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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
Sean Albiston	Steve Gardeen	Andrew Gustafson

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.

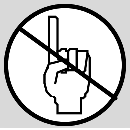
The three components of the course - lecture, discussion section, and laboratory - each serve a different purpose. The laboratory is where physics ideas, often expressed in mathematics, come to grips with the real world. Because different lab sections meet on different days of the week, sometimes you 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, without fail, 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, without fail, 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.

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.

LABORATORY I
LABORATORY SKILLS

In this laboratory you will become familiar with some of the skills needed to successfully complete the physics investigations found in this lab manual. You will also become familiar with the process of clearly recording and reporting your laboratory results.

The problems in this laboratory will direct you to perform some investigations of the physics of motion while at the same time supplying directions concerning how to record and present your findings. Knowing how to record and present findings is important for all physics laboratories, and especially important when constructing presentations and reports.

OBJECTIVES:

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

- Use the concept of constant velocity motion to solve problems.
- Clearly record laboratory procedures and findings in your lab journal.
- Make an accurate and well labeled graph.
- Understand the names and behavior of simple mathematical functions.
- Use the lab video cameras to record and analyze motion.
- Understand how measurement uncertainty can affect laboratory results.

PREPARATION:

Obtain a lab notebook with graph lined paper. Study and understand the meaning of velocity and average velocity. Be able to describe and write equations for functions of the types listed in the bullet points below.

Before coming to lab you should be able to:

- Be able to explain the difference between velocity and average velocity.
- Be able to describe the equations for simple functions that go by the titles: line, parabola, polynomial, power law, exponential, logarithm, sinusoidal.

LABORATORY NOTEBOOK:

Your laboratory notebook is an important document. Keeping it neat is a necessary skill. In a research setting your notebook is the record of your lab work and results. It should be organized so that anyone who reads it can understand your methods. The records in your lab notebook can defend you if your results are challenged, or your methods are questioned. This can be especially important in biological and medical settings.

You laboratory notebook should have graph-lined paper to help you plot data.=

In your lab notebook you should:

- Record all information regarding equipment, setup, and procedures necessary to reproduce your work. A sketched diagram can much improve clarity.
- Record all data you obtain during the lab. If you use a computer to record data print the data and add it to the notebook. Data must be recorded honestly; you must record the outcome of your measurements even if they don't match your predictions. If you think an error was made make a note of it. Also note the uncertainties you think are present in your measurement equipment.
- Never remove a page. If you make a mistake neatly cross it out.
- Date every entry. Indicate the month, day, and year. For clarity it is often best to write the month in word form because different regions have different ways of abbreviating the date. (In the U.S.A. the abbreviation is usually month/day/year, so 1/2/09 would be January 2, 2009. In Britain the abbreviation is usually day/month/year, so 1/2/09 would be February 1, 2009.)
- Try to be as clear as possible.

PROBLEM #1: CONSTANT VELOCITY MOTION 1

To help you become familiar with how to use this laboratory manual the first laboratory 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.

This laboratory manual may be unlike others you have seen before. You will not find 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 benefit of these labs comes from your learning by comparing your ideas about physics to how things actually behave. Remember that there is no benefit to just taking measurements.*

If the laboratory instructions are not clear then you may not understand some important physics concepts. **Part of the lab manual design is to make many of the problems easy to solve if you understand what you are doing, and very difficult if you do not.** If you do not understand a lab problem that is your signal to learn more by reading the textbook, discussing with fellow students, and asking your TA or professor. If you ask your TA a question it is likely they will ask you some questions in return to determine how you are thinking about physics. Everyone has unique learning styles and ways of thinking; your TA will try to help you develop yours. *Learning is the goal. Learning is not easy and no one can do it for you by telling you the answer.*

Each laboratory problem begins with a statement of the physical investigation. The initial statement should allow you to answer the following questions that are important for meaningful learning: What is the purpose of doing this lab problem? How is it related to the real world? The first paragraphs usually describe a possible situation that raises the problem you are about to study.

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 a gel substrate. You have been asked to measure their velocity. One technique to determine the velocity is to measure the time the protein takes to travel a measured distance. To determine if this is a good method, you decide to measure the protein motion with a marked measuring rod and a stopwatch.

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. You then take several measurements of the cart's position at different time instants while it is in motion using the measuring rod and stopwatch. By analyzing the position data you try to determine if the cart is experiencing constant velocity motion, and what the velocity is.

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 problem.

For this problem, you will use a cart and an aluminum track. You will also have a stopwatch, and a meter stick. Additionally you have a computer with software for data analysis and presentation.

PREDICTION

Everyone has "personal theories" about the way the world works. One purpose of this lab is to help you clarify your conceptions 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.

If you cannot initially complete the prediction or are not sure if it is correct the "Warm-up Questions" are designed to help, but first do your best to make a prediction using your current knowledge.

What are you trying to determine in this laboratory problem? What would you expect a position vs. time graph to look like for an object traveling with a constant velocity? What would you expect a velocity vs. time graph to look like for an object traveling with constant velocity? Do you expect the cart to travel with constant velocity on the track?

What assumptions are you making when analyzing this problem?

WARM UP

Warm-up Questions are intended to help you solve the experimental problem. They can help you both make your prediction and 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.** The warm-up questions may appear simple or extremely confusing depending on whether you currently understand all of the physics ideas involved. *If you get stuck or are not sure of an answer ask for help.*

After you complete the warm-up questions look again at your prediction to see if you still agree with it. If you decide to change your prediction pay attention to how your ideas or understanding of the problem have changed and why.

Special Note on Graphing:

These warm up questions ask you to draw graphs. Being able to make clean and understandable graphs is extremely important. When constructing lab reports you will nearly always need a graph to present your data. Here are some things every graph must have:

- Every graph needs to have its **axes labeled <u>including units</u>**. For example, on a graph showing velocity as a function of time the axis representing velocity could be labeled "Velocity (meters/second)". Likewise the axis representing time could be labeled "Time(seconds)". Even when making prediction graphs include the units you expect to measure.
- Every graph needs a title. The title should be clear and explain what the graph is showing. An example title for a velocity graph would be "Object Velocity vs. Time". **If you choose to use "vs." in your title the quantity on the vertical axis goes before "vs." the quantity on the horizontal axis goes after.**
- Microsoft Excel is a useful program for generating graphs from simple data. The laboratory computers have this program and you should become familiar with how to use it to make correctly labeled graphs. Excel can also be used to fit simple functions to data, which is a desirable feature when analyzing data from some experiments.

To make your prediction, you need to think about how to measure and represent the motion of an object. The following questions should help.

Read Sternheim & Kane: sections 1.1-1.6, 1.7.

1. How would you expect an *instantaneous velocity vs. time graph* to look for an object with constant velocity? Make a rough graph and explain your reasoning. Write an equation that describes this graph. What is the meaning of each quantity in your equation? How does each quantity in your equation affect the shape of your graph?

2. How would you expect a *position vs. time graph* to look for an object moving with constant velocity? Make a rough graph 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 and describe the meaning of each quantity in your equation. How does each quantity in your equation affect the shape of your graph? In terms of the quantities in your equation, what is the velocity?

3. Now imagine an object is moving with slightly increasing velocity. Draw rough graphs for *position vs. time* and *velocity vs. time* for this case. Explain how these graphs are different from the graphs you made in Warm-Up Questions 1 and 2.

4. Now imagine an object is moving with slightly decreasing velocity. Draw rough graphs for *position vs. time* and *velocity vs. time* for this case. Explain how these graphs are different from the graphs you made in Warm-Up Questions 1 and 2.

5. What labels do graphs need to be clear and complete? Do your graphs have these labels? In a graph titled "Position vs. Time" what quantity corresponds to the vertical axis? In a graph titled "Time vs. Position" what quantity corresponds to the vertical axis?

EXPLORATION

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 your intuition about the physical world.

This section is extremely important—carefully explore that your equipment actually works and devise a plan for taking data before you actually take data. **If you do not understand your equipment and make a careful plan you may waste effort or become lost.**

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.

Practice taking distance and time measurements of the cart while it is in motion. Make a plan for how you will record the cart's position at different times. Determine how you can use these measurements to determine the cart's velocity.

MEASUREMENT

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

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

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?

Use Excel to make a position vs. time graph of your measurement data. Explore the program consulting the help features as needed until you understand how to make a correctly labeled graph. After you have made graph use Excel to fit a trend-line to your data. Display the equation for the trend-line on your graph (you may need to consult the program help features to learn how to do this).

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

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.**

Did your graphs agree with your predictions regarding their shape? If not, why? What is the meaning of the fit equations you added to your graphs? Can you determine the cart velocity from the fit equations? 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?

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.*

PROBLEM #2: CONSTANT VELOCITY MOTION 2
COMPUTER ASSISTED MEASUREMENT

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 a gel 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 a cart a push so that it moves down a horizontal track, and then 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 the 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.

EQUIPMENT

For this problem, you will use a cart and an aluminum track. You will also have a stopwatch, a meter stick, a video camera and a computer with a video analysis application written in LabVIEW™ (described in Appendix D). The LabVIEW™ application programs on your computer disk include VideoRECORDER and MotionLab. Each frame of the video shows you the object's position at the time that the frame was recorded. The time between frames is usually 1/30 second.

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 describes the relationship between position and velocity. 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

Special Note on Functions:

In this lab problem you will need to fit mathematical functions to gathered data. Understanding how different functions look and behave is important. Here are the names of some common functions with some simple example equations.

- Line (or "linear function", though sometimes this phrase can mean other things): An example equation for a straight line is $f(x) = mx + b$. The constant m is the line slope, the constant b is the value of the function at $x = 0$.
- Parabola: An example equation for a parabola is $f(x) = ax^2$. What makes a function a parabola is that the variable is squared (and not raised to some other power; for example another function called a "cubic" function has the variable raised to the power 3 instead of 2). A parabola is **<u>not</u>** an exponential function.
- Polynomial: An example equation for a polynomial is $f(x) = A + Bx + Cx^2 + Dx^4$. Here A, B, etc. are constants. A polynomial is a sum of terms involving a variable raised to an integer power. You may notice that a parabola is a specific type of polynomial.

- Power Law: An example equation for a power law function is $f(x) = ax^b$. Here a and b are constants. It is called a *power* law function because the variable x is raised to the *power* b. b could be a positive or negative number, and is not necessarily an integer though it could be. You may notice that a parabola is a specific type of power law function. A power law function is **not** the same as an exponential function.
- Exponential: An example equation for an exponential function is $f(x) = Ab^{cx}$. Here A, b, and c are constants. It is called an *exponential* function because the variable x appears in the *exponent* of a constant b; b is called the *base* of the exponential. Most commonly the number e is used as the base for exponential functions ($e = 2.7182818...$). If some quantity is described as increasing or decreasing *exponentially* it means that it could be described by an *exponential function*. Parabolas and power law functions are **not** exponential functions.

To make your prediction, you need to think about how to measure and represent the motion of an object. The following questions should help.

Read Sternheim & Kane: sections 1.1-1.6, 1.7.

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 and 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? Does your graph and equation represent a type of function with a common name?

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 and describe 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? Does your graph and equation represent a type of function with a common name?

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. Is it correct to say that a hypothetical function $f(x) = mx + b$ increases exponentially with x? Does the function $f(x) = x^2$ increase exponentially with x?

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? The camera can be focused by twisting the ring around the lens. 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 for analysis.

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

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

MEASUREMENT

1. Take a good video of the cart's motion using the video cameras and the VidoeRECORDER software.
2. Analyze the video with the MotionLab software which allows you to predict and fit functions for *position vs. time* and *velocity vs. time*.

The directions on how to analyze a video are shown on the computer screen by the MotionLab analysis software. These directions will walk you through how to analyze a motion video; read them carefully.

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.

A convenient way to save your MotionLab data is to "print" it to a pdf file. Once your analysis is complete select "print", followed by "print to pdf". After selecting "print to pdf" a window showing a preview of the pdf file will appear. From the pdf preview window select "save as" and choose a file name. Emailing lab members the analysis pdf files can be a good way to back up your data.

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

ANALYSIS

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 changing 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?

PROBLEM #3: MEASUREMENT AND UNCERTAINTY

You work in a biochemistry lab and you often have to perform experiments in which you need to repeatedly read a gauge indicating pH values. You wonder if there might be some mistakes in your readings and what type of uncertainty this might introduce into your recorded data. In order to better understand the nature of the uncertainty present in repeated measurements you decide to repeat a simple measurement several times and see if the result varies. You decide that the simple measurement you perform will be measuring the length of a lantern battery to the greatest precision possible using a meter stick. To make each measurement independent you decide to put down the battery and meter stick between measurements. For a more interesting analysis you decide to compare the results of your repeated measurements with those of others.

EQUIPMENT

For this problem you will use a lantern battery and a meter stick.

PREDICTION

Do you think value of your measurements will change between trials? What is the greatest precision you can obtain using the equipment available?

WARM UP

Special Note on Error and Uncertainties:

When performing any measurement there are limitations on how precisely you can determine the measurement value. It is important to record these limitations so that others can understand the meaning of your data. Uncertainties are often recorded using plus or minus notation; for example a distance measurement might be reported as 3.1 ± 0.05 meters. This means that the reported distance is no more than 0.05 meters larger or smaller than the actual distance. You need to report the estimated uncertainty on all of your measurements for your data to be meaningful. If many measurements have the same uncertainty you may report it once at the beginning of the measurement table. You will perform many length measurements in the course of this laboratory; a good rule of thumb for the uncertainty present on length measurements is that it is half the smallest increment on the measuring device (assuming you are rounding your length measurements to the nearest marking on the measuring device).

When you collect data errors in your equipment may cause unexpected behavior. There are two main types of error, random and systematic. Random error tends to throw values off by small amounts, and will be equally likely to make a measurement larger or smaller than expected. Systematic error results from a flaw in the system or measuring equipment that makes all measurements different than expected in a systematic manner. It can be difficult to tell the difference between a systematic error and a flat out disagreement with theory.

When you analyze the data obtained from any lab you should answer the questions: Did the data agree with what we expected based on physical arguments? Is there error present in the data? Report the percent difference between the measured and expected values. Is the error within the expected uncertainty? Is the error random or systematic? Does the data have the expected shape? If systematic error appears to be present what might have been the cause? Are you sure it is systematic error and not a flaw in the prediction or some other flaw?

1. How can data be recorded so that the accuracy of the data is understood?

2. What is the difference between random error and systematic error?

3. When analyzing whether your data agrees with what you expected what types of questions should you ask? What is something that you can report to convey the difference between measured and expected values?

EXPLORATION

Practice measuring one dimension of the lantern battery in a way that can be easily repeated.

MEASUREMENT

Measure one dimension of the lantern battery repeatedly. To make the measurements independent put down the battery and ruler between measurements.

ANALYSIS

After you have completed the measurements see if any of the values differed from the others. If so, what might be the cause? Compare your measurements with those made by others. Are there any differences?

CONCLUSION

Was there any error present in your measurements? What kind of error was it? Can you think of ways to perform many measurements like this more accurately?

TAs 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 name: ______________________________

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 to conclusion; 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
MOTION AND FORCE

In this laboratory you will study forces and the way forces affect the motion of objects. You will apply Newton's Laws of Motion to experimental situations, and use them to solve problems. This laboratory aims to increase your ability to use the concepts of force and acceleration to understand and predict how physical systems behave.

Objectives:

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

- Describe the motion of an object moving in one or two dimensions using position, time, velocity, and acceleration.
- Understand how the concepts of force and acceleration are related and use them 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:

Reading material regarding the concepts in this section is located in Sternheim and Kane, chapters 1, 2, and 3. The warm-up questions for each lab problem contain information regarding the reading sections relevant to that problem. 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 and explain the concepts of force and acceleration and how they are related.
- Define and use sine, cosine and tangent for a right triangle.
- Recognize the difference between mass and weight.
- Draw and use force diagrams.
- Be able to write down position and velocity equations for objects experiencing constant acceleration.
- Explain the difference between average velocity and velocity.

PROBLEM #1: 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. One of your friends believes that the answer is simple; humans are heavier than cats and therefore fall faster. Your friend believes that 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 correct explanation. Understanding how falling injuries occur is important for many types of athletic medicine so you decide to test your friend's proposal that heavier things fall faster.

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. You also try to use your knowledge of force, gravity, and acceleration, to make a reasoned prediction of how fast the falling balls will be traveling when they hit the ground. After thinking about the situation and performing the experiment you will be able to judge whether your friend's idea about heavier things falling faster is correct.

EQUIPMENT

For this problem, you will have a collection of balls of approximately the same size but with different masses. You will also have 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. Explain any approximations or assumptions that you are making. Write equations for the acceleration, velocity, and position of a falling ball as functions of time. From your equations draw an acceleration-vs-time graph, a velocity-vs-time graph, and a position-vs-time graph. Explain how these graphs resulted from your equations.

From your reasoning do you think objects with greater mass fall faster?

WARM UP

Read Sternheim & Kane: sections 1.1-1.7, 3.1-3.11.

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. Use your force diagram for the ball and Newton's Laws of Motion to write an equation for the acceleration of the ball. Does the ball fall with a constant speed or is it speeding up or slowing down? Draw an *acceleration vs. time graph* for the ball.
3. Write an equation for the ball's velocity as a function of time (Hint: use calculus and the equation for acceleration). Sketch a *velocity vs. time graph* for the ball. What is the shape of the velocity 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 velocity graph?
4. Write an equation for the ball's position as a function of time (Hint: use calculus and the equation for velocity). Sketch a *position vs. time graph* for the ball. Does the shape of the *velocity vs time* graph affect the *position vs. time* graph?
5. Draw a diagram of the ball in midair and label the distance the ball will fall before hitting the ground. Write an equation predicting the ball's velocity just before it hits the ground. In your equation does the ball's velocity just before it hits the ground depend on the mass of the ball?

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 can be used 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, your instructor may be able to adjust 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. Your calibration object needs to be as far away from the camera as the ball, otherwise it will appear smaller or larger than required for accurate calibration.

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. Consider adjusting the shutter speed.

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, if 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 balls of different mass.

ANALYSIS

Choose a function to represent the position-versus-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-versus-time graph. Calculate the values of the parameters of this function from the function representing the position-versus-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 how the velocity of a freefalling object changes with time? What do your measurements say about how the velocity of a freefalling object depends on the mass of the object? Was your friend's prediction that "heavier things fall faster" correct? What do your measurements say about how the velocity of a freefalling object just before it hits the ground depends on the height the object fell from? 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.

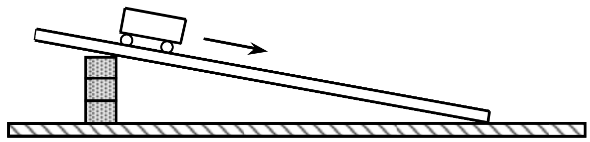
Do your results hold regardless of the mass of the ball? Would the character of the motion of a falling Styrofoam ball be the same as that of a falling baseball? Do the size and shape of the object matter? Is air resistance significant?

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. What do you think might be the reason for a cat being uninjured after falling a distance that would harm a human?

PROBLEM #2: MOTION DOWN AN INCLINE

You are a biologist studying penguins in the Antarctic. You notice that sometimes penguins slide down sloped ice into the sea water. You wonder about this behavior, and how the boost of speed penguins get while sliding down ice might help them catch prey or evade predators. To study this further you need to determine how fast a penguin is traveling while sliding down an ice slope. To model this situation you decide to use a cart and an inclined ramp. The wheels of the cart have low friction, similar to the low friction present on ice. You wish to determine how the speed of the cart increases as it is traveling down the slope, and the way the speed depends on properties of the ramp (such as angle) or the cart (such as the cart mass). You want to be able to accurately predict the speed of the cart at the bottom of the ramp.

EQUIPMENT



For this problem you will have a cart, a track with an end stop, a stopwatch, a meter stick, blocks, 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 speed of the cart at the bottom of the ramp. Make sure that you state any approximations or assumptions that you are making.

WARM UP

Read Sternheim & Kane: sections 1.1-1.7, 3.1-3.11.

Answering the following questions should help you to understand the physics involved in this problem:

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. From your coordinate system and free body diagrams, is there a dimension in which the net force adds to zero? Which dimension and how do you know this?
3. Write the force component responsible for accelerating the cart. If any angles are involved, write down how they are related to the angle of the track.
4. Calculate the acceleration of the cart in terms of quantities you know or can measure.
5. Using the acceleration of the cart write an equation for the velocity of the cart as a function of time. Sketch a graph of velocity vs. time.
6. Write an equation for the position of the cart along the ramp as a function of time (Hint: use calculus and your velocity equation). Sketch a graph of position vs. time.
7. Write an equation that predicts the speed of the cart at the bottom of the ramp in terms of quantities you know or can measure.

EXPLORATION

One aspect to examine is how the angle of the ramp affects the cart velocity. 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?

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? 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. How many different cart masses do you need to determine the effect of the mass of the cart on the final velocity?

Write down your measurement plan.

MEASUREMENT

Follow the measurement plan you wrote down.

When you have finished making measurements you should have saved copies of position and velocity graphs and good records in your lab journal 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-versus-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-versus-time graph. Calculate the values of the constants of this function from the function representing the position-versus-time graph. Check how well this works.

You can also estimate the values of the constants from the graph 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 change with time? How does the way the velocity behaves depend on the angle of the ramp and the mass of the cart? In what sense is the motion similar to free-fall? In what sense is it different? Extrapolate your results to the case of a vertically inclined track and compare with that of free-fall. Can you accurately predict the velocity of the cart at the bottom of the track?

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?

PROBLEM #3: MOTION UP AND DOWN AN INCLINE

You are a doctor working as 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. After the initial launch the car glides up and down the track under the influence of gravity. Near the top of the track is where the cart reverses its direction and rolls back down. You know the regulations regarding 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 using 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, 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 equation that gives the acceleration of the system. Make sure that you state any approximations or assumptions that you are making.

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

WARM UP

Read Sternheim & Kane: sections 1.1-1.7, 3.1-3.11.

1. Make a free-body diagram for the cart moving up the inclined track. Show all forces on the cart. Explain which forces you can neglect and do so. Indicate the direction of acceleration.
2. Draw a coordinate system with two perpendicular axes for the analysis of the forces. Choose the directions of these two axes to make the calculation as easy as possible. Transfer your forces to this coordinate system. How are any angles between the forces and the coordinate axes related to the angle of the track?
3. Find components of the forces along the axes.
4. Write Newton's Second Law for each axis separately. How do you determine the sign of each term in the equation? Determine the acceleration (magnitude and direction) in terms of other quantities that you know or can measure.
5. Repeat steps 1-4 for the cart moving down the incline.
6. Repeat steps 1-4 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.
7. Compare the three expressions for the acceleration obtained from questions 4, 5, and 6 in both magnitude and direction. How does the acceleration change during the motion up and down the ramp?

8. Use calculus to determine the cart's velocity as a function of time from its acceleration. From this equation determine if there is any time at which the velocity of the cart is zero. From your equation what is the cart's acceleration at that time?

9. Use calculus to determine 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, determine the velocity of the cart at that time. From your equation, determine the acceleration of the cart at that time.

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?

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

From the velocity versus time graph determine if the acceleration changes as the cart goes up and then down the ramp. Use the functions representing the velocity versus time graph and the position-versus-time graph to calculate the acceleration of the cart as a function of time. Do the two calculations agree? Make a graph of acceleration-versus-time. Can you tell from your acceleration-versus-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-versus-time and velocity-versus-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? 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?
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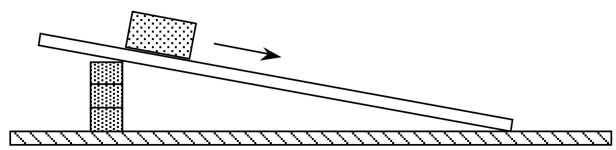
PROBLEM #4: NORMAL FORCE AND FRICTIONAL FORCE

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 kinematics. 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 the frictional force versus the normal force. This is what you will test in the laboratory. In summary, you wish to perform experiments that will allow you to create a plot frictional force vs. normal force, and see if this plot has the expected shape or if under some lab conditions the shape might be different.

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 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 equations that give 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.

WARM UP

Read Sternheim & Kane: sections 1.1-1.7, 3.1-3.12.

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 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 expression for the acceleration of the block in terms of quantities you know or can measure. Is the acceleration positive, negative, or zero? What is would be the difference between a positive and negative acceleration in this case?
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

Note: Getting consistent results for the frictional force requires a clean track. Make sure your track is very clean; you may need to clean it with a wet paper towel.

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.

See the table of friction coefficients on page Lab II – 25.

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 that 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?

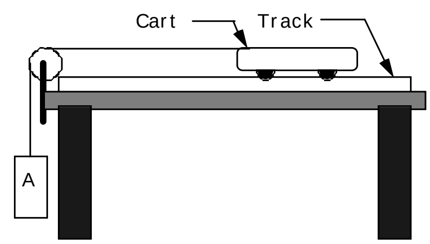
PROBLEM #5: VELOCITY AND FORCE

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 launch mechanism will use a falling weight to accelerate the gliding models. To set this up you first use a hanging weight to accelerate a cart. The cart begins its motion when the hanging object attached to it by rope going over a pulley is allowed to fall. You want to predict how the velocity of the cart changes while the hanging weight is falling, and what the velocity of the cart will be once the weight reaches the floor.

EQUIPMENT

For this problem you will have an aluminum track, a 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 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 for the acceleration of the cart using force arguments. Make sure that you state any approximations or assumptions that you are making. Use your acceleration equation and calculus to write an equation for the cart's velocity as a function of time. Use your velocity equation to find an equation for the cart's position as a function of time.

Sketch a graph of 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.

WARM UP

Read Sternheim & Kane: sections 1.1-1.7, 3.1-3.11.

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. What is happening to the velocity of the cart during the first time interval? During the second time interval?
2. Make a drawing of the physical situation for each time interval. Draw and label vectors to represent quantities that describe the motion of the cart and hanging object *and also* the forces acting on them. If two quantities have the same magnitude, use the same symbol *and* write down your justification for doing so. Define a convenient coordinate system. In each time interval, what quantities are constant and what quantities are changing.
3. Using the forces acting on your system for while the hanging weight is falling find the net force on the cart. Write down an equation for the acceleration of the cart for while the hanging weight is falling.

4. Use your equation for the acceleration of the cart and calculus to write down an equation for the velocity of the cart as a function of time while the hanging weight is falling. Next determine an equation for the position of the cart as a function of time while the hanging weight is falling.
5. Write down equations for the acceleration, velocity, and position of the cart *after* the hanging weight has hit the ground.
6. Determine an equation for the maximum velocity the cart will reach in terms of quantities you know or can measure.

EXPLORATION

Adjust the length of the string such that the hanging object hits the floor well before the cart runs out of track. You will be analyzing a video of the cart both *before* and *after* the hanging object has hit the floor. 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 the hanging object that allows the cart to achieve a reliably measurable velocity before object it hits the floor. Make sure you include masses of the hanging object 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 <u>before</u> 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 the hanging object. Record the height through which hanging object 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 acceleration experienced by the cart while the hanging object, and how it depends on the mass of the cart and the mass of the hanging object. 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 acceleration of the cart while the hanging mass is falling depend on the cart mass and the hanging object mass? How does the maximum 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?

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 why this does or does not make sense to you.

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?

PROBLEM #6: TWO-DIMENSIONAL PROJECTILE 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 at some angle, 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

Beginning with basic physics principles, show how you get equations that give the position, velocity, and acceleration of a ball tossed through the air at some angle. Make sure that you state any approximations or assumptions that you are making.

WARM UP

Read Sternheim & Kane: sections 1.1-1.7, 3.1-3.11.

The following questions will help you to arrive to the prediction.

1. Draw a picture of the trajectory of the 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. Make a free-body diagram of the ball. What forces are you assuming 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 consistent, 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 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. Explain your reasoning.
4. Write down the equation that gives the definition of the horizontal acceleration. 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.

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.

Digitize the position of the ball in enough frames of the video so that you have sufficient data to accomplish your analysis. Make sure you set the scale for the axes of your 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 versus 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-versus-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?

Table of Coefficients of Friction*

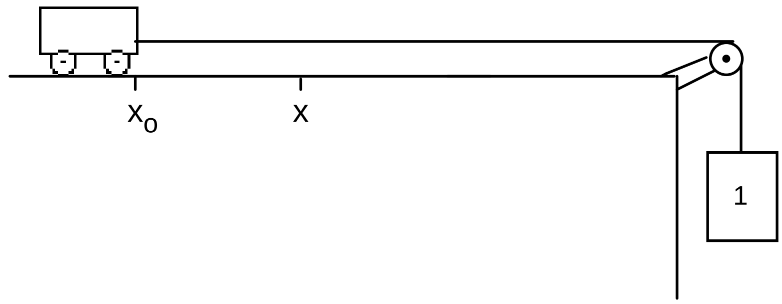
Table of Approximate Friction Coefficients

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.

TAs 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 name: ____

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 to conclusion; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

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

LABORATORY III
STATICS

In biological systems most objects of interest are in equilibrium or close to it. When an object is in equilibrium it is 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 in these situations is an important step to understanding 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 relationships among forces that result in the equilibrium of an object or system of objects.

PREPARATION:

Read Sternheim & Kane: chapter 4, review chapters 1, 2, 3. 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.
- Write down the relationship between the force exerted by a spring and its elongation.

PROBLEM #1: SPRINGS AND EQUILIBRIUM I

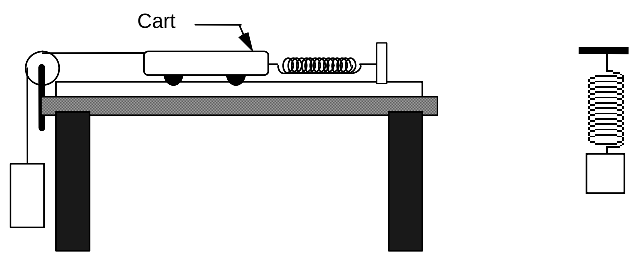
You work for a biophysics research group studying the mechanics of DNA during cell division. One common technique involves securing one end of a DNA molecule to a surface and, with optical tweezers, measuring the force required to slightly straighten the DNA molecule from its normal coiled state. The 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 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 attached to the track.

You want to determine how the spring stretch in the two situations will compare. This will serve as your simple model for how DNA stretching compares with and without an optical bead.

EQUIPMENT

You will have a spring, a mass hanger and masses, a cart, cart weights, a cart track, an end-stop, a piece of 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. This equation will be a relationship between the extension of a spring and the weight of the hanging object, in each situation described in the problem (when the system has reached equilibrium). Illustrate each relationship with a graph of *spring extension vs. weight*.

WARM UP

Read Sternheim & Kane: sections 3.1-3.8, 4.1-4.2, 4.10, 9.1.

1. Draw a picture of a spring attached to a hanging object. On your picture, show and label the extension 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 if the object is in equilibrium?
4. Write an equation that relates the spring's extension to the force it exerts. Use this equation and the result of the previous step 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*.
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. 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 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 determine the relationship between the extension of the spring and the weight of the hanging object. Sketch a graph of *spring extension vs. weight.*

EXPLORATION

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 and 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

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

For each case, make a graph of the extension of the spring against the mass hanging weight. 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, and explain the physical significance of the slope. Why don't all of the data points fall exactly on your line?

CONCLUSION

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. 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.

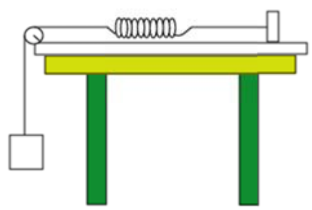
What conclusions can you draw about the corrections you will have to make for the bead's mass on the DNA measurement described in the original problem?

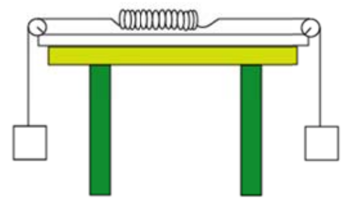
PROBLEM #2: SPRINGS AND EQUILIBRIUM II

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 from 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 and fixed at the other 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, a 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

Read Sternheim & Kane: sections 3.1-3.8, 4.1-4.2, 4.10, 9.1.

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. Determine the 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 and 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? Should the slope be independent of what is pulling on the spring?

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 will a cell stretch if only one force is acting on it?

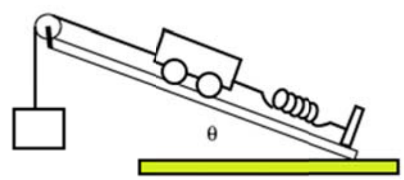
PROBLEM #3: LEG ELEVATOR

You are a medical consultant to a health 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.

The traction device is a simple mechanism for putting steady tension on a leg held at an angle through the use of a hanging weight. You model the system using a ramp, spring, cart, and hanging weight. The spring is attached to the cart and the end of the ramp; by measuring the extension of the spring you can determine the force on the cart. A string is attached to the other end of 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 forces acting on the cart, and how they may depend on the angle of the ramp. If you correctly understand the force balance you will be able to predict the spring extension in your model. You will test your calculations in the lab by building the model and exploring different weight and angle combinations.

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, write down an equation that gives the force exerted by the spring on the cart in terms of quantities you can measure. 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 and which will remain constant? How does the spring force relate to the appropriate masses and the track angle?

WARM UP

Read Sternheim & Kane: sections 3.1-3.8, 4.1-4.7, 4.10, 9.1.

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 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. Is the cart in equilibrium? Use a convenient 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 determine this 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 how you will measure the spring constant.

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.

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 elongation of the spring vary with the angle of the track? How does the elongation of the spring vary with the mass of the cart? How does the elongation 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.

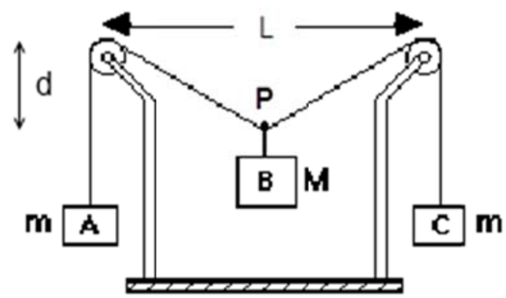
PROBLEM #4: EQUILIBRIUM IN A WALKWAY

You have a 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 and still 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 counterweight 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 collection.



PREDICTION

Beginning with basic physics principles, write an equation that gives the sag of the central weight in terms of measurable quantities. 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

Read Sternheim & Kane: sections 3.1-3.8, 4.1-4.2, 4.10.

1. Draw a free-body diagram of forces acting on object B. Do the same for objects A, C and point P. Although no mass is attributed to point P, for that point not to accelerate the net force acting at that point must still be zero.
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? Find an equation that gives the sag of the central mass.
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 central 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 (measured and predicted) 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

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.

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

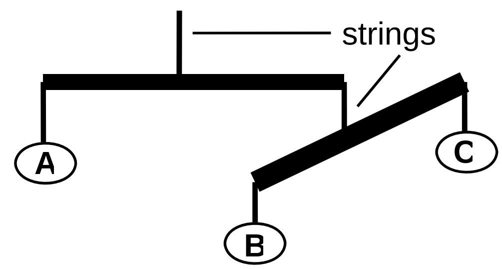
PROBLEM #5: DESIGNING A MOBILE

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. You know that the pivot point from which each rod hangs will depend on the hanging objects. Your instructions are to balance the rods, but selecting the three objects is up to you. However, there are a limited number of objects so you decide to prepare yourself for anything by writing an equation for each pivot point 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. You want to plan your mobile before you construct it.

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 for each pivot point of a hanging rod. 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 and which will remain constant?

WARM UP

Read Sternheim & Kane: sections 4.1-4.3. Review sections 1.3-1.5, 2.1, 3.1-3.4.

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. Do the masses of the rods matter? 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. Identify any torques on each rod.

3. For each free-body diagram, write down the conditions for equilibrium. 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?

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 variables that you won't be able to measure in more than one equation, solve for that variable in each equation. See if they cancel out. If there 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. Design your mobile <u>first</u>, and then try to construct your design.

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.

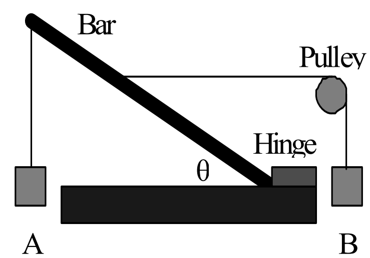
PROBLEM #6: MECHANICAL ARM

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 attachment point of the lifting cable varies as a function of the mass of the object being lifted in order to hold the bar steady. 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. In essence you want your arm to "balance," with the lifted object held steady. You will test your calculations in the laboratory with the equipment shown below.

WARNING: The equilibrium in this system is unstable, it is strongly recommended that you keep your hand near the bar while the system is balancing to catch it if it falls. Be careful not to let the system fall or fling equipment.

EQUIPMENT

You will have an aluminum bar, a pulley, a pulley clamp, two mass hangers, a mass set, and some strings. It helps to tape the hinge point of the bar against the pulley clamp so it can freely move up and down



PREDICTION

Beginning with basic physics principles, show how you get an equation that gives the the attachment point of the lifting cable of the apparatus. 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

Read Sternheim & Kane: sections 4.1-4.3, 4.5-4.10. Review sections 1.3-1.5, 2.1, 3.1-3.4.

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).
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. Sketch a graph of the balance angle of the arm vs. the weight being lifted assuming all other quantities are constant.

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.

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? If you change the position of the attachment of the support cable to the bar?

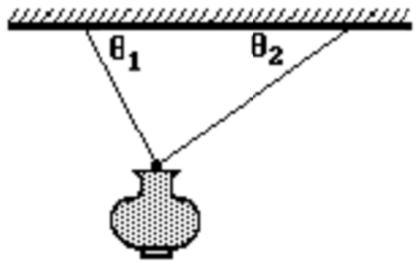
CONCLUSION

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?

☑ CHECK YOUR UNDERSTANDING

Explain why the string lengths were (or

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



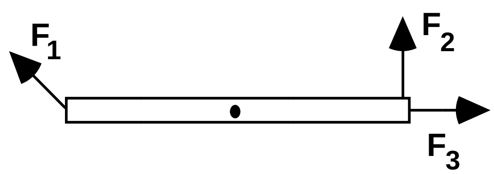
a. Draw the force diagram of the *lamp*. Clearly describe each force drawn.

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.

TAs 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 name: _____________________________________

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 to conclusion; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

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

LABORATORY IV
CIRCULAR MOTION AND ROTATION

In this section you will begin to study the behavior of objects experiencing circular motion or rotation. Real objects usually rotate as well as move along trajectories. You already have a lot of experience with rotating objects from your everyday life. Every time you open or close a door, something rotates. Rotating wheels are everywhere. Balls spin when they are thrown. The earth rotates about its axis. Rotations are important whether you are discussing galaxies or subatomic particles.

An object's rotational motion can be described with the kinematic quantities you have already used: position, velocity, acceleration, and time. In these problems, you will explore the connection of these familiar linear kinematic quantities to a more convenient set of quantities for describing rotational kinematics: angle, angular velocity, angular acceleration, and time. Often, the analysis of an interaction requires the use of both linear and rotational kinematics.

OBJECTIVES:

Successfully completing this laboratory should enable you to:

- Use linear kinematics to predict the outcome of a rotational system.
- Choose a useful system when using rotational kinematics.
- Identify links between linear and rotational motion.
- Decide when rotational kinematics is more useful and when it is a not.
- Use both linear and rotational kinematics as a means of describing the behavior of systems.

PREPARATION:

Read Sternheim & Kane: chapter 5, review chapters 1, 2, 3. 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:

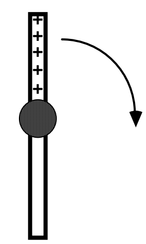
- Analyze the motion of an object using linear kinematics and video analysis.
- Identify the connection between the linear description of motion and rotational description of motion
- Calculate the angle of rotation in radians.
- Calculate the angular speed of a rotating object.
- Calculate the angular acceleration of a rotating object.

PROBLEM #1: 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 equations that give the position, velocity, and acceleration of a point on the rotating beam. Make sure that you state any approximations or assumptions that you are making.

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

WARM UP

Read Sternheim & Kane: sections 5.1-5.3. Review sections 1.3-1.5, 2.1-2.4, 3.3-3.8.

1. Draw the trajectory of an object moving in a 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. Write down the equation for the other component of position. Since angular speed is constant, write down an equation for the angle as a function of time. Substitute this into your equations for position.

3. Use calculus (and the Chain Rule) to determine the components of the velocity. Remember 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, calculate the speed of the object. Is the speed a function of time or is it constant? Use this equation to relate the angular speed to the speed of the object.

4. Use calculus and your equations for the components of the velocity of the object to write down the equation for each component of the acceleration of the object.

5. Using your equations for the components of the acceleration of the object as a function of time, calculate 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 determine 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

Digitize 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.

ANALYSIS

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

Check your data and analysis procedure by comparing the speed that you extract 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.

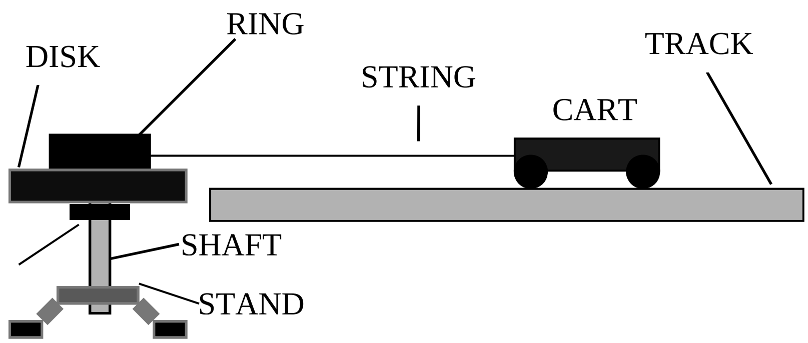
Compare the magnitude of the acceleration of the object that you calculate from your measurements to the "centripetal acceleration" that you can calculate from the speed and the radius of the object.

PROBLEM#2: ROTATION AND LINEAR MOTION AT CONSTANT SPEED

You are working in a bio-technology lab and need to repair a centrifuge with a broken drive mechanism. The centrifuge consists of a wheel for holding and spinning test tubes, and a drive belt wrapped around the wheel and connected to an engine which provides the power. The drive belt and engine have broken and you need to install replacements. You know the angular velocity that the centrifuge wheel should spin at, but are not sure how this relates to the linear velocity of the drive belt. Before attempting the repair you decide to model the situation in the lab.

You construct a model of the centrifuge using a spinning wheel, and a string to represent the drive belt. In your model you connect the string to a moving cart so that you will be able to measure the velocity of the string by observing the cart's velocity. You use your knowledge of rotational and linear motion to predict how the velocity of the string is related to the angular velocity of the rotating wheel, and then test your prediction using your model.

EQUIPMENT



You will have a disk mounted horizontally on a sturdy stand, with a ring coaxially fastened on the disk. Together, the disk and the ring represent the centrifuge. The disk and the ring rotate freely about a vertical shaft through their center.

You will attach one end of a string to the outside surface of the ring, so that it can wrap around the ring. The other end of the string will be connected to a cart that can move along a level track. You also have a stopwatch, a meter stick, an end stop, some wooden blocks and the video analysis equipment.

PREDICTION

Restate the problem. What are you trying to calculate? Which experimental parameters will be determined by the laboratory equipment, and which ones will you control?

WARM UP

Read Sternheim & Kane: sections 5.1-5.3. Review sections 1.3-1.5, 2.1-2.4, 3.3-3.8.

The following questions will help you to reach your prediction.

1. Draw a top view of the system. Draw the velocity and acceleration vectors of a point on the outside edge of the ring. Draw a vector representing the angular velocity of the ring. Draw the velocity and acceleration vectors of a point along the string. Draw the velocity and acceleration vectors of the cart. Write an equation for the relationship between the linear velocity of the point where the string is attached to the ring and the velocity of the cart (if the string is taut).

2. Choose a coordinate system useful for describing the motion of the point where the string is attached to the ring. Select a point on the outside edge of the ring. Write equations for the perpendicular components of the position vector as a function of the distance from the axis of rotation and the angle the vector makes with one axis of your coordinate system. Calculate how that angle depends on time and the constant angular speed of the ring. Sketch three graphs, (one for each of these equations) as a function of time.

3. Using your equations for the components of the position of the point, determine equations for the components of the velocity of the point. Graph these equations as a function of time. Compare these graphs to those representing the components of the position of the object.

4. Use your equations for the components of the velocity of the point to calculate its speed. Is the speed a function of time or is it constant?

5. Now write an equation for the cart's speed as a function of time, assuming the string is taut.

EXPLORATION

Try to make the cart move along the track with a constant velocity. (To account for friction, you may need to slant the track slightly. You might even use some quick video analysis to get this right.) Do this before you attach the string.

Try two different ways of having the string and the cart move with the same constant velocity so that the string remains taut. Try various speeds and pick the way that works most consistently for you. If the string goes slack during the measurement you must redo it.

(1) Gently push the cart and let it go so that the string unwinds from the ring at a constant speed.
(2) Gently spin the disk and let it go so that the string winds up on the ring at a constant speed.

Where will you place the camera to give the best recording looking down on the system? You will need to get data points for both the motion of the ring and the cart. Try some test runs.

Decide what measurements you need to make to determine the speed of the outer edge of the ring and the speed of the string from the same video.

Outline your measurement plan.

MEASUREMENT

Make a video of the motion of the cart **and** the ring for several revolutions of the ring. Measure the radius of the ring. What are the uncertainties in your measurements? (See Appendices A and B if you need to review how to determine significant figures and uncertainties.)

Analyze your video to determine the velocity of the cart and, because the string was taut throughout the measurement, the velocity of the string. Use your measurement of the distance the cart goes and the time of the motion to choose the scale of the computer graphs so that the data is visible when you take it. If the velocity was not constant, adjust your equipment and repeat the measurement.

Analyze the same video to determine the velocity components of the edge of the ring. Use your measurement of the diameter of the ring and the time of the motion to choose the scale of the computer graphs so that the data is visible when you take it.

In addition to finding the angular speed of the ring from the speed of the edge and the radius of the ring, also determine the angular speed directly (using its definition) from either position component of the edge of the ring versus time graph.

ANALYSIS

Use an analysis technique that makes the most efficient use of your data and your time.

Compare the measured speed of the edge of the ring with the measured speed of the cart and thus the string. Calculate the angular speed of the ring from the measured speed of the edge of the ring and the distance of the edge of the ring from the axis of rotation. Compare that to the angular speed measured directly.

CONCLUSION

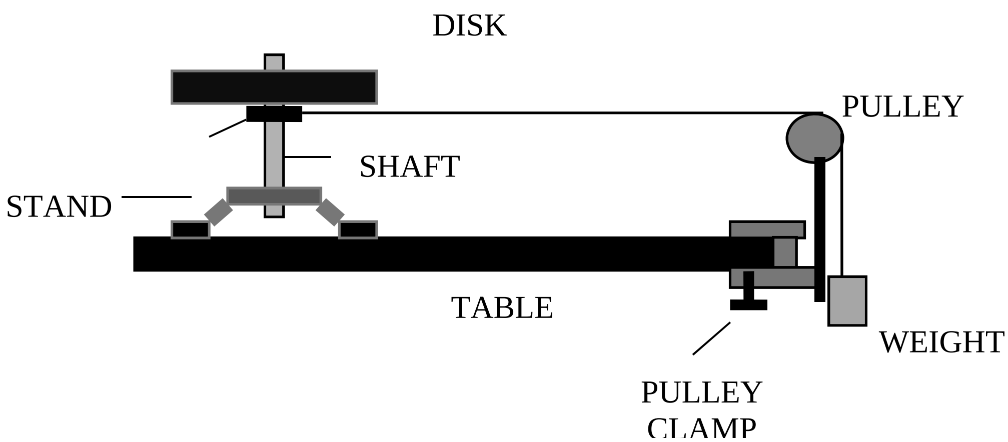
What did you determine regarding how the linear velocity of the string is related to the angular velocity of the wheel? Did your measurements agree with your initial prediction? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

Explain why it is difficult to keep the string taut in this measurement, by considering the forces exerted on each end of the string? Determine the force of the string on the cart and the force of the cart on the string. Determine the force of the string on the ring and the force of the ring on the string. What is the string tension?

PROBLEM #3: ANGULAR AND LINEAR ACCELERATION

You are working in a bioengineering laboratory when the building power fails. An ongoing experiment will be damaged if there is any temperature change. There is a gasoline powered generator on the roof for just such emergencies. You run upstairs and start the generator by pulling on a cord attached to a flywheel. It is such hard work that you decide to design a gravitational powered generator starter for future incidents. The generator you design has its flywheel as a horizontal disk that is free to rotate about its center. One end of a rope is wound up on a horizontal ring attached to the center of the flywheel. The free end of the rope goes horizontally to the edge of the building roof, passes over a vertical pulley, and then hangs straight down. A heavy block is attached to the hanging end of the rope. When the normal power fails the block is released; the rope unrolls from the ring giving the flywheel a large enough angular acceleration to start the generator. To see if this design is feasible you must determine the relationship between the angular acceleration of the flywheel, the downward acceleration of the block, and the radius of the ring. Before putting more effort in the design, you test your idea by building a laboratory model of the device.

EQUIPMENT



You will have a disk mounted horizontally on a sturdy stand. The disk represents the flywheel and is free to rotate about a vertical shaft through its center. You will attach the string to a spool under the center of the disk, in place of the ring in your flywheel design. A string has one end wrapped around the horizontal spool. The other end of the string passes over a vertical pulley lined up with the tangent to the spool. An object (a mass hanger) is hung from the free end of the string so that it can fall past the table. You also have a stopwatch, a meter stick, a pulley clamp, a mass set, a mass hanger and the video analysis equipment.

PREDICTION

Reformulate the problem in your own words to understand its target. What do you need to calculate?

WARM UP

Read Sternheim & Kane: sections 5.1-5.4. Review sections 1.3-1.6, 2.1-2.4, 3.1, 3.3-3.10, 4.1-4.2, 4.10.

The following questions are designed to help you solve the problem in an organized way.

1. Draw a top view of the system. Draw the velocity and acceleration vectors of a point on the outside edge of the spool. Draw a vector representing the angular acceleration of the spool. Draw the velocity and acceleration vectors of a point along the string.

2. Draw a side view of the system. Draw the velocity and acceleration vectors of the hanging object. What is the relationship between the linear acceleration of the string and the acceleration of the hanging object if the string is taut? Do you expect the acceleration of the hanging object to be constant? Explain.

3. Choose a coordinate system useful to describe the motion of the spool. Select a point on the outside edge of the spool. Write equations giving the perpendicular components of the point's position vector as a function of the distance from the axis of rotation and the angle the vector makes with one axis of your coordinate system. Assume the angular acceleration is constant and that the disk starts from rest. Determine how the angle between the position vector and the coordinate axis depends on time and the angular acceleration of the spool. Sketch three graphs, (one for each of these equations) as a function of time.

4. Using your equations for components of the position of the point, calculate the equations for the components of the velocity of the point. Is the *speed* of this point a function of time or is it constant? Graph these equations as a function of time.

5. Use your equations for the components of the velocity of the point on the edge of the spool to calculate the components of the *acceleration* of that point. From the components of the acceleration, calculate the *square of the total acceleration* of that point. It looks like a mess but it can be simplified to two terms if you can use: $\sin^2(z)+\cos^2(z) = 1$.

6. From step 5, the magnitude acceleration of the point on the edge of the spool has one term that depends on time and another term that does not. Identify the term that depends on time by using the relationship between the angular speed and the angular acceleration for a constant angular acceleration. If you still don't recognize this term, use the relationship among angular speed, linear speed and distance from the axis of rotation. Now identify the relationship between this time-dependent term and the centripetal acceleration.

7. We also can solve the acceleration vector of the point on the edge of the spool into two perpendicular components by another way. One component is the centripetal acceleration and the other component is the tangential acceleration. In step 6, we already identify the centripetal acceleration term from the total acceleration. So now you can recognize the tangential acceleration term. How is the tangential acceleration of the edge of the spool related to the angular acceleration of the spool and the radius of the spool? What is the relationship between the angular acceleration of the spool and the angular acceleration of the disk?

8. How is the tangential acceleration of the edge of the spool related to the acceleration of the string? How is the acceleration of the string related to the acceleration of the hanging object? Explain the relationship between the angular acceleration of the disk and the acceleration of the hanging object.

EXPLORATION

Practice gently spinning the spool/disk system by hand. How long does it take the disk to stop rotating about its central axis? What is the average angular acceleration caused by this friction? Make sure the angular acceleration you use in your measurements is much larger than the one caused by friction so that it has a negligible effect on your results.

Find the best way to attach the string to the spool. How much string should you wrap around the spool? How should the pulley be adjusted to allow the string to unwind smoothly from the spool and pass over the pulley? Practice releasing the hanging object and the spool/disk system.

Determine the best mass to use for the hanging object. Try a large range. What mass will give you the smoothest motion? What is the highest angular acceleration? How many useful frames for a single video?

Where will you place the camera to give the best top view recording on the whole system? Try some test runs. Since you can't get a video of the falling object and the top of the spinning spool/disk at the same time, attach a piece of tape to the string. The tape will show up in the video and will have the same linear motion as the falling object.

Decide what measurements you need to make to determine the angular acceleration of the disk and the acceleration of the string from the same video.

Outline your measurement plan.

MEASUREMENT

Make a video of the motion of the tape on the string **and** the disk for several revolutions. Measure the radius of the spool. What are the uncertainties in your measurements?

Digitize your video to determine the acceleration of the string and, because the string was taut throughout the measurement, the acceleration of the hanging object. Use your measurement of the distance and time that the hanging object falls to choose the scale of the computer graphs so that the data is visible when you take it. Check to see if the acceleration is constant.

Use a stopwatch and meter stick to directly determine the acceleration of the hanging object.

Digitize the same video to determine the velocity components of the edge of the disk. Use your measurement of the diameter of the disk and the time of the motion to choose the scale of the computer graphs so that the data is visible when you take it.

ANALYSIS

From an analysis of the video data for the tape on the string, determine the acceleration of the piece of tape on the string. Compare this acceleration to the hanging object's acceleration determined directly. Be sure to use an analysis technique that makes the most efficient use of your data and your time.

From your video data for the disk, determine if the angular speed of the disk is constant or changes with time.

Use the equations that describe the measured components of the velocity of a point at the edge of the disk to calculate the tangential acceleration of that point and use this tangential acceleration of the edge of the disk to calculate the angular acceleration of the disk (it is also the angular acceleration of spool). You can refer to the Warm up questions.

CONCLUSION

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

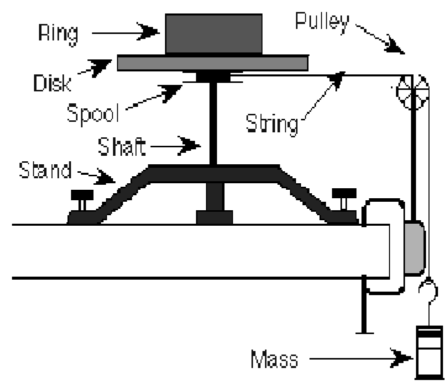
Explain why it is not difficult to keep the string taut in this measurement by considering the forces exerted on each end of the string? Determine the pull of the string on the hanging object and the pull of the hanging object on the string, in terms of the acceleration of the hanging object. Determine the force of the string on the spool and the force of the spool on the string. What is the string tension? Is it equal to, greater than, or less than the weight of the hanging object?

PROBLEM #4: MOMENT OF INERTIA OF A COMPLEX SYSTEM

While redesigning a medical fluid pump you notice that the drive wheel is made up of a ring and a disk. This ring is fastened to the top of a heavy solid disk, "a flywheel," and that disk is attached to a shaft. You are interested in this configuration and decide to determine its moment of inertia. You have a friend who thinks you can add the moment of inertial by parts to get the moment of inertia of the system. To test this idea you decide to build a laboratory model described below to determine the moment of inertia of a similar system from the acceleration of the hanging weight.

EQUIPMENT

For this problem you will have a disk, which is mounted on a sturdy stand by a metal shaft. Below the disk there is a metal spool on the shaft to wind string around. A ring sits on the disk so both ring and disk share the same rotational axis. A length of string is wrapped around the spool and then passes over a pulley lined up with the tangent to the spool. A weight is hung from the other end of the string so that the weight can fall past the edge of the table.



As the hanging weight falls, the string pulls on the spool, causing the ring/disk/shaft/spool system to rotate. You will also have a meter stick, a stopwatch, a pulley clamp, a mass hanger, a mass set and the video analysis equipment in this experiment.

PREDICTION

Restate your friend's idea as an equation.

What quantities will you measure in the lab? What relationships do you need to calculate in order to test your friend's ideas in the lab?

WARM UP

Read Sternheim & Kane: sections 5.1-5.4, 5.8-5.9. Review sections 1.3-1.6, 2.1-2.4, 3.1, 3.3-3.10, 4.1-4.2, 4.10.

The following questions will help you figure out the prediction, and find a way to test your friend's idea in the lab. It is helpful to use a problem-solving strategy such as the one outlined below:

1. Draw a side view of the equipment. Draw the velocity and acceleration vectors of the weight. Add the tangential velocity and tangential acceleration vectors of the outer edge of the spool. Also, show the angular acceleration of the spool. What are the relationships among the acceleration of the string, the acceleration of the weight, and the tangential acceleration of the outer edge of the spool if the string is taut?
2. To relate the moment of inertia of the system to the acceleration of the weight, you need to consider a dynamics approach (Newton's second law) especially considering the torques exerted on the system. The relationships between rotational and linear kinematics will also be involved.
3. Draw a free-body diagram for the ring/disk/shaft/spool system. Show the locations of the forces acting on that system. Label all the forces. Does this system accelerate? Is there an

angular acceleration? Check to see if you have all the forces on your diagram. Which of these forces can exert a torque on the system? Identify the distance from the axis of rotation to the point where each force is exerted on the system. Write down an equation that gives the torque in terms of the distance and the force that causes it. Write down Newton's second law in its rotational form for this system. Remember that the moment of inertia includes everything in the system that will rotate.

4. Draw a free-body diagram for the hanging weight. Label all the forces acting on it. Does this weight accelerate? Is there an angular acceleration? Check to see if you have included all the forces on your diagram. Write down Newton's second law for the hanging weight. Is the force of the string on the hanging weight equal to the weight of the hanging weight?
5. Can you use Newton's third law to relate pairs of forces shown in different force diagrams?
6. Is there a relationship between the angular acceleration of the ring/disk/shaft/spool system and the acceleration of the hanging weight? To decide, examine the accelerations that you labeled in your drawing of the equipment.
7. Solve your equations for the moment of inertia of the ring/disk/shaft/spool system as a function of the mass of the hanging weight, the acceleration of the hanging weight, and the radius of the spool. Start with the equation containing the quantity you want to know, the moment of inertia of the ring/disk/shaft/spool system. Identify the unknowns in that equation and select equations for each of them from those you have collected. If those equations generate additional unknowns, search your collection for equations that contain them. Continue this process until all unknowns are accounted for. Now solve those equations for your target unknown.
8. For comparison with your experimental results, calculate the moment of inertia of the ring/disk/shaft/spool system using your friend's idea.

EXPLORATION

Practice gently spinning the ring/disk/shaft/spool system by hand. How long does it take the disk to stop rotating about its central axis? What is the average angular acceleration caused by this friction? Make sure the angular acceleration you use in your measurements is much larger than the one caused by friction so that it has a negligible effect on your results.

Find the best way to attach the string to the spool. How much string should you wrap around the spool? How should the pulley be adjusted to allow the string to unwind smoothly from the spool and pass over the pulley? Practice releasing the hanging weight and the ring/disk/shaft/spool system.

Determine the best mass to use for the hanging weight. Try a large range. What mass will give you the smoothest motion?

Decide what measurements you need to make to determine the moment of inertia of the system from your Prediction equation. If any major assumptions are involved in connecting your measurements to the acceleration of the weight, decide on the additional measurements that you need to make to justify them.

Outline your measurement plan.

Make some rough measurements to make sure your plan will work.

MEASUREMENT

Follow your measurement plan. What are the uncertainties in your measurements? (See Appendices A and B if you need to review how to determine significant figures and uncertainties.)

Don't forget to make the additional measurements required to determine the moment of inertia of the ring/disk/shaft/spool system from the sum of the moments of inertia of its components. What is the uncertainty in each of the measurements? What effects do the hole, the ball bearings, the groove, and the holes in the edges of the disk have on its moment of inertia? Explain your reasoning.

ANALYSIS

Determine the acceleration of the hanging weight. How does this acceleration compare to what its acceleration would be if you just dropped the weight without attaching it to the string? Explain whether or not this makes sense.

Using your Prediction equation and your measured acceleration, the radius of the spool and the mass of the hanging weight, calculate the moment of inertia (with uncertainty) of the disk/shaft/spool system.

Adding the moments of inertia of the components of the ring/disk/shaft/spool system, calculate the value (with uncertainty) of the moment of inertia of the system. What fraction of the moment of inertia of the system is due to the shaft? The disk? The ring? Explain whether or not this makes sense.

Compare the values of moment of inertia of the system from these two methods

CONCLUSION

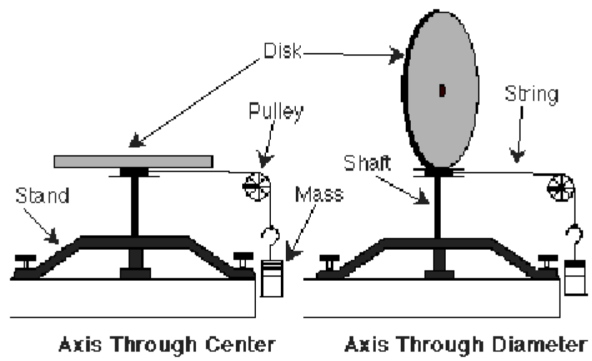
Did your measurements agree with your initial prediction? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

PROBLEM #5: MOMENTS OF INERTIA ABOUT DIFFERENT AXES

Continuing your redesign of a medical fluid pump you wonder what about the effect of orienting the flywheel in different ways. You wonder if the flywheel's moment of inertia spinning on its edge is the same as if it were spinning about an axis through its center and perpendicular to its surface. You do a quick calculation to decide. To test your prediction, you build a laboratory model with a disk that can spin around two different axes, and find the moment of inertia in each configuration by measuring the acceleration of a hanging weight attached to the spinning system by a string.

EQUIPMENT

For this problem you will have a disk, which is mounted on a sturdy stand by a metal shaft. The disk can be attached to the shaft so it rotates about its central axis or about its diameter, as shown below.



Below the disk there is a metal spool on the shaft to wind string around. A weight is hung from the other end of the string so that the weight can fall past the edge of the table. As the hanging weight falls, the string pulls on the spool, causing the disk/shaft/spool system to rotate. You will also have a meter stick, a stopwatch, a mass hanger, a mass set, a pulley clamp and the video analysis equipment in this experiment.

PREDICTION

Restate the problem. What are you asked to predict? What relationships do you need to calculate to use the lab model?

WARM UP

Read Sternheim & Kane: sections 5.1-5.4, 5.8-5.9. Review sections 1.3-1.6, 2.1-2.4, 3.1, 3.3-3.10, 4.1-4.2, 4.10.

To figure out your prediction, you need to determine how to calculate the rotational inertia of the disk from the quantities you can measure in the laboratory. It is helpful to use a problem solving strategy such as the one outlined below:

1. Draw a side view of the equipment with all relevant kinematic quantities. Write down any relationships that exist between them. Label all the relevant forces.
2. Determine the basic principles of physics that you will use. Write down your assumptions and check to see if they are reasonable.
3. If you decide to use dynamics, draw a free-body diagram of all the relevant objects. Note the acceleration of the object as a check to see if you have drawn all the forces. Write down Newton's second law for each free-body diagram either in its linear form or its rotational form or both as necessary.
4. Use Newton's third law to relate the forces between two free-body diagrams. If forces are equal give them the same labels.

5. Identify the target quantity you wish to determine. Use the equations collected in steps 1 and 3 to plan a solution for the target.
6. For comparison with your experimental results, calculate the moment of inertia of the disk in each orientation.

EXPLORATION

Practice gently spinning the disk/shaft/spool system by hand. How long does it take the disk to stop rotating about its central axis? How long does it take the disk to stop rotating about its diameter? How will friction affect your measurements?

Find the best way to attach the string to the spool. How much string should you wrap around the spool? How much mass will you attach to the other end of the string? How should the pulley be adjusted to allow the string to unwind smoothly from the spool and pass over the pulley? Practice releasing the hanging weight and the disk/shaft/spool system.

Determine the best mass to use for the hanging weight. Try a large range. What mass will give you the smoothest motion?

Decide what measurements you need to make to determine the moment of inertia of the system from your Prediction equation. If any major assumptions are involved in connecting your measurements to the acceleration of the weight, decide on the additional measurements that you need to make to justify them. If you already have this data in your lab journal you don't need to redo it, just copy it.

Outline your measurement plan. Make some rough measurements to make sure your plan will work.

MEASUREMENT

Follow your measurement plan. What are the uncertainties in your measurements? (See Appendices A and B if you need to review how to determine significant figures and uncertainties.)

Don't forget to make the additional measurements required to determine the moment of inertia of the disk/shaft/spool system by adding all of the moments of inertia of its components. What is the uncertainty of each of the measurements? What effects do the hole, the ball bearings, the groove, and the holes in the edges of the disk have on its moment of inertia? Explain your reasoning.

ANALYSIS

Determine the acceleration of the hanging weight. How does this acceleration compare to its acceleration if you just dropped the weight without attaching it to the string? Explain whether or not this makes sense.

Using your Prediction equation and your measured acceleration, the radius of the spool and the mass of the hanging weight, calculate the moment of inertia (with uncertainty) of the disk/shaft/spool system, for both orientations of the disk.

Adding the moments of inertia of the components of the disk/shaft/spool system, calculate the value (with uncertainty) of the moment of inertia of the system, for both orientations of the disk.
Compare the results from these two methods for both orientations of the disk.

CONCLUSION

How do the measured and predicted values of the disk's moment of inertia compare when the disk rotates about its central axis? When the disk rotates around its diameter?

Is the moment of inertia of a flywheel rotating around its central axis larger than, smaller than, or the same as its moment of inertia when it is rotating around its diameter? State your results in the most general terms supported by the data.

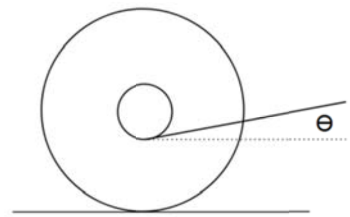
Did your measurements agree with your initial predictions? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

PROBLEM #6: ROLLING AND TORQUE

You work for NASA designing a probe to search for new life on other planets. The probe is deployed from a lander after it touches down on the planet being explored. The probe sensor needs to be moved a short distance from the lander after touchdown, and you are looking for a simple and inexpensive mechanism to accomplish this. One of your colleagues suggests rolling the sensor away from the lander on a single spool-like wheel. Your colleague believes that by pulling on a cord wrapped around the spool the wheel can be made to roll while the cord is unwinding. The ground where the lander will be located will be rough, so the spool will roll but won't "slide." You are not certain your colleague's idea will work. Another colleague suggests that the angle of the cord will affect how well this method works. You decide to build a model of the situation in lab to determine if pulling on a cord wrapped around a spool will make it roll, and whether the angle of the pull is significant.

EQUIPMENT

The equipment for this lab consists of a spool and a string wrapped around the spool center. Also supplied is a measuring rod.



PREDICTION

Will pulling on a string wrapped around the center of a spool resting on the ground (as pictured) cause the spool to roll? Assume that the point of contact between the spool and the ground or table is "rough" so that the spool won't slide. Does the angle that the string is pulled at affect whether the spool rolls or what direction it rolls? If so, how does the angle matter?

WARM UP

Read Sternheim & Kane: sections 5.1-5.4. Review sections 1.3-1.6, 2.1-2.4, 3.1, 3.3-3.10, 4.1-4.2, 4.10.

1. Sketch a diagram of the spool and draw all of the forces acting on it. Indicate forces that cause a torque on the spool. Write an expression for the total torque acting on the spool about the spool center.

2. Is the angle that the string is pulled at present in your total torque equation? Which direction will the total torque cause the spool to roll? Does the angle the string is pulled at affect which direction the spool will roll? Is there any special angle at which the behavior changes? Do your calculations make any approximations?

3. While pulling on the string will the spool be accelerating? Describe the motion of the spool.

EXPLORATION

Set up the system as shown in the equipment section. Try pulling on the string to see which direction the spool moves. Try pulling the string at different angles to see if the string angle influences the behavior. Explore all possible angles (there is about 180 degrees of possible angle). Pull on the string with steady pressure, not with sharp tugs.

MEASUREMENT

Record which direction the spool rolls when you pull on the string at specific angles. Determine whether the behavior changes at a particular angle, and whether this agrees with your predictions. Can you explain the behavior of the spool in terms of torque?

ANALYSIS

Can you explain the behavior of the spool in terms of torque? Did the behavior of the pool change when you pulled at a particular angle? If so, what angle was this and why did the behavior change? Explain how the different forces acting on the spool work together to cause the behavior you observed.

CONCLUSION

How did the system behavior agree with your predictions? Did you make any approximations in your calculations that might affect your prediction accuracy? Explain the behavior of the system in terms of torque.

TAs 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 name: ____

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 to conclusion; 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
CONSERVATION OF ENERGY

In this lab your will become familiar with using conservation of energy to solve problems and predict physical behavior. Conservation of energy is particularly applicable to biological systems which often involve energy cycles or energy transer. This lab will help you develop your understanding of how conservation of energy is an important idea for understanding the physical world.

Objectives:

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

- Understand the concepts of conservation of energy and in what situations it is relevant.
- Use conservation of energy to solve problems.

PREPARATION:

Read Sternheim & Kane: 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:

- Write down the conservation of energy equation for any system of one object.
- Understand the difference between energy transfer 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.

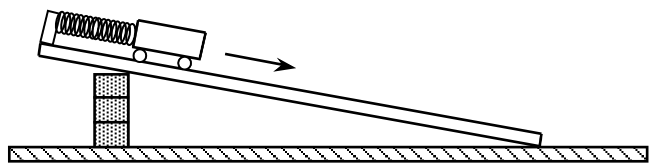
PROBLEM #1:
ELASTIC AND GRAVITATIONAL POTENTIAL ENERGY

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 equations for the maximum extension of the spring and the position where maximum velocity occurs. Make sure that you state any approximations or assumptions that you are making.

WARM UP

Read Sternheim & Kane: sections 6.1-6.6.

1. Draw a picture of the situation at three different times: one where the cart is traveling down the track, one where the cart is at maximum extension, and one where the cart is traveling back up the track. Label all relevant quantities on the diagram for each time.
2. Define the system of interest so that you can use gravitational potential energy, spring potential energy, and kinetic energy. Write the energy conservation equation for the system that relates its initial energy to its energy at any point during its motion.
3. Solve your conservation of energy equation for the velocity of the cart and determine the position when it is maximum. Remembering that acceleration is the time derivative of velocity, what must be true of the acceleration when the velocity is at a maximum/ minimum? Write down the calculus expression for where velocity is maximum and use that in your equation. Make a graph of velocity as a function of position and verify that your calculus does give you the maximum.
4. Write the energy conservation equation for the system that relates its initial energy to its energy when the spring has its maximum extension. What is the value of the maximum extension? What is the value of the velocity of the cart at that time?

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, 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. Determine the maximum extension of the spring. 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 just the graph of position vs. time.

CONCLUSION

Do your measurements match your predictions? If not, why not?

PROBLEM #2: PENDULUM VELOCITY

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

Read Sternheim & Kane: sections 6.1-6.6.

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. Write down the 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. maximum 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 angle.

CONCLUSION

Were your predictions consistent with your measurements? If not, 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?

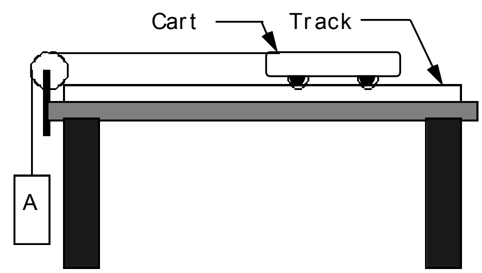
PROBLEM #3: VELOCITY AND ENERGY

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 after the launch is complete and the hanging weight has reached the ground. You believe that using the concept of conservation of energy could make this calculation easier. You decide to try the calculation and compare the results to the behavior of the system.

EQUIPMENT

For this problem you will have an aluminum track, a 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 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 velocity you need and another equation that determines the force of the string on the cart. Make sure that you state any approximations or assumptions that you are making. Also use your first equation and calculus to determine the position of the hanging object as a function of time. Then use calculus again to determine the velocity of the cart as a function of time.

Sketch a graph of 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.

WARM UP

Read Sternheim & Kane: sections 6.1-6.6.

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. In the first time interval what is happening to the kinetic energy of the cart?
2. Make a drawing of the problem situation for each time interval. Draw and label vectors to represent quantities that describe the motion of the cart and hanging object *and also* the forces acting on them. If two quantities have the same magnitude, use the same symbol *and* write down your justification for doing so. Define a convenient coordinate system. In each time interval, what types of energy are present? Are any energy changes occurring?
3. To use conservation of energy, you must first define your system. There are three useful systems that might be chosen and all are equally useful. For the time interval from when the hanging object is released until it hits the ground, define the system that you want to use. Draw a free-

body diagram of your system. Only forces caused by objects outside your system should be on your free-body diagram. 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.

4. 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. This should allow you to eliminate the unknown. Solve your equations for the velocity of the cart after the hanging weight has reached the ground.
5. 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.
6. Draw a free-body diagram of the hanging object. Use this diagram and what you know about the motion of that object to explain why the force of the string on the weight cannot be equal to the weight. Use what you know about the motion of the cart to explain why its final velocity is not the distance it goes divided by the time it takes to go that distance.

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. 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 <u>before</u> 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 after the hanging object hits the floor. See if this velocity agrees with your prediction made using conservation of energy. 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? Were you able to predict the maximum cart velocity using conservation of energy? If not, why? Were there any forms of energy change that were ignored in your predictions?

PROBLEM #4: KINETIC ENERGY AND WORK I

You are working at a biotechnology company that designs medical devices to be implanted in humans. You want your medical devices to be as energy efficient as possible so that they can operate a long time without needing to recharge. You are considering a device that uses tiny magnets to change the direction of its small moving parts. You know that magnets will be able to induce motion without touching, which seems efficient, but you wonder if some energy can still be lost. You decide to measure the energy efficiency of a system that used magnets to change motion in the lab.

You decide to model the situation using a cart with a magnet colliding with a magnetic bumper. You will use a level track, and use a video data acquisition system to measure the cart's velocity before and after the collision. You begin to gather your camera and data acquisition system when your colleague suggests a method with simpler equipment. Your colleague claims it would be possible to release the cart from rest on an inclined track and make measurements with just a meter stick. You are not sure you believe it, so you decide to measure the energy efficiency both ways, and determine the extent to which you get consistent results. *For this problem, you will use the level track. For problem #5, you will work with the inclined track.*

EQUIPMENT

You will use the video analysis equipment to analyze the motion of a cart colliding with an end stop (the magnetic bumper) on the track. You will also have a meter stick, a stopwatch and a balance to measure the mass of the cart.

PREDICTION

Calculate the energy efficiency of the collision in terms of the least number of quantities that you can easily measure in the situation of a level track. Calculate the energy dissipated during the impact with the bumper in terms of those measurable quantities.

WARM UP

Read Sternheim & Kane: sections 6.1-6.6.

It is useful to have an organized problem-solving strategy. The following questions will help with your prediction and the analysis of your data.

1. Make a drawing of the cart on the level track before and after the impact with the bumper. Define your system. Label the velocity and kinetic energy of all objects in your system before and after the impact.

2. Write an expression for the efficiency of the bumper in terms of the final and initial kinetic energy of the cart.

3. Write an expression for the energy dissipated during the impact with the bumper in terms of the kinetic energy before the impact and the kinetic energy after the impact.

EXPLORATION

Review your exploration notes for measuring a velocity using video analysis. Practice pushing the cart with different velocities, slowly enough that the cart will never contact the bumper (end stop) during the impact when you make a measurement. Find a range of velocities for your measurement. Set up the camera and tripod to give you a useful video of the collision immediately before and after the cart collides with the bumper.

Although the effect of friction is small in our lab, you may want to estimate it.

MEASUREMENT

Take the measurements necessary to determine the kinetic energy before and after the impact with the bumper. What is the most efficient way to measure the velocities with the video equipment? Take data for several different initial velocities.

ANALYSIS

Calculate the efficiency of the collision for the level track. Does your result depend on the velocity of the cart before it hits the bumper?

CONCLUSION

What is the efficiency of the magnetic collisions? How much energy is dissipated in an impact? What is effect of friction in your experiment? State your results in the most general terms supported by your analysis.

If available, compare your value of the efficiency (with uncertainty) with the value obtained by the different procedure given in the next problem. Are the values consistent? Which way to measure the efficiency of the magnetic bumper do you think is better? Why?

PROBLEM #5: KINETIC ENERGY AND WORK II

You are working at a biotechnology company that designs medical devices to be implanted in humans. You want your medical devices to be as energy efficient as possible so that they can operate a long time without needing to recharge. You are considering a device that uses tiny magnets to change the direction of its small moving parts. You know that magnets will be able to induce motion without touching, which seems efficient, but you wonder if some energy can still be lost. You decide to measure the energy efficiency of a system that used magnets to change motion in the lab.

You decide to model the situation using a cart with a magnet colliding with a magnetic bumper. You will use a level track, and use a video data acquisition system to measure the cart's velocity before and after the collision. You begin to gather your camera and data acquisition system when your colleague suggests a method with simpler equipment. Your colleague claims it would be possible to release the cart from rest on an inclined track and make measurements with just a meter stick. You are not sure you believe it, so you decide to measure the energy efficiency both ways, and determine the extent to which you get consistent results. *For this problem, you will use the inclined track.*

EQUIPMENT

You will have a meter stick, a stopwatch, cart masses and a wooden block to create the incline. You may also use the video analysis equipment to estimate the effect of friction.

PREDICTIONS

Calculate the energy efficiency of the collisions (with friction and without) in terms of the least number of quantities that you can easily measure in the situation of an inclined track.

WARM UP

Read Sternheim & Kane: sections 6.1-6.6.

The following questions will help you to make your prediction and analyze your data.

1. Make a drawing of the cart on the ***inclined track*** at its initial position (before you release the cart) and just before the cart hits the bumper. Define the system. Label the kinetic energy of all objects in your system at these two points, the distance the cart traveled, the angle of incline, and the initial height of the cart above the bumper.
2. Now make another drawing of the cart on the inclined track just after the collision with the bumper *and* at its maximum rebound height. Label kinetic energy of the cart at these two points, the distance the cart traveled, the angle of the ramp, and the rebound height of the cart above the bumper.
3. Write an expression for the efficiency of the collisions in terms of the kinetic energy of the cart just before the impact and the kinetic energy of the cart just after the impact.
4. Draw a force diagram of the cart as it moves down the track. Which force component does work on the cart (i.e., causes a transfer of energy into the cart system)? Write an expression for the work done on the cart. How is the angle of the ramp related to the distance the cart traveled and the initial height of the cart above the bumper? *How does the kinetic energy of the cart just before impact compare with the work done on the cart?*
5. Draw a force diagram of the cart as it moves up the track. Which force component does work on the cart (i.e., causes a transfer of energy out of the cart system)? Write an expression for the work done on the cart. *How does the kinetic energy of the cart just after impact compare with the work done on the cart?*

6. Write an expression for the efficiency of the collision in terms of the cart's initial height above the bumper and the cart's maximum rebound height above the bumper.

7. Write an expression for the energy dissipated during the impact with the bumper in terms of the kinetic energy of the cart just before the impact and the kinetic energy of the cart after the impact. Re-write this expression in terms of the cart's initial height above the bumper and the cart's maximum rebound height above the bumper.

8. Repeat the procedure, considering the effect of friction.

EXPLORATION

Find a useful range of heights and inclined angles that will not cause damage to the carts or bumpers. Make sure that the cart will never contact bumper (end stop) during the impact. Decide how you are going to consistently measure the *height* of the cart.

You may want to estimate the effect of friction. Make a schedule to test the effect of friction by the video analysis equipment. How can you find the average frictional force when the cart moves on the inclined track? How much energy is dissipated by friction?

MEASUREMENT

Take the measurements necessary to determine the kinetic energy of the cart just before and after the impact with the bumper. Take data for several different initial heights.

ANALYSIS

Calculate the efficiency of the collisions for the inclined track. Does your result depend on the velocity of the cart before it hits the bumper?

CONCLUSION

What is the efficiency of the magnetic collisions? How much energy is dissipated in an impact? State your results in the most general terms supported by your analysis. Is effect of friction significant?

If available, compare your value of the efficiency (with uncertainty) with the value obtained by the different procedure given in the preceding problem. Are the values consistent? Which way to measure the efficiency of the magnetic bumper do you think is better? Why?

TAs 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 name: ____

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 to conclusion; 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
CONSERVATION OF MOMENTUM

In this lab your will become familiar with using conservation of momentum to solve problems and predict physical behavior. Conservation of momentum is an especially important tool for understanding collisions and explosions. Conservation of angular momentum is important when predicting the outcome of rotational interactions. Momentum conservation is a fundamental property of the physical world that needs to be understood for a complete understanding of physical processes.

Objectives:

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

- Understand the concept of conservation of momentum and in what situations it is relevant.
- Use conservation of momentum to solve problems.

PREPARATION:

Read Sternheim & Kane: chapter 7. 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 momentum equation for a system of two objects.
- Write down the conservation of angular momentum equation for a system of two objects.
- Describe the relationships between velocity, mass, and momentum.
- Describe the relationships between angular velocity, moment of inertia, and angular momentum.
- Describe how force, acceleration, and momentum are related.
- Describe how torque, angular acceleration, and angular momentum are related.

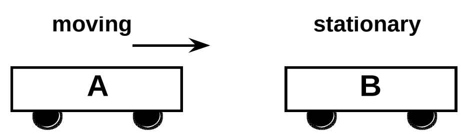
PROBLEM #1: PERFECTLY INELASTIC COLLISIONS

You are a biologist studying the effects of gravity on biological systems. You have an experiment that will soon be launched into space on a space shuttle. Your experiment relays data back to earth, and because of this you need to make sure your receivers are correctly pointed at the shuttle to receive this data. The shuttle is scheduled to dock with another shuttle midway through its mission. You are concerned that when this docking takes place the velocity of the shuttle will change, and you decide to try to calculate how much the velocity will change using conservation of momentum.

Since the shuttles may be carrying different payloads and different amounts of fuel, their masses may not be identical: the shuttles could be equally massive, the moving shuttle could be more massive, or the stationary shuttle could have a larger mass. You need to calculate the magnitude and direction of the velocity of the pair of docked shuttles, as a function of the initial velocity of the moving shuttle and the mass of each shuttle. You may assume that the total mass of the two shuttles is constant. You decide to model the problem in the lab using carts to check your predictions.

EQUIPMENT

You will use a track and a set of carts. For this problem, cart A is given an initial velocity towards a stationary cart B. Pads at the end of each cart allow the carts to stick together after the collision. Video analysis equipment is available. You will also need a meter stick, a stopwatch, two end stops and cart masses.



PREDICTION

Restate the problem to identify your target and get the relationships useful for the three cases considered in the problem.

WARM UP

Read Sternheim & Kane: Chapter 7.

The following questions are designed to help you with your prediction and the analysis of your data.

1. Make two drawings that show the situation (a) before and (b) after the collision. Show and label velocity vectors for each object in your drawings. If the carts stick together, what must be true about their final velocities? Define your system.

2. Write down the momentum conservation equation for the system; identify all of the terms in the equation. Are there any of these terms that you cannot measure with the equipment at hand? Is the momentum of the system conserved during the collision? Why or why not?

3. Write down the energy conservation equation for the system; identify all the terms in the equation Are there any of these terms that you cannot measure with the equipment at hand? Is the energy of the system conserved? Why or why not? Is the *kinetic* energy of the system conserved? Why or why not?

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

EXPLORATION

Practice rolling the cart so the carts will stick together after colliding. Carefully observe the carts to determine whether either cart leaves the grooves in the track. Minimize this effect so that your results are reliable.

Try giving the moving cart various initial velocities over the range that will give reliable results. Note qualitatively the outcomes. Choose initial velocities that will give you useful videos.

Try varying the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass the stationary cart while keeping the total mass of the carts the same. Is the same range of initial velocities useful with different masses? What masses will you use in your final measurement?

MEASUREMENT

Record the masses of the two carts. Make a video of their collision. Examine your video and decide if you have enough frames to determine the velocities you need. Do you notice any peculiarities that might suggest the data is unreliable?

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 about how the final velocity of both carts in this type of collision depends on velocity of the initially moving cart and the masses of the carts.

ANALYSIS

Determine the velocities of the carts (with uncertainty) before and after each collision from your video. Calculate the momentum of the carts before and after the collision.

Now use your Prediction equation to calculate each final velocity (with uncertainty) of the stuck-together carts.

CONCLUSION

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

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

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

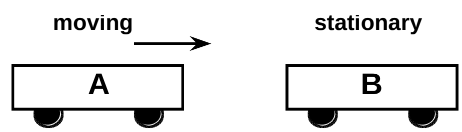
PROBLEM #2: ELASTIC COLLISIONS

You are a biologist studying the effects of gravity on biological systems. You have an experiment that will soon be launched into space on a space shuttle. Your experiment relays data back to earth, and because of this you need to make sure your receivers are correctly pointed at the shuttle to receive this data. The shuttle is scheduled to dock with another shuttle midway through its mission. You are concerned that when this docking takes place the velocity of the shuttle will change, and you decide to try to calculate how much the velocity will change using conservation of momentum.

Your supervisor wants you to consider the case which could result from the pilot missing the docking mechanism or the mechanism failing to function. In this case the shuttles gently collide and bounce off each other. Your supervisor asks you to calculate the final velocity of both shuttles as a function of (a) the initial velocity of the initially moving shuttle, (b) the masses of both shuttles, and (c) the fraction of the moving shuttle's initial kinetic energy that is *not dissipated* during the collision (the "energy efficiency"). You may assume that the total mass of the two shuttles is constant. You decide to check your calculations in the laboratory using the most efficient bumper you have, a magnetic bumper.

EQUIPMENT

You will use a track and a set of carts. For this problem, cart A is given an initial velocity towards a stationary cart B. Masses can be added to the top of either cart. Video analysis equipment allows you to determine the cart velocities before and after the collision. Magnets at the end of each cart are used as bumpers to ensure that the carts bounce apart after the collision. You will also have a meter stick, a stopwatch, two end stops and cart masses.



PREDICTION

Restate the problem such that you understand and identify its goal then get the equations necessary to test your lab model.

WARM UP

Read Sternheim & Kane: Chapter 7.

The following questions are designed to help you with your prediction and the analysis of your data.

1. Draw two pictures that show the situation before the collision and after the collision. Draw velocity vectors on your sketch. If the carts bounce apart, do they have the same final velocity? Define your system.
2. Write down the momentum of the system before and after the collision. Is the system's momentum conserved during the collision? Why or why not?
3. If momentum is conserved, write the momentum conservation equation for this situation; identify all of the terms in the equation.
4. Write down the energy of the system (a) before and (b) after the collision.
5. Write down the energy conservation equation for this situation and identify all the terms in the equation.
6. Write the expression for the energy dissipated in the collision in terms of the energy efficiency and the initial kinetic energy of the system (see Laboratory IV, Problem #4). Can you assume that no energy will be converted into internal energy?
7. Solve the equations you wrote in previous steps to find the final velocity of each cart in terms of the cart masses, the energy efficiency of the collision, and the initial speed of the moving cart. *Warning: the algebra may quickly become unpleasant! Stay organized.*

EXPLORATION

Practice setting the cart into motion so that the carts don't touch when they collide. Carefully observe the carts to determine whether or not either cart leaves the grooves in the track. Minimize this effect so that your results are reliable.

Try giving the moving cart various initial velocities over the range that will give reliable results. Note qualitatively the outcomes. Keep in mind that you want to choose an initial velocity that gives you a good video.

Try varying the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass the stationary cart while keeping the total mass of the carts the same. Be sure the carts still move freely over the track. What masses will you use in your final measurement?

MEASUREMENT

Record the masses of the two carts. Make a video of their collision. Examine your video and decide if you have enough frames to determine the velocities you need. Do you notice any peculiarities that might suggest the data is unreliable?

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 about how the final velocities of both carts in this type of collision depend on the velocity of the initially moving cart, the masses of the carts, and the energy efficiency of the collision.

ANALYSIS

Determine the velocities of the carts (with uncertainty) before and after each collision from your video. Calculate the momentum and kinetic energy of the carts before and after the collision.

Calculate the energy efficiency of each collision from the initial and final kinetic energy of the system. Graph how the energy efficiency varies with mass of the initially moving cart (keeping the total mass of both carts constant). What is the function that describes this graph? Repeat this for energy efficiency as a function of initial velocity. Can you make the approximation that no energy goes into internal energy of the system (energy efficiency = 1)?

Now use your Prediction equation to calculate the final velocity (with uncertainty) of each cart, in terms of the cart masses, the initial velocity of the moving cart, and the energy efficiency of each collision.

CONCLUSION

Did your measurement agree with your prediction? Why or why not? Was the collision perfectly elastic in the three different cases? What are the limitations on the accuracy of your measurements and analysis?

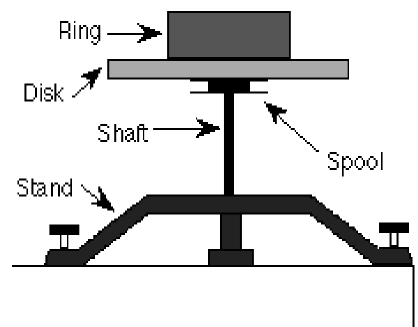
What conditions must be met for a system's *total momentum* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment. What conditions must be met for a system's *total energy* to be conserved? Describe how those conditions were or were not met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

PROBLEM #3: CONSERVATION OF ANGULAR MOMENTUM

You are designing a medical pump for fluids that uses different gears in order to pump fluid at different speeds. The gears in the device are wheel shaped and rotate around the same axis. When the pump speeds up and needs to shift, one of these gear assemblies is brought into connection with another one. You are concerned about how the pump might suddenly slow down during a gear shift until the new gear is brought up to speed. You decide to use angular momentum to try to calculate how suddenly adding a non-rotating wheel to an already rotating one could cause a change in angular velocity. Both gear wheels will be able to rotate freely about the same central axis. To test your calculation you decide to build a laboratory model of the situation in which you drop a wheel shaped ring onto an already spinning disk and measure the change in angular velocity.

EQUIPMENT

You will use the same basic equipment in the previous problems.



PREDICTION

Restate the problem. What quantities do you need to calculate to test your idea?

WARM UP

Read Sternheim & Kane: Chapter 7.

To figure out your prediction, it is useful to use a problem solving strategy such as the one outlined below:

1. Make two side view drawings of the situation (similar to the diagram in the Equipment section), one just as the ring is released, and one after the ring lands on the disk. Label all relevant kinematic quantities and write down the relationships that exist between them. Label all relevant forces.

2. Determine the basic principles of physics that you will use and how you will use them. Determine your system. Are any objects from outside your system interacting with your system? Write down your assumptions and check to see if they are reasonable.

3. Use conservation of angular momentum to determine the final angular speed of the rotating objects. Why not use conservation of energy or conservation of momentum? Define your system and write the conservation of angular momentum equation for this situation:

   Is any significant angular momentum transferred to or from the system? If so, can you determine it or redefine your system so that there is no transfer?

4. Identify the target quantity you wish to determine. Use the equations collected in steps 1 and 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 addition equation. If not, see if one of the unknowns will cancel out.

EXPLORATION

Practice dropping the ring into the groove on the disk as gently as possible to ensure the best data. What happens if the ring is dropped off-center? What happens if the disk does not fall smoothly into the groove? Explain your answers.

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

Outline your measurement plan.
Make some rough measurements to be sure your plan will work.

MEASUREMENTS

Follow your measurement plan. What are the uncertainties in your measurements?

ANALYSIS

Determine the initial and final angular velocity of the disk from the data you collected. Using your prediction equation and your measured initial angular velocity, calculate the final angular velocity of the disk. If your calculation incorporates any assumptions, make sure you justify these assumptions based on data that you have analyzed.

CONCLUSION

Did your measurement of the final angular velocity agree with your calculated prediction value? Why or why not? What are the limitations on the accuracy of your measurements and analysis?

Could you have easily measured enough information to use conservation of energy to predict the final angular velocity of this system? Why or why not? Use your data to check your answer.

TAs 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 name: ____

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 to conclusion; 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 VII
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 Sternheim & Kane: chapter 9. 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.

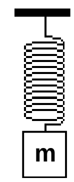
PROBLEM #1:
MEASURING SPRING CONSTANTS

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.

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™.



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 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

Read Sternheim & Kane: Chapter 9.

Method #1:

1. Draw a free-body diagram of a suspended object. Write down the equilibrium condition for the object using Newton's second law. 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. Draw a free-body diagram of the object at this position and label the forces acting on it. Next to the diagram draw a vector representing the acceleration of the object.
3. Write down the 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

DO NOT STRETCH THE SPRINGS PAST THEIR ELASTIC LIMIT (ABOUT 40 CM) OR YOU WILL DAMAGE THEM.

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 mass measurements you will need to make a reliable determination 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 spring extension as a function of the mass of the object. 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.

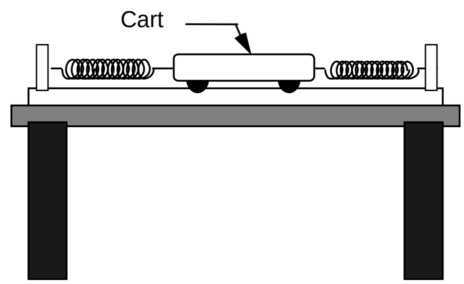
What is the spring constant of a polymer extended to 2 nanometers with a force of 0.2 $\times 10^{-12}$ Newton? What would be its oscillation period?

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 period of oscillation. 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

Read Sternheim & Kane: Chapter 9.

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 directions 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. 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. You must chose an unstretched position for each spring. These positions may have different signs. Use your coordinate system sign convention to assign the appropriate signs. Then reform the equation so that the displacement variable only appears once.
4. Solve your equation for the acceleration of the cart as a function of its mass, the spring constants, the displacement of the cart from its equilibrium position, and the unstretched position constants.
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 displacement 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 40 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 if 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?

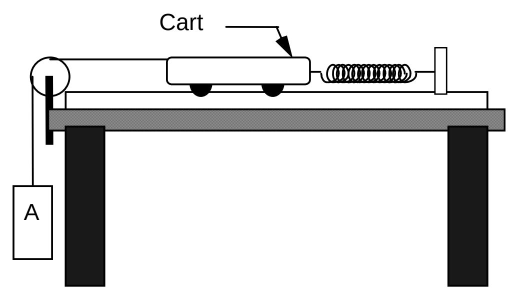
PROBLEM #3: OSCILLATION FREQUENCY OF AN EXTENDED SYSTEM

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 frequency of oscillation. 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

Read Sternheim & Kane: Chapter 9.

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 SPRINGS PAST THEIR ELASTIC LIMIT (ABOUT 40 CM) OR YOU WILL DAMAGE THEM,** 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

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?

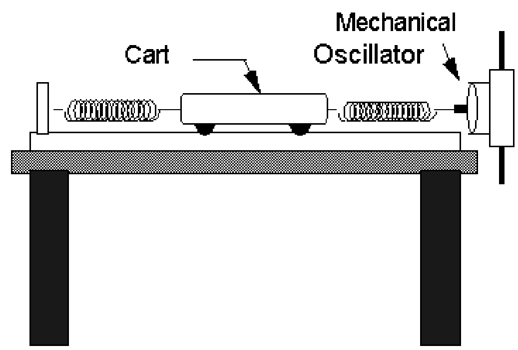
If you were to use this device on the surface of the moon, where the gravitational field is much weaker than on the earth's surface, would you expect the frequency to be any different? Use physics arguments and your prediction equation to justify your explanation.

PROBLEM #4: DRIVEN OSCILLATIONS

You are working as 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? At some frequency "resonance" may occur, where the system has a large oscillatory response.

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

Read Sternheim & Kane: Chapter 9.

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 period of oscillation of the pendulum. Make sure that you state any approximations or assumptions that you are making.

WARM UP

Read Sternheim & Kane: Chapter 9.

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. Of course, 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 determine 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 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. 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 (for example, period-squared vs. length-cubed). 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

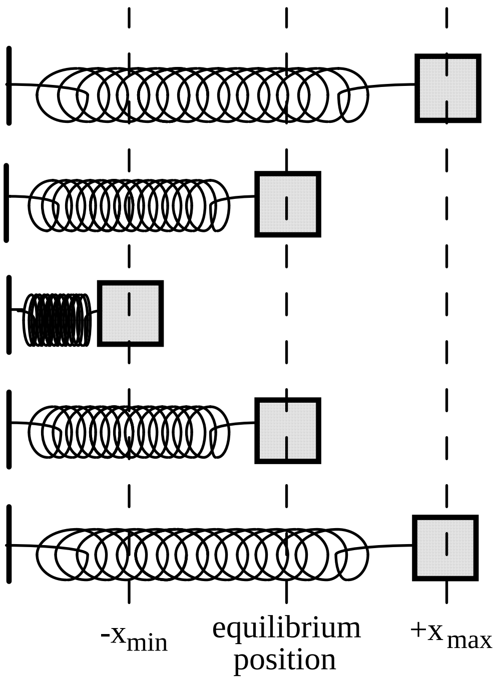
Did the measured period follow your predictions? If not, explain why.

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 to which we are accustomed, what effect should that have on the pendulum's period?

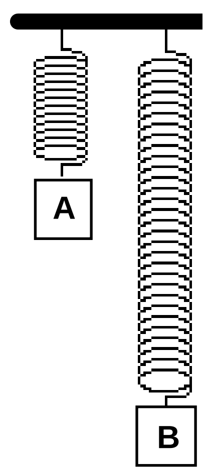
☑ CHECK YOUR UNDERSTANDING

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.

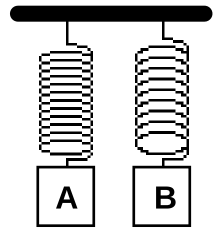
   b. Which mass will have the greater acceleration at the instant of release, or will they have the same acceleration? Explain.

   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.

☑ CHECK YOUR UNDERSTANDING

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.

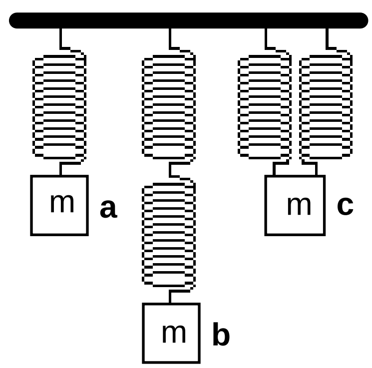
   c. The instant after release, which mass has the greater acceleration? Explain.

   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.

TAs name:____________________

PHYSICS 1201_ LABORATORY REPORT
Laboratory VII

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ________________________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's name: ____

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 to conclusion; 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 VIII
HEAT ENERGY AND FLUID MOTION

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 study the relationship between temperature and internal energy, and the concept of specific heat (also known as heat capacity). You now know that energy can be transferred from one object to another by mechanical means (work). In this laboratory you will also explore the very common energy transfer from an object at higher temperature to an object of lower temperature. That energy transfer is called heat.

At the end of this lab your will explore motion through a fluid. Motion through a fluid is a topic relevant to many biological systems as many biological processes take place in water. Understanding motion through a fluid can shed light on many microscopic biological effects.

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 mechanical, electrical, and thermal.
- 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.
- Use the concepts of buoyancy and fluid friction to solve problems.

PREPARATION:

Read Sternheim & Kane: sections 10.1, 10.2, 10.6, 11.1-11.3, 12.1-12.6, 13.1-13.6, 14.1-14.6.

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 specific heat to determine the change in internal energy of a system.
- Define what is meant by efficiency.
- Describe how buoyancy and friction can affect motion in a fluid.

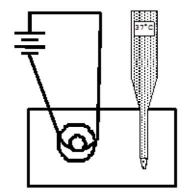
PROBLEM #1:
POWER AND TEMPERATURE CHANGE

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 resistor connected across a known voltage as a power source. You know that the power output by the resistor is just the current through the resistor times the voltage across the resistor. 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 resistor, the current through the resistor, the specific heat of the water, and the mass 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 resistor heating apparatus, 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 for the change in the temperature of the water as a function of time. Make sure that you state any approximations or assumptions that you are making.

WARM UP

Read Sternheim & Kane: 10.1, 10.2, 10.6, 11.1-11.3, 12.2-12.6.

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 the 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 filament.

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, calculate 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 in other ways that you have neglected.

EXPLORATION

Assemble the circuit. Verify that you can measure current flowing in your circuit and voltage across the filament. Determine if you need to do these measurements continuously or just once by making the measurements several times before putting the filament 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 filament 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 process.

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 each measurement will last. The longer the measurement takes, the larger will be the effects 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 resistor 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 versus time. Determine the power input to the water from that graph.

Compare the electrically measured power output of the resistor to the 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.

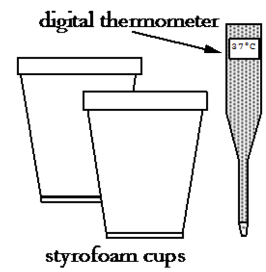
How do these two values of the resistor's power output compare? Are they within the uncertainty of your measurement accuracy? How significant is the energy transferred to the surrounding air?
Can you use this type of apparatus to make your measurements of metabolic processes? What modifications might 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. You decide to heat the object in a warm liquid bath, and then move it to a cold liquid bath (simulating the cooling of an organ). Measuring the temperature change of the metal object and the cold liquid bath should allow you to calculate the specific heat of the metal object. In order to determine if the specific heat depends on temperature you decide to try several temperature combinations.

EQUIPMENT



You will have two different homogenous metal objects. Styrofoam cups, a digital thermometer, a balance, a stopwatch, string, 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 specific heat of the metal object in terms of known or measurable quantities. Make sure that you state any approximations or assumptions that you are making.

WARM UP

Read Sternheim & Kane: 10.1, 10.2, 10.6, 11.1-11.3, 12.2-12.6.

1. Make two sketches of the situation: one just after the heated metal object is placed into the unheated water and the other 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. Your possible choices are the object, the water, or both the object and the water. Choose one of these systems and write down the 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.
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.
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, or burned by 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 approximate amount of time you will need to do your measurement. This tells you the time over which 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.

You cannot measure the temperature of a metal object by sticking a thermometer in it or putting a thermometer on it. Determine 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 if 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 quickly or slowly? 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.

Determine the specific heat for each metal object.

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 and temperature combination used. Does specific heat depend on temperature? How do any differences compare to the measurement uncertainty?

Use the chart at the end of this laboratory to look up the specific heat of your objects.

CONCLUSION

Did your results agree with your prediction? Explain.

Does the specific heat of an object depend on its temperature?

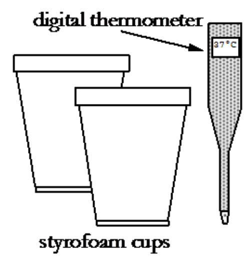
If you knew the specific heat of an organ and wished to cool it from body temperature to a certain final temperature by immersing it in a certain amount of liquid, what formula would you use to determine what the initial temperature of the liquid should be?

PROBLEM #3: HEAT CAPACITY 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 is an object consisting of two different kinds of metal that you will immerse in a liquid bath. You decide to heat the object in a warm liquid bath, and then move it to a cold liquid bath (simulating the cooling of an organ). Measuring the temperature change of the complex metal object and the cold liquid bath should allow you to calculate the specific heat of the metal object. In order to determine if the specific heat depends on temperature you decide to try several temperature combinations.

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, string, 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.

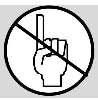
WARM UP

Read Sternheim & Kane: 10.1, 10.2, 10.6, 11.1-11.3, 12.2-12.6.

1. Make two sketches of the situation: one just after the heated metal object is placed into the unheated water and the other 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. Your possible choices are the object, the water, or both the object and the water. Choose one of these systems and write down the 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.

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.
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 calculated mass of each material making up the complex object.

EXPLORATION



WARNING: Be careful not to get scalded while handling heated water, or burned by the hot plates.

Optimal use of the Styrofoam cups can minimize the energy transfer from the water. First you need to determine the approximate amount of time you will need to do your measurement. This tells you the time over which 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.

You cannot measure the temperature of a metal object by sticking a thermometer in it or putting a thermometer on it. Determine 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 if 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 quickly or slowly? 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 have to determine the mass of each material that makes up the object. You cannot take the object apart and directly measure each mass. You can however determine 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.

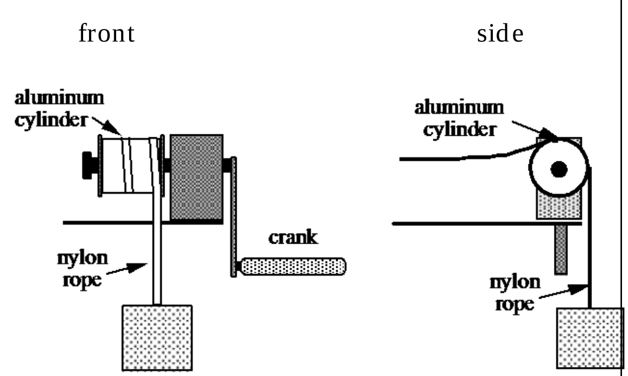
EQUIPMENT

WARNING: The crank apparatus is attached to a surface by a clamp. Through energetic operation an insecure clamp may fall. **KEEP YOUR FEET CLEAR FROM THE AREA BENEATH THE HEAVY HANGING MASS**. Make sure the crank is firmly secured and be careful not to dislodge it.

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

Read Sternheim & Kane: 10.1, 10.2, 10.6, 11.1-11.3, 12.2-12.6.

1. Make 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. Determine the relationship between the friction force between rope and the cylinder and the weight of the block. Explain why you believe this relationship is tru e.
5. Determine 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.

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: MOTION IN A FLUID

You are studying how bacteria 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. You 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. Depending on how fast the object is moving the drag friction may be proportional to either the velocity of motion or the square of the velocity of motion. You consider both cases and try to determine which applies to your lab system.

EQUIPMENT

For this problem you will have cylinders filled with a viscous fluid containing beads of various sizes, 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

Read Sternheim & Kane : 13.1-13.6, 14.1-14.6.

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 the expression for the buoyant force acting on the bead. What is the direction of this force?
3. Write down the expression for the drag force encountered by the bead as it moves through the fluid, first assuming that the drag force is given by Stokes' law. Next consider the case where the drag force is proportional to the square of the velocity and write down a corresponding drag equation. What is the direction of the drag force relative to the velocity? How does this force depend on the properties of the bead and the syrup?
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 your equations 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

Use a stopwatch to estimate the terminal 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? Does the drag force seem to be proportional to bead velocity? To bead velocity squared?

CONCLUSION

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

How fast does the bead reach terminal velocity? Can you tell how this depends on the properties of the bead? How does the drag force depend on the bead velocity?

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.

TAs name:___________________

PHYSICS 1201_ LABORATORY REPORT
Laboratory VIII

Name and ID#:____

Date performed: ______________ Day/ Time section meets: ______________________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's name: ____

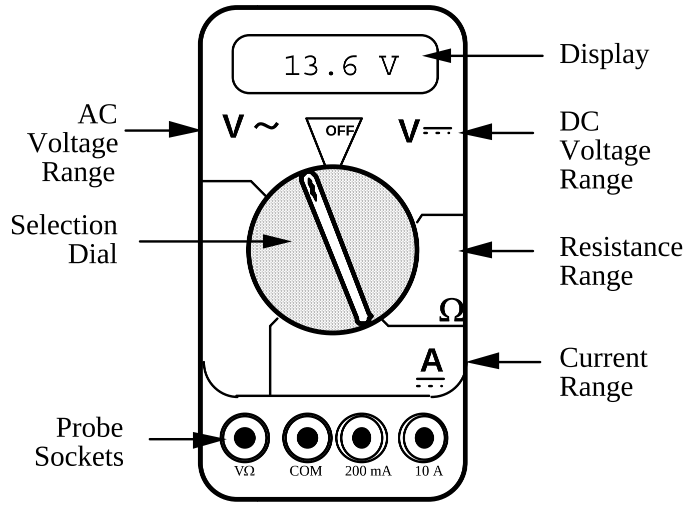
Grading Checklist	Points *
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and Warm-up Questions completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:	
ORGANIZATION (clear and readable; logical progression from problem statement to conclusion; 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.

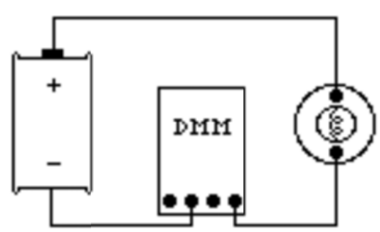


> The DMM can measure currents anywhere from 10 amps to a microamp (10^{-6} amps). This versatility makes the DMM fragile. For example, measuring a 1 ampere current while the DMM is on the 2 milliamp scale will definitely blow a fuse! If this happens, your instructor can change the fuse. However, you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

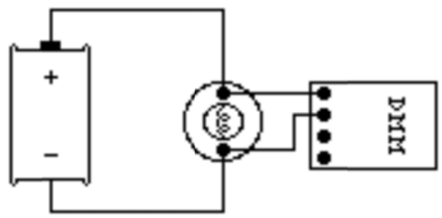
3. If no number appears while the DMM is at the 10A setting, move the wire from the 10A socket to the 200mA socket and then turn the selection dial to the 200 milliamp (200m) setting. If there is still no reading, change the dial to the 20 milliamp setting, etc.

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:

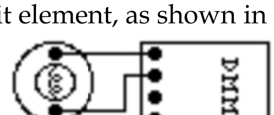
*The element whose resistance you are measuring **must** be free from all other currents (due to other batteries, power supplies, etc.) for the DMM to work*. That means you must **remove** it from a circuit.

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.

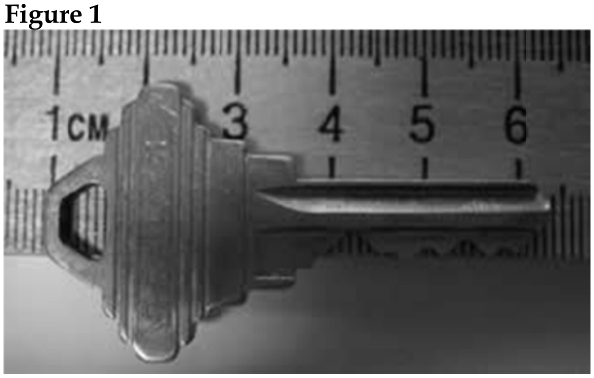


4. If no number appears, try a different measurement scale. Begin at the largest scale (20 MΩ) and work your way down.

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 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 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 C 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 1 gives some examples.

Table 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 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 C 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**
23)269**1**	75)187**5**
2**3**	15**0**
3**9**	3**75**
23	**375**
161	
161	
1.**2** x 10^2	2.**5** x 10^1

PRACTICE EXERCISES

1. Determine the number of significant figures 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.

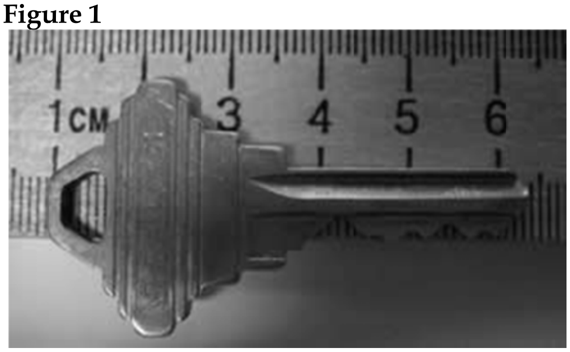
How do I determine the uncertainty?

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 1.

Figure 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 2 and 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 2

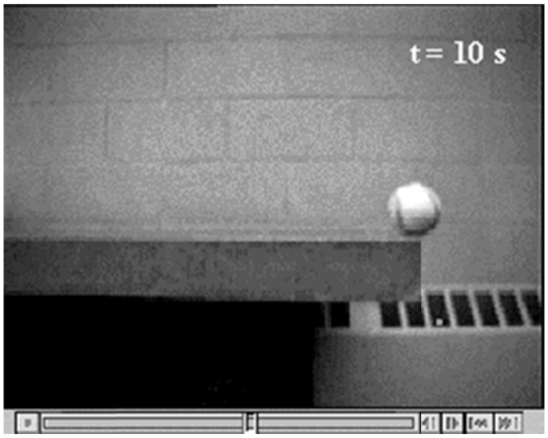
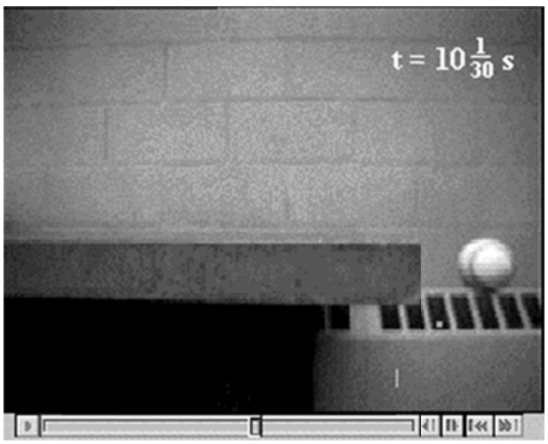


Figure 3



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

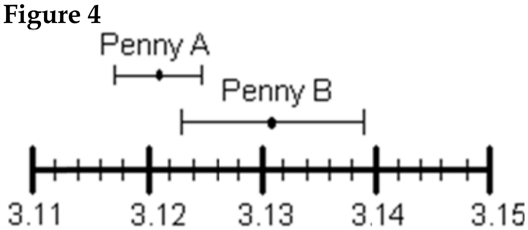
Mass (grams)
3.140
3.133
3.144
3.118
3.126
3.125
3.131 average
The deviations are: 0.009g, 0.002g, 0.013g, 0.013g, 0.005g, 0.006g
Sum of deviations: 0.048g
Average deviation: (0.048g)/6= 0.008g
Mass of penny B: 3.131 ± 0.008g

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 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 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:

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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

</td>
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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:

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

</td>
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<tr>
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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.

</td>
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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.

</td>
</tr>
</table>

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:

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%

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: $18.4 \pm 0.3\ cm^2$

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.

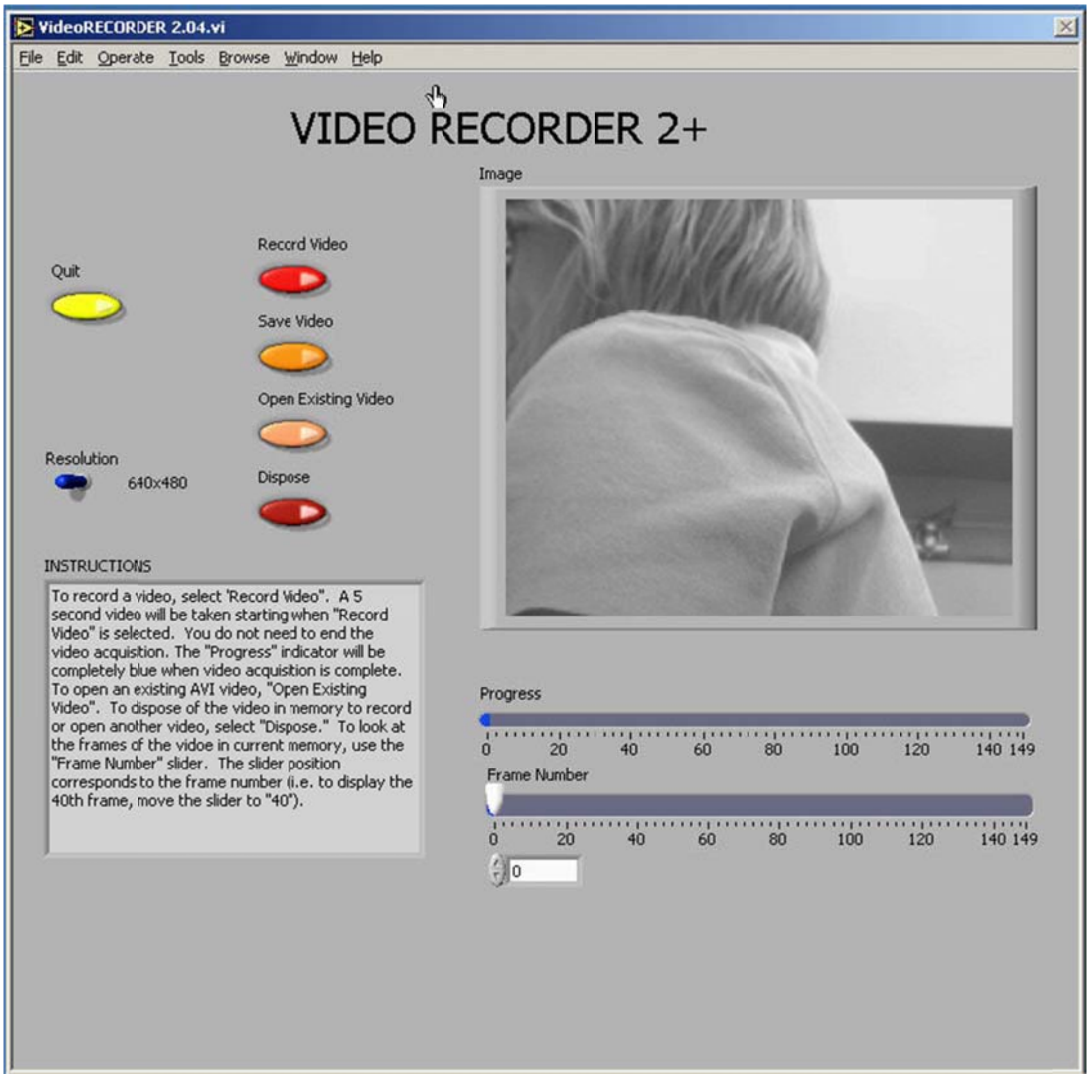
Cart (grams)	**Mass set 1** (grams)	**Mass set 2** (grams)
201.3	98.7	95.6
201.5	98.8	95.3
202.3	96.9	96.4
202.1	97.1	96.2
199.8	98.4	95.8
200.0	98.6	95.6

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 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.

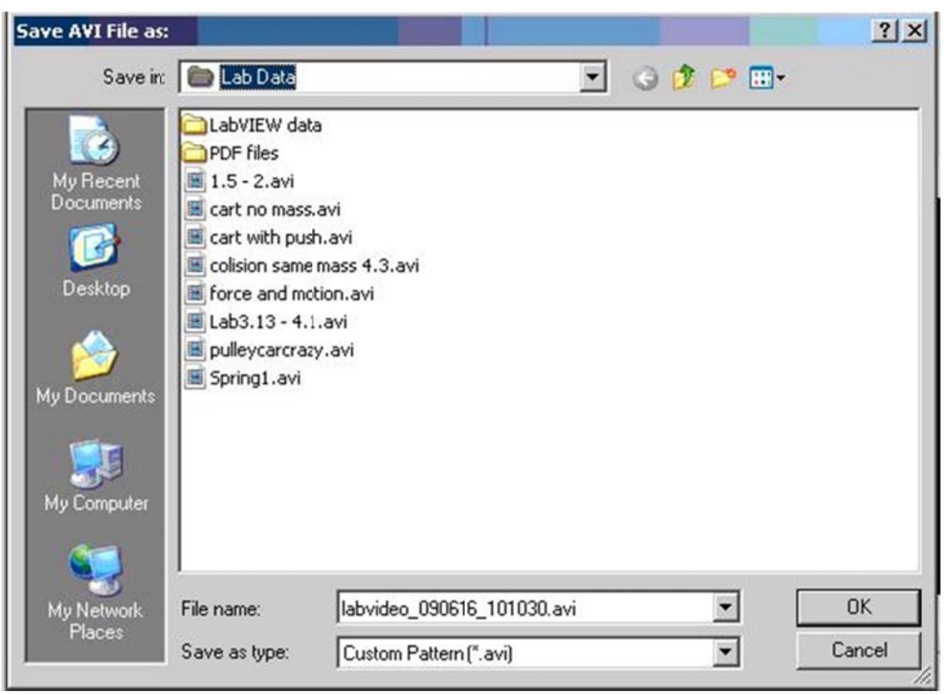
The controls are fairly self-explanatory; pressing the *Record Video* button begins the process of recording a 5-second video image. While the video is recording, the blue *Progress* bar beneath the video frame grows. Once you have finished recording, you can move through the video by dragging the *Frame 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 recorded motion does not appear smooth, or if the object skips irregularly, 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.

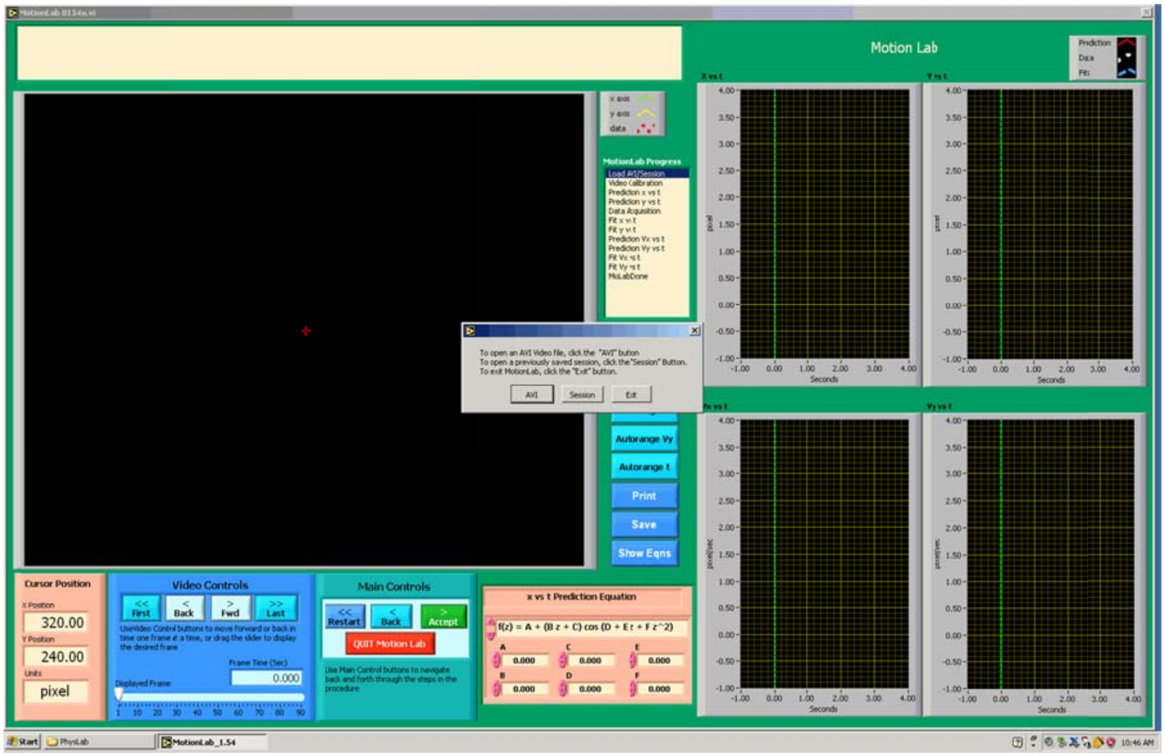
Once you have recorded a satisfactory video, save it by pressing the *Save Video* button. You will see a *Save* window, as shown on the next page.

To avoid cluttering the computer, you will only be able to save your video in the *Lab Data* folder located on the desktop. 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).

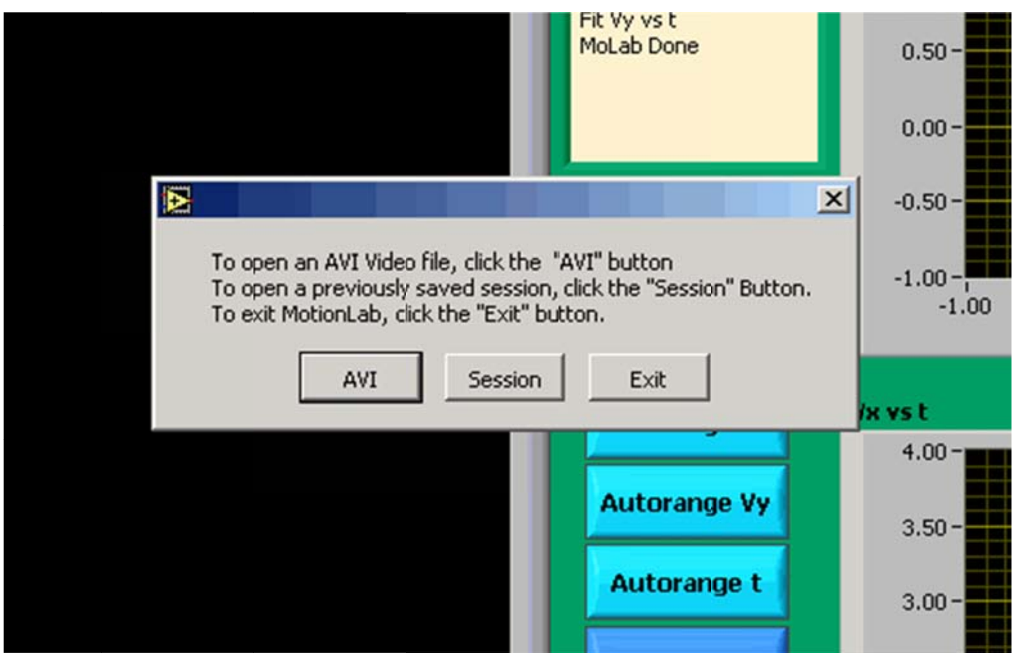


(2) ANALYSIS BASICS

Open the video analysis application by clicking the icon labeled *MotionLab* located in the PhysLab folder on the desktop.   You should now take a moment to identify several elements of the program. As a whole the application looks complex, once it is broken down it is easy to use.

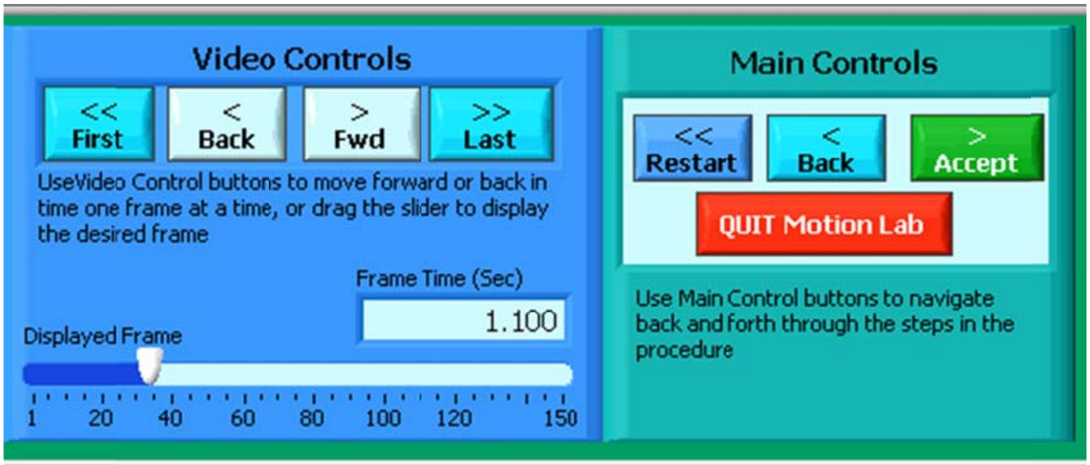


The application will prompt you to open a movie (or previously saved session) as shown below.



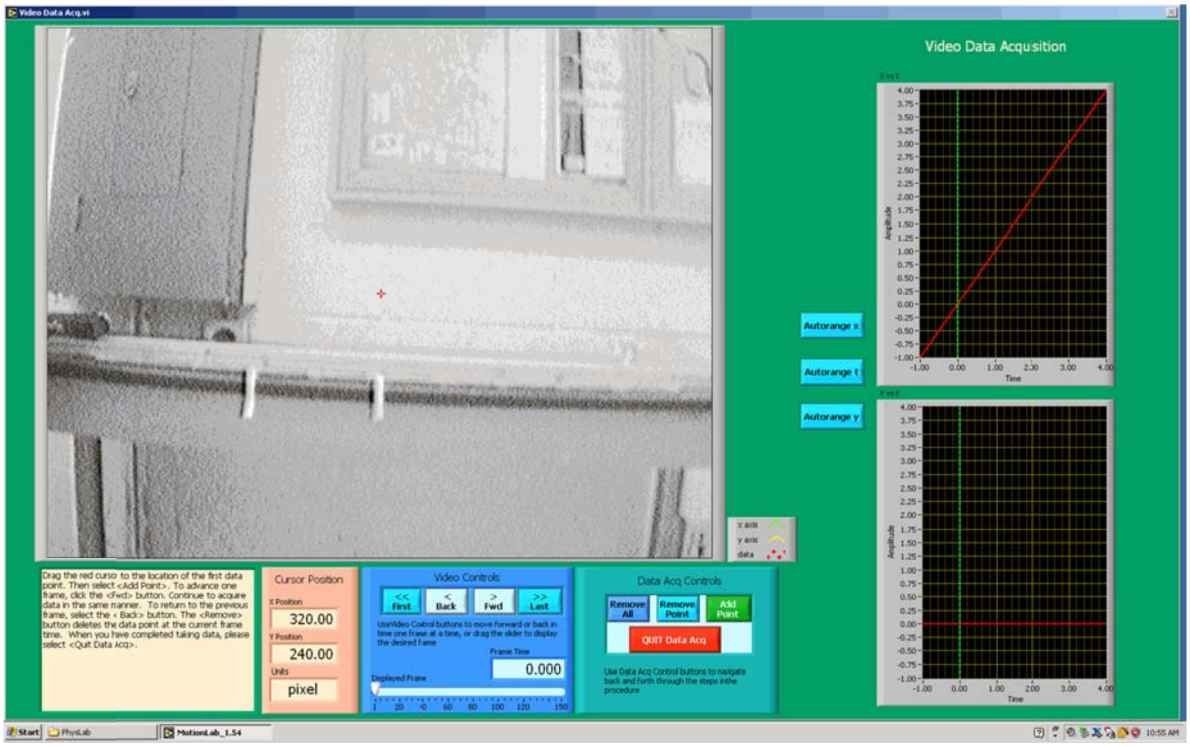
The upper left corner displays a dialog box with instructions for each step during your movie analysis. To the right of the video screen is a progress indicator. It will highlight which step you are currently performing.

Below the video display is the Video Controls for moving within your AVI movie. The slider bar indicating the displayed frame can also be used to move within the movie. Directly to the right of the Video Controls is the Main Controls. The Main Control box is your primary session control.   Use the Main Control buttons to navigate back and forth through the steps shown in the progress box. The red Quit Motion Lab button closes the program.



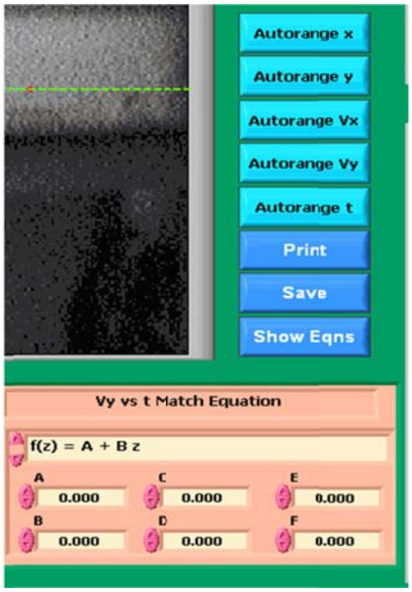
During the course of using MotionLab, bigger video screens pop up to allow you to calibrate your movie and take data as accurately as possible. The calibration screen is shown below. The calibration screen has the instructions box to the right of the video with the Main Controls and Video Controls directly below. The calibration screen automatically opens once an AVI movie has been loaded.

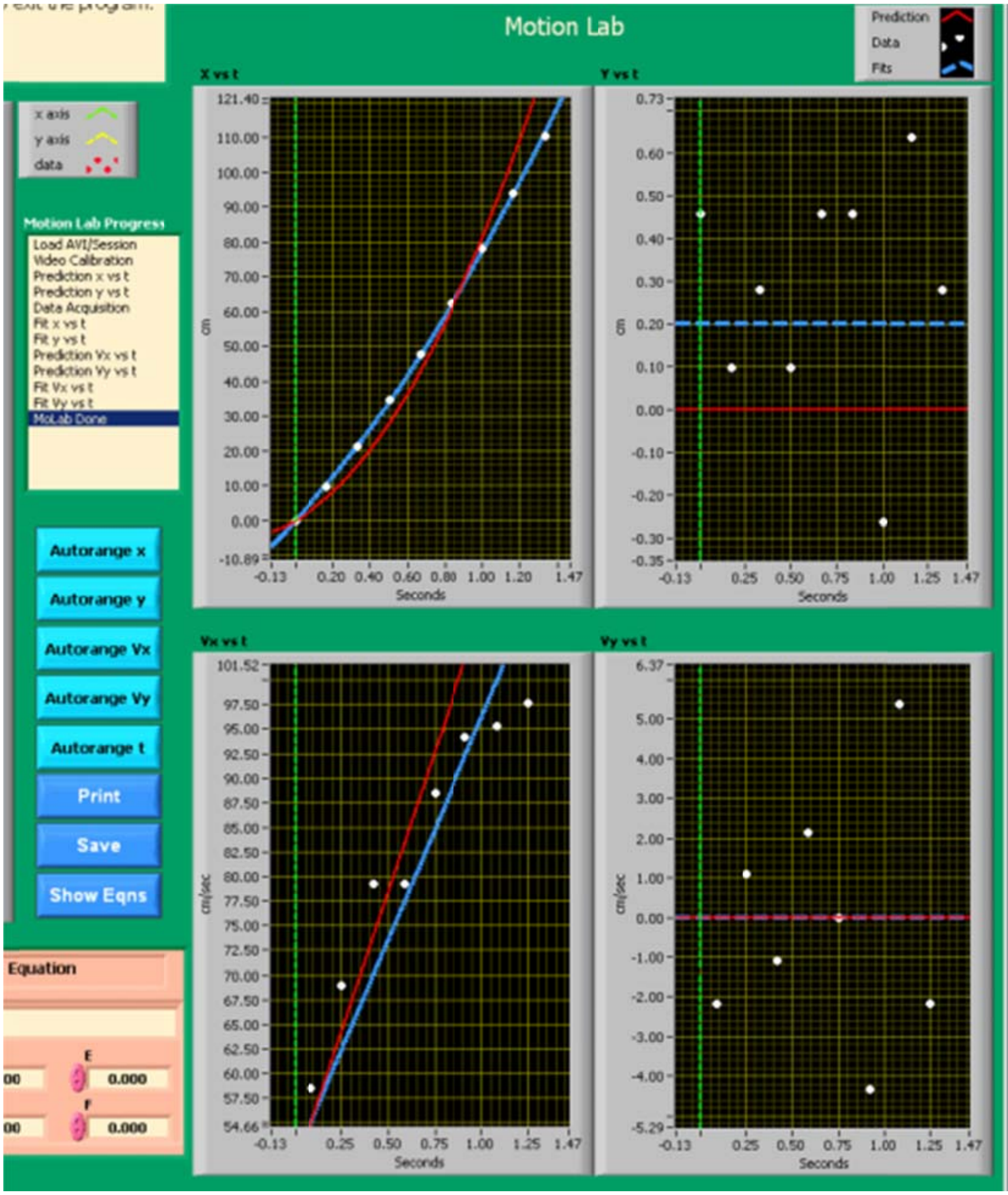
The data acquisition screen is shown below. To get to the data acquisition screen you need to first enter predictions (the progress indicator will display which step you are at.) More will be said about predictions in a bit. The data acquisition screen has the same instructions box and Video Controls, along with a Data Acquisition Control box. The Data Acquisition controls allow you to take and remove data points. The red Quit Data Acq button exits the data collection subroutine and returns to the main screen once your data has been collected. The red cursor will be moved around to take position data from each frame using your mouse.



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*.

There are just a few more items to point out before getting into calibration, making predictions, taking data and matching your data in more detail. To the right the picture shows the equation box for entering predictions and matching data. Directly above this and below the progress indicator you have controls for setting the range of the graph data and controls for printing and saving. The graphs that display your collected data are shown on the next page. Your predictions are displayed with red lines, fits are displayed with blue lines.





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 the calibration screen will open automatically. 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. 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. Read the directions in the *Instructions* box carefully.

Lastly, decide if you want to rotate your coordinate axes. If you choose not to rotate the axes, the computer will use the first calibration point as 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 on the screen once the process is complete. 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 Quit Calibration.

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. The available equations are shown to the right.

- ✓ u(t) = A + B t
- u(t) = A + B t + C t^2
- u(t) = A + B t + C t^2 + D t^3
- u(t) = A + B t + C t^2 + D t^3 + E t^4
- u(t) = A + B sin(C + D t + E t^2)
- u(t) = A + B cos (C + D t + E t^2)
- u(t) = A + B exp (- C t)
- u(t) = A + B (1 - exp (- C t))
- u(t) = A + (B + C t) sin (D + E t + F t^2)
- u(t) = A + (B + C t) cos (D + E t + F t^2)

You can change the equation to one you would like to use by clicking on the arrows to the left of the equation

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 "*Accept*" in the *Main Controls*. 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. 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 *ADD Data Point* button in Data Acquisition control box. 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 *ADD 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. The data will automatically appear on the 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 *Quit Data Acq* from the *controls*

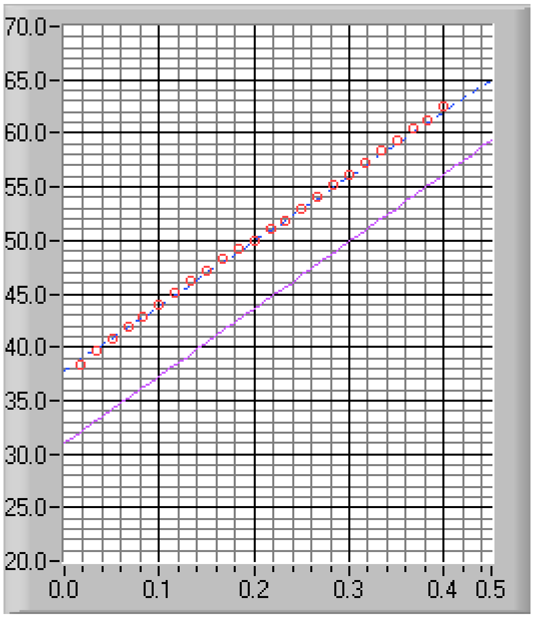
FITTING YOUR DATA

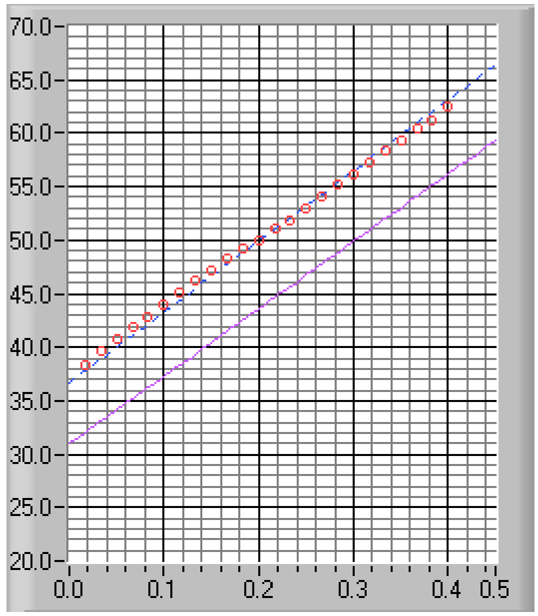
Deciding which equation best represents your data is the most important part of your data analysis. The actual mechanics of choosing the equation and constants is similar to what you did for your predictions.

First you must find your data on your graphs. Usually, you can find your full data set by using the Autorange buttons to the left of the graphs.

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.

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: A Review of Graphs

Graphs are visual tools used to represent relationships (or the lack thereof) among numerical quantities in mathematics. In particular, we are interested in the graphs of functions. Before we go into functions, let us consider the more primitive idea of relations.

Relations and Functions

A relation is any mapping from one set of quantities to another. For example, the following is a relation:

$$a \to \alpha$$
$$b \to \beta$$
$$c \to \beta$$
$$c \to \gamma$$

In this relation, the set of Roman letters $\{a, b, c\}$ is the domain – the thing from which the relation maps; the set of Greek letters $\{\alpha, \beta, \gamma\}$ is the range – the thing to which the relation maps.

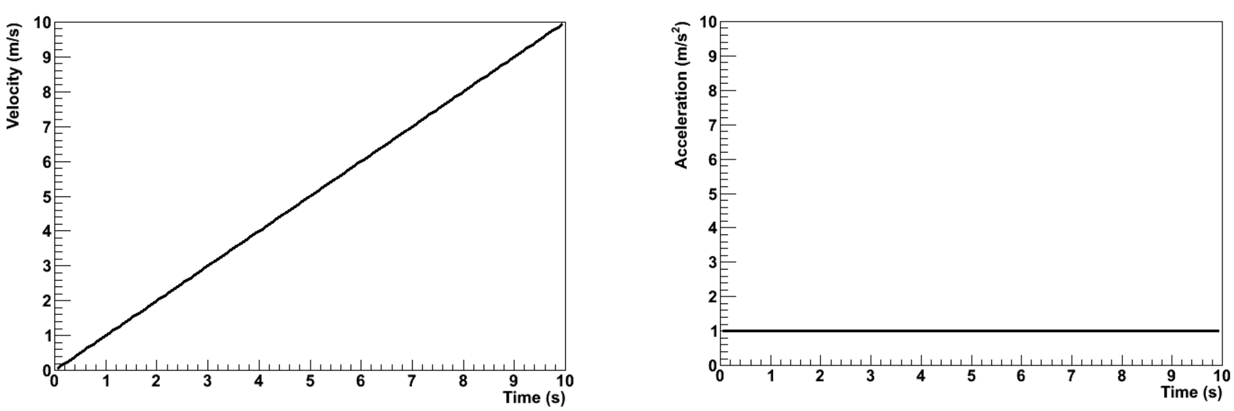
Functions are special kinds of relations. All functions are relations, but not vice-versa. A function can map each element of the domain to only one element of the range: in the above relation, c maps to both β and γ; this is not allowed. A function can, however, map two different elements of the domain to the same element of the range: in the above relation, both b and c map to β; this is allowed.

We represent a function f of a variable $t$with the notation$f(t)$; this means "the value of f evaluated at t." Strictly speaking, f is a function and $f(t)$ is a number.

What is a graph?

In this course, we will be dealing almost exclusively with graphs of functions and relations. When we graph a quantity A with respect to a quantity B, we mean to put B on the horizontal axis of a two-dimensional region and A on the vertical axis and then to draw a set of points or curve showing the relationship between them. We do not mean to graph any other quantity from which A or$B$ can be determined. For example, a plot of acceleration versus time has acceleration itself, $a(t)$, on the vertical axis, not the corresponding velocity $v(t)$; the time t, of course, goes on the horizontal axis. See Figure 1.

Canonically, we call the vertical axis the "y-" axis; the horizontal axis, the "x-" axis. Please note that there is nothing special about these variables. They are not fixed, and they have no special meaning.



(a) (b)

Figure 1: Graphs of acceleration a and velocity v for an object in 1-dimensional motion with constant acceleration.

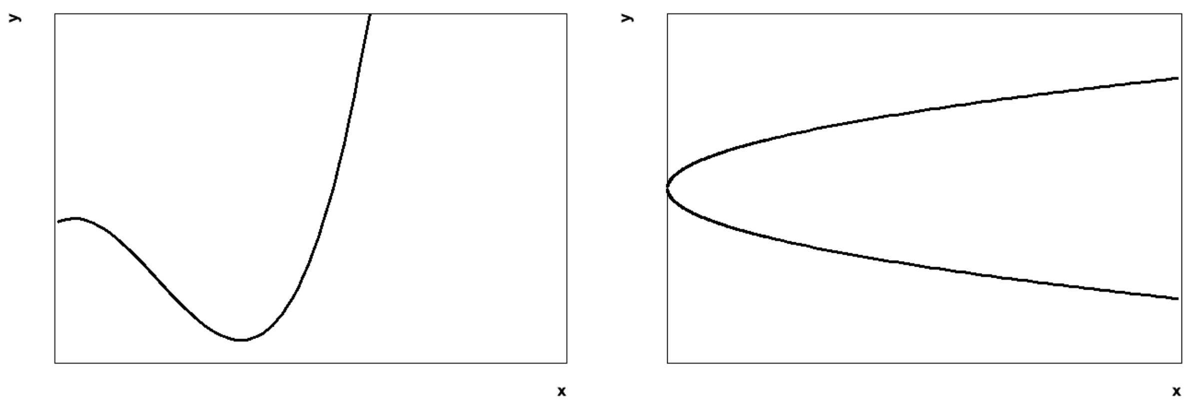
If we are graphing, say, a velocity function $v(t)$with respect to time t, then we do not bother trying to identify

$v(t)$ with y or t with x; in that case, we just forget about y and x. This can be particularly important when representing position with the variable x, as we often do in physics. In that case, graphing $x(t)$ with respect to $t$would give us an $x$on both the vertical and horizontal axes, which would be extremely confusing. We can even imagine a scenario wherein we should graph a function x of a variable $y$such that $y$would be on the horizontal axis and $x(y)$ would be on the vertical axis. In particular, in MotionLab, the variable z, not x, is always used for the horizontal axis; this represents time. Both x and y are plotted on vertical axes as functions of the time z.

Graphs of Functions

On a graph, the idea that a function maps one element of the domain to only one element of the range means that any possible vertical line can cross the function not more than once. This is because the horizontal axis is canonically used to represent the independent variable, or domain, while the vertical axis is canonically used to represent the dependent variable, or range; if the vertical line crossed the function twice or more, that would represent mapping one element of the domain to more than one element of the range.

We will almost always be graphing functions in this class; fits to data, for example, will always be functions. Relations which are not functions will be relevant only as data itself. For example, if we measured the acceleration due to gravity of two balls with the same mass, and if we did not measure exactly the same acceleration for the two, then a graph of acceleration versus ball mass would be a graph of a relation, not of a function.



(a) (b)

Figure 2: Graphs of a function (a) and of a relation which is not a function (b). Note that the latter does not pass the vertical line test.

Data, Uncertainties, and Fits

When we plot empirical data, we are still plotting relations; it is just not necessarily obvious that we are doing so. Our data will typically come as a set of ordered pairs (x, y); this can be seen as a relation from a small, discrete domain to a small, discrete range. Instead of plotting a curve, we just draw dots or some other kind of marker at each ordered pair.

Empirical data also typically comes with some uncertainty in the independent and dependent variables of each ordered pair. We need to show these uncertainties on our graph; this helps us to interpret the region of the plane in which the true value represented by a data point might lie. To do this, we attach error bars to our data points. Error bars are line segments passing through a point and representing some confidence interval about it.

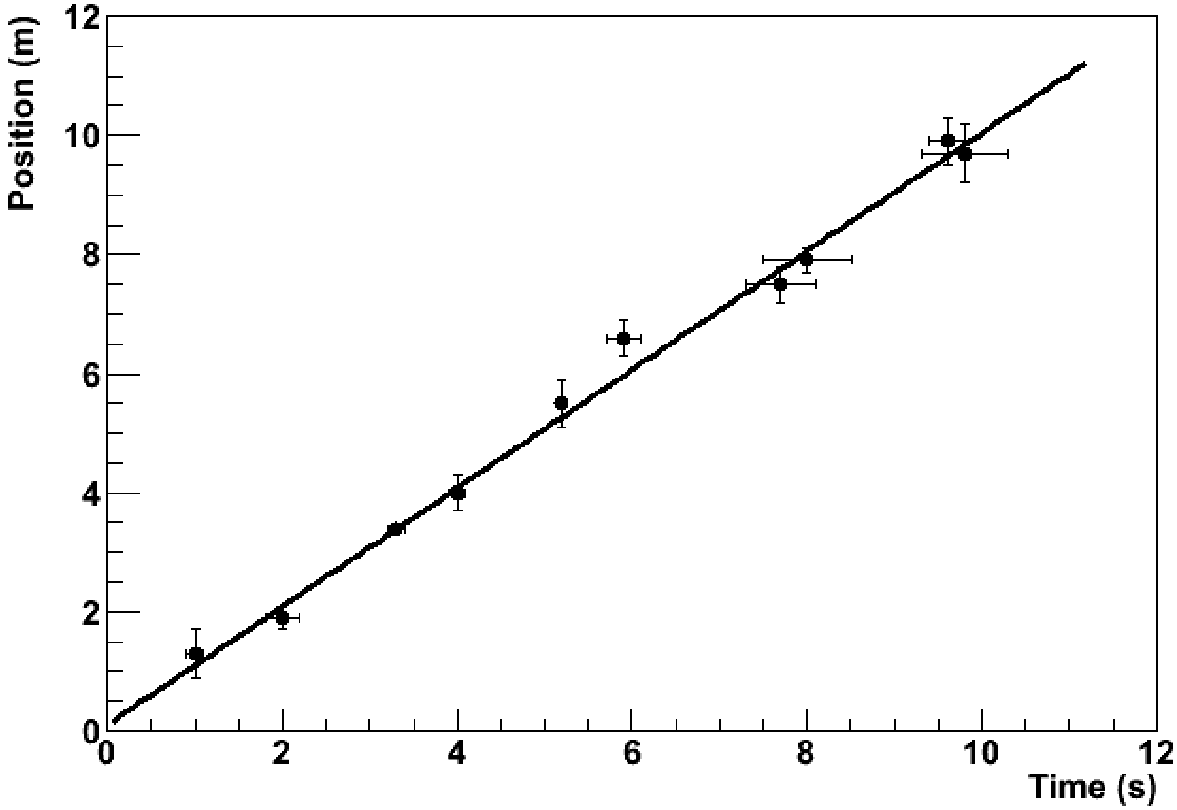


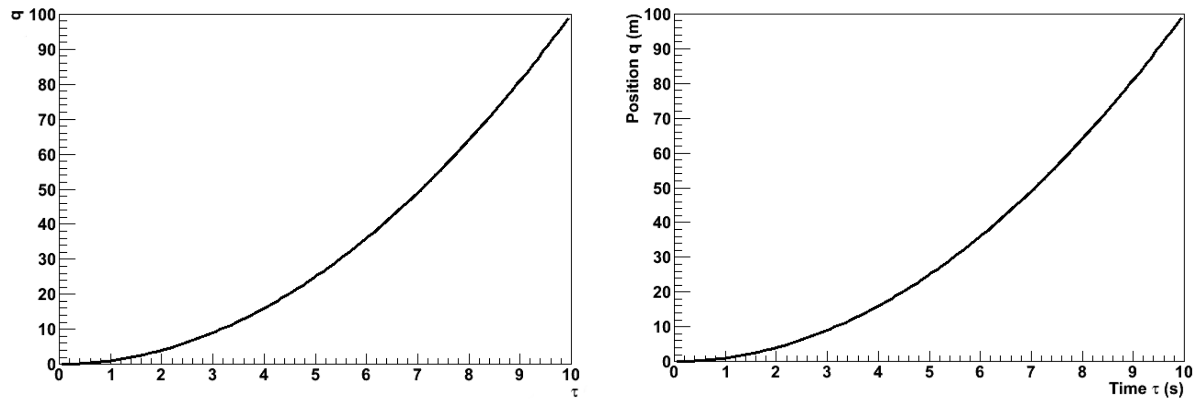
Figure 3: An empirical data set with associated uncertainties and a best-fit line.

After we have plotted data, we often need to try to describe that data with a functional relationship. We call this process "fitting a function to the data" or, more simply, "fitting the data." There are long, involved statistical algorithms for finding the functions that best fit data, but we won't go into them here. The basic idea is that we choose a functional form, vary the parameters to make it look like the experimental data, and then see how it turns out. If we can find a set of parameters that make the function lie very close to most of the data, then we probably chose the right functional form. If not, then we go back and try again. In this class, we will be almost exclusively fitting lines because this is easiest kind of fit to perform by eye. Quite simply, we draw the line through the data points that best models the set of data points in question. The line is not a "line graph;" we do not just connect the dots (That would almost never be a line, anyway, but a series of line segments.). The line does not need to pass through any of the data points. It usually has about half of the points above it and half of the points below it, but this is not a strict requirement. It should pass through the confidence intervals around most of the data points, but it does not need to pass through all of them, particularly if the number of data points is large. Many computer programs capable of producing graphs have built-in algorithms to find the best possible fits of lines and other functions to data sets; it is a good idea to learn how to use a high-quality one.

Making Graphs Say Something

So we now know what a graph is and how to plot it; great. Our graph still doesn't say much; take the graph in Figure 4(a). What does it mean? Something called $q$apparently varies quadratically with something called τ, but that is only a mathematical statement, not a physical one. We still need to attach physical meaning to the mathematical relationship that the graph communicates. This is where labels come into play.

Graphs should always have labels on both the horizontal and vertical axes. The labels should be terse but sufficiently descriptive to be unambiguous. Let's say that $q$is position and $\tau$is time in Figure 4. If the problem is one-dimensional, then the label "Position" is probably sufficient for the vertical axis (q). If the problem is two-dimensional, then we probably need another qualifier. Let's say that the object in question is moving in a plane and that q is the vertical component of its position; then "Vertical Position" will probably do the trick.



(a)

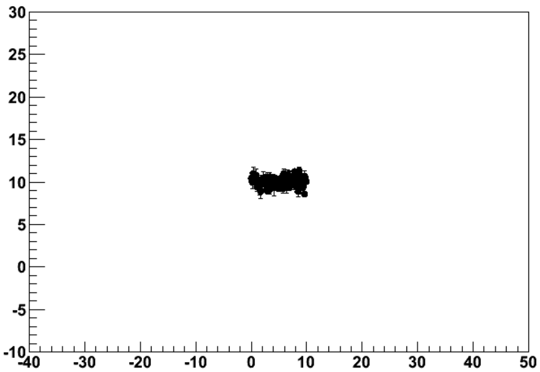
(b) Position q with respect to time τ for a mass of 3kg. The acceleration is constant.

Figure 4: Poorly- versus well-labeled and -captioned graphs. The labels and caption make the second graph much easier to interpret.

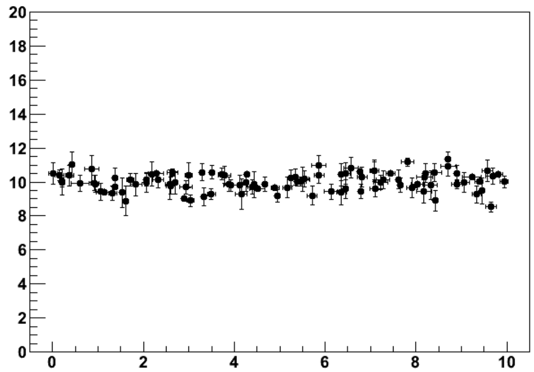
There's still a problem with our axis labels. Look more closely; where is the object at $\tau = 6\text{s}$? Who knows? We don't know if the ticks represent seconds, minutes, centuries, femtoseconds, or even some nonlinear measure of time, like humans born. Even if we did, the vertical axis has no units, either. We need for the units of each axis to be clearly indicated if our graph is really to say something. We can tell from Figure 4(b) that the object is at $q = 36\text{m}$ at $\tau = 6\text{s}$. A grain of salt: our prediction graphs will not always need units. For example, if we are asked to draw a graph predicting the relationship of, say, the acceleration due to gravity of an object with respect to its mass, the label "Mass" will do just fine for our horizontal axis. This is because we are not expected to give the precise functional dependence in this situation, only the overall behavior. We don't know exactly what the acceleration will be at a mass of 10g, and we don't care. We just need to show whether the variation is increasing, decreasing, constant, linear, quadratic, etc. In this case, it might be to our advantage to include units on the vertical axis, though; we can probably predict a specific value of the acceleration, and that value will be meaningless without them.

Every graph we make should also have some sort of title or caption. This helps the reader quickly to interpret the meaning of the graph without having to wonder what it's trying to say. It particularly helps in documents with lots of graphs. Typically, captions are more useful than just titles. If we have some commentary about a graph, then it is appropriate to put this in a caption, but not a title. Moreover, the first sentence in every caption should serve the same role as a title: to tell the reader what information the graph is trying to show. In fact, if we have an idea for the title of a graph, we can usually just put a period after it and let that be the first sentence in a caption. For this reason, it is typically redundant to include both a title and a caption. After the opening statement, the caption should add any information important to the interpretation of a graph that the graph itself does not communicate; this might be an approximation involved, an indication of the value of some quantity not depicted in the graph, the functional form of a fit line, a statement about the errors, etc. Lastly, it is also good explicitly to state any important conclusion that the graph is supposed to support but does not obviously demonstrate. For example, let's look at Figure 4 again. If we are trying to demonstrate that the acceleration is constant, then we would not need to point this out for a graph of the object's acceleration with respect to time. Since we did not do that, but apparently had some reason to plot position with respect to time instead, we wrote, "The acceleration is constant."

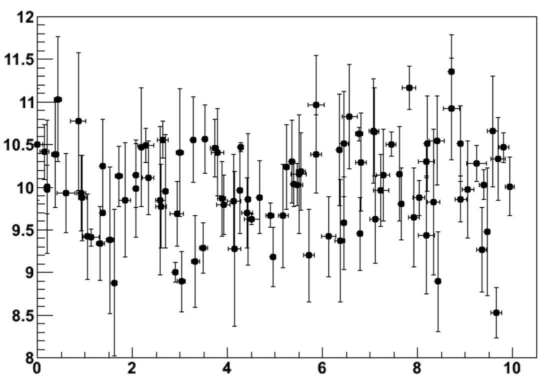
Lastly, we should choose the ranges of our axes so that our meaning is clear. Our axes do not always need to include the origin; this may just make the graph more difficult to interpret. Our data should typically occupy most of the graph to make it easier to interpret; see Figure 5. However, if we are trying to demonstrate a functional form, some extra space beyond any statistical error helps to prove our point; in Figure 5(c), the variation of the dependent with respect to the independent variable is obscured by the random variation of the data. We must be careful not to abuse the power that comes from freedom in plotting our data, however. Graphs can be and frequently are drawn in ways intended to manipulate the perceptions of the audience, and this is a violation of scientific ethics. For example, consider Figure 6. It appears that Candidate B has double the approval of Candidate A, but a quick look at the vertical axis shows that the lead is actually less than one part in seventy. The moral of the story is that our graphs should always be designed to communicate our point, but not to create our point.



(a)



(b)



(c)

Figure 5: Graphs with too much (a), just enough (b), and too little space (c) to be easy to interpret.

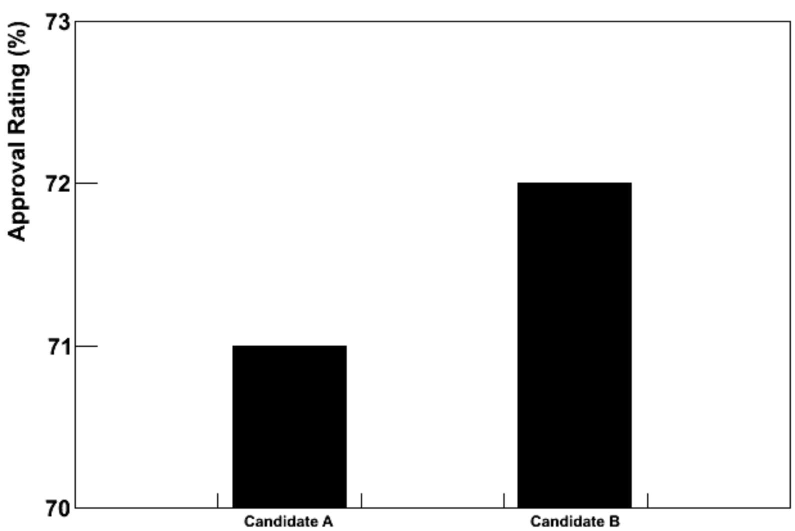


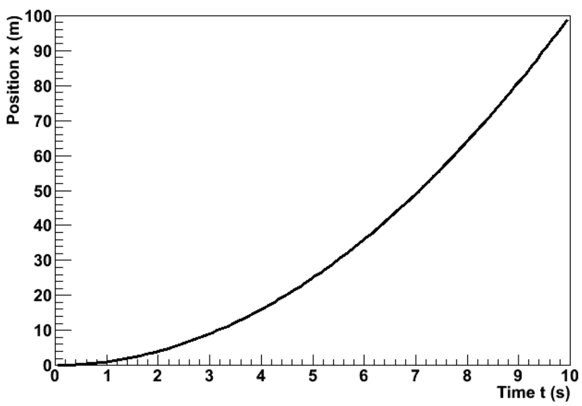
Figure 6: Approval ratings for two candidates in a mayoral race. This graph is designed to mislead the reader into believing that Candidate B has a much higher approval rating than Candidate A.

Using Linear Relationships to Make Graphs Clear

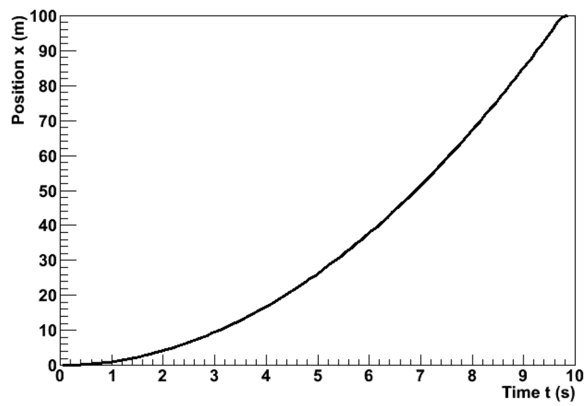
The easiest kind of graph to interpret is often a line. Our minds are very good at interpreting lines. Unfortunately, data often follow nonlinear relationships, and our minds are not nearly as good at interpreting those. It is sometimes to our advantage to force data to be linear on our graph. There are two ways that we might want to do this in this class; one is with calculus, and the other is by cleverly choosing what quantities to graph.

The “calculus” method is the simpler of the two. Let’s say that we want to compare the constant accelerations of two objects, and we have data about their positions and velocities with respect to time. If the accelerations are very similar, then it might be difficult to decide the relationship from the position graphs because we have a hard time detecting fine variations in curvature. It is much easier to compare the accelerations from the velocity graphs because we then just have to look at the slopes of lines; see Figure 7. We call this the “calculus” method because velocity is the first derivative with respect to time of position; we have effectively chosen to plot the derivative of position rather than position itself. We can sometimes use these calculus-based relationships to graph more meaningful quantities than the obvious ones.

The other method is creatively named “linearization.” Essentially, it amounts to choosing non-obvious quantities for the independent and/or dependent variables in a graph in such a way that the result graph will be a line. An easy example of this is, once again, an object moving with a constant acceleration, like one of those in Figure 7. Instead of taking the derivative and plotting the velocity, we might have chosen to graph the position with respect to $t^2/2$; because the initial velocity for this object happened to be 0, this would also have produced a graph with a constant slope.



(a)



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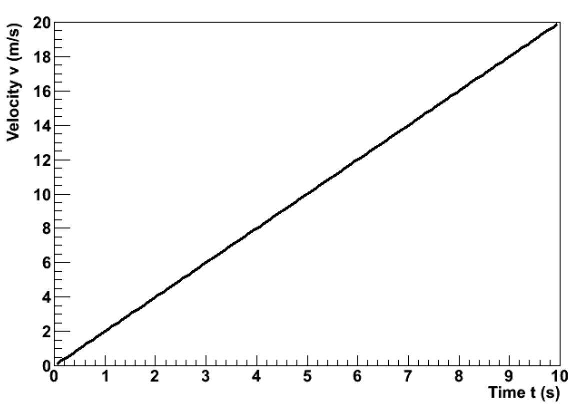

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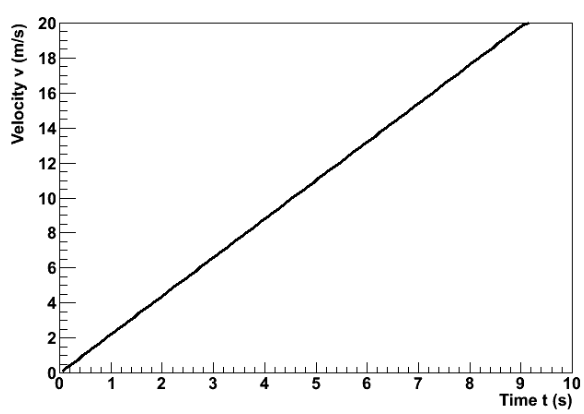

(d)

Figure 7: Position and velocity with respect to time for an objects with slightly different accelerations. The difference is easier to see in the velocity graphs.

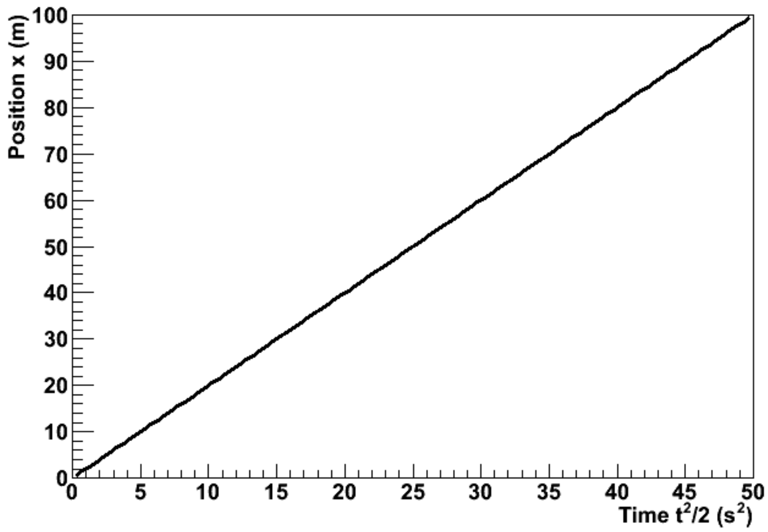

Figure 8: The position of the first object from Figure 7 plotted with respect to t2 /2. The relationship has been linearized.

The Bottom Line

Ultimately, graphs exist to communicate information. This is the objective that we should have in mind when we create them. If our graphs can effectively communicate our point to our readers, then they have accomplished their purpose.

Appendix F: What is a Lab Report?

Glad you asked. A lab report is an analysis of an experiment that you personally performed in this class's lab setting. It is a self-contained document; the reader should not have to consult any other source to understand what you did or why you did it. It should present a cogent, coherent, complete analysis which moves from a statement of a question (expressed in terms of one or more empirical quantities) toward a clear, pre-established goal (an evaluation of those empirical quantities) which answers that question.

This makes a lab report a somewhat unique assignment in the context of science classes you may have taken in the past. To this point, work has always been about finding an answer; to this point, the product of the work has been the answer. Lab reports do seek to answer a question, yes, but the product of a lab report is the *process*. Your purpose in writing a lab report (as an assignment, not as a composition) is to demonstrate to your instructors that you understand the process of science.

Audience

Your audience when writing a lab report is an arbitrary scientifically literate person. You should assume that your audience is well-acquainted with science in general and physics and mathematics in particular, both in theory and in practice. You should also assume that your audience knows absolutely nothing about what specific experiment you have performed, why you have performed it, or what the result ought to be. This means that you can use the language, methods, and writing style of physics without explaining them, but that you must explain your experimental procedure and analysis in detail.

Technical Style

A lab report is a technical document. This means that it is stylistically quite different from documents you may have written in English, history, rhetoric, or other humanities classes. The sample lab reports in this manual, real scientific papers, manuals, design reports, and such things are good examples of technical writing.

A lab report is divided into sections. It does not rely on language to create transitions from one topic to the next, and each section should be comprehensible by itself. This is not to say that the sections should duplicate information; reading the “Procedure” section of a lab report will not tell the reader the goal or the result of the experiment, but it should completely communicate the experimental procedure used.

A lab report does not need to use the active voice. In many kinds of writing, the active voice is encouraged for sounding brief and clear, and the passive voice is discouraged for sounding verbose and distant. In technical writing, the passive voice is often encouraged to shift the focus of the writing to the science rather than the scientist. Either voice is acceptable in your report. You should use whichever feels natural and accomplishes your intent, but you should be consistent.

A lab report presents much of its information with media other than prose. Tables, graphs, diagrams, and equations frequently can communicate far more effectively than can words. Technical writing embraces these media. You should integrate them smoothly into your report.

A lab report is a persuasive document, but it does not express opinions. Your predictions should be expressed as objective hypotheses. Your experiment and analysis should be a disinterested effort to confirm or deny your predictions, not an attempt to convince your audience that they are correct. Please note that your thesis, which your report should always confirm, will not necessarily coincide with your predictions. Whether or not your report supports your predictions, it should support your thesis objectively.

A lab report does not entertain. If you read the sample reports, you will probably find them boring. A lab report *ought* to be boring. Your audience is not reading your report to have a good time; he is reading your report to learn. The science in your report should be able to stand for itself. If your report needs to be entertaining, then its science is lacking.

Spelling, Grammar, Mechanics, and So Forth

You should write your lab report in standard, formal, American English. You should use proper grammar, syntax, orthography, and so on. Bad spelling, in particular, is inexcusable; while electronic spelling checkers are not perfect, they are good enough to render spelling mistakes in finished products all but extinct. You are a college student; you ought to be able to do these things properly.

With that said, these linguistic components of the report are the emphasis neither of this course nor of this assignment. If they are sufficiently lacking to compromise the understandability of your report, you will be penalized. Otherwise, they are of secondary importance.

Physical Style

Physical style refers to the visual, as opposed to the logical, attributes of a document. In lab reports, this basic philosophy holds true: content is important; appearance is not. You should therefore consider physical style to be of secondary importance.

This is not to say that you may simply write your lab report by hand on notebook paper. Your report should be typeset using a computer. Your graphs should be produced with a high-grade plotting program, not with a drawing program like Microsoft Paint or Adobe Illustrator. Your headings should stand out. Your equations should be rendered using a tool specifically for typesetting mathematics, not simply typed using a word processor's text mode. It *is* to say that your specific choices of fonts, heading sizes, paragraph delimitation, etc. are up to you. Ultimately, the physical style is subservient to the logical style. It should serve to communicate information. Your headings should be obvious, your mathematics should be unambiguous, your graphs should be accurate, and so forth.

When in doubt, your best practice is to ask your TA. He may or may not have specific desires in this area, and he can always provide an acceptable suggestion. If you need to see something personally, this lab manual, particularly the sample reports, is a good example of physical style done well.

Graphs, Tables, Diagrams, Math

A lab report utilizes a variety of media to communicate its message. An old cliché tells us, "A picture is worth a thousand words;" you should embrace this sentiment when you write your reports, but you should not limit yourself to pictures. Your goal should be to make your point to your reader as clearly and tersely as possible. When a graph will do better than words, use a graph. When a table will do better than a listing, use a table. When a diagram will do better than a long description, use a diagram.

You should label these media when you write your report. Graphs, diagrams, and other pictures should be labeled with "Figure X," wherein X is an identifying integer. Tables should be labeled similarly, with "Table." Equations typically only receive a number; convention places the numbers at the right end of the line, and the word "Equation" is omitted for space. However, you should still refer to an equation as "Equation X" in the text.

You should caption every table and figure you include in your report. Your goal in the caption, at the very least, is to accomplish what a title otherwise would: to declare to the reader what information the object is presenting. Depending on the circumstance, you should also explain any relevant, non-obvious details, such as assumptions or important numerical quantities not presented in the object itself. For example, if you include a graph of the position of a ball with respect to time in a report where you measured this quantity for balls of several masses, your caption should indicate the mass of the ball for which the data is presented. Finally, if the object is intended to demonstrate some derived piece of information, such as a conclusion or a fit to a graph, you should include this in your caption.

As valuable as these media are, they do not contain enough information to stand without context. You should not merely add these sorts of objects without addressing them in the text of your report. They should be naturally integrated into the discussion. When you come to a point that you wish to make with a graph, state that the information is contained in Figure X. When you reference data that is included in a table, tell your reader to refer to Table Y. Be sure to state and explain the salient conclusion that the reader should draw from the object that she has just examined. Sometimes, these two functions can even be combined into a single sentence.

These media are powerful tools, and they are at your disposal to help you make your case in your report. You should use them whenever you can make your argument more elegantly by doing so than by not. If you find yourself in a situation where trying to use one only makes things more confusing, it is best to stick with tried-and-true prose. Use your best judgment.

Quantitativeness

A lab report is quantitative. Quantitativeness is the power of scientific analysis. It is objective, and it allows us to know precisely how well we know something. Your report is scientifically valid only insofar as it is quantitative.

You must follow one, simple rule to make your report quantitative: give numbers. Give numbers for everything. You should report the numerical values of every relevant quantity that you measure or calculate. You should report some numerical evaluation of every result you derive and every conclusion you draw. You should report the numerical errors in every quantity you measure, and you should propagate the numerical errors in every quantity you compute. If you find yourself using words like "big," "small," "close," "similar," and etc., then you are probably not being sufficiently quantitative. Try to replace vague statements like these with precise, quantitative ones.

If there is a single "most important part" to quantitativeness, it is error analysis. This lab manual contains an appendix about error analysis; read it, understand it, and take it to heart.

Making an Argument

The single most important part of any lab report is the argument. You need to be able communicate and demonstrate a clear point. If you can do this, and do it in a scientifically valid manner, your report will be a success. If you cannot, your report will be a failure.

You have certainly written a traditional five-paragraph essay at some point. Recall its structure:

1. An opening paragraph stating a thesis.
2. A middle paragraph explaining a first supporting point.
3. A middle paragraph explaining a second supporting point.
4. A middle paragraph explaining a third supporting point.
5. A closing paragraph restating the thesis.

A lab report is not so trite and formulaic a document as this, but you can, nevertheless, learn an important lesson from it. Good technical writing states a thesis, supports it with argument, and then restates the thesis. By "giving away the ending," so to speak, you accomplish two things. First, you entice the audience to finish reading the report. Second, you let the audience know where the report is about to take her, an act which will help her to keep track of her train of thought as she reads. Once this is done, you must defend your thesis through logical, scientific argument. Your audience is trained to react to anything you say with skepticism, so you must rigorously justify it. Finally, by restating the thesis with which you opened, you emphasize the point, remind your audience what she just learned, and give your audience a sense of closure.

In science, this is typically implemented by structuring a report in four basic sections: introduction, methodology, results, and discussion; this is sometimes called the "IMRD method." You should state your thesis, along with enough background information to explain it and a brief preview of the succeeding sections, in your introduction. You should defend that thesis in the methodology and results sections. You should restate your thesis, this time with an evaluation of its veracity and its implications, in your discussion. N.B.: Your report does not need to have exactly four sections entitled "Introduction," "Methodology," "Results," and "Discussion;" this is just the logical progression by which you should structure it. Several more specific, more finely divided sections are recommended below.

An Example Format

We here present an example of how to structure your report. You should not interpret this as a strict, required format. It is, however, one possible good implementation of the IMRD method. Any format that you choose should be such a good implementation and should include all of the information presented in the format below. Much of the advice given below is useful in general.

Abstract

You should think of the abstract as your report in miniature. It should be only a few sentences long, but should emulate the IMRD method. You should state the question you are trying to answer. You should then state the method you used to answer that question. You should finally summarize your results and conclusion.

The abstract serves the same purpose for your report that a teaser serves for a film. It is the first thing that your audience will encounter, and it is what will convince her that reading the rest of your report is worth her time.

Although the abstract is first piece of your report, it can be helpful to write it last. After you have written the rest of the report is when you best understand it and can best summarize it.

Your abstract should not be an integrated component of your report as a whole; it should not replace any other part of the report, and the report should be complete and comprehensible in its absence.

Introduction

You should do three things in your introduction. First, you should provide enough context so that your audience can understand the question that your report tries to answer. This typically involves a brief discussion of the hypothetical, real-world scenario presented at the beginning of the experiment's prompt in the lab manual. Second, you should clearly state the question. Third, you should provide a brief statement of how you intend to go about answering it.

Students sometimes balk at hypothetical scenarios used in the lab manual to provide context to the experiment. There is some fairness to the objections; the stories are often awkward and far-fetched. That is not really the point. You should include the discussion of context in your report. Think of it as the part where you justify yourself to your oversight committee or funding agency. The realism you perceive in the story is not important; the skill that it helps to develop is.

Predictions

You should include the same predictions in your report that you made prior to the beginning of the experiment. They do not need to be correct. If they do turn out to be correct, then you must prove that they are so by means of your analysis. If they do not, then you must prove that, too, and explain the reality exposed by your analysis. Either way, you will be doing the same work; only a few words will change. You will receive far more credit for an incorrect, well refuted prediction than you will for a correct, poorly supported one.

The lab manual will often ask you for an equation or a graph as your prediction. Just as they cannot in any other part of the report, these things cannot stand by themselves. You must discuss them in prose.

Your prediction will often be expressible as an equation that you can derive from the physical principles and formulas that you will learn in the lecture portion of this class. If so, then you should include a brief, mathematical derivation of that prediction. You should not include every step in the calculation, but only the ones which constitute important, intermediate results.

Procedure

You should explain what your actual, experimental methodology was in the procedure section. You should discuss the apparatus and techniques that you used to make your measurements.

You should exercise a little conservatism and wisdom when deciding what to include in this section. You should include all of the information necessary for someone else to repeat the experiment, but only in the important ways. It is important that you measured the time for a cart to roll down a ramp through a length of one meter; it is not important who released the cart, how you chose to coordinate the person releasing it with the person timing it, or which one meter of the ramp you used. You should also omit any obvious steps. If you performed an experiment using some apparatus, it is obvious that you gathered the apparatus at some point. If you measured the current through a circuit, it is obvious that you hooked up the wires. One aspect of this which is frequently problematic for students is that a step is not necessarily important or non-obvious just because they find it difficult or time-consuming. Try to decide what is scientifically important, and then include only that in your report.

Students approach this section in more incorrect ways than any other. You should not provide a bulleted list of the equipment. You should not present the procedure as a series of numbered steps. You should not use the second person or the imperative mood. You should not treat this section as though it is more important than the rest of the report. You should rarely make this the longest, most involved section.

Data

This will be your easiest section. You should record your empirical measurements here: times, voltages, fits from MotionLab, etc.

You should not use this as the report's dumping ground for your raw data. You need to think about which measurements are important to your experiment and which are not. For example, consider a lab wherein you measure acceleration by fitting position and velocity as functions of time. You probably will have estimated some of the coefficients in the fits by making measurements with a meter stick and stopwatch. However, because those “by hand” measurements do not contribute to values of the acceleration that you actually used in your analysis, you should not record them in your report. You may not even need to record the fit functions themselves; it would be appropriate for you just to include the corresponding values of acceleration.

You should also only include data in processed form. Use tables, graphs, and etc. with helpful captions, not long lists of measurements without any logical grouping or order.

Remember to include the uncertainties in all of your measurements.

There is some exception to the “smoothly integrate figures and tables” rule in this section. You should actually include little to no prose in the Data section; most of the discussion of this information actually belongs in the Analysis section. The distinction between the Data and Analysis sections exists largely to make the interpretation of your report easier on your TA.

Analysis

You should do the heavy lifting of your lab report in the Analysis section. This is where you should take the empirical data that you included in the Data section, perform some kind of scientific analysis on it, present your results, and finally answer the question that you posed in your Introduction. You *must* do this quantitatively. This is arguably the most important section of your report, and it has any scientific meaning only if it is quantitative.

Your analysis will almost always amount to quantifying the errors in your experimental measurements and in any theoretical calculations that you made in the Predictions section. You should then answer the following question: are the error intervals in my measurements and predictions consistent with one another? If you are measuring some quantity, say a voltage V, then you need to see whether the error intervals for the experimental value V_e and the theoretical value V_t overlap. If you are trying to confirm some functional form, say, $x(t) = 3t + 12$, then you need to determine whether or nor your fit function passes through the error regions for your experimental data points (t_e, x_e). This manual contains an appendix about error analysis: read it, understand it, and take it to heart.

If your prediction turns out to be incorrect, you should show that it is incorrect as the first part of your analysis. You should then propose the correct result, which your TA should have helped you determine before you left lab, and show that it is, in fact, correct as the second part of your analysis.

You should finally discuss any shortcomings of your procedure or analysis. This includes sources of systematic error for which you did not account, approximations that are not necessarily valid, etc. You should try to decide how badly these shortcomings affected your result. If you confirm your prediction to a high degree, then you can probably dismiss them as insignificant. If you cannot, then you should estimate which are the most important and how they might be addressed in the future.

Conclusion

You should consider your conclusion as the wrapping paper and bow tie, the finishing touches, of your report. At this point, all of the important things ought to have already been said, but this is where you collect them together in one place. You should remind your audience of the important points of your report: what you did and what your result was. You should leave her with a sense of closure.

A good way to go about doing this is to quote your result from the Analysis section and to interpret it in the context of the hypothetical scenario that you discussed in your Introduction. If you determined that there were any major shortcomings in your experiment, you might also propose future work in which the experiment could be done so as to overcome them. If the Introduction included your attempt to justify your funding, then the Conclusion includes your attempt to secure more for the future.

One way to evaluate whether or not your Introduction and Conclusion work well together is to read them in the absence of the intermediate sections. Imagine that you are the person who hired you to perform this work, and that you are so busy that you don't have time to read the whole report. If you can tell what the purpose of the experiment was and what question it was trying to answer in the Introduction, and if you can tell what the answer to that question was in the Conclusion, then chances are good that you have written a solid report.

What Now?

You should now read the sample reports included in this manual. There are two; one is an example of the advice in this document implemented well, and the other is an example of the advice in this document implemented poorly. Hopefully, they should help to clear up any lingering questions about what any of this means. It might be helpful to read the sample reports, then re-read this document, examining the relevant parts of the samples as they are discussed herein.

You should then talk to your TA. She can answer any remaining questions you have and can tell you her preferences about how you should write your report for her, specifically. She can tell you when something written above might not quite apply to a particular experiment. At the end of the day, she determines what is right and what is wrong, so communication is important — and by communication, we do not mean one frantic email that you write to her at 11:30 the night before the report is due.

There is a lot of information here, so implementing it and actually writing your lab report might seem a little bit overwhelming. If so, then go back to the idea that the most important part of the report is the argument. Go back to the idea that the lab report seeks to answer a question. Go back to the idea that the product of the lab report is not so much the answer but the process by which you find it. You should complete your analysis and answer the question before you ever sit down to write your report. At that point, the hard part of the writing should be done: you already know what the question was, what you did to answer it, how the analysis was performed, and what the answer was. You then just need to put that on paper.

GOOD SAMPLE LAB

Lab II, Problem 5: Velocity and Force

Paul Athos
July 14, 2011
Physics 1201W, Professor Mark, TA Melchior

Abstract

The final velocity of a gravity-driven launch cart for a pterosaur model was determined. The mechanism was tested for four driving masses at similar launch heights. The final velocity predicted by Newton's second law and kinematics was confirmed to within experimental error.

Introduction

A research group is investigating the hypothesis that modern birds are the descendants of pterosaurs. As part of this investigation, the flight of pterosaurs is being studied via models. The models are to be launched by a mechanism consisting of a cart accelerated down a straight, level track by a string. The string runs horizontally, over a pulley, and then vertically to a hanging mass which is pulled downward by gravity. It is necessary to be able reliably to predict the final velocity of the cart. This experiment studied the final velocity as a function of the driving mass and the height of its release.

Prediction

The final velocity can be easily calculated by application of Newton's second law and kinematics. Let the mass of the cart be M; the hanging mass, m; and the release height, h. The force on the system is the downward force of gravity on the hanging mass, $F = mg$; using Newton's second law for the compound system,

$$a = g\frac{m}{m+M}$$

Letting the initial position be 0m and the initial velocity by 0m/s, kinematics then yields the final velocity:

$$v_f = \sqrt{2\text{gh}\frac{m}{m+M}}$$

Procedure

A cart was placed on a straight, level, elevated track with a pulley at one end. A string was tied to the cart and run over a pulley. A mass was tied to the other end and allowed to hang down over the edge of the track. The string was pulled taught, and the mass was allowed to fall from rest, pulling the cart with it. Its initial height was less than the length of string between cart and pulley so that the cart would undergo an initial, accelerating phase and a final, coasting phase in its motion. This mechanism is depicted in Figure 1. The motion of the cart was recorded with a video camera. MotionLab software was used to plot the position and velocity of the cart with respect to time. The position and velocity were then fit by eye in two stages, one for the accelerating and one for the coasting phase. The final velocity was taken to be the parameter in a zeroth-order monomial fit to the coasting phase of the velocity measurements.

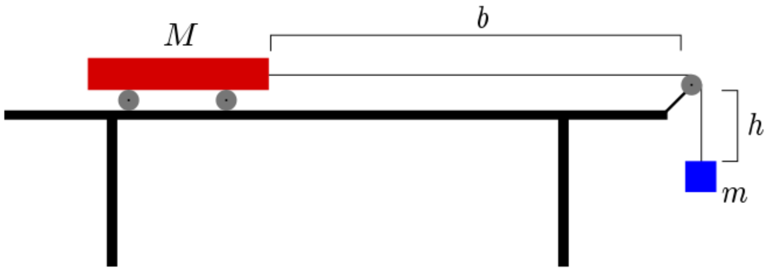

Figure 1: The test mechanism used for this experiment. $b > h$.

Data

m(g)	h(m)	experimental v_f(m/s)	theoretical v_f(m/s)
50.0	0.46	$1.25^{+0.20}_{-0.35}$	$1.24^{+0.04}_{-0.03}$
70.0	0.41	$1.35^{+0.25}_{-0.15}$	$1.34^{+0.04}_{-0.03}$
100.0	0.47	$1.65^{+0.15}_{-0.30}$	$1.64^{+0.04}_{-0.04}$
150.0	0.48	$1.90^{+0.25}_{-0.20}$	$1.94^{+0.04}_{-0.04}$

Table 1: The masses m, release heights h, and experimental and theoretical values of the cart's final velocity v_f. The error in all of the masses is 0.3g. The error in all of the release heights is 0.02m.

Analysis

The experimental measurements and theoretical predictions of the final velocity are given in Table 1 in the Data section. The errors in the experimental measurements were calculated by the parameters in a minimum zeroth-order monomial greater than and a maximum zeroth-order monomial less than all measured data points in the coasting phase. The errors in the theoretical predictions were calculated by the "worst case" propagation of error technique, using the errors quoted above and $g = (9.80 \pm 0.02)$m/s. The entire error intervals of the theoretical predictions are within the respective error intervals of the experimental measurements, so this experiment did confirm the predictions to within error.

There are numerous sources of error not addressed in this experiment. One is the compound effect of friction and drag retarding the motion of the cart and pulley. This was unquantified. Another was the acceleration produced by any deviation from the horizontal of the track; this was determined to be zero within the static friction in the axles of the cart in that it was incapable of accelerating the cart from rest. Another was the distortion in the videos due to the camera. Another was the masses of the string and the pulley, which were assumed to be massless in the theoretical calculation. All of these, and any other sources of error not mentioned here, are believed to be insignificant in comparison to the random error in that the error interval is much wider than the difference between the theoretical and experimental values of the final velocity.

Conclusion

A proposed launching mechanism for a pterosaur model to be used in the investigation of the ancestry of modern birds was modeled by a cart on a track. The cart was accelerated from rest by each of four hanging masses pulled by gravity via a string run over a pulley. The final velocity of the cart after the hanging mass reached the ground was measured and compared to the predictions of kinematics and Newton's second law. The predictions were confirmed in that they and the measurements both lay within one another's error intervals. The research group is justified in using the predicted formula for v_f to calculate the final velocity of the cart used to launch the model. However, it must take into account the mass of the model by using the sum of the model's and the cart's masses rather than just the mass of the cart in its calculations.

BAD SAMPLE LAB

Lab II, Problem 5

Lachesis Megaera
July 15, 2011
Physics 1201W, Professor Mark, TA Melchior

Abstract

We try to study the flight of pterosaurs because of their possible relationship to modern birds. To do so, we need to launch a model at a reproducible velocity. We simulate the launch mechanism with a cart on a track driven by a falling mass pulling it with a string. We test for a number of various masses. We compare the result to a prediction formulated by the application of Newton's second law and basic kinematics. The result is that theory agrees with experiment. The statistical and systematic errors are not significant.

Introduction

We are working as part of a research group studying pterosaurs, a kind of flying reptile from the Mesozoic era. Our group believes that pterosaurs might be related to modern birds. We need to determine the possibility of this evolutionary ancestry, so we are investigating their respective mechanisms of flight as one way of demonstrating this lineage.

As part of the study, we are designing a mechanism which can be employed to propel models of pterosaurs into gliding. The mechanism is a cart on a straight, eminently horizontal, aluminum track. The cart is connected to a string. The string lies over a pulley and then dives straight down. The terminal end of the string is affixed to a set of lab masses. The masses fall under the uniform influence of gravity and pull the string, accelerating the cart from motionlessness. The mechanism needs to have a reliable launch velocity. We must therefore confirm that we can predict the velocity for given values of initial height for the falling mass and of the magnitude of that mass itself.

Prediction

We can calculate the final velocity. We start with Newton's second law for the hanging mass.

$$F = mg - T = ma$$

We do the same for the cart

$$F = T = Ma$$

We set the Ts equal to each other and simplify.

$$T = Ma = mg - ma$$
$$Ma + ma = mg$$
$$(M + m)a = mg$$
$$a = \frac{mg}{M + m}$$

We now have a. We also have the formula

$$x = x_0 + v_0 t + at^2$$

With x = y, v0 = 0, and y0=0, we get

$$y = \frac{1}{2}at^2$$

We set y=h. We already have a.

$$h = \frac{1}{2}\frac{m}{m + M}gt^2$$

We now need t.

$$\frac{2h(M+m)}{mg} = t^2$$

$$t = \sqrt{\frac{2h(m+M)}{mg}}$$

We can use

$$v = v_0 + at$$

to find vf. We already said v0=0.

$$v_f = at = \left(\frac{m}{m+M}g\right)\left(\sqrt{\frac{2h(m+M)}{mg}}\right) = \sqrt{\frac{2hgm}{m+M}}$$

And thus we have theoretically derived our prediction.

Procedure

1. Collect materials: meter stick, lab masses on hook, string, track, video camera, tripod, computer, pulley
2. Set up track on table with pulley at one end.
3. Attach string to cart on one end and hook on the other.
4. Put cart on track and string over pulley so that hook hangs off edge of table.
5. Add mass to hook.
6. Face video camera at cart on track.
7. Let mass fall and pull cart from rest. Record motion with VideoRecorder.
8. Open MotionLab.
9. Set t=0.
10. Calibrate length.
11. Define coordinate system.
12. Predict x(t) and y(t).
13. Acquire data.
14. Fit x(t) and y(t).
15. Predict Vx(t) and Vy(t).
16. Fit Vx(t) and Vy(t).
17. Print data.
18. Repeat for new mass and height.

Data

Masses

Trial 1: 50.0+/-0.05g
Trial 2: 70.0+/-0.05g
Trial 3: 100.0+/-0.05g
Trial 4: 150.0+/-0.05g

Heights

Trial 1: 46.0+/-0.05cm
Trial 2: 41.0+/-0.05cm
Trial 3: 47.0+/-0.05cm
Trial 4: 48.0+/-0.05cm

MotionLab Fits — Accelerating Phase

Trial 1:
x(t)=0.82t2
Vx(t)=1.6t

Trial 2:

x(t)=1.08t2
Vx(t)=2.1t

Trial 3:
x(t)=1.33t2
Vx(t)=2.66t

Trial 4:
x(t)=1.65t2
Vx(t)=3.3t

MotionLab Fits — Non-accelerating Phase

Trial 1:
x(t)=1.25t
Vx(t)=1.25

Trial 2:
x(t)=1.35t
Vx(t)=1.35

Trial 3:
x(t)=1.65t
Vx(t)=1.65

Trial 4:
x(t)=1.90t
Vx(t)=1.90

Analysis

The final velocities for the assorted trials can be directly extracted from the final velocity fit functions from the MotionLab data presented in the preceding section. These give us vf=1.25m/s for Trial 1, vf=1.35m/s for Trial 2, vf=1.65m/s for Trial 3, and vf=1.90m/s for Trial 4.

We have to compare these with the results of the theoretical prediction. These give us vf=1.24m/s for Trial 1, vf=1.34m/s for Trial 2, vf=1.64m/s for Trial 3, and vf=1.94m/s for Trial 4.

The analysis in this case is trivial. The measured final velocities differ by only insignificant amounts from the theoretical final velocities. We have not yet discussed a plethora of critical sources of error in this experiment. We have assumed that the cart and the pulley are frictionless. We have also assumed that the pulley and string are massless. The track may not have been perfectly straight or level. The camera lens produced a poor image near its edges. Then there was human error. The errors were not more than 0.04m/s for any of the trials.

Conclusion

We showed in the analysis section that the deviation between empirical measurements and theoretical calculations are no more than 0.04m/s for this scenario. We also saw that the errors were not statistically significant. This proves that the prediction in Equation 13 was the physically correct one. Our experiment was therefore successful, and the launcher mechanism can be built as planned.