Contents

This collection of Laboratory Exercises is the introductory physics laboratory manual used by Hunter College. The original exercises were developed by the Physics Faculty over thirty years ago. A number of revisions have since been made. In particular, major revisions led by Professors Robert A. Marino in 1994 and by Mark Hillery and Y.C. Chen in 2002, introduced several new exercises involving modern electronic and optical equipment and computerized data acquisition systems. We are indebted to the faculty and students who participated in the creation and revision of the manual over the years.

Physics Faculty
Hunter College
June,2002

How to Succeed in Physics Lab

Read the lab manual before coming to class to become familiar with the experiment. Lecture and Lab are NOT in perfect synch, so you may have to give the textbook a look also.

You should take responsibility to learn safe operating procedures from the lab instructor. The lab manual is also occasionally a good source of safety tips. With electrical circuits, no power is to be supplied unless OK'd by instructor or lab tech. *Report any accidents immediately!*

You will work with a lab partner to take data, but you are individually responsible for your own data. All subsequent calculations, graphs, etc. are also your own individual responsibility.
Original data MUST be in ink. If you change your mind, cross out with a single stroke, and enter new datum nearby.

Do not leave the lab room without obtaining the instructor's signature on your original data sheet. Without it, your lab report will not be accepted. No exceptions.

The lab has been designed to be a "low pressure" experience. We hope it is an enjoyable one as you take the time to become familiar with new equipment and experiences. Still, you should aim to complete all data-taking, all necessary calculations, reach all conclusions, and at least *sketch* all graphs before you leave. It's well known (to those who know it well) that once you walk out that door, all work on lab reports will take longer. Besides, most of the grade for the course will come from the lecture part, so spend your time accordingly.

Before taking good data, run through the experiment once or twice to see how it goes. It is often good technique to sketch data as you go along, whenever appropriate.

The Report:
Your Lab Report should be self-contained: It should still make sense to you when you pass it on to your grandchildren. It should include:

a) Front page: your original data sheet with your name, partners and date. The original data MUST be in ink. Report not acceptable if original data is in pencil or if data sheet was not signed by your instructor. (So... don't leave lab room without it.)

b) Additional pages with data and calculations in neat tabular form. If the original came out messy, you should rewrite your data before continuing with calculations.

c) Any graphs. Neatness counts! It's one of the aims of this lab to produce students that know how to produce a decent graph.

d) Answers to any Questions

e) An Appendix made up of the pages from the lab manual that describes the experiment. Including them relieves you from having to rewrite the essential points of the procedure, description of equipment, etc.

Lab reports are due the next time the lab meets. *At the beginning of the period!* It is department policy to penalize you for lateness in handing in lab reports. This is to discourage you from working on stale data with the lab experience no longer fresh in your mind. A schedule will be announced.

Laboratory Grade: The lab instructor will make up a grade 90% based on the average of your lab reports, and 10% on his/her personal evaluation of your performance in the laboratory. This grade is then reported to your lecturer for inclusion in the final course grade (15% weight factor). The list below will give you an idea of the criteria used by your lab instructor in grading your lab report:

1. Quality of measurements. Logical presentation of report contents.
2. Accuracy and correctness of calculations resulting from proper use of data and completion of calculations.
3. Orderly and logical presentation of data in tabular form, where appropriate.
4. Good-looking graphs, easiness to read, good choice of scales and labels.
5. Comparison with theory.
6. Answers to Questions; Conclusions.
7. Clarity, Neatness, Promptness.

TUTORIAL # 1

On Errors and Significant Figures

Errors

We could distinguish among three different kinds of "errors" in your lab measurements:

1. *Mistakes or blunders.* We all make these. But with any kind of luck, and some care, we catch them and then repeat the measurement so that these errors can be corrected.

2. *Systematic Errors*. These are due either to a faulty instrument (a meter stick that shrank or a clock that runs fast) or by an observer with a consistent bias in reading an instrument. These errors affect all of the measurements in the same way, i.e. they make them all too big or too small. For example, if our clock runs fast, all of our measurements of time intervals will be too long.

3. *Random Errors*. Small accidental errors present in every measurement we make at the limit of the instrument's precision. These errors will sometimes make a measurement too big and sometimes too small. To deal with these we repeat a measurement several times and take the average. The average gives the best estimate of the quantity we are trying to measure, and the spread of the values about the average gives us an estimate of the uncertainty.

After blunders are eliminated, the *precision* of a measurement can be improved by reducing random errors (by statistical means or by substituting a more precise instrument, i.e., one that yields more significant figures for the same measurement.) *Accuracy* can be increased by reducing any systematic errors as well as by increasing the precision.

Significant Figures, Error, Fractional Error

No measurement of a physical quantity can ever be made with infinite accuracy. As an honest experimentalist, you should relay to the reader just how good *you* think your measurement is. One simple way to relay this information is by the number of *significant figures* you quote. For example, 3.4 cm says one thing, 3.40 cm tells a different story. The last digit you write down can be your best estimate made between the markings of a scale, but it still represents a willfully reported number, it still is a *significant* figure.

The placement of the decimal point does not change the number of significant figures. For example, 20.8 grams and 0.00208 grams each have three significant figures; each is assumed to be uncertain by at least ±1 in the last figure, i.e., ±1 part in 208.

Normally, figuring out how many significant figures are in a stated number gives no problems, except when zeros are involved. For example, is it obvious how many significant figures are expressed in 5500 feet, 250 years, or $1,300,000 ? A good way to tell the reader which is, in fact, the last significant figure is by using *scientific notation*. For example, 5.50 x 10^3 feet, 2.5 x 10^2 years, and 1.300 Megabucks, telegraph that the number of digits in which any confidence can be placed was three, two, and four, respectively.

Another way of representing the error is to explicitly indicate it. Suppose that we measure a length, which we find to be 1.520 m, and we believe that this measurement is accurate to within a centimeter. We could then write the result of our measurement as 1.520±0.005 m, which means that our result is between 1.515 m and 1.525 m. In general, if we are measuring a quantity x, we can write the result of a measurement of x as $x_{best} \pm \Delta x$, where x_{best} is our best estimate of the quantity being measured, and Δx, which is a positive number, is the value of the uncertainty in our measurement. We can also use what is called the fractional error. This is just $\Delta x / | x_{best} |$. To get the percent error, we just multiply the fractional error by 100. In our example, we have that x_{best} =1.52 m, Δx =0.005 m, the fractional error is 0.0032 and the percent error is 0.32. Note that the fractional error and the percent error have no units.

Finding the uncertainty

We have been discussing representing the result of a measurement as $x_{best} \pm \Delta x$, but given a set of readings from an instrument, how do we find x_{best} and Δx? We find x_{best} by taking the average of the readings, so if we have made three measurements of a length, and have found the results 1.26 m, 1.28 m and 1.25 m, we have that x_{best} = (1.26 m + 1.28 m +1.25 m)/3 = 1.26 m. Finding Δx is a bit trickier. First, it cannot be any smaller than the precision of our measuring instrument. If we are using a meter stick to measure a length, and the smallest units marked on the meter stick are millimeters, then the uncertainty in our measurements will be approximately one millimeter (it can actually be a bit less than this, because we can estimate the length to a fraction of a millimeter – this would give us an uncertainty of about 0.3 mm). However, it might be bigger due to random errors. In order to do a detailed analysis of random errors, it is necessary to know a lot more about probability theory and statistics than you do now, so we will just give you the answer. Suppose you have made N measurements and the results are x_1, x_2, …x_N. You first calculate the average value of the measurements, x_{best}, and then you use it to find what is called the standard error, s, which is given by $s = [(x_1 - x_{best})^2+(x_2 - x_{best})^2+\ldots(x_N - x_{best})^2]^{1/2}/[N(N-1)]^{1/2}$. The uncertainty, Δx, will just be the sum of the uncertainty due to the measuring instrument and the standard error, s.

Computations using raw data

How do you combine your carefully gathered data with other numbers in an expression? With a little common sense, and a hand calculator, you can verify that the following rules should be followed:

Addition and Subtraction:

Suppose we want to add two measured lengths, 0.36±0.01 m and 0.48±0.02 m. Why would we want to do this? Each length might be the length of a block, and then the sum would correspond to the length of the object we get when we put the two blocks together. What can we say about the length of the combined blocks? Our best estimate of their combined length is just 0.36 m + 0.48 m = 0.84 m, but we have to worry about the uncertainties too. The longest the combined blocks can be is (0.36 m + 0.01 m)+(0.48 m + 0.02 m) = 0. 87 m, and the shortest they can be is (0.36 m - 0.01 m)+(0.48 m - 0.02 m) = 0. 81 m. We can then write the combined length as 0.84 ± 0.03 m.

This gives us the following rule. Suppose that q=x+y, and that x and y are measured quantities, which we represent as x_{best}±□x and y_{best}±□y. Then q_{best}= x_{best} + y_{best} and □q=□x+□y. The same rule holds for subtraction, if q = x-y, where x and y are measured quantities, then q_{best}= x_{best} - y_{best} and □q=□x+□y.

One conclusion that can be drawn from this is that when adding numbers with different numbers of significant figures, the number with the least number of significant figures determines the number of significant figures in the sum. For example, 3.1 m +1.11 m is 4.2 m, and not 4.21 m. Similarly, 1.11 x 10^3 m + 3.33 x 10^4 m is, unfortunately, just 3.44 x 10^4 m.

Note: To see this you have to write it out in ordinary notation (even better: line-up one under the other):

1,110 + 33,300 = 34,410 mathematically

but the *tens* position is not significant in one of the terms, so it cannot be significant in the final sum. The answer is 34,400, or 3.44 x 10^4.

Multiplication and Division:

Suppose we have measure the sides of a rectangle and we want to find its area. In particular, we found the length to be 0.240±0.002 m and the width to be 0.120±0.001 m. Our best estimate for the area is just A_{best}=(0.240 m)(0.120 m) = 0.0288 m^2, but what is the uncertainty? The biggest A can be is (0.242 m)(0.121 m)=.0293 m^2, and the least it can be is (0.238 m)(0.119 m) =0.0283 m^2, so □A=0.005 m^2. Can we use this example to come up with a rule? Let us look at the fractional errors. The fractional error for the length is (0.002 m)/(0.240 m)=0.0083, the fractional error for the width is (0.001 m)/(0.120 m)=0.0083, and the fractional error for the area is (0.005 m)/(0.0288 m)=0.172. Notice that the fractional error for the area is approximately the sum of the fractional errors of the length and the width, (0.0083+0.0083=0.0166). This is, in fact, a good general rule, when multiplying the results of two measurements, the fractional error for the product is approximately the sum of the fractional errors of the factors.

Let us see why this is true. Suppose that q=xy, where x and y are measured quantities, so x= $x_{best}\pm\Delta x$ and y=$y_{best}\pm\Delta y$. We can write q=$q_{best}\pm\Delta q$, where $q_{best}=x_{best}y_{best}$. This means that $q_{best}\pm\Delta q=(x_{best}\pm\Delta x)(y_{best}\pm\Delta y)\approx x_{best}\ y_{best}\pm\ (x_{best}\Delta y+y_{best}\Delta x)$, where we have assumed that is □x□y small compared to everything else. If we now divide both sides by $|q_{best}|$ and then subtract $q_{best}/|q_{best}|$ from both sides, we get that $(\Delta q/|q_{best}|) =(\Delta x/|x_{best}|)+(\Delta y/|y_{best}|)$. The same rule works if q=x/y, but we won't show the derivation explicitly. Summarizing, we have that the fractional error of a product of two measured quantities is just the sum of the fractional errors of the factors, and the fractional error of a quotient of two measured quantities is just the sum of the fractional error of the numerator and the fractional error of the denominator.

What does this mean in terms of significant figures? Roughly there are as many significant figures in your final answer (product or quotient) as there were in the *least precise* value you used. For example, 3.481 x 1.75 gets reported as 6.09, not 6.092.

Of course, you should only round off the *final* answer. If a number is used again in another computation, you should not round it off in between, or you may make a small but significant error.

TUTORIAL # 2

Making a Good Graph by Hand

Start thinking about a nice title. e.g., " The Square of the Period (T^2) of a Simple Pendulum vs. its Length (L)" [A shorter title would have been even better]

Keep your axes straight: If you need to plot "A vs B", or "A as a function of B", then A is on the vertical axis and B is on the horizontal axis.

vertical axis = y-axis = the "ordinate"
horizontal axis = x-axis = the "abscissa"

The crucial part is choosing the range and scale for each axis. Two examples:

a) 0 to 5 sec; 5 graph boxes =1 sec.
b) -300 to +200 degrees; 2 boxes =100 degrees

The range must be: just large enough to accommodate all your data, yet allow a *readable* scale.
The scale should be: spread out enough so your data take up most of the graph area, and *labeled so plotting (and reading) is easy.*

Label the x and y axis with the appropriate magnitudes. These should be round numbers which cover the entire range of values that you will be plotting. A common mistake is to label too many boxes. If you are trying to show that one quantity is proportional to another, or if you are not told otherwise, zero is part of the range and must be located at the Origin. The numbers should be evenly spaced with the same number of boxes between the same increase in numbers including the space from zero to the first non-zero number. Choose an appropriate number of boxes between numbers. It is better to have 5 boxes between numbers than 4 since it is easier to interpolate in the first case than in the second. (Similarly 10 is better than 8, and 2 is better than 3.)

Plot the results of your measurements on this graph. Where appropriate, you should include error bars to indicate the uncertainty in your measurements. These error bars *are not* of arbitrary size but should be of the size of your uncertainty on the scale dictated by the numbers on the axis of your graph.

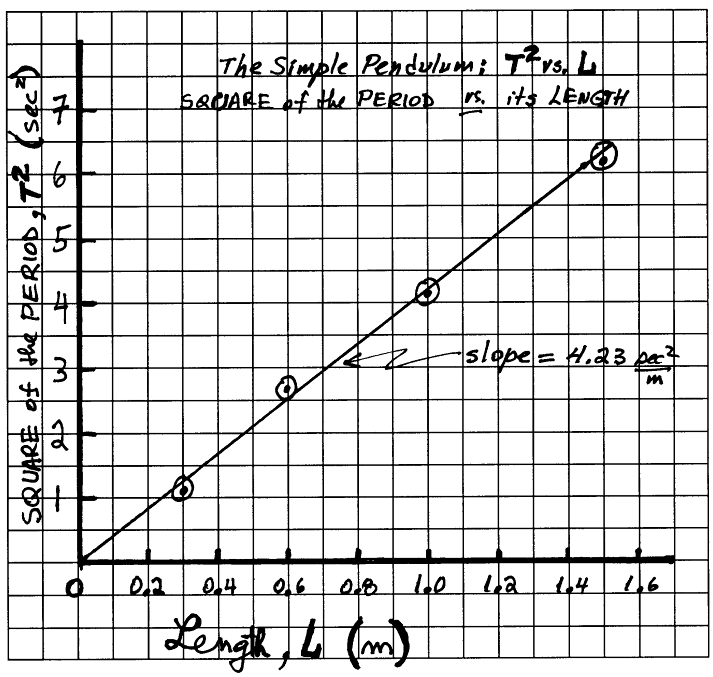
When you draw the line that best fits your data, the line should be a smooth one that need not go through any points. In general, there should be as many points on one side of the line as on the other. If you have done your work properly, the line should pass inside of the error bars for each point. (If it does not, that may be an indication that there is something wrong with the point in question. Perhaps you miss-recorded a measurement, or your estimate of the error was too small, or there was something wrong with the apparatus, or with the technique you applied, etc.) If your graph shows that one quantity is proportional to another, it should be a *straight line* that starts at the origin and passes through the plotted data with as many points on one side as the other.

If you are asked to find the *slope of the line*, choose two points *on the line* which are as *far apart as possible.* This will minimize the error that is introduced in reading the value of those points. The slope is the difference between the vertical values of those points divided by the difference in the horizontal values of those points.

A common mistake is to measure the slope of *the segment connecting two actual data points*: this does not yield the slope of the straight line you fitted to your data!

Note: Normally. the slope of your graphs has its own units. e.g., The slope of graph of velocity vs. time has units of (m/s)/(s) = m/s^2.

Here is a graph so messy, you can surely do better with a little practice:



Remember that:

Scientific experiments are done by trial and errors. Please be patient and resilient.
Please BE RESPECTFUL to the instructors, staff and your peers.
Please TAKE YOUR TIME to get familiar with all parts of the equipment.
Please be CAREFUL and GENTLE when handling the equipment.
Please DO NOT OVER TIGHTEN the screws.
Please RETURN the equipment to its original place after use.
Please TURN OFF the computers and the power supply of the equipment.
Please MAKE SURE your lab bench is CLEAN and TIDY before you leave (Each lab room is equipped with paper tower and garbage can).

LABORATORY EXERCISE #1

Density; Significant Figures

Objectives

To become familiar with instruments to measure length (meter stick, vernier caliper, micrometer) and to appreciate the difference between accuracy and precision of experimental measurements. Incidentally, to learn the concept of mass density, and practice proper use of significant figures.

Equipment and Supplies

Metal samples, electronic balance, meter sticks (long and short), vernier caliper, vernier model, micrometer calipers.

Discussion

The *mass density* of a body measures the amount of mass per unit volume of that body. *Definition:*

Density of a body = (body's mass)/(body's volume) or D = M / V

The density of a substance does not depend on the shape or the particular amount of that substance. For example, the density of a small gold ring and the density of a large gold brick should be the same number, i. e., the density of gold.

As part of your density calculations you will need to compute the *volume* of a regular solid from its linear dimensions. The quality of your volume measurements will thus depend on how precisely you can measure lengths. You will use three progressively more precise instruments: a wooden "meter stick", vernier calipers and a micrometer. Your instructor will demonstrate how to use each one. In each case, you should read the instrument to the smallest division plus one more digit by estimation. So, a meter stick with millimeter markings can be used to estimate a length to the nearest tenth of a millimeter, e.g., 12.4 mm, or 1.24 cm. This estimate by "eye" is often only good to ±2 or 3, as you can verify by repeating the measurement or asking your partner to do the estimating. A *vernier* is an invention that removes the uncertainty in reading to the nearest tenth between adjacent markings, thus increasing the *precision* of the final measurement. Your instructor will demonstrate how this is done with the vernier model, prominently displayed in the front of the laboratory room.

On Errors and Uncertainty in a measurement:

When you work out a *math* computation, the numbers are usually considered exact, e.g., 1.1 x 1.2 x 1.3 = 1.716. But when a number represents a *physical measurement,* it is **never** exact because of the limitations of the instrument used, or the way it was employed, etc. It is essential, therefore, that each experimental result be presented in a way that indicates its reliability. A very simple way to do this is by the use of *significant figures.* (See Tutorial #1, on Significant Figures)

As an example, consider how different the following three cases are, even though they refer to exactly the same steel block:

a) 1.1 cm x 1.2 cm x 1.3 cm = 1.7 cm^3

b) 1.13 cm x 1.20 cm x 1.29 cm = 1.75 cm^3

c) 1.127 cm x 1.195 cm x 1.293 cm = 1.741 cm^3

What is different about these three reports, is the *precision* with which the data was taken. (By the way, all three workers used significant figures correctly.)

Now, how *accurate* are the results? This concept reports on how close the reported answer is to the "accepted answer". What determines accuracy? Examples are the calibration of the measuring instruments or systematic errors on the part of whoever is taking the data. The following somewhat oversimplified table may be useful in thinking about these concepts:

Problem	Remedy
Mistakes and blunders	Repeat measurements several times to check on yourself
Systematic errors	Use calibrated instruments, use them properly
Random errors	Treat data statistically and report on the average magnitude of errors

Procedure

A. Estimating the number of kilograms of air contained in this room when it is empty.
Estimate the volume of the room by the following procedure. First measure the height, width and length ignoring protruding structural columns. Use the long meter sticks, and make full use of the geometric tiles on the floor (they are very nearly 12" x 12"). The resulting volume yields the mass of the air when multiplied by the density, 1.29 kg/m^3. Your answer here should reflect the number of significant figures of your raw data.

B. Finding the density of a metal block. First weigh the block carefully with the balance provided. Then, measure the dimensions of the block with three different instruments:

B1. Use of meter stick. Lay block on meter stick, measure the position of each edge, estimating to the nearest 0.1 mm. Take several readings on different parts of the specimen.

B2. Use of vernier calipers. Examine the calipers. What is the distance corresponding to the smallest markings on this instrument? How many significant figures can be obtained when measuring a length between 1 and 10 cm? Is the "zero" calibrated correctly, or do you need to correct for a misalignment? Take several readings on different parts of the specimen, estimating to 0.01 mm.

B3. Use of micrometer calipers. Examine this fine instrument, noting the proper use of the slip clutch to prevent forcing the gears. What is the distance between smallest markings on the shaft? Open the jaws to the 1-mm mark. Rotate the micrometer thimble through two revolutions: record the reading. Rotate by one revolution. Record the reading again. Careful consideration of your data should lead you to understand how the micrometer can be read correctly to 0.001 mm. When you are satisfied that you can use and read this instrument, obtain several readings of each of the three dimensions of the metal block. Note any misalignment of the "zero" and correct your data accordingly.

C. Repeat procedure B for a cylindrical metal block, time permitting.

Calculations and Conclusions

A. Complete and sign the statement in the Data Sheet.

B. For each of the three methods in part B, compute the density of the metal block to the appropriate number of significant figures.

1. Are the three results consistent with one another? What criteria did you use to answer the question?
2. For your best value of the density, compute the percent deviation from the accepted value (obtained from your instructor).

Note on the "propagation of errors":

The equation for the volume of a rectangular solid is $V = l\,w\,h$ Applying our rule for products, that means that the fractional error of the volume is just the sum of the fractional errors of the for the length, width and height. You can use this to find the uncertainty, ΔV, in the volume itself.

$$\frac{\Delta V}{V} = \sqrt{\frac{(\Delta l)^2}{l^2} + \frac{(\Delta w)^2}{w^2} + \frac{(\Delta h)^2}{h^2}}$$

*Just ONE significant figure is appropriate, here.

LABORATORY EXERCISE #1

Data Sheet: Density; Significant Figures

Date:________

Name:______________________________ Partners:_________________

Instructor's signature:____________________

A.

I have measured the volume of the air in this laboratory room and hereby report that using an assumed density of ____________ kg/m^3*, I find that the room contained _________ kg of air.* {How close you come to the "true" answer is how accurate your measurement was.} *I certify that, should another careful experimentalist attempt to make the same measurement, she (he) will come within** ± ________*%, approximately, of my value.* {Too high a number here, will show you to be a sloppy experimentalist, unable to squeeze the best from the tools available. Too low a number will expose you as a fraud, claiming a precision unwarranted by your instruments and methods of using them.}

____
(signed)

B. For each of the three methods in part B, compute the density of the metal block to the appropriate number of significant figures. Present data, calculations and answers below. Use additional sheets if necessary.

B1. Are the three results consistent with one another? What criteria did you use to answer the question?

B2. For your best value of the density, compute the percent deviation from the accepted value (obtained from your instructor).

Post-Lab Test : Density; Significant Figures

Name:__________________________

Complete the homework problems on this sheet and include with your Lab report.

Problem 1.

A block of wood has dimensions 10.20 cm by 10.15 cm by 2.45 cm. What is the volume of this block in units of cubic centimeters? (By all means, use your calculator.)

a) 253.6485
b) 253.65 Answer:__________________
c) 253.7
d) 254

Now, if the mass of the block is 175.2 g, find the density.
Density = _________________ g/cc

Assume that the accepted value is 0.665 g/cc. Determine the percent deviation of your result from the expected value. { cm^3 = cc}

Percent Deviation :____________________%

Note: Percent Deviation is the difference between your value and the accepted value times 100 then divided by the accepted value.
In this course we shall report percent deviations to at most two significant figures.

Problem 2.

A student measures the mass of 49.4 cc of water and finds the mass to be 50.2 g. Assume that the accepted value is 1.00 g/cc. Compute the density of the water and the percent deviation.

Computed Density = ___________________
Percent Deviation = ______________%
Remember to include the units with the density.

Note: If you did these problems correctly, your value of density should have agreed with the expected value to within four percent, in Problem 1. In Problem 2, on the other

Laboratory Exercise #2

Position and Velocity

With an Introduction to Graphical Analysis Software

Objectives: To understand the relation between position and velocity, and to understand how to represent each of them graphically; To familiarize with the tools used in mechanics experiments.

Equipment and supplies: Sensor cart (green), track with end stop, computer, Graphical Analysis software.

Computer and software

In this semester we will do a series of experiments to explore kinematics, dynamics, momentum, and energy using one or two sensor carts on a track. The data of motion will be collected by wireless sensors and analyzed by a computer. We will first learn how to connect the sensors to your computer.

A. How to connect the cart sensors to the computer.

1. Place the green sensor cart on the track. The arrow should points to the end stop. Disconnect the charging cable from the cart if it has not yet been disconnected.

2. Open **Graphical Analysis** program. When the window opens up,
   a. Click “Sensor Data Collection”.
   b. Select the sensor number that matches the number on your green cart. Then click “Done”. Two graphs, the Position graph and Velocity Graph, will appear on the screen.
   (If you do not see the correct sensor number, press the switch on the side of the cart to turn it on.)
   c. We will need only one plot only. To do this, click “View Options” at the upper right corner. Choose “One Graph”.
   d. Set duration of data collection
   Click “Mode” on the lower left corner to open the Time Based window. Under “End Collection”, type in 15 seconds. Then click “Done”. This will set the total time for data collection to 15 seconds.
   e. Zeroing the position axis
   Move the cart to the starting point at the opposite end of the track from the end stop. Click “Position” on the right lower corner and click zero. This will make current position on the track to be position zero.

B. Plotting Position-Time Graph with hands.

1. Starting at the far end of the track from the end stop use your hand to move the cart slowly and steadily toward the end stop. Practice this motion and try to complete the motion through the track in approximately 15 seconds. Sketch the position-time graph (1) for this motion in the report sheet and label the axes with appropriate scales and units.

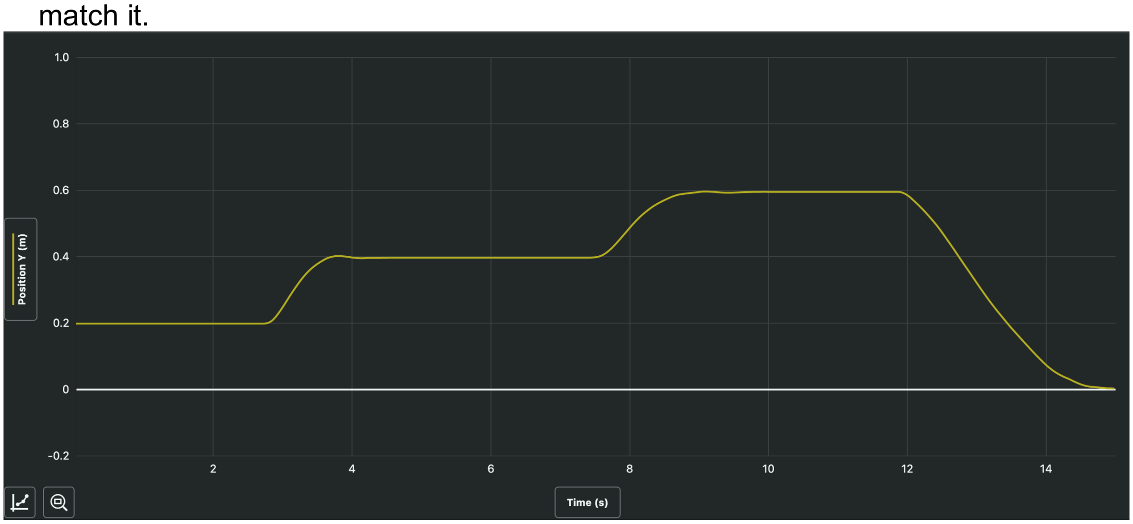
2. Repeat, but this time move a little faster to complete this motion in 5 seconds. Sketch graph (2).
3. Make a position-time graph by moving the cart from the end stop toward the other end slowly and steadily and complete the travel in 15 seconds. Sketch graph (3).
4. Repeat Step 3, but this time complete the motion in 5 seconds. Sketch the graph (4) in the report sheet.

Note: When you sketch these graphs, it is not crucial to include all the fine details. However, be sure to label and number the axes as they appear on the screen, and provide a title (e.g. Position vs. Time.).

5. Sketch your prediction of the position-time graph on graph (5) produced by the following: Starting from the left end of the track, move slowly and steadily to the end stop for 5 seconds, stop for 5 seconds, then move more quickly and steadily toward the left for 3 seconds.
6. Now test your prediction with the data collected by the computer. Click "COLLECT" and carry out the motion sequence in Step 5. You may repeat this procedure. When you are satisfied with the outcome, take a screenshot with your mobile phone.

(Does your result match your prediction in Step 5? If not, make the necessary adjustments to your prediction and/or your motion until the graphs agree).

7. Now let us see if we can do the reverse, given the following graph we want to move to match it.



Move the cart in such a way to make your data look as much like the above plot as possible. Take a screenshot for the best graph you can produce.

C Velocity-Time Graphs

We will examine how velocity varies with time for different types of motion. We can do this by generating velocity-time graphs.

We will repeat Steps in B 1 - 4, but this time make corresponding velocity-time graphs (a) to (d) in the report sheets.

D Position and Velocity Graphs

We now want to study the relation between position and velocity. We will measure the position and velocity of a moving cart simultaneously. This will give us better data.

1. **Open two graphs**
   Click " View Option" on the upper right corner. Select "Two Graphs".
   You should see two sets of plots on the screen, a position-time graph and a velocity-time graph.
2. Practice the following moves: Place the cart at the opposite end of the track from the end stop. Gently push the cart to set the cart n motion and stop the cart before it hits the end stop. **Avoid using too much force which can cause damages to the cart.** Exert appropriate force to let the cart travel the entire length of the track in about 3 seconds.
3. When you are comfortable with the execution, click "COLLECT" and than push the cart and observe the distance and velocity data being plotted on the screen.
4. Click the magnifying glass on the lower left corner of each plot to enable auto-scaling to make the curves filling the graph. Take a screenshot.
5. Reading data from the graphs
   a. The readings of position and velocity at a given time can be read by moving the cursor along the time axis.
   b. Click "Graphic Options" at the lower left corner of the Position-Time graph. Enable "Tangent". The graph will display the reading of the slope of the curve. Record the positions and slopes at five different points along the time axis.
   c. To find the average value of velocity between time t_1 and t_2, highlight the segment of data between t_1 and t_2, click "Graphic Options" and select "View Statistics". The mean value of velocity will be displayed in a pop-up window. Compare to the average value of the slope in the position-time graph in mean value of velocity.

6. **Comparing manual and automated measurements**
   Next we compare the velocity on the graph with the velocity obtained the old fashion way using a ruler and a stopwatch. We will first determine the velocity by measuring the time it takes for the cart to travel through a distance.

   a. Turn on the stopwatch function in your mobile phone. Set the cart in motion from the opposite end of the track toward the end stop and measure the time duration for the cart to travel between the two red marks on the track. Practice this operation several times until you feel comfortable with your execution. When you are ready, zero the initial position, set the cart in motion and measure the time of travel using your stopwatch, while your partner simultaneously clicks "COLLECT" to start data collection. Record the stopwatch reading Δt and the positions x_1 and x_2 of the red marks. Calculate the average velocity ($\bar{v} = \frac{\Delta x}{\Delta t}$) between the two red marks .

b. Next find the average velocity from the graph. This can be done by recording, from the position graph, time t_1 and t_2 when the cart passes the red marks on the track and find the average velocity during this period from the Velocity graph using View Statistics Function. Compare the velocity measured manually in (a) with the average velocity reading from the graph. Present a screenshot of the graph using a mobile phone.

E. Verifying the equation $x_2 = x_1 + v(t_2 - t_1)$

7. Suppose we want to find position information from a velocity graph. If an object is moving with a constant velocity, then the distance it travels between two times, t_1 and t_2, is just the velocity measured at t_1 multiplied by (t_2-t_1). We can see if our graphs confirm this.

   Set the cart in motion and start collecting data. Zoom in all graphs. Take screenshot.

   Choose two times in the region where the velocity is nearly constant, which we shall call t_1 and t_2, and find the positions corresponding to them using the position-time graph. Let us call these positions x_1 and x_2. Read the velocity at t_1. Calculate x_2.

   Compare the calculated x_2 with the measured value.

8. Repeat Step 7 for 2 more pairs of t_1 and t_2.

At the end of this experiment, re-connect the charging cable to the cart and place the cart on the track.

Laboratory Exercise #2

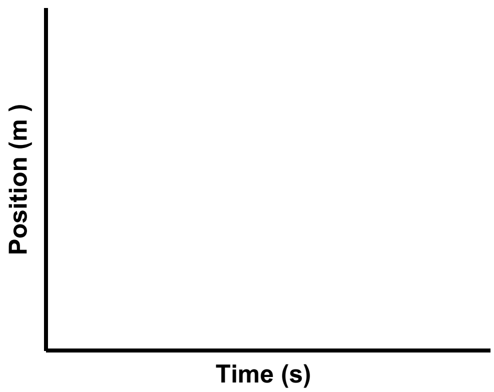
Position and Velocity

Date ______________

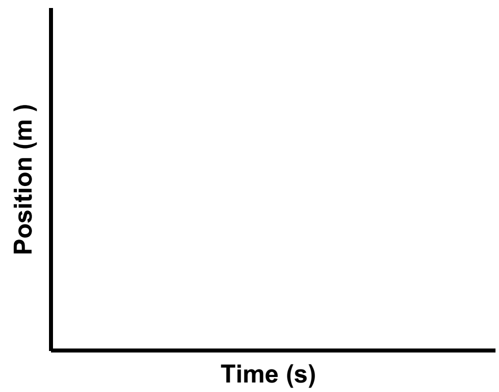
NAME:______________________________Partners:________________________

Position-Time Graphs

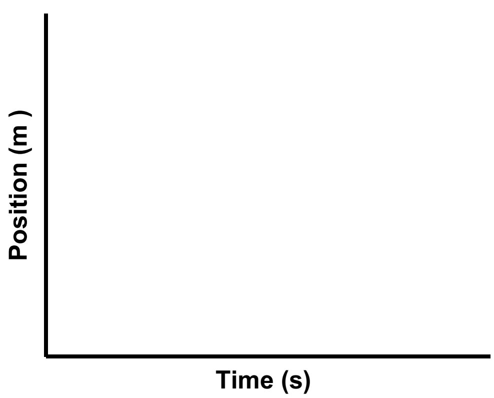
(1) Slow and steady motion to the end stop



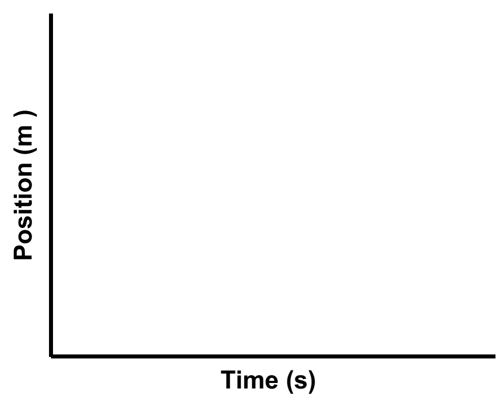
(2) Faster and steady motion to the end stop



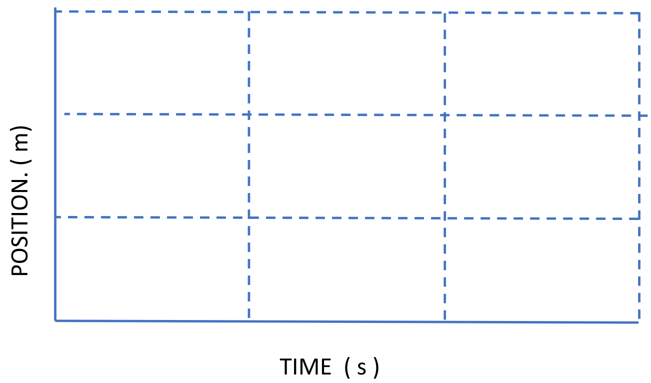
(3) Slow and steady moving away from end stop



(4) Faster and steady moving away from end stop



(5) Prediction

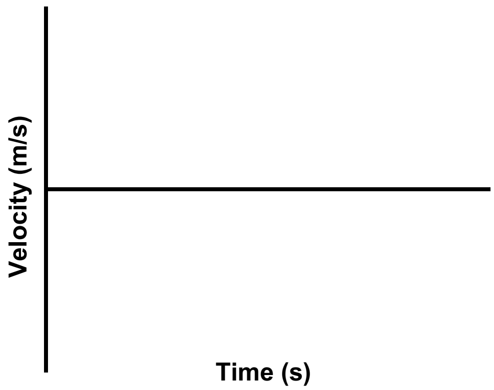


(6) Screenshot of position- time graph which corresponds to the prediction in (5).

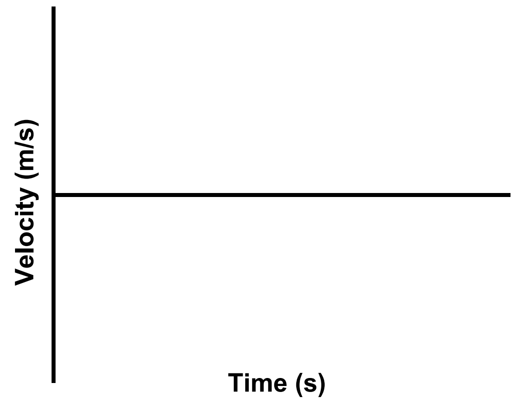
(7) Paste the screenshot that reproduces the Position-Time graph shown in Section 7.

Velocity-Time Graphs

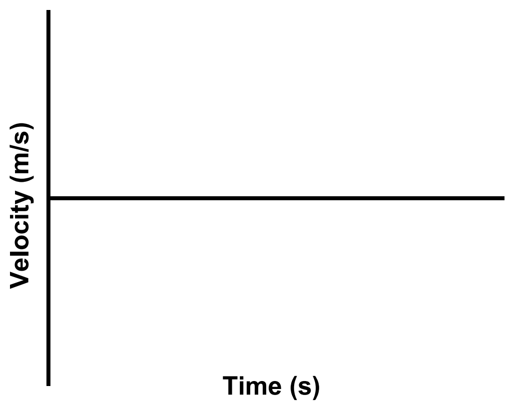
(a) Slow and steady moving toward end stop



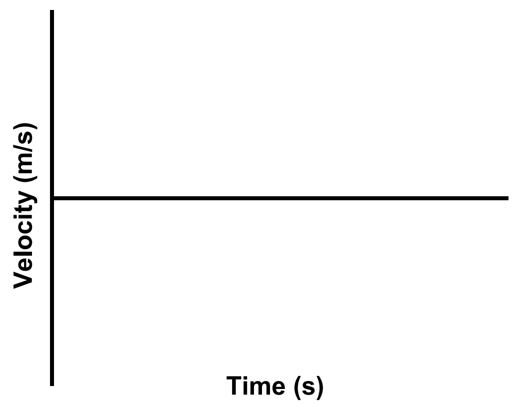
(b) Faster and steady moving toward end stop



(c) Slow and steady moving away from end stop



(d) Faster and steady moving away from end stop



D Position and Velocity Graphs

Provide a screenshot for position and velocity graphs obtained in D.

Data from the position-time graph:

Record five points (with units) from the position-time graph, calculate the average value.

Position, *x*	Time, *t*	$Velocity = \frac{\Delta x}{\Delta t}$ (slope)

Average velocity =

Comparing the average velocity with the average velocity reading from the View Statistics function.

D 6
Campare manual and automated measureents
Positions of red marks

X_1=___________________. X_2=__________________________

Stopwatch reading:____________________________________

Average Velocity=_____________________________________

Provide a screenshot of the position- and velosity-graphs.

Deduce the average velocity from the graph and compare with the average velocity obtained manually.

Verifying the equation $x_2 = x_1 + \bar{v}\,(t_2 - t_1)$

Paste the screenshot to be used for the analysis.

Use the position, x_1, corresponding velocity, v, at a given time, t_1, to predict the position x_2 at time t_2 using the equation $x_2 = x_1 + v(t_2 - t_1)$. Find the x_2 values for three different t_2.

Compare the predicted x_2 with the readings from the position-time graph. If the predicted values do not match the experimental values, explain why.

LABORATORY EXERCISE #3

Acceleration

Objectives:

To study the relation between position, velocity, and acceleration when the acceleration is constant.

Equipment:

Sensor cart, track with end stop, 10-g, 20-g cylindrical masses, pulley, strings.

Introduction:

Velocity tells us how position changes with time, and acceleration tells us how velocity changes with time. If an object, like a cart, has a constant acceleration, then we can find what the acceleration is by calculating $\Delta v/\Delta t$, where the velocity of the object changes by an amount Δv in a time interval Δt. The relation between acceleration and position is more complicated. In particular, the position of an object with constant acceleration depends not only on the acceleration, *a*, but on the initial velocity, v_0 and initial position, x_0, of the object as well. The exact relation is $x(t) = \frac{1}{2}at^2 + v_0t + x_0$.

A. Velocity and Acceleration

Our first task is to understand the relation between velocity and acceleration. We will again use the cart on a track, but this time there will be weight attached to the cart to make it accelerate. First we will look at the velocity and acceleration of the cart when it is speeding up, and then we will look at them when the cart is slowing down.

1. Set up the cart on the track with the pulley attached to the end of the track. The 20-gram weight is then attached to the cart through a string which is laid over the pulley.

2. Open Graphical Analysis software. Connect the sensor to the computer. You should see two graphs on the screen. Change the vertical labels to velocity-time graph, acceleration-time graph.

3. What you are going to do is to move the cart to the far end of the track with the weight lifted to the height of the pulley, zero the position, click Collect and release the cart. The position sensor will collect data while the cart is moving. Before you do this, sketch in graphs (1) and (2) a picture of what you think the velocity-time graph and acceleration-time graphs will look like (hint: the weight gives the cart a constant acceleration). Now do it and see how the actual graph and your prediction compare. When you do the experiment, hold on to the cart until you are ready to take the data, and then release it (do not give it a push). Catch the cart before it hits the pulley.

4. Read off four pairs of points from the velocity-time graph. Calculate $(\Delta v/\Delta t) = (v_2 - v_2)/(t_2 - t_2)$ for each pair, and find their average value. Now use the

View Statistics feature to read average acceleration and compare to the computed average values in the corresponding time range.

5 Deceleration (negative acceleration)

a. Now we want to try something a bit different. You are now going to start the cart with the **10g** weight laying over the pulley and hanging in the air, give the cart a gentle push away from the pulley. (Push too hard can result in the weight hitting the pulley and make the analyze difficult.) The cart will move away from the pulley, decelerate, turn around and come back. Before you do this, sketch a prediction for the velocity-time and acceleration-time plots in graphs (3) and (4). Pay particular attention to what you think is going to happen to the velocity and the acceleration at the turning point.

b. Before taking the data, we need to re-defined the positive direction because the initial velocity of the cart is in the opposite direction of the arrow. Click Position on the lower right corner of screen, enable Reverse.
Then Click Collect. Repeat this procedure if necessary until the velocity-time graph has at least two seconds of straight line. Click the magnifier to zoom in. Take a screenshot.

B. Position, Velocity and Acceleration

We now want to understand how position is related to acceleration and velocity when there is a constant acceleration.
1. Click View Options to choose 3 Graphs. Change the vertical labels to display Position-, Velocity, and Acceleration graphs. From class we know that the velocity will be a linear function of time, $x(t) = At + B$, and the position should be a quadratic function of time, $x(t) = At^2 + Bt + C$. We want to figure out what those functions are for the data in our last run. The coefficients that appear in those functions are related to the acceleration, initial velocity (at t=0) and the initial position (at t=0).

2. Choose a segment in the velocity-time graph, which should look something like a straight line, Apply Curve Fit (under Graph Options). What physical quantities do A and B represent? Is either one related to your acceleration graph? If so, compare the value you found for A or B to the relevant value on the acceleration graph.

3. Now go to the position-time graph. We want to find an equation for this curve, which should be something like a parabola. This means we should have, $x(t) = At^2 + Bt + C$. We want to find the coefficients A, B, and C. We can do this by using the Quadratic Fit under View Statistics Leave the fitting curves on the screen and take a screenshot.
Read off the values of A, B, and C. What physical quantities do A, B, and C represent? Are any of them related to either your acceleration graph or to your velocity-time graph? If so, compare the values you found here to the values you found from your acceleration and velocity-time graphs.

LABORATORY EXERCISE #3

Acceleration

Date ______________

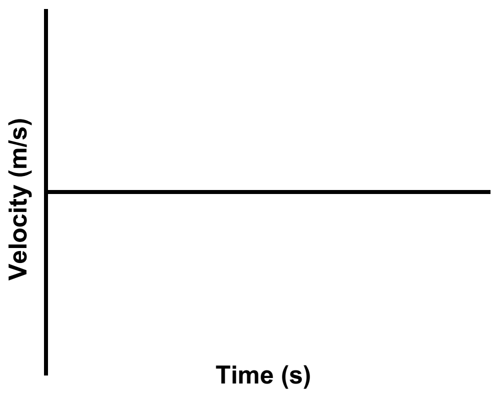
NAME:______________________________Partners:________________________

Instructor's Signature:____________________

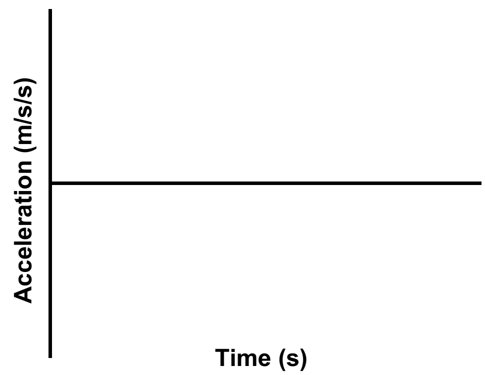
Velocity and acceleration

Predict the velocity-time and acceleration-time relations when the cart is pulled by the weight.

(1)



(2)



Paste the screenshot for the velocity and acceleration graphs for empty cart.

Read off four pairs of points from the velocity-time graph. Calculate $\frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_{1t}}$ for each pair,

Velocity , v	Time, t	Slope $a = \frac{\Delta v}{\Delta t}$

Average value=

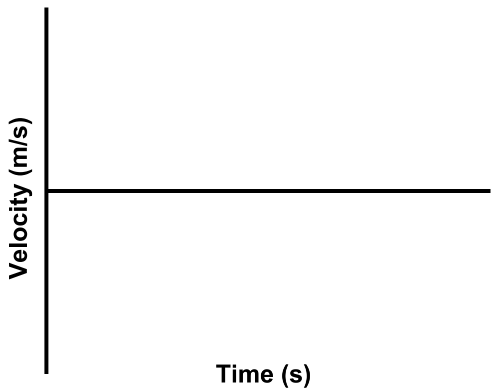
Average of four acceleration values from the acceleration-time graph =

How does the values of average acceleration from the acceleration-time graph compare to the average values of $(\Delta v/\Delta t)$?

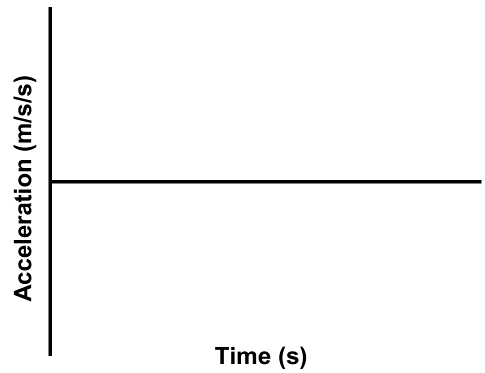
A 5

Sketch predicted velocity-time and acceleration-time graphs for the procedures outlined in step (5).

(3)



(4)



Paste the screenshot obtained in 5 b with the cart pulled by 10g over the pulley. Compare the measured with the predicted graphs. Use your own words to explain why the graphs make sense.

Use Apply Curve Fit over a linear segment in the velocity-time curve with the equation $v=At+B$ and find *A* and *B*.

What physical quantities do A and B represent? Is either one related to your acceleration graph? If so, compare the value you found for A or B to the relevant value on the acceleration graph. What are the physical meanings of A and B.

B. Paste the 3 graphs screenshot here.

Fit the position-time curve with $x(t) = At^2 + Bt + C$ and read off the values of A, B, and C. What physical quantities do A, B, and C represent? Are any of them related to either your acceleration graph or to your velocity-time graph? If so, compare the values you found here to the values you found from your acceleration and velocity-time graphs.

LABORATORY EXERCISE #4

Vectors

Objectives:

To learn adding vectors by their components and to compare the calculation with an experiment.

Equipment and Supplies

Force table, three low-friction pulleys, mass hangers, mass set.

Discussion

Consider a vector ***A*** that lies in a plane. It can be expressed as the sum of two components. The components are usually chosen to be along two perpendicular directions. An example is shown in Figure 1. The vector ***A*** can be resolved in to its *x*- and *y*-components by drawing two lines perpendicular to the *x*- and *y*-axes. Then A_x and A_y are the *x* and *y* components of ***A***, respectively. From Figure 1, $A_x = A\cos\theta$ and $A_y = A\sin\theta$.

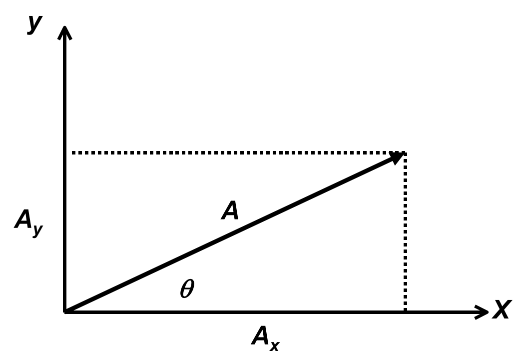


Figure 1

Consider then the addition of two vectors *A* and *B* to give a resultant vector *C*, as shown in Figure 2.

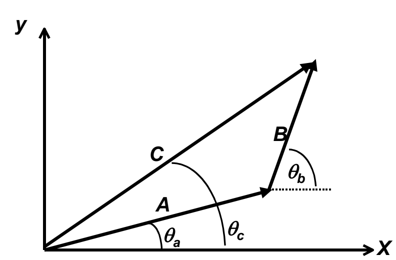


Figure 2

$$\boldsymbol{C}=\boldsymbol{A}+\boldsymbol{B} \quad (1)$$

The *x* and *y* components of these three vectors satisfy the following relations:

$$C_x = A_x + B_x \quad (2)$$

$$C_y = A_y + B_y \quad (3)$$

where

$$A_x=A\cos\theta_a \quad (4)$$

$$A_y = A\sin\theta_a \quad (5)$$

$$B_x=B\cos\theta_b \quad (6)$$

$$B_y = B\sin\theta_b \quad (7)$$

The magnitude and angle of *C* can be determined by:

$$C=(C_x^2+ C_y^2)^{1/2} \quad (8)$$

$$\theta_c= \tan^{-1}(C_y / C_x) \quad (9)$$

In the present experiment, the methods of vector addition is used to study the condition of equilibrium for three forces on a force table. These forces are created by the weights attached to the mass hangers. The diagram of the vectors involved is illustrated shown in Figure 3.

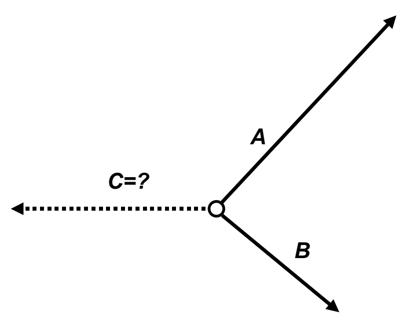


Figure 3

When the sum of three is zero, the knot is at the origin. We have

$$\boldsymbol{A}+\boldsymbol{B}+\boldsymbol{C} = 0 \quad (10)$$

Forces ***A*** and ***B*** are created by the weights of two known masses. To determine the unknown force ***C***, we can rewrite Equation (10) in the following form:

$$\boldsymbol{C} = -(\boldsymbol{A}+\boldsymbol{B}) = (-\boldsymbol{A}) + (-\boldsymbol{B}) \qquad (11)$$

Then the method described above can be directly applied to determine ***C***.

Procedure

A Set up the force table on a level plane. Attached three pulleys on the rim of the round table.

B. Hang the following masses on two of the pulleys and clamp the pulleys at the given angles:

Force ***A*** : 20 g at 0°
Force ***B*** : 10 g at 270°

Place the third pulley (Force ***C***) at 150° with 20 g on the hanger. Add masses to this hanger until the knot is centered at the origin. Due to a small friction in the pulley, you may help the gently tap the strings to help initiate the motion.

To correctly calculate the forces, the mass of the hanger (5 g) must also be included in each force. The force in Newtons equals the mass multiplied by 9.8 m/s^2.

C. Place two pulleys at 0° with 200 g on the hanger and 210° with 250 g on the hanger.

By trial and error, find the angle for the third pulley and the mass, which must be suspended from it that will balance the forces. Again, tapping the strings to help

Record the angle and mass.

Calculations and Conclusions

1. Calculate the magnitudes and the angles of the unknown vectors for the experimental conditions of **A** to **C**.
2. Tabulate the calculated and measured results.

LABORATORY EXERCISE #4

Data Sheet: Vector Analysis

Date:____________

NAME:_____________________________Partners:_______________________

Instructor's signature:___________________

Procedure B

Force **A**		Force **B**		Force **C** Experimental		Force **C** Calculated	
A	θ_a	*B*	θ_b	*C*	θ_c	*C*	θ_c
Kg		Kg		Kg		Kg	
N		N		N		N	

Newton = 9.8 Kg x m/s^2.
Don't forget to include the mass of the hangers into the calculation.

Show the calculation of Force ***C*** using the space below.

Procedure C

Force ***A***		Force ***B***		Force ***C*** Experimental		Force ***C*** Calculated	
A	θ_a	*B*	θ_b	*C*	θ_c	*C*	θ_c
Kg		Kg		Kg		Kg	
N		N		N		N	

Show the calculation of Force ***C*** using the space below.

Tension Force and Motion

Objectives:

To understand the relation between the total force acting on an object and its acceleration.

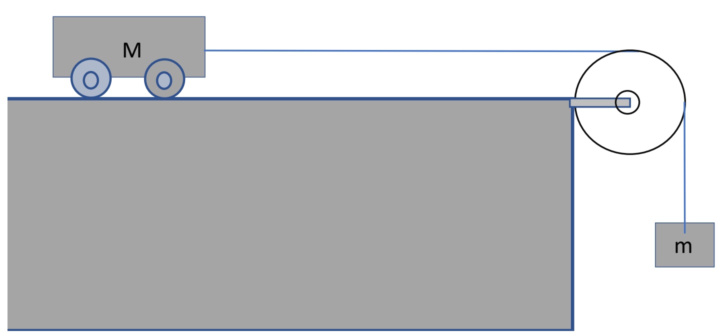
Equipment:

Sensor cart (green) with hook, track, end stop, 20 g and 50 g cylindrical masses with hooks, string, pulley wheel, and electronic balance.
Setup: Pulley at one end of track, end stop on the other end, hook on cart.

Introduction

According to Newton's Second Law, the acceleration of an object is proportional to the total force acting on the it. In this experiment you will look at a situation in which the force is a tension force. A cart on a track will have a string attached to it, and the string will go over a pulley wheel and have a weight hanging from it. You will study the acceleration of the cart as a function of how much mass is hanging from the string. You have to be careful, though, because if the mass hanging from the string is *m*, then the tension in the string is not *mg* once the cart starts to accelerate. Before you come to this lab, you should work out the following problem:

A cart of mass *M* moves on a frictionless track. It is attached to a string, which goes over a pulley wheel, and has a mass *m* hanging from it. At *t=0* s the cart starts from rest and accelerates. What is the tension in the string when the cart is held stationary? What is the tension in the string when the cart is released and accelerate toward the pulley? What is the acceleration of the cart? Express the tension and acceleration using *m*, *M* and *g*.



Procedure:

1. Open Graphical Analysis program. Select "Sensor Data Collection". Select the cart number to Connect. Under "Sensor Channels", enable "Force" and "X-axis acceleration"

and disable other items. Then click “Done. You will see two graphs: Force- and Acceleration-Time graphs.

3. Force sensor calibration
Place the cart on the track with the arrow pointing toward the pulley. To improve accuracy, the force sensor needs to be calibrated.

a. Click “Force” at the lower right corner. Select “Calibration”.

b. Hold the cart, and attach the string to the hook on the force probe. Run the string over the pulley wheel and hang a 20 g mass from it. Type 0.196 N. then click “KEEP”.

c. Hang the 50 g mass on the string and type 0.49 N and click “KEEP”. Then click “APPLY”. The sensor is now calibrated.

4. To verify the calibration, hold the cart and hang the 20 g mass on the string. Click “Collect”. You will see the force reading on the graph to be 0.196 N.

5. Hold the cart with the 20 g mass on the string, click “Collect”, and wait for three seconds before releasing the cart. Catch the cart before it strikes the end stop. You will see the value of the force, which is the tension force in the string, changes when the cart is released. Use the **View Statistics** feature from the **Graph Options** at lower left of each graph to find the average value of the tension both before and after you release the cart. In addition, use **View Statistics** to find the average value of the acceleration after the cart is released. Do this run three times and compute the average value of your results for the tension force and the average value of your results for the acceleration.

Take a screenshot of a representative screen.

6. Repeat steps 5, but with 50 g and then with 70 g (=20 g+50 g) hanging from the string. Find the average values of the tension force and the acceleration for each case.

7.Use the electronic balance to find the combined mass of the cart.

Plot (by hand) your force and acceleration data. On the x axis plot the acceleration and on the y axis plot the tension force. You will have three points, one each for hanging masses of 20 g, 50 g, and 70 g. Fit the best straight line you can to your data, and find its slope. To what quantity should the slope correspond (assuming Newton’s Second Law is correct), and can you compare it to any other quantity you have measured? If you can, do so. Does your data support Newton’s Second Law?

8. If you have done the problem at the beginning of the lab, you should have a formula that gives you the tension force in terms of the combined mass of the cart and force probe and the hanging mass. Make a table comparing the calculated values for the tension and the measured values.

LABORATORY EXERCISE #5

Tension Force and Motion

Date ______________

NAME:______________________________Partners:________________________

Instructor's Signature:____________________

Paste a screenshot of force and acceleration graphs for cart pulsed by 20 g of mass over a pulley.

Tension before release=__________________

Tension after release=+__________________

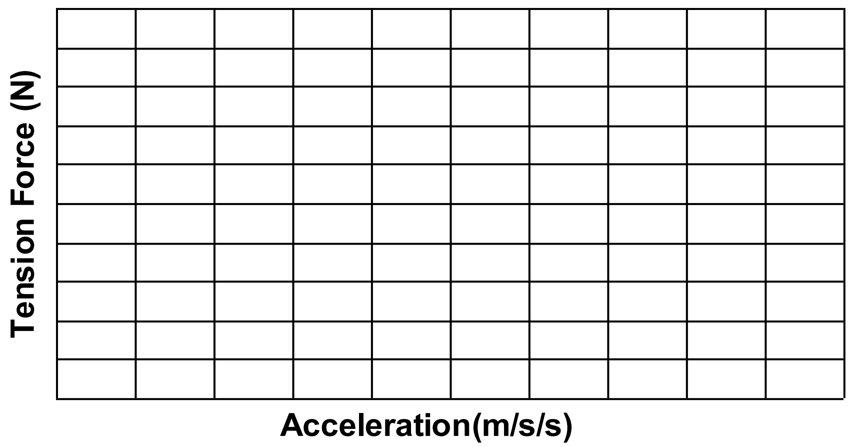
Acceleration=__________________________

Record of measured tension and acceleration data of cart pulled by three different masses over the pulley

	Tension Before Release	Tension After Release	Acceleration After Release
20g			
	Ave:	**Ave:**	**Ave:**
50g			
	Ave:	**Ave:**	**Ave:**
70g			
	Ave:	**Ave:**	**Ave:**

The mass of the cart =____________________

Plot measured tension force vs acceleration. Choose suitable scales and units and mark the axes clearly.



Fit the best straight line you can to your data, and find its slope.

Slope=_____________________

To what quantity should the slope correspond (assuming Newton's Second Law is correct), and can you compare it to any other quantity you have measured? If you can, do so. Does your data support Newton's Second Law?

If you have done the problem at the beginning of the lab, you should have a formula that gives you the tension force in terms of the combined mass of the cart and force probe and the hanging mass. What is the formula? You will be asked to show and explain how you arrived at the formula.

Compare the calculated values for the tension according the formula and the measured values.

	Calculated Tension	**Measured Tension**
20 g + m_{cart} =		
50 g + m_{cart} =		
70 g + m_{cart} =		

LABORATORY EXERCISE #6

Conservation of Energy
and the value of *g*

Objectives: To study when mechanical energy is conserved and when it is not

Equipment: Sensor cart track, friction block, electronic balance, meter stick

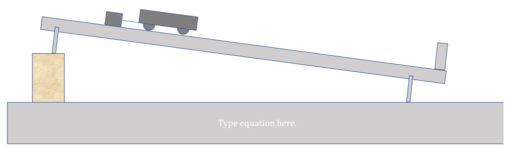


Figure 1 Experimental setup

Introduction

In this experiment we are going to consider two kinds of energy, kinetic energy and gravitational potential energy, and their sum, which is the total mechanical energy. We are going to apply these concepts to a cart moving down an inclined track. The cart will start from rest, and then accelerate down the track. As it does, it speeds up, and its height above the table decreases. This means that its kinetic energy increases and its potential energy decreases. We want to see if these changes compensate each other so that their sum stays the same. The second part of the experiment is the same as the first, except that a friction block will be attached to the cart. We will again want to see if the mechanical energy is constant.

From class you should remember that if an object of mass m is moving with a velocity v, then its kinetic energy is given by $\frac{1}{2}mv^2$. An object of mass m, which is a height *h* above the origin, has a gravitational potential energy given by mgh, where g=9.80 m/s^2. If there is no other source of potential energy around (like a spring, for instance), then the total mechanical energy of the mass is just the sum of the two,

$$E = \frac{1}{2}mv^2 + mgh$$

If there is no friction present, this quantity will be conserved. If there is friction present, the mechanical energy will decrease, and we will have that

(work done by friction)=(final mechanical energy)-(initial mechanical energy)

.

The work done by the friction force, F_f, is just $-F_f x$, where *x* is the distance the object moved. Because the work done by the friction force is negative, the above equation implies that the final mechanical energy is less than the initial mechanical energy.

Procedure

Conservation of Energy

1. Slip the spacer block under the leveling feet as shown in Figure 2. Measure the distance between the leveling feet, *L*, the elevation of the higher end, *H*, and the mass of the cart, *M*. Calculate the angle θ.

   Place the cart on the track. The arrow should points to uphill.

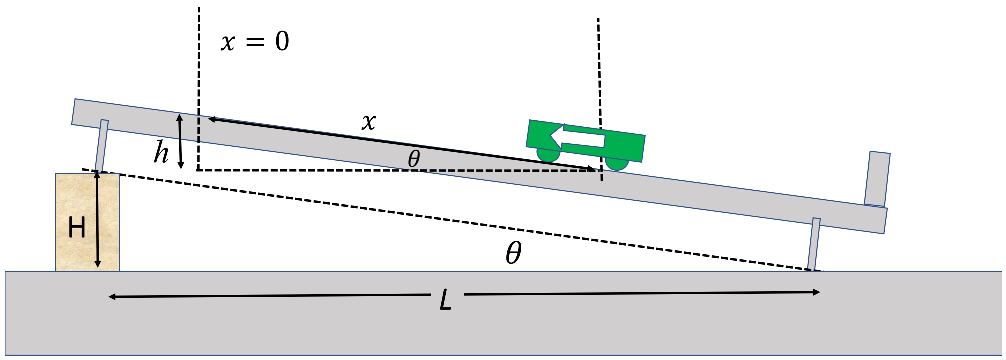


Figure 2

2. Open Graphical Analysis software. Connect the sensor to the computer. You shall see two graphs: position-time and velocity-time graphs.

   Click Position at the low right corner. Choose Reverse to make downhill direction positive.

3. You will be asked to hold the cart all the way up the ramp and then let it go. Before doing that, sketch your predictions for the kinetic energy versus time plot, the potential energy versus time plot, and the total mechanical energy versus time plot.

4. Now while holding the cart all the way up the ramp, click Position at the lower right corner of the screen to Zero the position, click Collect and let the cart go. Catch the cart before it hits the end stop.

5. Use the magnifiers to zoom in. Take a screenshot.

6. Record the position and velocity readings at five different times. Also record the acceleration readings from the Velocity graph using Tangent under Graph Options.

7. Calculate the potential energy and kinetic energy and total energy and plot the energies as a function of time. In the calculation for potential energy, *g* is assumed to be 9.8

m/s/s.

Compare the predicted and measured graphs and comments on any discrepancies.

Measuring *g*

8. So far, we assume that the value of g is the accepted value of 9.8 m/s/s. From the vector diagram shown in Figure 3, the acceleration of cart is the component of g along the direction of the ramp. Thus the acceleration measured in Step 6 can lead to the value of g using the relation:

$$g = \frac{a}{sin\theta}$$

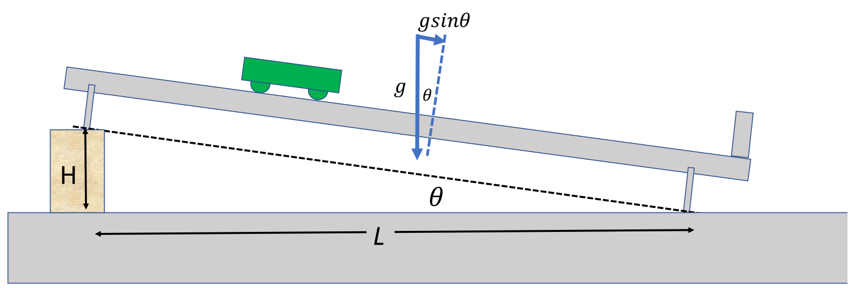


Figure 3

How does the value of g obtained this way compared to the accepted value?

Friction

9. Now attach the friction block to the cart as shown in Figure 1.

10. Lightly press the friction block to stop the cart from sliding down hill.

    What is the friction when the cart is not moving?

11. You will be again asked to hold the cart all the way up the ramp and then let it go. Sketch your predictions for the kinetic energy versus time plot, the potential energy versus time plot, and the total mechanical energy versus time plot.

12. Now while holding the friction block, zero the position of the cart, click Collect, and let the cart go. Use the magnifiers to zoom in. Take a screenshot.

    Record the position and velocity readings at five different times and calculate the potential energy and kinetic energy and total energy and plot the energies as a function of time.

Use the fact that the change in the mechanical energy is equal to the work done by friction to find the value of the friction force acting on the cart. This force is due to the friction block. Use the electronic balance to find the mass of the friction block, and then find the coefficient of dynamic friction between the friction block and the track.

LABORATORY EXERCISE #6

Conservation of Energy

Date ______________

NAME:______________________________Partners:________________________

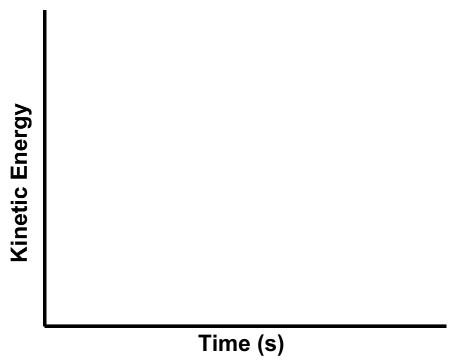
Instructor's Signature:____________________

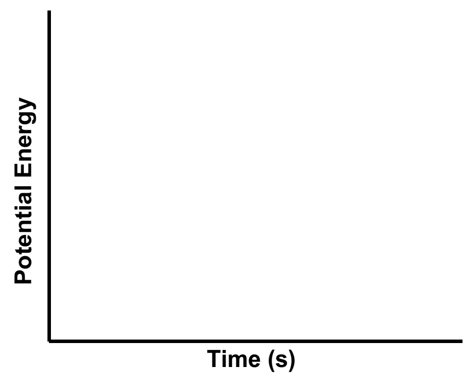
Distance between the leveling feet =_________________________

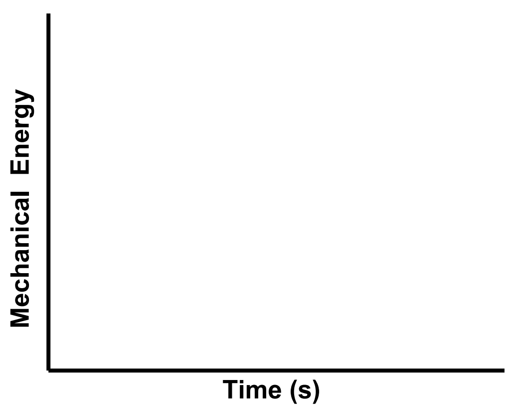
Elevation of the higher feet, *H* =__________________

Mass of the cart, *M* =___________________________

Predicted energy-time relation and explain why







Paste the screenshot of the graphs obtained in Step 3.

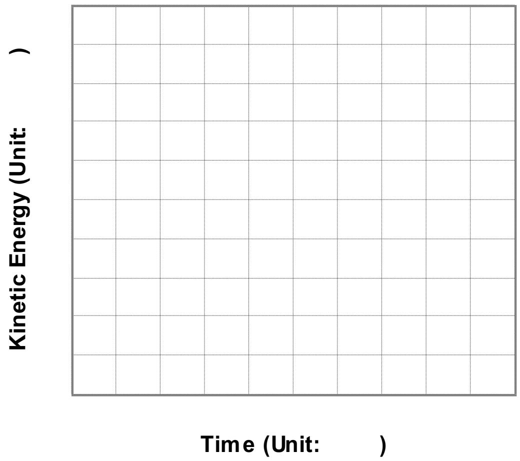
Record position and velocity readings in five different times on the graphs and complete the following table.

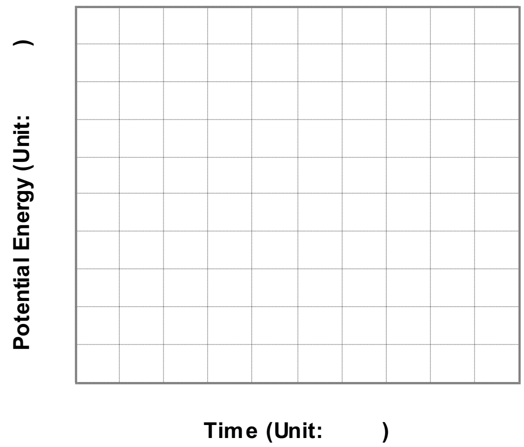
Table I

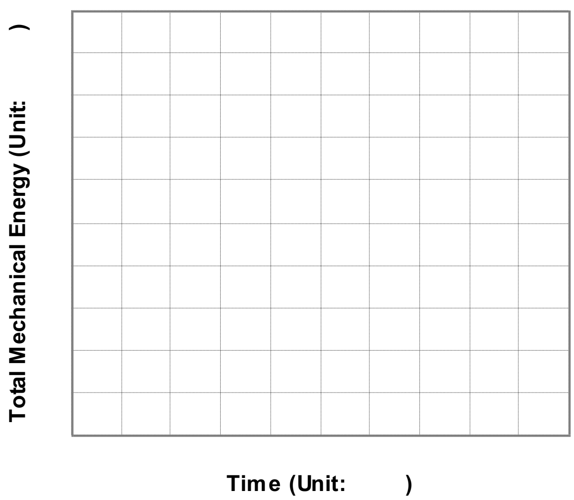
	Time	Position x	Height $h = x\sin\theta$	Potential Energy $=mgh$	Velocity v	Kinetic Energy $=\frac{1}{2}mv^2$	Total Energy $= PE + KE$
1							
2							
3							
4							
5							

Record the acceleration of the cart :____

Plot kinetic energy, potential energy and total energy in Table I as a function of time and compare with the predicted graphs.







Measuring *g*

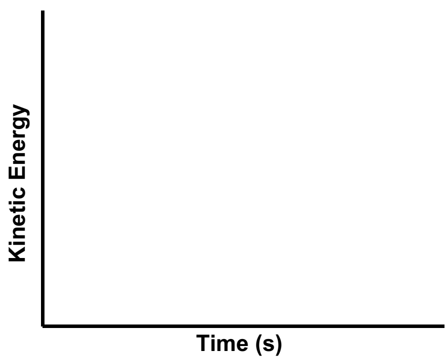
Based on the acceleration obtained from the Velocity graph, find the value of *g.*

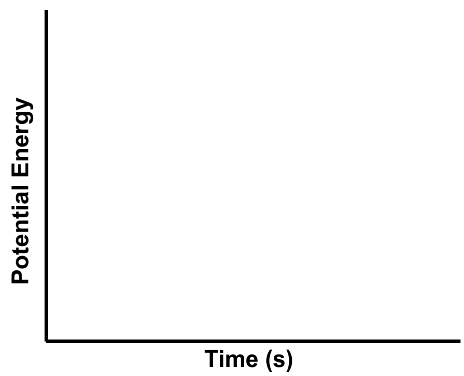
Effect of friction

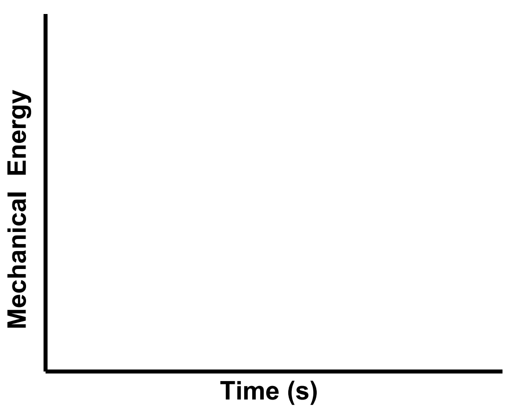
What is the static friction when the cart on the ramp is not moving? Provide an analysis to support your answer.

In the case of a cart remain stationary on the ramp, does the static friction depend on how hard you press the friction block?

Draw a conclusion from the predicted and measured energies vs time graphs.







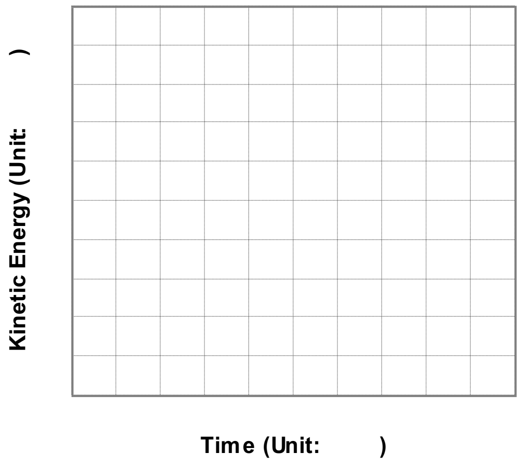
Paste the screenshot of the position and velocity graphs of cart motion with friction.

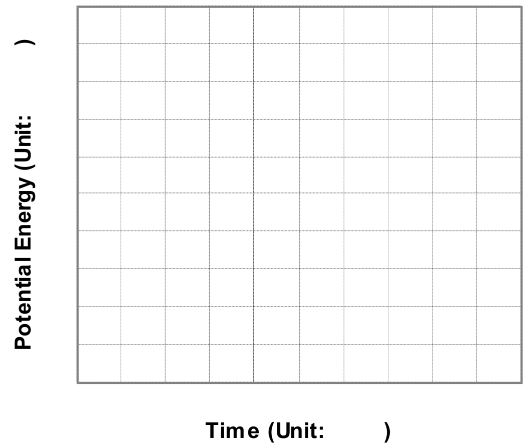
Record position and velocity readings in five different times on the graphs of cart motion with friction and complete the following table.

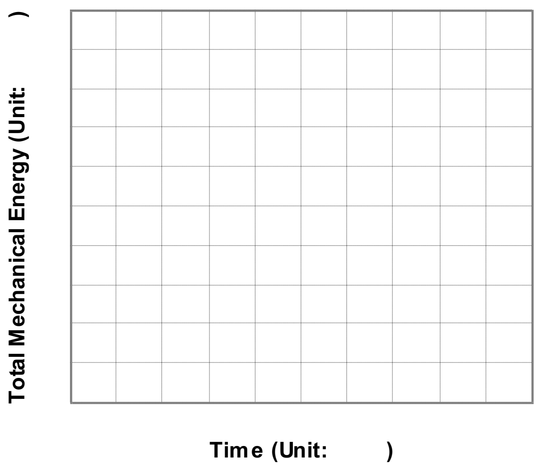
Table II

	Time	Position x	Height $h = x sin\theta$	Potential Energy $=mgh$	Velocity v	Kinetic Energy $= \frac{1}{2}mv^2$	Total Energy $= PE + KE$
1							
2							
3							
4							
5							

Plot the measured energy-time relations with friction using Table II







Use the fact that the change in the mechanical energy is equal to the work done by friction over a distance to find the value of the friction force acting on the cart.

Use the electronic balance to find the mass of the friction block, and then find the coefficient of friction between the friction block and the track.

Laboratory Exercise #7

Collisions and Momentum

Objectives: To study the relation between force and change in momentum, and to determine whether momentum is conserved in inelastic collisions

Equipment: Two sensor carts with bumpers, yellow cart with a bumper, electronic balance, masses, track with end stops, three 125 g masses.

Introduction

Instead of writing Newton's Second Law as F=ma, we can also write it as $F = \frac{\Delta p}{\Delta t}$. This means that if a constant force is acting on an object for a time Δt, then its momentum will change by an amount $F\Delta t$, called impulse. Let us assume that the force starts acting at a time t_0. If we plot the force as a function of time, it will be zero until t_0, F between t_0 and $t_0+\Delta t$, and then zero again after that. The area under the force versus time plot is just $F\Delta t$, which is the change in momentum. If the force is not constant, it is still true that the area under the force versus time plot will be the change of the momentum of the object.

When two objects collide in the absence of external forces, Newton's Third Law guarantees that the total momentum is unchanged. If the two colliding objects are object A and object B, then when they collide, the force exerted by A on B will have the same magnitude as the force that B exerts on A, but its direction will be opposite. This means that the change in momentum of object A will be the opposite of the change in the momentum of object B, so that the sum of their changes in momentum is zero. Therefore, the total momentum before the collision is the same as the total momentum after the collision. In terms of equations, if $p_A=m_Av_A$ is the initial momentum of object A $p_B=m_Bv_B$ is the initial momentum of object B, $p_A=m_Av_A$ is the final momentum of object A, and $p_B=m_Bv_B$ is the final momentum of object B, then

$$p_A+p_B=P_A+P_B \quad .$$

In this lab, we want to verify Newton's Third Law, show that the change in momentum is equal to the area under the force versus time graph, and study momentum conservation in an inelastic collision. The collision will involve two carts, one initially moving and the other sitting still, that stick together when they hit. This means that if the initially stationary cart is object B, then $v_B=0$ and $V_A=V_B$.

Procedure

1. Elastics Collision

You should have two cars with built-in force sensors. The bumpers are mounted on the force sensors. Place them both on the track with the arrows pointing to each other. The arrow of the green cart should point to the end stop.

a. Place the green cart at the end and the yellow cart in the middle of the track. You will be asked to push the green cart, not too hard, toward the yellow cart so that that they collide. Before you take data, sketch you predictions for what the force versus time plots for each cart will look like. Note that the force is positive if it is in the same direction of the arrow.

b. Open Graphical Analysis software. Click Senor Data Collection to connect the two sensors whose IDs match the ones on your carts.

When both sensors are connected, click SENSOR CHANNELS, enable both Position and Force sensors. Do this for both sensors. Then click Done.

Now you will see three graphs on the screen. Use View Options at the upper right corner to select two graphs.

Click the vertical label of the upper graph to select Velocity G and Velocity Y and deselect all other items. (G means Green and Y means Yellow)

Click the vertical labs of the lower graph to select Force G and Force Y and deselect all other items.

Click Force G and Force Y on the lower right corner to zero the force sensors.

Click Position Y and Force Y to reverse the direction. This is done because the arrow on the yellow cart points to the opposite direction of the green cart which is taken as the positive direction.

c. Now place the yellow cart in the middle of the track, click COLLECT and gently push the green cart toward the yellow cart so that that they collide. The force sensor will measure the forces on each of the carts. Catch the cart before they strike the end stop.

Use magnifiers to zoom in and then take a screenshot using your mobile phone.

What does the Force-Time graph tell you about Newton's Third Law?

d. We now want to see if the total momentum is conserved before and after collision. From the graph, record the velocity of the green and yellow carts before and after collision.

Next we will test whether the change in the momentum of the initially motionless (yellow) cart is equal to the applied impulse which is the area under the force versus time plot. Use the electronic balance to find the mass of the cart that was initially at rest, and then make use of your velocity-time plot to find change in momentum of this cart due to the collision. This is just the momentum after the collision minus the momentum before the collision.

Now use the **View Integral** function under **Graph Options** at the lower left corner of the Force-Time graph to find the area under the force curve. Compare the change in momentum to the area under the force-time graph.

e. Next we will repeat the same experiment except that a 475 g is loaded on the stationary yellow cart. Before you take data, sketch you predictions for what the velocity versus time plots for each cart will look like.

Then repeat Steps c and d with the yellow cart carrying 475 g (3 x 125g) masses.

2. Inelastic collision:

Now rearrange the empty carts so that the two ends with Velco pads face each other.

You want to have the yellow cart initially moving and the green cart initially at rest in the middle of the track. The collision will cause the two carts to stick together when they hit (again, not too hard!).

You can follow the step outlined in Step 1c to obtain velocity data and thereby find the momentum before and after the collision. Now do the experiment and compare the initial and final momentum.

Laboratory Exercise #7

Collisions and Momentum

Date ______________

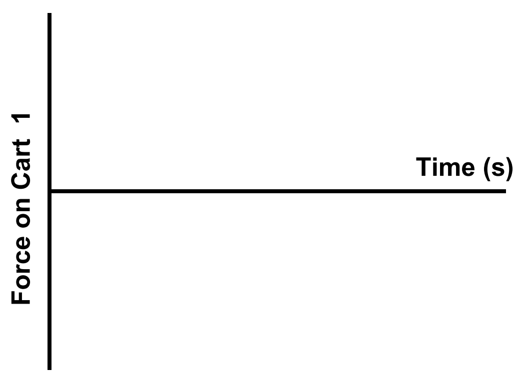
NAME:______________________________ Partners:________________________

Instructor's Signature:____________________

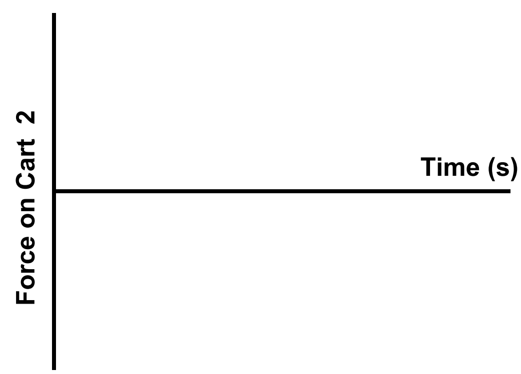
Collison between two cart of equal masses

Sketch predictions for what the force versus time plots for each cart will look like during collision.

Green Cart



Yellow cart



Paste the screenshot of the force and velocity graphs during the colllision

What does your Force-Time graph tell you about Newton's Third Law?

Velocity Green Cart
Before collision________________.   After collison=__________________.

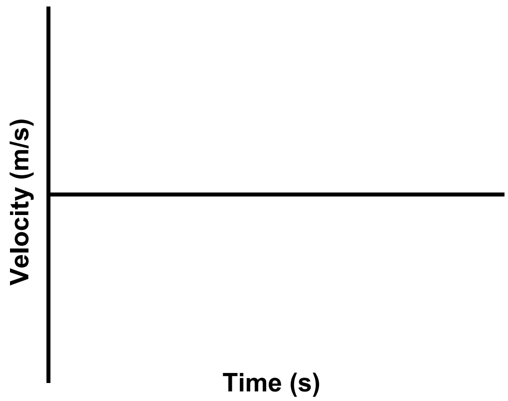
Velocity of Yellow Cart
Before collision________________.   After collison=__________________.

Compare the total momentum of the green and yellow cart before and after collision. Present your analysis.

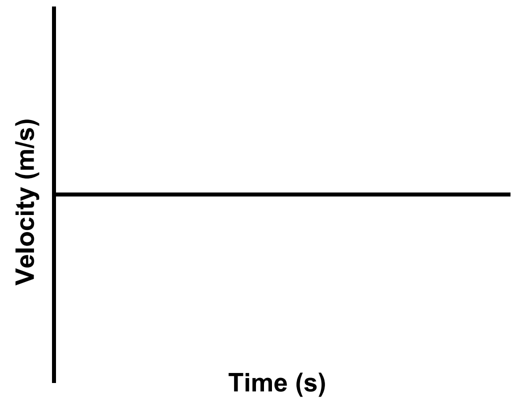
Compare the momentum gained by the yellow cart after the collision with the area under the Force-Time graph.

Collison with a mass on the stationary cart
Sketch predictions for what the **velocity** versus time plots for each cart will look like during collision when a 475g of mass is loaded on the yellow cart.

Green



Yellow



Paste the screenshot of the force and velocity graphs for the collision with a 475 g mass on the yellow cart during the colllision

Velocity of Green Cart

Before collision_________________. After collison=___________________.

Mass of Green Cart______________

Velocity of Yellow Cart

Before collision_________________. After collison=___________________.

Mass of Yellow Cart_______________

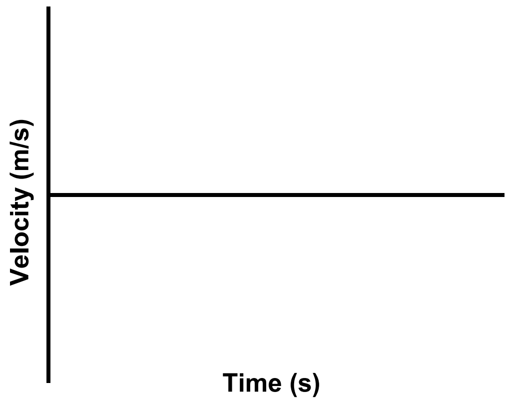
Compare the total momentum of the green and yellow cart before and after collision. Present your analysis.

Compare the momentum gained by the yellow cart after the collision with the area under the Force-Time graph.

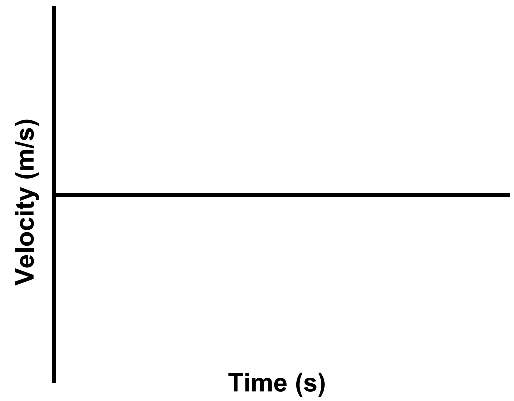
Inelastic Collision

Sketch a prediction for the velocity plots for the two carts before and after collision.

Yellow Cart



Green Cart



Past the screenshot

Velocity Yellow Cart
Before collision_________________.   After collison=___________________.

Velocity of Green Cart
Before collision_________________.   After collison=___________________.

Compare the total momentum before and after collision.
Present your analysis.

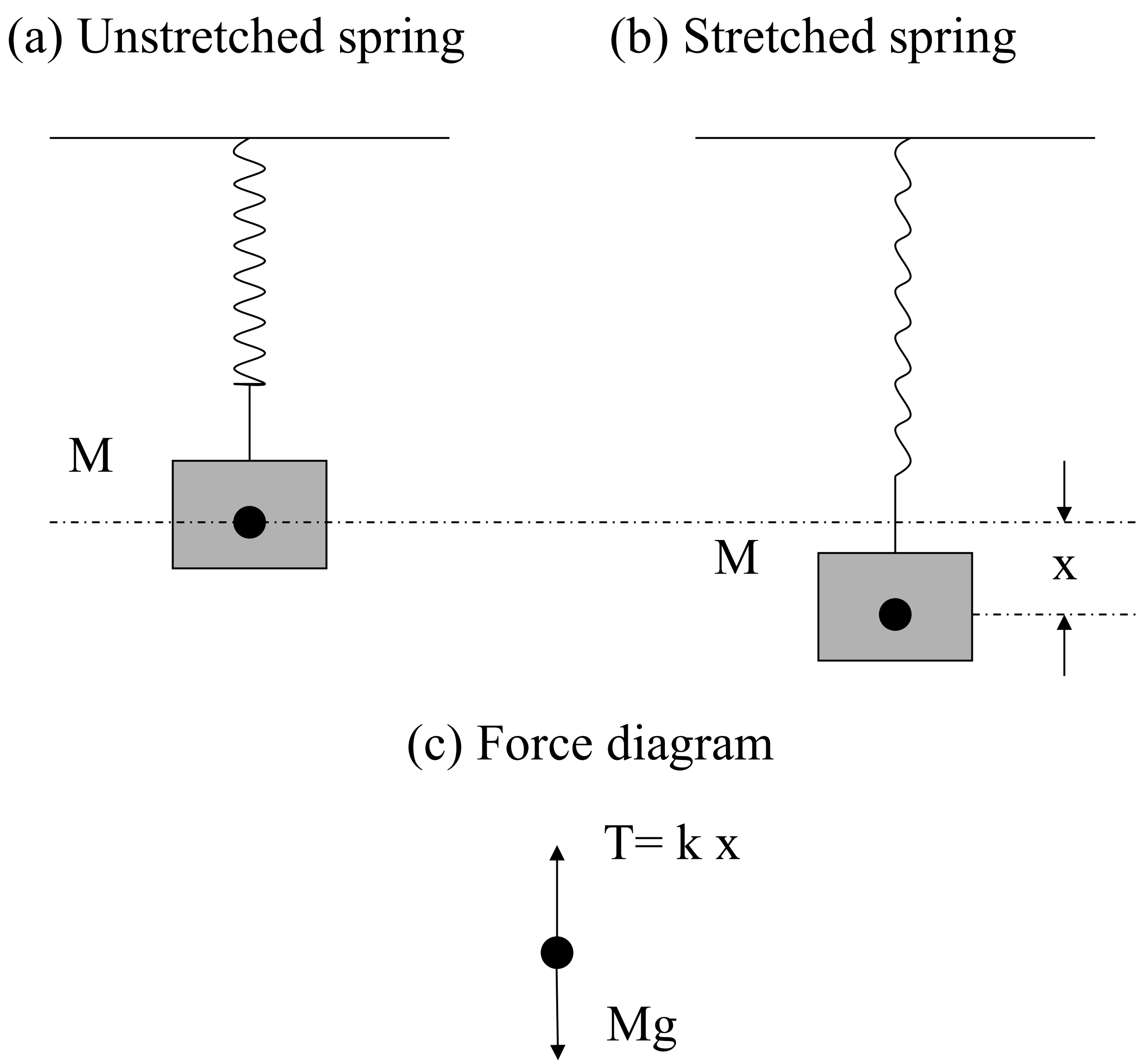
Part I: Simple Harmonic Motion

Objectives

To study the force law for a spring (Hook's Law). To verify the equation for the period of a vibrating spring.

Equipment and Supplies

Spring, support for suspending spring, set of weights, stop clock, meter stick, balance.



Discussion

When a stretching force F is applied to a spring, the elongation of the spring x is found to be proportional to F if the elastic limit is not exceeded. The force is a *restoring* force, i.e., always opposite to the displacement. This empirical law is called Hook's law:

$$F = -kx$$

where k is called the *force constant,* or the *stiffness* of the spring. The general equation of motion for the mass M with acceleration *a* which is vertically hung from the spring as seen in the figure is

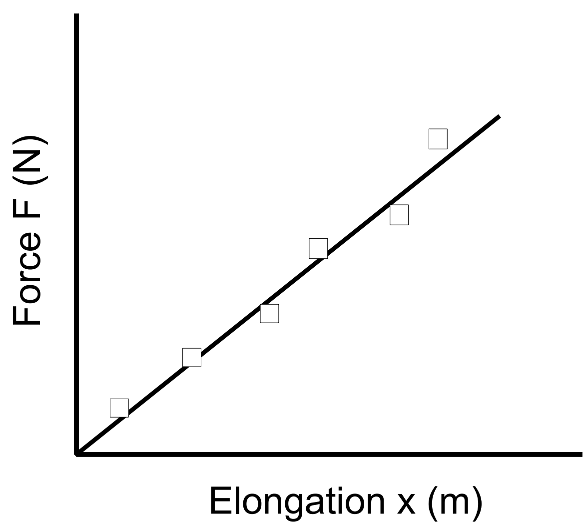
$$Ma = Mg - kx$$

within the elastic limit. Here, we completely neglect the mass of the spring which in our experiment is much smaller than the mass attached.

(1) If the mass M is in an equilibrium state, the equation is reduced to

$$Mg = kx$$

since $a = 0$. The elongation *x* of the spring can be measured as a function of the weight hung on it when varying the mass M of the suspended weight $F = Mg$ and a plot of F vs x is a straight line, as illustrated below.



The slope of the straight line is the stiffness k of the spring. In the MKS units it is N/m.

(2) If a mass, *M*, hung from the end of an elastic spring is pulled down and released, it will oscillate up and down. This is an example of *simple harmonic motion*. The acceleration a

must not be neglected since the mass is not in equilibrium. In this case the equation of motion is rewritten as

$$x'' + \frac{k}{M}x = g$$

where $x'' = a$ and the displacement at time t is

$$x = \frac{g}{\omega^2} + A\cos(\omega t - \delta)$$

where $\omega = \sqrt{\frac{k}{M}}$ depends on the mass *M* and the stiffness of the spring. If the time *t* is replaced by $t+2\pi/\omega$, then the displacement x is unchanged. This means that the displacement has the same value after time *T,*

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{M}{k}}\ .$$

This is the period of the oscillation. *A* is the amplitude of the oscillation and δ is determined by the initial displacement of the mass.

Actually, since all parts of the spring also execute simple harmonic motion, the mass of the spring needs to be included in some way. Since not all parts of the spring execute the full motion, it turns out that *m'*, the "effective mass" of the spring is just 1/3 of the full inertial mass, *m*. So, the parameter *M* should be the sum of the mass of the hung weight, M_0, plus 1/3 of the mass of the spring:

$$M = M_0 + m' = M_0 + m/3$$

where, M_0 is the mass of the suspended weight,
m is the mass of the spring, and
m' is the effective mass of the spring (*m'* = *m/3*).

Procedure

1. *F vs. x data*.
Measure the elongation *x* of the spring as a function of the weight hung on it. Vary the mass of the suspended weight from 200 grams to 800 grams in 100 g steps. Take the position when 200 g is suspended to be zero displacement (the origin).

Do not exceed 800 g.

2. *T vs. M data.*
Hang a mass of 200 grams from the spring and make at least three determinations with a stop clock of the time for 50 complete oscillations of the mass. Use a different initial amplitude in each determination. Repeat with masses of 350, 550 and 700 grams.

Calculations and Conclusions

A. From the data in Procedure **1**, calculate analytically and graphically the force constant of the spring and compare the two values. The analytic calculations involve using Hook's law for each of your data points. The graphical method involves plotting F *vs.* x, and measuring the slope of the best straight line through the data points (see the sketch above).

B. Plot T^2 *vs.* M, i.e., the square of the period on the vertical axis and the mass of the suspended weight on the horizontal axis. From the graph, calculate the value of the stiffness k.

C. Compare the values of k found in **A** and **B**. This means, by what percent do they differ? Now, in summary, considering both measurements, what is the precision (expressed as a percent) of your measurement of k ?

D. Does the period of simple harmonic motion depend on the amplitude? How well does your data justify your answer ?

LABORATORY EXERCISE # 8 Part I

Data Sheet :Simple Harmonic Motion

Date:________

Name:_______________________________ Partners:______________________

Instructor's Signature:________________________

Mass of spring:________________

M_0 Suspened Mass (kg)	F= $M_0 g$ Force (N)	x Elongation of the spring (m)
.200	Take as 0	Take as 0
.300	(.300-0.200) x 9.80 =	
.400		
.500		
.600		
.700		
.800		

Hung mass:	200 g	350 g	550 g	700 g
Time for 50 cycles (sec) amplitude #1				
Time for 50 cycles (sec) amplitude #2				
Time for 50 cycles (sec) amplitude #3				
Average of three above times (sec)				
Period, T (sec)				
T^2 (sec^2)				

LABORATORY EXERCISE # 8

Part II: The Simple Pendulum

Objective

To study how the period of a simple pendulum depends on its length. To measure the acceleration due to gravity in the laboratory room.

Equipment and Supplies

Metal sphere suspended by a fine string, stop clock, meter stick, vernier calipers.

Discussion

A *simple* pendulum is one where all the mass is concentrated at a small "bob". A good approximation is made by using a massive weight held with a light string from a sturdy support. If the motion is restricted to "small angles", the motion is closely *simple harmonic.* *T*, the period of the motion, depends only on the length of the string, and the acceleration of gravity. Surprisingly, the period does not depend on the value of the suspended mass:

$$T = 2\pi\sqrt{\frac{L}{g}} \tag{1}$$

where, *T* is the period of oscillation.
L is the distance from the support point to the center of the massive bob, and
g is the local acceleration due to gravity.

Procedure

1. *T vs. L data.*
Adjust the pendulum so that *L* is about 100 cm. Measure *L* using the meter stick and vernier calipers. Determine the time for 50 oscillations with the amplitude of motion less than 10□.

2. Repeat Procedure **1.** using a length approximately 30 cm, and again with *L* about 60 cm.

Calculations and Conclusions

A. Plot your data as T^2 *vs. L*. The theory, given by Eq. (1), predicts that your data points should fall on a straight line of slope 2□/*g*. Thus by measuring the slope of the best straight line fit, you can pull out the value of *g* in the lab. What is the value of *g* you obtain, and what is the precision you claim for your measurement (expressed as a percent) ?

B. You have just finished measuring *g*, the acceleration due to local gravity. Express your result as in the form wxy ±z %. In exercise #2, several weeks ago, you also measured *g*, using an entirely different method. For the two results summarize the following information:

a) claimed precision

b) agreement with accepted value

Do the two results agree? The key here is the criterion you used to answer the question.

Add any further relevant comments.

LABORATORY EXERCISE # 8 Part II

Data Sheet : Simple Pendulum

Date ____________

Name:______________________________ Partners:__________________________

Instructor's Signature:___________________________

Nominal length Of pendulum, L	100 cm	60 cm	30 cm
Actual length, L			
Time for 50 oscillations (sec)			
Period, T (sec)			
T^2 (sec^2)			

LABORATORY EXERCISE # 9

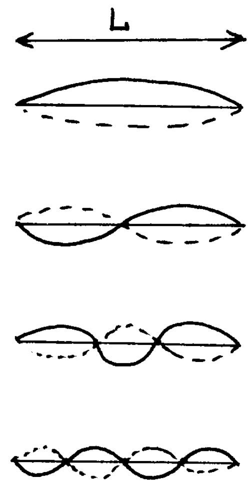
The Sonometer: Vibrations of a Taut String

INTRODUCTION

When you pluck a taut fixed string of length L, the resultant vibrations are a superposition of many simpler "standing wave" patterns, depicted below:

Mode	Wavelength	Frequency
$n = 1$	$\lambda_1 = 2L$	$f_1 = \frac{v_0}{\lambda_1}$
$n = 2$	$\lambda_2 = L$	$f_2 = \frac{v_0}{\lambda_2} = \frac{\lambda_1 f_1}{\lambda_2} = 2f_1$
$n = 3$	$\lambda_3 = \frac{2L}{3}$	$f_3 = \frac{v_0}{\lambda_3} = \frac{\lambda_1 f_1}{\lambda_3} = 3f_1$
$n = 4$	$\lambda_4 = \frac{L}{2}$	$f_4 = \frac{v_0}{\lambda_4} = \frac{\lambda_1 f_1}{\lambda_4} = 4f_1$

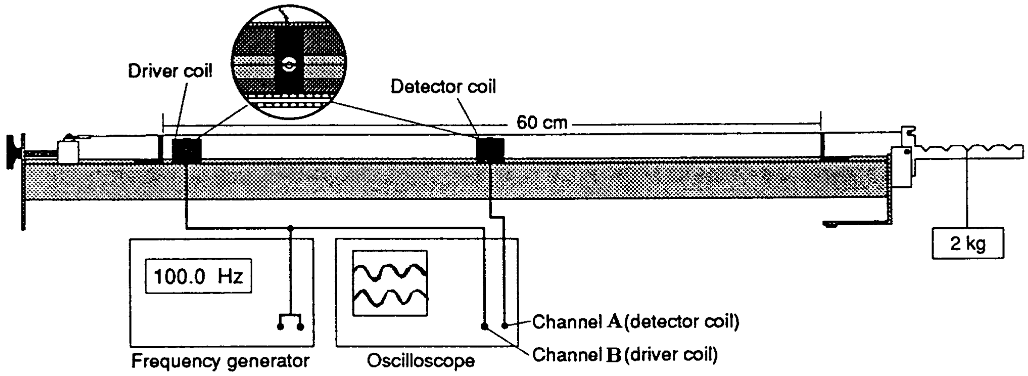
etc. for $n = 5, 6, 7, \ldots$



Note that, in general, $\lambda_n = 2L / n$, and $f_n = nf_1$, meaning that all harmonics are an integer multiple of a fundamental frequency, f_1. Also note, that the place on a standing wave where there is no vibration is called a **node**, and the place where there is maximum amplitude is called an **antinode.**

PURPOSE

In this exercise you will excite and study the first few vibrational modes of the taut string. You will use a *sonometer*, a single-string "musical" instrument. See figure below.



EQUIPMENT AND SUPPLIES

1. Sonometer from Pasco Scientific Company. This instrument allows a known tension to be placed on a guitar string whose vibrating length can be varied between movable "bridges."

2. A function generator. It can "drive" an electromagnet with AC current in the lower audio range. Note: The guitar string will be attracted to the AC electromagnet twice each AC cycle, because both the North and South poles are equally good at attracting the steel string.

3. "Detector" coils capable of picking up the AC motion of a steel string.

4. A dual-trace oscilloscope to display both the driving frequency and the detected string vibrational frequency.

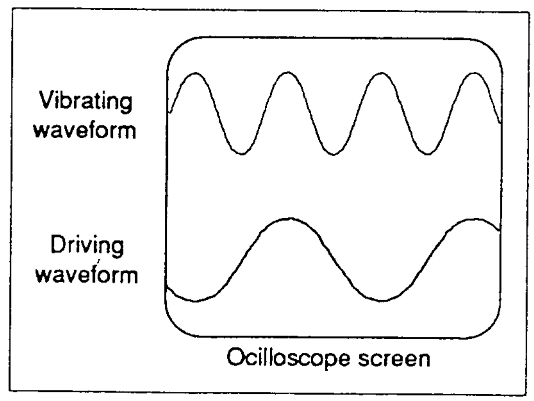


Figure 2. String vibrations at twice the driving frequency

PROCEDURE

A1. Set up the sonometer system. Set the bridges 60 cm apart. Hang a 2 kg mass from the tensioning lever. Adjust the string tensioning knob so the tensioning lever is horizontal.

A2. Position the driver coil about 5 cm from one of the bridges and the detector about 35 cm away from the same bridge.

A3. Gently pluck the string with a fingertip. The detector coil will pick up an induced voltage which you can see displayed on the oscilloscope. You can excite different waveforms by plucking in different places or with a different technique.

Play with this a while. You are seeing a different mix of excited harmonics (another name for the different modes corresponding to different values of *n*.)

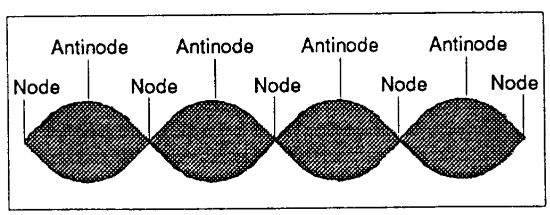
Note: If the oscilloscope does not display, adjust the TRIGGERING: all three levers in the upper right corner should be flipped up, and the *level* knob pulled out (auto mode.) Also, adjust the trace *position* knobs as necessary.

A4. Set the signal generator to produce a *sine* wave and set the gain of the oscilloscope of channel B to 5 mV/cm.

A5. With the function generator amplitude set at about 12 o'clock slowly increase the frequency of the signal to the driver coils, starting from about 5 Hz. (This part will require a gentle hand and some patience.)

Listen for an increase in sound from the sonometer and/or an increase in size of the detector signal on the oscilloscope screen. Frequencies that result in maximum string vibrations are the resonant frequencies. Determine the lowest frequency at which resonance occurs. This is the first or fundamental mode (n = 1). Measure this frequency and record it on the data sheet provided. Note: Because of the effect noted in the equipment section, the resonant frequency is twice the driving frequency.

Note: For the n = 1 mode, you should actually hear the sonometer hum and produce enough amplitude vibration to clearly see the central antinode and the nodes at the bridges.



A6. Continue increasing the frequency to find successive resonant frequencies for each mode - at least five or six. For each resonant mode you find, locate all the nodes, and record the distance between adjacent nodes. There are two ways to locate notes:

1. Use the "detector" provided as follows: Start with the detector as close as you can to the free bridge. Watch the oscilloscope display as you slide the detector slowly along the vibrating string. When you reach a node, the amplitude on the scope will drop to a minimum. (This method breaks down when you get too close to the "driver" and start to pick up its field directly.)

2. Use your fingers. Watch the oscilloscope display as you slide your fleshy fingertips along

the vibrating string. Even a light touch will kill the vibrations everywhere except when you touch a node, where there is no vibration to kill, in any case. (Make sure that the detector is not accidentally left under a node, or this won't work.)

A7. From your results, determine and record the wavelength of each resonant mode you find. Make use of the fact that the wavelength is twice the distance between adjacent nodes.

B1. Repeat the experimental procedure A, for a string length of 50 cm, obtained by moving one or both of the bridges.

Compute the average value, and quote the uncertainty of your measurement as a percent.

LABORATORY EXERCISE # 9

Data Sheet :Sonometer

Date ______________

Name:______________________________ Partners:_______________________

Instructor's Signature:__________________________

1. What mathematical relationship holds, for a given value of n, between the length L and the wavelength □ ?

Procedure A: String length, L = __________

n = 1 Driver frequency =__________

Actual string frequency f (twice driver frequency) = __________

Distance between nodes =__________ wavelength =□1 = ____________

n = 2 Driver frequency =__________

Actual string frequency f2 (twice driver frequency) = __________

Distance between nodes =__________ wavelength =□2 = ____________

n = 3 Driver frequency =__________

Actual string frequency f3 (twice driver frequency) = __________

Distance between nodes: __________ __________

Average distance between nodes =__________ wavelength =□3 = ____________

n = 4 Driver frequency =__________

Actual string frequency f4 (twice driver frequency) = __________

Distance between nodes: __________ __________ __________

Average distance between nodes =__________ wavelength =□4 = ____________

n = 5 Driver frequency =__________

Actual string frequency f5 (twice driver frequency) = __________

Distance between nodes: __________ __________ __________ ________

Average distance between nodes =__________ wavelength =□5 = ____________

n = 6 Driver frequency =__________

Actual string frequency f6 (twice driver frequency) = __________

Distance between nodes: __________ __________ __________ __________

Average Distance between nodes =__________ wavelength =□6 = ____________

n = 7 Driver frequency =__________

Actual string frequency f7 (twice driver frequency) = __________

Distance between nodes: __________ __________ __________ ________

Average distance between nodes =__________ wavelength =□7 = ____________

2a. Plot your values of the resonant frequencies versus n, the mode number. On the same graph, draw the best straight-line fit that goes through the origin. This line is the theoretical result,

$$fn = n\ f1$$

2b. The slope of this best straight-line fit to the data (which passes through the origin) is just the fundamental frequency (f1) abstracted from all of your data, not just your first measurement. How good is the agreement?

Procedure B: Use your own data sheet for this part. Take all necessary data, and present data and calculations in neat tabular form.

3. To what extent do your results in Procedure B verify the relationship given in the answer to question 1?

4. For each mode you identified and recorded in the data sheets, compute the wave speed.

LABORATORY EXERCISE # 10

Properties of Sound Waves: Speed and Standing Waves

To prepare for this lab please familiarize yourself with the following: speed of waves, standing waves and resonance
These topics can be easily located at the website " The Physics Classroom"

Anyone observing a trombone player recognizes immediately that the musician changes the pitch by altering the length of the convoluted tube (If you haven't, check out this Youtube link https://www.youtube.com/watch?v=ZxODzxY6AvI)
In physics parlance what is being done is that the musician is adjusting the standing wave within the trombone by altering the length of the resonance chamber. This in turn alters the wavelength and frequency of the sound wave. Our ears detect the change in frequency as a change in pitch.

In this lab we will be using our ears to detect the resonant frequency of an air chamber and by doing so, determine the wavelength of the sound wave. We can then easily calculate the speed of sound in air. We are also going to see how cooling the air (changing the property of the medium) affects the speed of sound.

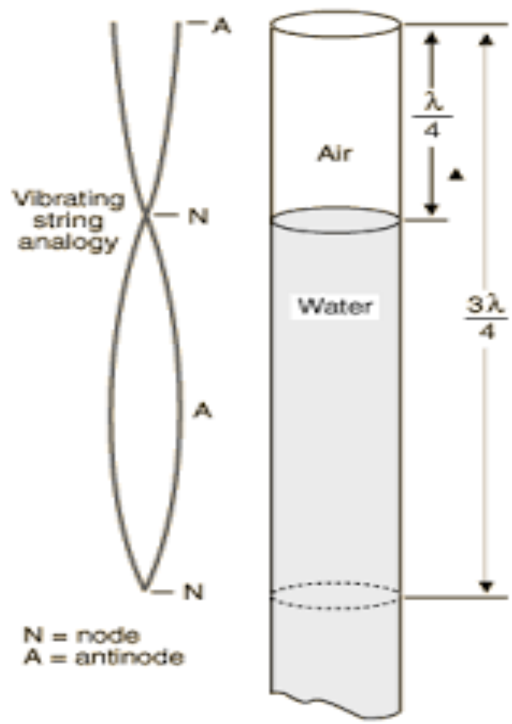
Since you are working with liquid be prepared to do immediate cleanup of surfaces after any spills.

A Determine the Speed of Sound In a Tube

Apparatus;This exercise needs two people.
Plastic 2 liter graduated cylinder. 4.5 cm wide PVC tube that fits into the graduated cylinder. Striker, 3 tuning forks 256 Hz,512 Hz.and a tuning fork of an unknown frequency, red and blue dyes, water that is at both refrigerated/ cooled and at room temperature.
DO NOT STRIKE THE TUNING FORKS ON ANY SURFACE!!! Strike the tuning forks with the mallet.

Your lab instructor will demonstrate. First fill the graduated cylinder to 800 ml mark. **PUT 3 DROPS OF RED DYE INTO THE WATER AND GENTLY SWIRL IT AROUND**. This improves visual acuity. Insert the PVC tube making sure the water level reaches just below the top.
PLACE THE GRADUATED CYLINDER WITH THE TUBE INSIDE ON THE CHAIR, NOT ON THE TABLE. This improves the ergonomics of the procedure.
Practice lifting the tube partially out of the water and holding it for 15 seconds. Then return it into the cylinder.

The set up should look something like this:



Take the 256 Hz tuning fork and strike it with the striker. Practice it a few times. When you are comfortable with this, strike it one more time. While holding the fork with one hand, raise the tube out of the water with the other hand. Bring the tuning fork over the tube, holding the fork horizontally over the tube. SLOWLY raise or lower the tube. Carefully listen for a sudden change in the amplitude of the sound. Do not be afraid to put your ear as close as possible to the pipe. When the amplitude increases and decreases sharply, stop. While holding the tube at this height, your lab partner should measure the length "L" of the air chamber that is created.

The length L is measured from the top of the top of the tube to the surface of the water. Play with this a bit to see how varying the length of the air chamber affects the amplitude of the sound. Practice this a number of times so that you feel comfortable locating the point of maximum amplitude. Once you feel confident about locating this spot take 5 separate measures of the length and record the average the data inTable 1.

Here, the air chamber has one open end at the top and a closed end (the water) at the bottom. In this case, the wavelength ƛ is four times the length L. Reading the text will explain why this is so. Note that there is a small correction factor included in the equation to account for the magnitude of the inner diameter "d" of the tube. of the air chamber. Remember that d is in meters not centimeters. Now calculate the wavelength.

$$\lambda = 4 \times (L + 0.3\, d)$$

Enter that value in the space provided in Table 2. Now calculate the speed of the sound wave for both the 256Hz and 512Hz conditions using the formula below. ***Remember to convert your length measured in centimeters to meters.***

$$V = \lambda \times f$$

Trial	**250Hz cm.**	**500Hz cm.**	**Unknown cm.**
1			
2			
3			
4			
5			
$L_{Avg.}$			

Table 1

	256Hz	512 Hz	**$f_{unknown}$ = Hz**
L_{avg} m			
ƛ m.			
V m/s			V_{avg}=

Table 2

Now that you have made a determination of the speed of sound, see if your results are precise. Take the tuning fork with an unknown value and repeat the previous procedures for determining the wavelength of the unknown tuning fork.. Divide the wavelength value of the unknown frequency into the previously obtained average speed to obtain the frequency of the unknown tuning fork.

$$f_{unknown} = V_{avg} / \lambda$$

Once everyone in the class has completed this procedure, your lab instructor will tell you the actual frequency of the tuning fork.

Calculated frequency of the unknown tuning fork__________________________Hz.

Actual frequency of the unknown tuning fork __________________________Hz.

Calculate the % error using the actual value as the accepted value and your derived value as the experimental value.

% Error $_{freq}$=_______________________________

B Speed of Sound and Temperature

The speed of a sound wave also depends on the temperature of the air. You can compare your calculated value of the speed of sound to its theoretical value based on the temperature of the room (in Celsius)

Room Temperature=______________C. (The thermometer is located in the front of the room.)

Compared to zero celsius, this value will become **Δ**T.

At zero degrees Celsius in air at ordinary pressure, the speed of sound is accepted as 331 m/s. Now calculate the speed of sound at the higher room temperature " **Δ**T" use the following formula:

$$V = 331 + (0.6 m/s)\Delta T ^\circ C$$

Record the average value of the speed of sound that you obtained from the two known tuning forks below and compare it the temperature dependent value.

V_{Temp} = _____________m/s **$V_{Average}$ = _____________m/s**

% Error_________________

If they are close (within 10%), congratulations. Otherwise, list some factors that might contribute to significant disparities between your values and theoretical values. Please don't just say "human error".
Factors:

C Changing the speed of sound by cooling the tube.

Since the speed of sound is dependent on the temperature of the air, changing the temperature, should change the wavelength of the standing wave.

We are going to see how much the speed of sound changes as the air chamber is cooled. For this step use only the 256 Hz tuning fork. Now get ready to cool the air chamber.

Empty the cylinder of the room temperature water you have just used. Go to the refrigerator and take out one bottle of cooled water. Notice that the cold water is tinted blue with a food dye. Pour cold water from the cold water bottle to the 800 ml mark. Place the tube in the water and give it a moment to cool. Prepare to measure and record air chamber lengths as you did before. Since the tube will be colder, it will cool the air inside as well. To anticipate the warming of the air chamber as the tube is lifted, have the tuning fork and meter stick positioned for rapid measurement.

Lift the tube as before and strike the tuning fork. As before, hold it horizontally over the tube as you raise it. When you detect the resonant sound, measure the length of the air chamber. Lower the tube back into the cold water.
Do this for five trials and record the data. Then determine the average value of the length.

Trial	**1**	**2**	**3**	**4**	**5**
Length cm					

Length $_{\text{Average}}$ _________________cm = _____________m

Calculate the wavelength using the equation:

$$\lambda = 4 \times (L + 0.3\, d)$$

Calculate the experimental speed of sound from

$$V_{exp} = \lambda \times f$$

Now using data from the 256 Hz tuning fork, compare the calculated speed of sound in cool air to the speed of sound obtained in warm room temperature air.

V_{warm} = ______________m/s **V_{cool} = ___________________m/s**

Theoretically, the speed of sound changes by 0.6 meters per second per degree Celsius. While it is not feasible to actually measure the cooler temperature inside the chamber, we can get an estimate of how cold the air inside the chamber is. Using your value of **V_{cool}** and the equation **$V_{cool} = 331 + (0.6 m/s)\Delta T°C$,** determine the temperature for your chamber. On the board, let the class list the temperature calculated by each table. Discard the highest and lowest values and find the average of the remaining values. Show your work.

Air Chamber Temperature$_{\text{Class Average}}$ _______________Celsius

1. Investigate how the speed of sound is directly proportional to the temperature of the air chamber. Be brief.

2. Investigate how the speed of sound in air changes with changes in atmospheric pressure.

3. Describe two other instruments that alter their resonant frequency by adjusting the length of the air chamber.

LABORATORY EXERCISE # 11

The Mechanical Equivalent of Heat

Objective

The purpose of this Laboratory Exercise is to prove the mechanical equivalence of heat and to verify that 1 kcal = 4186 Joules.

Equipment and Supplies

Commercial apparatus is provided which consists of the following:

1. An aluminum cylinder whose specific heat you know, whose mass you will soon measure, and whose temperature is conveniently sensed by a built-in thermistor. [A *thermistor* is a resistor whose resistance varies with temperature]. You are provided with a digital ohmmeter and a Table to tell you what temperature corresponds to what resistance. This often requires *interpolation*. If you are rusty on interpolation, ask your instructor.

2. A hand-crank and digital counter to record the number of revolutions.

3. A nylon rope with a "10 kg" weight at one end. The rope is wrapped a few times around the aluminum cylinder so that tangential frictional forces are set up between rope and aluminum cylinder when you turn the crank. **CAUTION:** *Allowing the 10 kg weight to rise more than a few inches off the floor is dangerous both to student feet and to the delicate one-way digital counter.*

CAUTION: **The Proper Procedure for turning and stopping the crank will be demonstrated by your instructor. It may look simple enough, but in fact it is easy to hurt yourself or damage the equipment. Respect this warning!**

Discussion

Mechanical Work, which for linear motion is simply "force times distance", takes on the following expression for circular motion:

W = (Torque) x angle,
W = (Tangential force x Radius) x angle,
W = F□R□□, where □ is in *radians.*

For example, a force of 2.00 N acting for one complete revolution (2□ radians) around a circle of radius 1.00 meter does an amount of work given by,

W =F□R□□= (2.00 N)(1.00 m)(2□ radians) = 4□ J = 12.6 Joules.

The heat energy Q transferred to a body of mass m and heat capacity c, will raise its temperature by an amount □T degrees, where

$$Q = mc\Delta T$$

For example, if the temperature of 0.10 kg of Aluminum (c = 0.220 kcal/kg °C) is seen to rise from 21.5 °C to 38.5°C, we can conclude that an amount of heat Q must have been added to the aluminum, where

$$Q = m\,c\Delta T = (0.10\text{ kg})(0.220\text{ kcal/kg°C})(38.5\text{°C} - 21.5\text{°C}) = 0.38\text{ kcal}.$$

Procedure

A. Introduction:

A1. Familiarize yourself with the apparatus. Find all the parts in the diagram below.

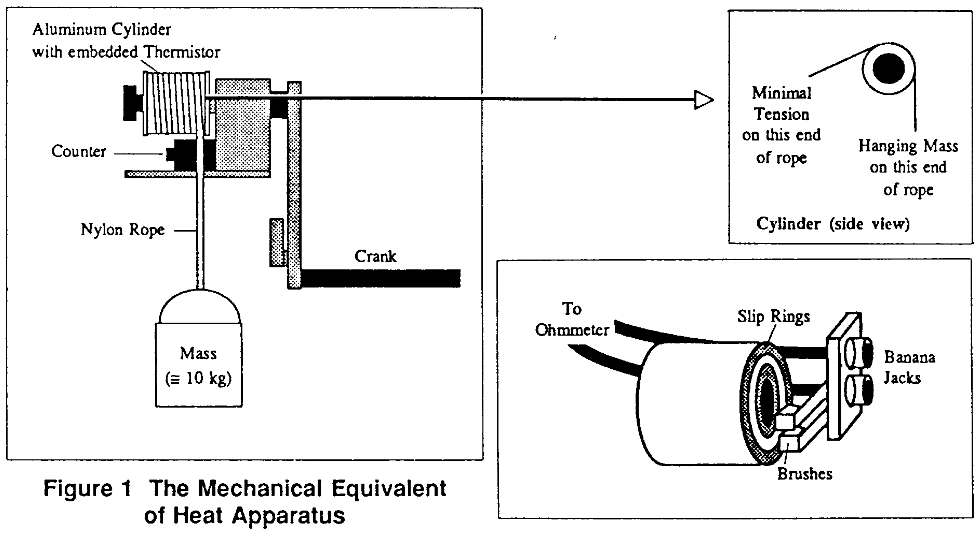


Figure 1 The Mechanical Equivalent of Heat Apparatus

A2. Note how sensitive the thermistor resistance is to the touch of your hot little hands, and how quickly or slowly thermal equilibrium is approached. Now you know the timescale of the response of this equipment.

A3. When confident, unscrew the black knob that holds the aluminum cylinder in place and weigh the cylinder. Measure its diameter alone, and the diameter of the cylinder plus rope, when tightly wound.

A4. Weigh the "10 kg" mass to 3 significant figures.

B. "Quick and Dirty" Run

B1. Note the approximate initial temperature of the aluminum cylinder. Look-up what thermistor resistance corresponds to a "target" final temperature about 8 Celsius degrees higher. Your aim is to do enough mechanical work to heat up the aluminum cylinder to the target temperature.

B2. Reset the counter. Enter the actual initial temperature in your data sheet and start cranking vigorously! Now you are finally getting "physical" in your physics class!

B3. When you get to your target temperature, stop cranking BUT DO NOT LET GO OF THE CRANK. Allow the "10 kg" weight to drift to the floor before slowly returning the crank to its equilibrium position. **Do not let go prematurely** or the crank will snap back, possibly damaging the plastic clicker and invaluable body parts.

Continue to watch the thermistor resistance carefully and enter in your data sheet the lowest value (highest temperature) it drifts to.

B4. Record the total number of turns and complete the calculations called for in your data sheet.

C. Serious Run

Even when done by an expert student, one of the major sources of error in Procedure B is that some of the heat generated will go to heat up the surroundings rather than the aluminum cylinder. To counteract this, in this procedure you will precool the cylinder so that during your run the temperature of the block will be as much below room temperature as above it. Then there should be as much heat gained from the surroundings as lost to them. It is by tricks of this nature that successful experiments are accomplished.

C1. Note the temperature of the room. Plan your target initial and final temperatures to be about 8°C below and above room temperature, respectively.

C2. Remove the aluminum cylinder and cool it in the ice chest provided. Use plastic baggies, if available, to prevent wetting. You may not need to cool it all the way to 0°C. In any event, the heat from your hands can now be skillfully used to make-up for too much precooling.

NOTE: Carefully dry any condensed water from the aluminum cylinder with the tissue paper provided. Do this before re-wrapping the friction rope. Evaporating water could carry away a considerable amount of heat; heat that would otherwise go to warm up the aluminum.

Now, re-assemble the apparatus, reset the counter and get ready. Watch the ohmmeter carefully as the thermistor resistance drifts toward your predesignated "target" for the initial temperature. When it gets there, start cranking vigorously.
Crank until the temperature reaches approximately one degree short of your designated final temperature. Then crank slowly until you reach your target. Record the actual maximum temperature (minimum resistance) reached. Record the total number of turns. **REMEMBER THE SAFE STOPPING PROCEDURE. A MISTAKE CAN RESULT IN YOUR HURTING YOURSELF.**

C3. Compute the work done, the heat input, and the mechanical equivalent of heat as guided by your data sheet. Compute the percent deviation from the accepted value.

D. Consider the possible reasons (mechanisms) why your answer is different from the accepted value. Do you have any suggestions to improve this experiment?

Resistance versus Temperature for your thermistor:

Res. (□)	T (□C)	Res. (□)	T (□C)	Res. (□)	T (□C)	Res. (□)	T (□C)
351,020	0	95,447	26	30,976	52	11,625	78
332,640	1	91,126	27	29,756	53	11,223	79
315,320	2	87,022	28	28,590	54	10,837	80
298,990	3	83,124	29	27,475	55	10,467	81
283,600	4	79,422	30	26,409	56	10,110	82
269,080	5	75,903	3	25,390	57	9,767.2	83
255,380	6	72,560	32	24,415	58	9,437.7	84
242,460	7	69,380	33	23,483	59	9,120.8	85
230,260	8	66,356	34	22,590	60	8,816.0	86
218,730	9	63,480	35	21,736	61	8,522.7	87
207,850	10	60,743	36	20,919	62	8,240.6	88
197,560	11	58,138	37	20,136	63	7,969.1	89
187,840	12	55,658	38	19,386	64	7,707.7	90
178,650	13	53,297	39	18,668	65	7,456.2	91
169,950	14	51,048	40	17,980	66	7,214.0	92
161,730	15	48,905	41	17,321	67	6,980.6	93
153,950	16	46,863	42	16,689	68	6,755.9	94

146,580	17	44,917	43	16,083	69	6,539.4
95						
139,610	18	43,062	44	15,502	70	6,330.8
96						
133,000	19	41,292	45	14,945	71	6,129.8
97						
126,740	20	39,605	46	14,410	72	5,936.1
98						
120,810	21	37,995	47	13,897	73	5,749.3
99						
115,190	22	36,458	48	13,405	74	
109,850	23	34,991	49	12,932	75	
104,800	24	33,591	50	12,479	76	
100,000	25	32,253	51	12,043	77	

LABORATORY EXERCISE # 11

DATA SHEET : Mechanical Equiv. of Heat

Date:_____________

Name:________________________________ Partners:____________________

Instructor's Signature:__________________

A. Fixed parameters

Specific heat of Aluminum, c = 0.220 kcal/kg□C Mass of Aluminum cylinder, m = ___

Diameter of cylinder, D_1=_________ Diameter of cylinder plus rope, D_2=_______

Average, Do = (D_1 + D_2)/2=_________ Average Radius, R = Do/2=_________

Mass of "10 kg" mass, to 3 significant figures, m=__________kg

Weight of "10 kg" mass, to 3 significant figures, F=__________Newtons

B. "Quick and Dirty" Run

B1. Approximate *initial* temperature: Thermistor Resistance =_________

Corresponding Temperature = __________

"Target" *final* temperature: Target Temperature =_________

Thermistor Resistance=__________

B2. Actual *starting* temperature: Thermistor Resistance =__________

Corresponding Temperature =________

B3. Actual *final* temp.: Thermistor Resistance =__________

Corresponding Temperature =___________

B4. Number of turns, N =__________ Total angle, □ = 2□N=___________radians

B5. Computed total work you did, W = F R □ =___________Joules

Computed heat input to Aluminum cylinder, Q = mc□T = ___________kcal

Your computed Mechanical Equivalent of Heat, (ratio of above two results):_______________

What is the percent deviation of your result from the accepted value of 4186 J/kcal?

____________ %

C1. Room Temperature today____________□C

Target initial temperature____________□C

Corresponding Thermistor Resistance__________□

Target final temperature_____________□C

Corresponding Thermistor Resistance____________□

C2. Actual initial temp.:
Thermistor Resistance =__________ Corresponding Temperature = ___________□C

Actual final temp:
Thermistor Resistance =__________ Corresponding Temperature = ___________□C

Number of Turns__________Total angle, □ = 2□ N =____________radians

C3. Compute the total work you did against friction:

W = FR□ = ___________Joules

Compute the amount of heat that must have been transferred to the Aluminum,

Q = mc□T = ____________kcal

Compute the Mechanical Equivalent of Heat and the percent deviation:

D. Did you do better in Part C than in Part B? If not, what went wrong? Give reasons.

LABORATORY EXERCISE # 12

Boyle's Law

Objectives

To study how changing the pressure on a gas makes the volume change. To compare your results with those obtained by Bobby Boyle.

Equipment and Supplies

A sample of air trapped at the bottom of a glass tube by a short column of mercury.
A ruler to measure the length of the air column.
A barometer somewhere in the room.

Discussion

According to Robert Boyle, if the temperature of a fixed amount of gas is not allowed to change, the following relationship will hold as the *volume, V,* and the *pressure, P,* are changed:

$$P \cdot V = \text{a constant number} \qquad (1)$$

The value of the constant depends on the number of moles of gas, the temperature, and the particular units used to measure Pressure and Volume. Boyle's Law accurately describes the constancy of the pressure-volume product for most common gases at moderate temperatures and pressures. Deviations from this Law may become significant if the pressure is too high or the temperature is too low. These limiting values vary drastically with different gases. For example, hydrogen obeys Boyle's Law at -200°C and 100 atmospheres; sulphur dioxide does not at 20°C and 1 atmosphere.

The apparatus for this experiment is elegant in its simplicity. The short mercury column in the glass capillary serves two purposes. First, it serves as a leak-proof piston to isolate your gas sample. Second, it provides additional pressure on the gas sample as the glass tube is inclined. By varying the vertical orientation of the glass tube, you can vary the pressure of the gas sample. To see how this works, note that the absolute pressure of the enclosed air in Figure (1a) is,

$$P = P_{atm} + \rho g\,(Y_1 - Y_2) \qquad (2)$$

where P_{atm} = atmospheric pressure,
ρ = the density of mercury, 13,000 kg/m^3, and
Y_1 and Y_2 = the *vertical* heights of the ends of the mercury column.

If atmospheric pressure is expressed in centimeters of mercury, call it B cm of Hg, (obtained directly from the mercury barometer at the end of your lab room) then the absolute pressure of the gas sample of Fig (1a) can be simply written as,

$$P = \rho g\,(B + Y_1 - Y_2) \qquad (3)$$

Life is

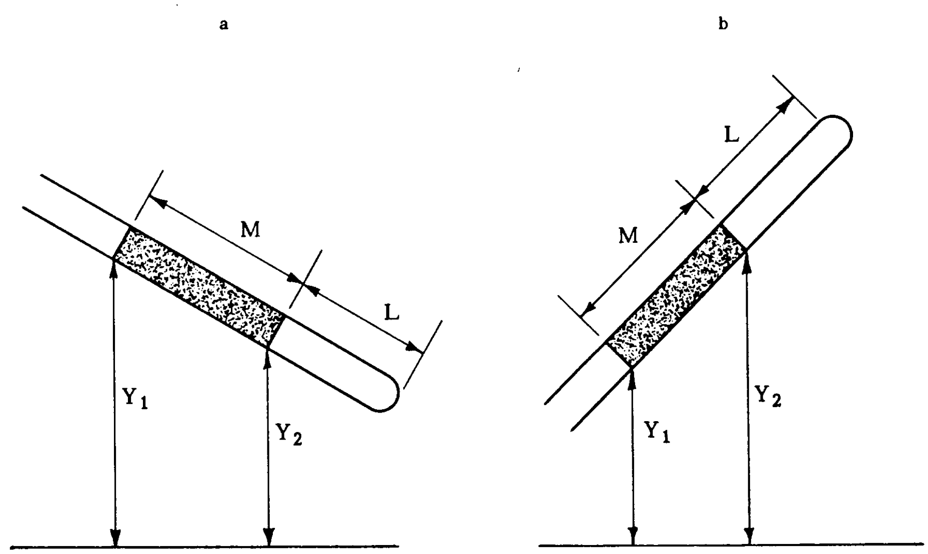


Figure 1.

M = Length of mercury column
L = Length of air sample

simplest if you express the pressure of the gas in units of cm of Hg instead of N/m^2. Equation (3) becomes,

$$P = B + Y_1 - Y_2 \qquad (4)$$

Now, for one more simplification: Because the cross-sectional area of the capillary is a constant, the volume of the gas is directly proportional to its length, *L*. As a result, Boyle's Law for your gas in the capillary is simply,

$$(B + Y_1 - Y_2)\, L = a\ constant\ number \qquad (5)$$

Note: When the open end of the capillary is lower than the closed end, ($Y_1 - Y_2$) is negative. See Figure (1b). As Equation (4) predicts, in that case the pressure of the gas will be *less than* atmospheric pressure. So, the extremes of pressure you can obtain are B + M and B - M.

Procedure

1. *Measure atmospheric pressure in cm of Hg using the classroom barometer.*
Locate the barometer, examine its parts. Adjust the barometer so that the surface of the mercury in the cup at the bottom of the instrument just touches the apex of the ivory cone. This marks the zero point of the barometer scale. Next, align the lower surface of the vernier slide with the top of the mercury column. (Use the top of the meniscus). Record the mercury level in your Data Sheet. Some days the pressure can change measurably during the course of the experiment; take another reading at the end of the lab period and use the average value if you notice a change.

2. *Measure the length of the air column as you vary the pressure of the gas.*
For ten positions of the apparatus, chosen to yield approximately equal increments of pressure, record the length, *L*, of the air column, and the heights Y_1 and Y_2. Two of the positions must correspond to the extremes of pressure. **Note: The best way to measure *L* is to measure the positions of the endpoints of the air column,** $L = X_1 - X_2$.

Calculations and Conclusions

1. *Plot P vs. L and P□L vs. L on a single sheet of graph paper.*
Calculate the product *P□L* for each value of *L* you chose, then plot the graphs requested. Suppress the origin of the abscissa so that the range of *L* observations covers the horizontal scale. Do not suppress the origin of the ordinates, otherwise the experimental errors will be magnified on the graph. Draw a smooth curve through the *P vs. L* points. Draw the best straight line through the *P□L vs. L* points. Which graph is better suited to judge how well your data follows Boyle's Law?

2. *Plot P vs. 1/L.*
Draw the best straight-line fit through the origin, representing "the theory", i.e., Boyle's Law. How well does your data follow the accepted theory? Comment on possible reasons for disagreement, if there is any in your case.

LABORATORY EXERCISE # 12

Boyle's Law: Data

Date ______________

NAME:______________________________Partners:________________________

Instructor's Signature:____________________

Boyle's Law

	B (Air Pressure, cm of H)	Temperature °C
Trail #!		
Trail #2		
Average		

Length of mercury column, M=______________________________

Trial #	X_1 cm	X_2 cm	$L=\Delta x$ cm	Y_1 cm	Y_2 cm	$\Delta Y = Y_1 - Y_2$	P, cm $=B+\Delta Y$	P x L cm^2

LABORATORY EXERCISE # 13

Part I: Heat of Fusion of Ice

Objective

To determine the heat of fusion of ice by the method of mixtures.

Equipment and Supplies

Calorimeter, balance, thermometer, ice cubes.

Discussion

The change of a substance from the solid to the liquid state, called melting or fusion, takes place at a definite temperature characteristic of each substance. During the transition no change in temperature occurs. To bring about this change of state a definite amount of heat must be supplied from the surroundings for each unit mass melted. This quantity of heat is called the *(latent) heat of fusion* of the substance.

Thus the amount of heat required to melt a solid of mass m and heat of fusion H_f *without changing its temperature is* mH_f *.*

This is also the amount of heat given up to the surroundings when the liquid changes to the solid state. In the metric system H_f is measured in calories/gram or kilocalories/kilogram. (Numerically these are the same.)

If two substances at different temperatures are mixed in a container thermally insulated from its surroundings, the final temperature of the mixture will be between the original temperatures. From the principle of the conservation of energy, the heat lost by the warmer substance must equal the heat gained by the colder:

Heat gained by colder body = Heat lost by warmer body

To determine the heat of fusion of water by this method of mixtures, a piece of ice at 0° C is dropped into a calorimeter containing warm water. The initial temperature of the water, its final temperature after being cooled by the ice and the masses of the ice, warm water and calorimeter are measured. If the specific heat of the calorimeter is known, the heat of fusion of water may be determined using the fact that the heat absorbed by the ice in melting, plus the heat needed to raise the temperature of the resulting cold water to the final temperature of the mixture equals the heat lost by the warm water and calorimeter:

$$[\, m H_f + m c \,\Delta T \,]_{ICE} = [\, m' c \,\Delta T'']_{WARM\ WATER} + [\, m'' c'' \,\Delta T'']_{CALORIMETER}$$

Here, m, m' and m'' are the masses of the ice cube, the warm water and the calorimeter, respectively. Also, c and c'' are the specific heats of water and aluminum. Finally, ΔT is the temperature rise of the ice, while $\Delta T''$ is the temperature fall of the warm water.

Procedure

1. Weigh the inner calorimeter vessel and stirrer, fill it approximately two-thirds full of water about five degrees above room temperature and weigh again to determine the mass of the water. Place the calorimeter vessel inside the calorimeter and insert a thermometer to determine the temperature of the water and vessel.

2. Stir the water in the calorimeter well and record its temperature. Dry an ice cube, place it in the water, replace the calorimeter cover and, when the ice has melted, stir the water and record its final temperature.

3. Weigh the calorimeter vessel, stirrer and contents to determine the mass of the ice used.

Calculations and Questions

A. Calculate from your data the heat of fusion of water.

B. Compare the value found in A and the generally accepted value for the heat of fusion of water.

C. Why was it desirable to have the initial temperature of the water slightly above the temperature of the room?

Note: The data sheet for this experiment and the next are combined into one. You will find it following the next experiment.

LABORATORY EXERCISE # 13

Part II: The Specific Heat of a Metal

Objective

Determine the specific heat of a metal by the method of mixtures.

Equipment and Supplies

Calorimeter, steam boiler, metal shot, balance, two thermometers, small beaker.

Discussion

The "specific heat", *c*, of a substance is the amount of heat required to raise the temperature of a unit mass one degree. If the specific heat is independent of the temperature[**], the amount of heat, *Q*, required to raise the temperature of a substance whose mass is *m* and whose specific heat is *c*, from an initial temperature T_i to a final temperature T_f, is,

$$Q = m\,c\,(T_f - T_i) = m\,c\,\Delta T$$

Since the calorie (kilocalorie) is defined as the amount of heat required to raise the temperature of 1 gram (1 kilogram) of water 1° Celsius from 14. 5° to 15. 5°, the specific heat of water is 1 cal/gm °C (1 kilocal/kgm °C).

If two substances at different temperatures are mixed in a container thermally insulated from its surroundings, the final temperature of the mixture will be between the original temperatures. From the principle of the conservation of energy, the heat lost by the warmer substance must equal the heat gained by the colder:

Heat gained by colder body = Heat lost by warmer body.

You will determine the specific heat of a metal by this method of mixtures. A mass of metal pellets at a high temperature is dropped into a calorimeter containing cold water. You will measure the initial temperature of the metal pellets and of the water, the final temperature of the mixture and the masses of the components (metal pellets, water and calorimeter.) If the specific heat of the calorimeter is known or if the calorimeter is made of the metal whose specific heat is being determined, the specific heat of the metal may then be determined by using the fact that the heat lost by the metal must equal the heat gained by the water and the calorimeter.

[**] Specific heats actually vary slightly with temperature. However, for the range of temperatures encountered in this experiment and for the expected precision, this variation may be safely neglected.

Procedure

1. Heat the water in the boiler. Weigh the boiler cup, fill it approximately two-thirds full of metal pellets (copper or aluminum) and weigh again to determine the mass of the pellets. Place the cup in the boiler and insert a thermometer in contact with the pellets.
2. While the metal pellets are heating, weigh the inner calorimeter vessel and stirrer, fill it approximately two-thirds full of water which is a few degrees below room temperature and weigh again to determine the mass of the water. Place the calorimeter vessel inside the calorimeter and insert a thermometer to determine the temperature of the water and vessel.

3. When the temperature of the metal pellets has become stationary at nearly 100°C, record its temperature and that of the water in the calorimeter. Be sure that the water has been stirred well. Then quickly pour the shot into the water being careful that no water is splashed out. Replace the calorimeter cover, stir well and record the highest temperature to which the water rises.

4. If the calorimeter is not made of the same metal as the shot, obtain from your instructor the specific heat of the calorimeter. (The calorimeter is made of aluminum.)

Calculations and Conclusions

A. Calculate from your data the specific heat of the metal used.

B. Compare the value found in A with the generally accepted value for the specific heat of the metal used.

C. Why was it desirable to have the initial temperature of the water slightly below the temperature of the room?

LABORATORY EXERCISE # 13

Data Sheet for both calorimetry Labs Date ____________

Name:______________________________Partners:______________________________

Instrutor's Signature:_________________

Calorimetry (1): Heat of Fusion of Water

1. (a) Mass of calorimeter & stirrer:_________________________________gm

(b) Mass of calorimeter and stirrer 2/3 full of water:__________________gm
{water is ~5□ above room temperature}

(c) Mass of water (difference of above two masses): _________________gm

2. (a) Initial temperature of water, calorimeter & stirrer:__________________□C

{Here, you added towel-dried ice cubes}

(b) Final temperature of water, calorimeter & stirrer and melted ice:______□C

(c) □*T* , temperature change, from the above two temperatures:_________□C

3. (a) Final mass of calorimeter & stirrer, original water plus melted ice:_____□C

(b) Mass of ice cubes {line 3(a) minus line 1(b)}:_____________________gm

Do not empty or add more water!
All will be used "as is" for the next exercise (# 14).

Calorimetry (2): The Specific Heat of a Metal

4. (a) Initial mass of boiler cup:____________________________________gm

(b) Mass of cup plus metal pellets:_______________________________gm

(c) Mass of metal pellets {line 1(a) minus line 1(b)}:__________________gm

5. (a) Mass of calorimeter & stirrer {same as line 1(a) from other side}:_____gm

(b) Mass of calorimeter & stirrer and cool water:_____________________gm
{same as line 3(a) if no water was added or removed}

(c) Mass of water { line 5(b) minus line 5(a)}:_______________________gm

6. (a) Temperature of hot metal pellets:______________________________°C

(b) Initial temperature of water and calorimeter & stirrer:_______________°C

(c) Final highest temperature of mixture:___________________________°C

7. (a) Specific heat of calorimeter & stirrer:______________________cal/gm°C
{given by instructor, if needed}