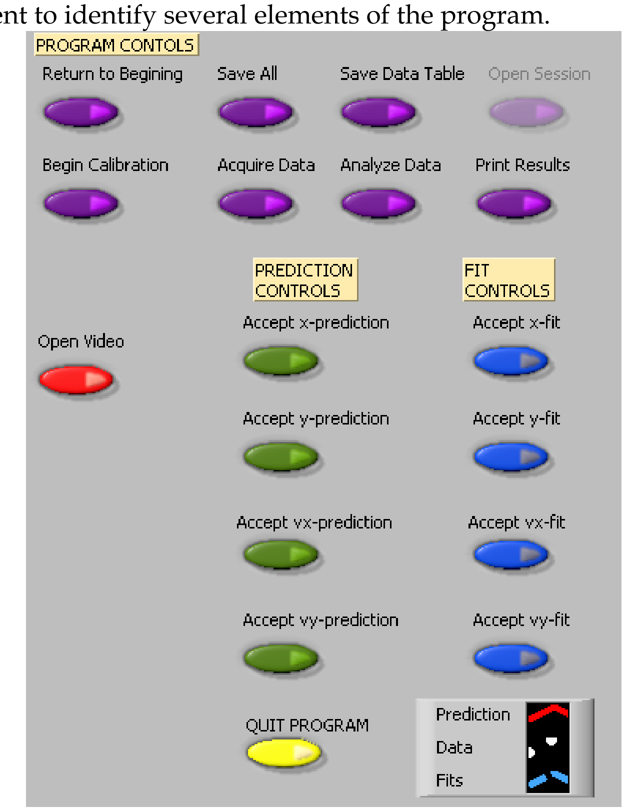
Once you have recorded a satisfactory video, save it by pressing the *Save Video* button. You will see a *Save* window, as shown on the next page.

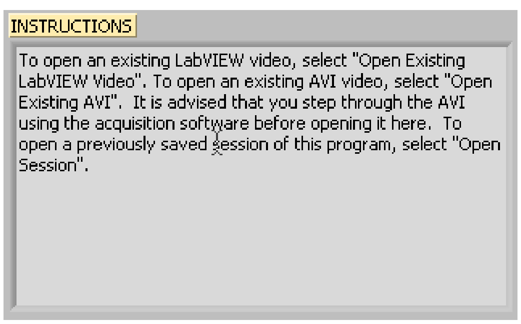
To avoid cluttering the computer, you will only be able to save your video to certain folders on the hard disk. One such folder is the *My Documents* folder located on the C drive. You should check with your lab instructor for the most suitable place to save your video. In the *File name* box, you should 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*).

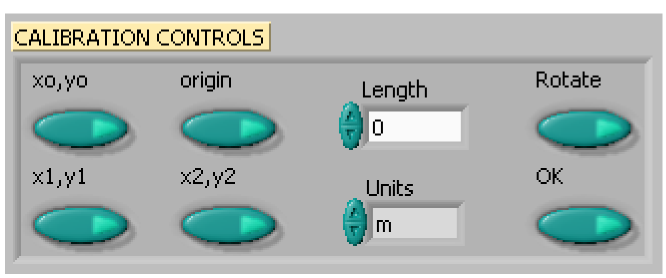
CALIBRATION

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.

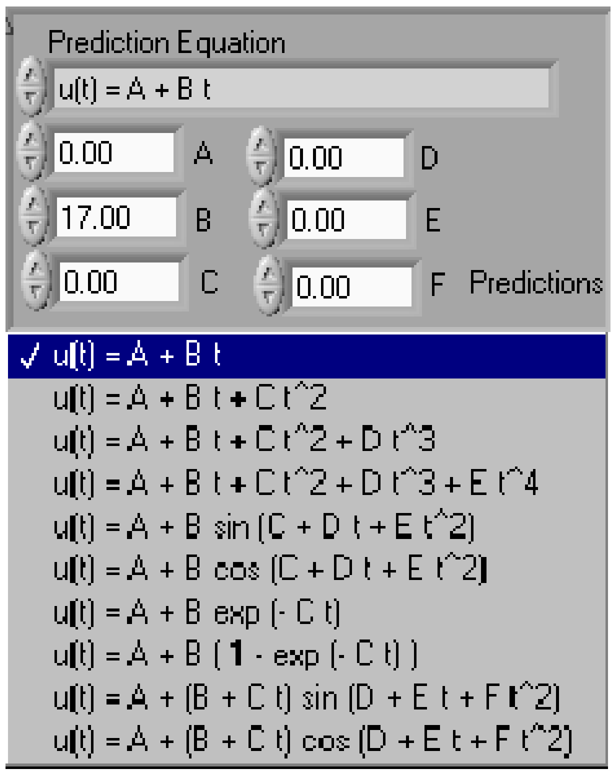
ANALYSIS PREDICTIONS

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.

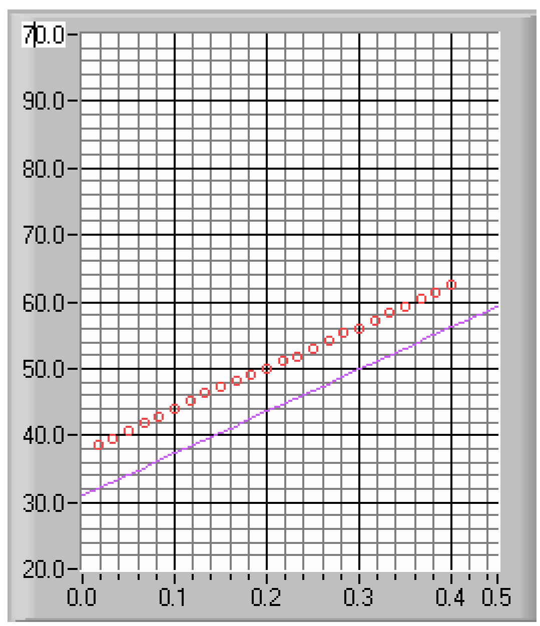
DATA COLLECTION

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.

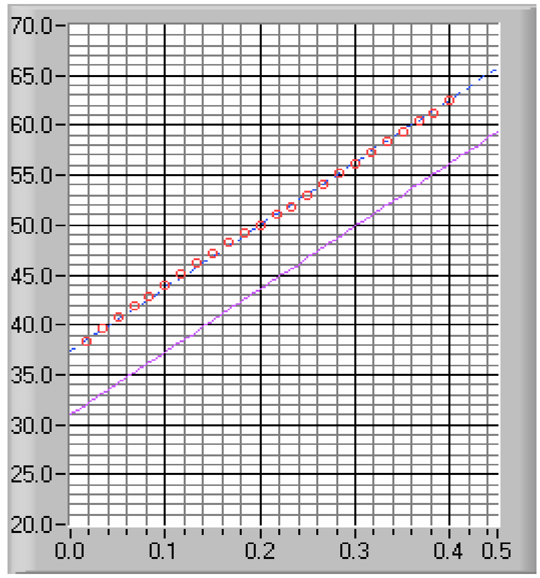
FITTING YOUR DATA

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.

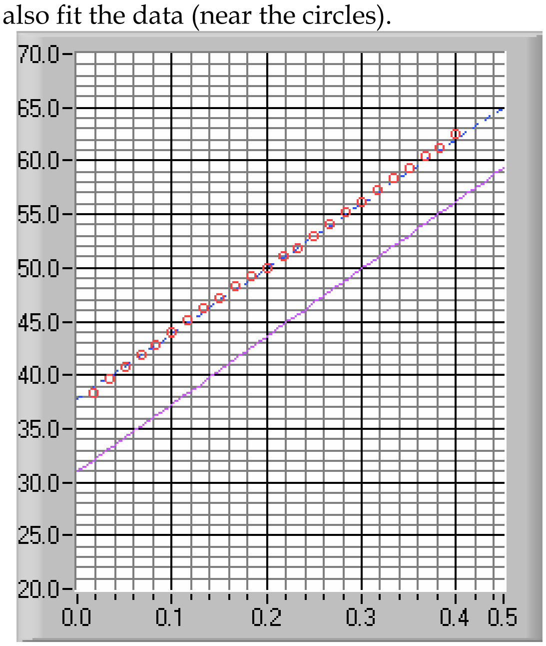


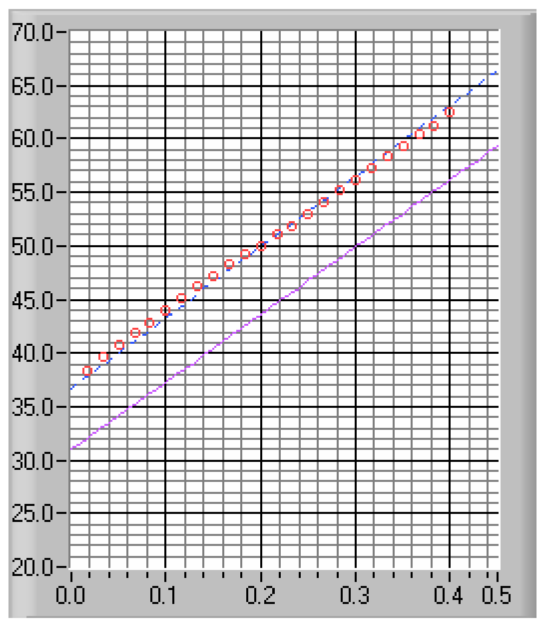
Secondly, after you find your data, you need to determine the best possible equation to describe this data. After you have decided on the appropriate equation, you need to determine the constants of this equation so that it best fits the data. Although this can be done by trial and error, it is much 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

STATEMENT OF THE PROBLEM

The experimental problem was to determine if the mass of an object affects the time it takes for the object to fall. We want to know this because we are part of a team building a single machine versatile enough to launch tennis balls, baseballs and softballs for sports practice. To properly design the machine, we need to know if the different balls will fall at different rates since the user must be able to aim the balls accurately.

PREDICTION

To predict the answer to this question, we relied on our experience of the behavior of everyday objects. We know that when you let go of something, it will fall because it is pulled down by the gravitational force. That force, also known as the object's weight, increases as the mass of the object increases. F=mg. Since the object starts out at rest, its velocity changes. That means it accelerates. Thus the force causes the object to accelerate. Since the force increases with the object's mass, the acceleration also increases with the object's mass.

To determine how that force affects the time for the object to fall, we used relationships among the object's acceleration, velocity, distance, and time. From experience, we know that if one object has a larger acceleration than another one and starts off with the same velocity, then the object with the larger acceleration will take a shorter time to fall the same distance. This can be shown from the definition of average acceleration. In this case, since the gravitational force on the object does not change during the fall, the acceleration is constant. For constant acceleration, the average acceleration equals the instantaneous acceleration.

The definition of average acceleration is: $a = (v_f - v_i)/\Delta t$.

Just dropping the ball means that the initial velocity, v_i, is 0, so $a = v_f/\Delta t$. Solving for time gives:

$$\Delta t = v_f/a.$$

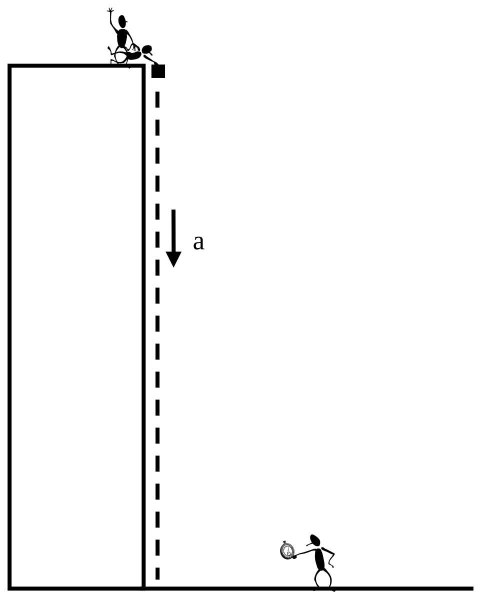
This equation says that a large acceleration gives a small time since 1/a would be small if a is large.

Thus we expect that balls with more mass, will have a larger acceleration and take less time to fall a given distance. This corresponds with our experience that a coin will hit the floor before a piece of paper when both are dropped from the same height.

EXPERIMENT AND RESULTS

We started by finding an open space on the roof of the physics building where we could safely drop the objects and see when and where they hit the ground. We used the southwest corner of the physics building. The person who timed the fall of the object was on the ground so they could observe when the object landed. The objects we used were laboratory masses of 10, 20, 50, and 100 grams. We also decided to drop the dime and quarter sideways to try to minimize the air resistance to compare with the laboratory masses.

A person on the roof dropped the objects while another person standing next to her signaled the drop to the person on the ground by lowering their hand. To ensure all objects were dropped from the same height, the person dropping the objects lay on the roof and released each object from the same height as the roof. The person on the ground started his stopwatch when he saw the hand drop and stopped it when the object hit the ground. A picture of the experiment is shown below. Because of the uncertainty of starting and stopping the stopwatch as well as dropping to object from exactly the same place, we repeated the measurement six times for each object to get an average.



We estimated that each object was dropped from the same height, with an uncertainty of a centimeter. We determined the uncertainty in the time by using the average deviation of six drop times for each object. It should be noted that the value of the average time for each drop is higher than the actual time due to the reaction time of the person using the stopwatch. We tried to increase our accuracy by having the person with the best reaction time do the timing. This reaction time was determined by how fast each of us could start and stop the stopwatch. The person with the best average time (around 0.09 seconds) was appointed to use the stopwatch. The time we recorded was the stopwatch time minus that average reaction time. The results are listed in Table 1 and graphed in Graph 1.

CONCLUSIONS

By looking at Graph 1, we saw no pattern between the mass of the object and the time it took to fall. Comparing the uncertainties of the times on Graph 1 we see that they overlap between 1.71 seconds and 1.73 seconds. Hence we must conclude that all of our objects took the same amount of time to fall. This disagreed with our initial prediction of heavier objects falling faster.

Reviewing our prediction we found two mistakes. First, although the gravitational force depends on the mass of an object, the acceleration caused by that force depends on both the force and the mass of the object, F = ma. Thus, a=F/m. Since the force depends on the mass of the object, the mass actually cancels out so the acceleration is independent of the mass.

$a = F/m$

$a = mg/m$

$a = g$ which does not depend on the mass in agreement with our data.

The second mistake in our prediction did not actually affect the answer but it was wrong anyway. We thought that $\Delta t = v_f/a$ meant that a large acceleration gives a small time since $1/a$ would be small if a were large. That is incorrect because the final velocity, v_f, also depends on the acceleration. A larger acceleration gives a larger v_f. Realizing this, Δt is the result of taking a number that increases and dividing by a number that also increases. Thus Δt could increase but it could also stay the same or even decrease with acceleration according to this equation.

We cannot use that equation to conclude that a larger acceleration would cause the object to fall in a smaller time. To draw such a conclusion, we need an equation in which only the acceleration and time are changing. To do this we can use:

$a = (v_f - v_i)/\Delta t$ the definition of average acceleration (with $a_{av} = a$)

$v_{av} = (v_f + v_i)/2$ if the acceleration is constant

$v_{av} = (y_f - y_i)/\Delta t$ the definition of average velocity

For a constant acceleration, an initial velocity of zero, and taking the initial position, y_i, as zero, these equations become:

$a = v_f/\Delta t$ the definition of average acceleration (with $a_{av} = a$)

$v_{av} = v_f/2$ if the acceleration is constant

$v_{av} = y_f/\Delta t$ the definition of average velocity

Now we need to find Δt, the time to fall, in terms of a, the constant acceleration of the object, and quantities that do not change if the acceleration changes. The quantity that does not change is y_f, the height of the building. We need an equation for Δt in terms of a and y_f.

		unknowns
Find Δt		Δt
$a = v_f/\Delta t$	[1]	v_f
Find v_f		
$v_{av} = v_f/2$	[2]	v_{av}
Find v_{av}		
$v_{av} = y_f/\Delta t$	[3]	

3 unknowns and 3 equations, OK to solve. The procedure is as follows:

Solve [3] for v_{av} and put into [2].

Solve [2] for v_f and put into [1].

Solve [1] for Δt.

Executing the plan:

$y_f/\Delta t = v_f/2$

$2y_f/\Delta t = v_f$ into [1]

$a = (2y_f/\Delta t)/\Delta t$

$a\,\Delta t = (2y_f/\Delta t)$

$a\,(\Delta t)^2 = 2y_f$

$(\Delta t)^2 = 2y_f/a$

$$\boxed{\Delta t = \sqrt{\frac{2y_f}{a}}}$$

Now this equation shows that if the acceleration is larger, the time to fall is smaller since the height of the building does not change when different objects are dropped.

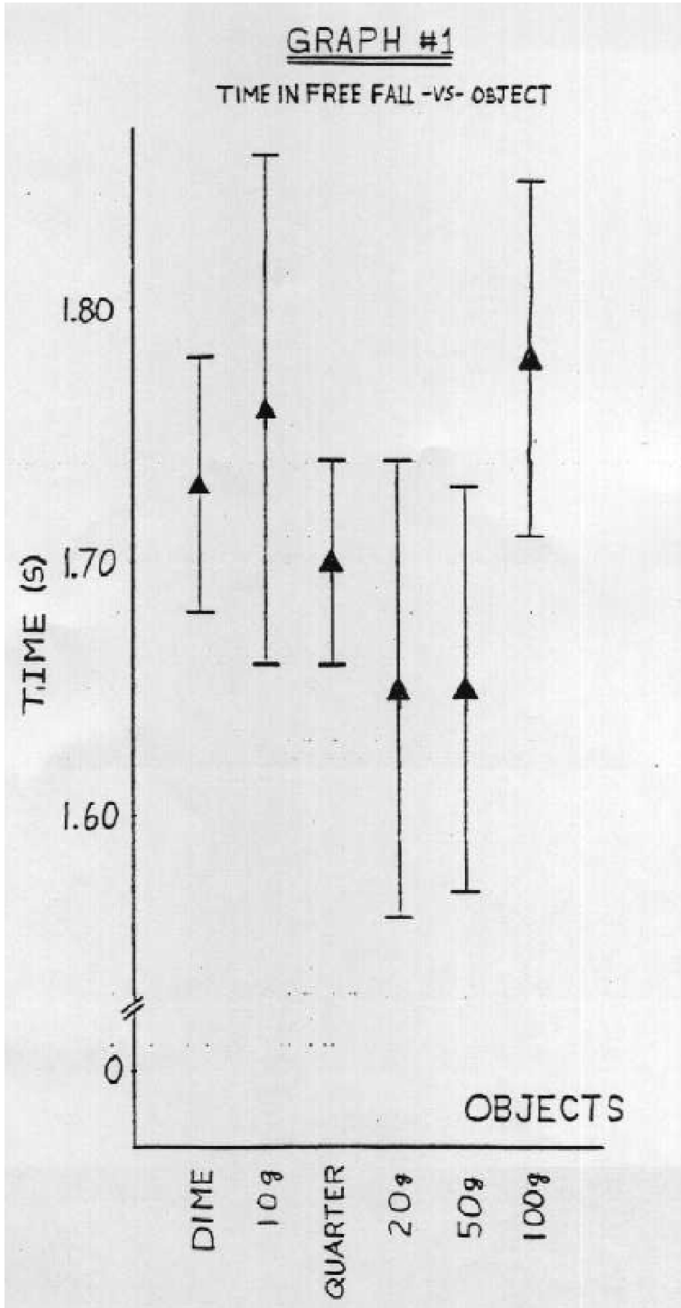
Now that we have shown that the results of our measurements are consistent with physics as we understand it, how do we explain our experience? We know that if we drop a coin and a piece of paper at the same time, the coin hits the ground first. We have shown that the reason cannot be because of their difference in weight. In this case, unlike our experiment, the air resistance is not negligible for the paper. There are two forces on it, the gravitational force that depends on its mass downward and the air resistance upwards. As we have shown, if the force depends on an object's mass then the falling time does not depend on the mass. That means that air resistance must not depend on the mass of an object. This is reasonable since if you wad a piece of paper up it has the same mass yet takes less time to fall.

Finally to check that our measurements, procedures, and calculations were correct, we computed the height of the building with 1.72 seconds as our time using $\Delta t = \sqrt{\frac{2y_f}{a}}$. We found the height of the building to be 14.5 meters or 47.6 feet. This agreed with our estimation that it was about 48 feet.

If air resistance is indeed negligible, no special alterations are necessary for constructing our tennis, baseball and softball launcher. All masses take the same amount of time to fall to the ground if they start from the same height with the same initial velocity. However, the amount of air resistance, especially for the lighter tennis ball, still needs to be checked before finalizing a design.

TABLE 1: Objects and Times in Free Fall

Object & Trial	Time (s)	Deviation From Average (s)	Object & Trial	Time (s)	Deviation From Average (s)
Dime 1	1.73	0.00	20 g 1	1.67	-0.02
2	1.71	0.02	2	1.59	0.06
3	1.80	-0.07	3	1.59	0.06
4	1.71	0.02	4	1.75	-0.10
5	1.70	0.03	5	1.57	0.07
6	1.75	-0.02	6	1.72	-0.07
Average	**1.73**	**0.05**	**Average**	**1.65**	**0.09**
Quarter 1	1.72	-0.02	50 g 1	1.72	-0.07
2	1.73	-0.03	2	1.61	0.04
3	1.70	0.00	3	1.59	0.06
4	1.66	0.04	4	1.59	0.06
5	1.67	0.03	5	1.68	-0.03
6	1.72	-0.02	6	1.74	-0.09
Average	**1.70**	**0.04**	**Average**	**1.65**	**0.08**
10 g 1	1.76	0.00	100 g 1	1.84	-0.06
2	1.68	0.08	2	1.80	-0.02
3	1.81	-0.05	3	1.80	-0.02
4	1.89	-0.13	4	1.71	0.07
5	1.73	0.03	5	1.82	-0.04
6	1.70	0.06	6	1.73	0.05
Average	**1.76**	**0.10**	**Average**	**1.78**	**0.07**


GRAPH #1
TIME IN FREE FALL -VS- OBJECT
TIME (S)
1.80
1.70
1.60
0
OBJECTS
DIME
10g
QUARTER
20g
50g
100g

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 does reproduce the problems you see in your data, then it might be the cause; if it fails to reproduce them, you should look elsewhere.

USING THE LABSIMS

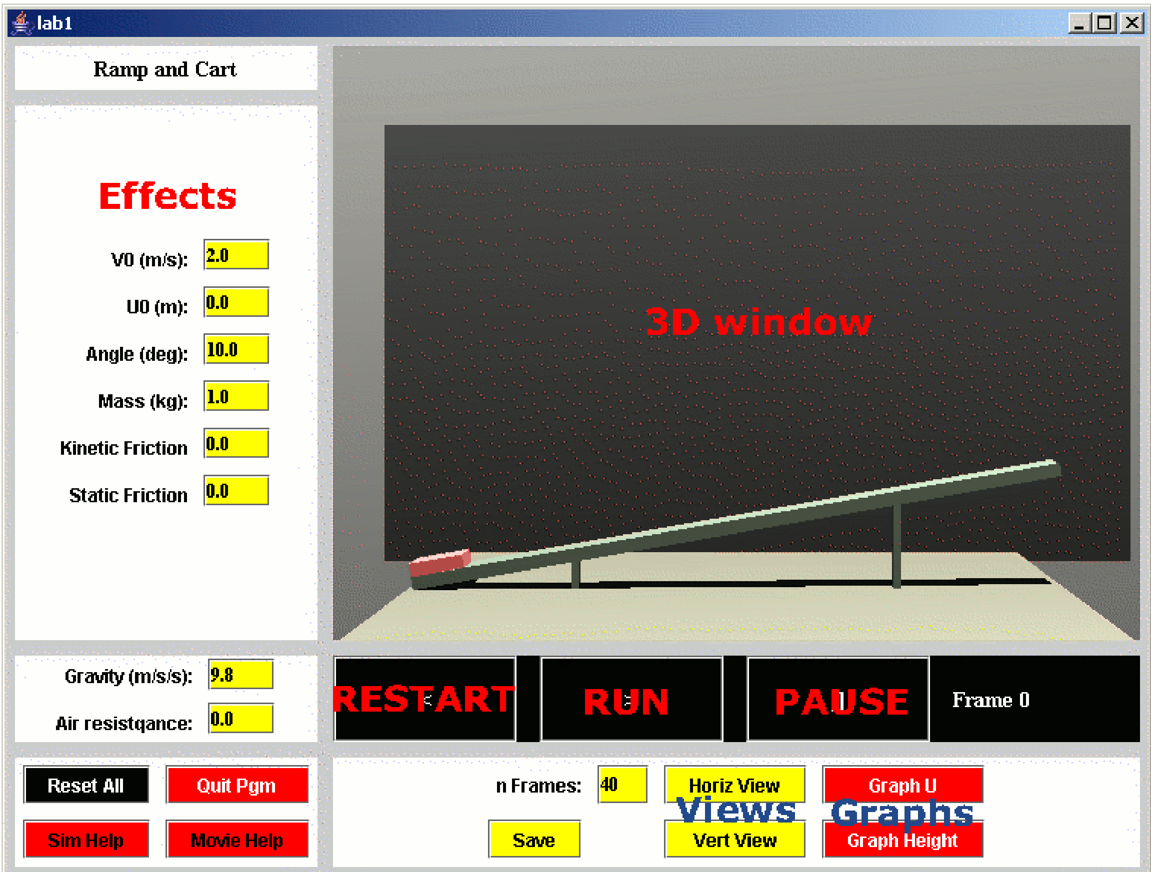
Once you get a LabSim program going, the easiest way to see what it does is to push the *Run* button, which is right under the 3D window (it's the black button with the ">" label). "Run" makes the LabSim go, using the *values in the yellow windows* to the left. You can change the length of a run by changing 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.