Physics 123L
Lab Manual

Katherine Rawlins
University of Alaska Anchorage

Spring 2018 Edition

Table of Contents

Administrative information and Grading

Prerequisites:

Prerequisites: PHYS A123 or concurrent enrollment
Registration Restrictions: High school trigonometry.

Contact Information:

If you have concerns or issues that need addressing…
1) Start with your lab instructor and see if your concerns can be resolved at that level. If you need further assistance,
2) Contact the physics lab manager:
Daniel Koepke dkoepke@alaska.edu, 786-1237, NSB 211, *or*
the physics department chair:
Dr. Katherine Rawlins krawlins@alaska.edu, 786-1709, CPISB 202G

Grading and Attendance Policy

Your grade for the course will be determined approximately by:

Prelab assignments	10%
Lab Reports	50%
Lab Final and midterm exam	20% each

There may also be some small adjustment in grades to ensure consistent and fair grading between the different sections.

Nondiscrimination Policy

The University of Alaska is an affirmative action/equal opportunity employer and educational institution. The University of Alaska does not discriminate on the basis of race, religion, color, national origin, citizenship, age, sex, physical or mental disability, status as a protected veteran, marital status, changes in marital status, pregnancy, childbirth or related medical conditions, parenthood, sexual orientation, gender identity, political affiliation or belief, genetic information, or other legally protected status. The University's commitment to nondiscrimination, including against sex discrimination, applies to students, employees, and applicants for admission and employment. Contact information, applicable laws, and complaint procedures are included on UA's statement of nondiscrimination available at www.alaska.edu/titleIXcompliance/nondiscrimination.

Ground Rules

1) **Attendance is expected at every lab**. If you are going to miss a lab, it *may* be possible to move to a different lab period or make it up later, *only* if you talk to your instructor ahead of time and clear it with all parties involved. If you miss a lab you will be given a zero for that lab. In addition, you need to show up on time, as the lab instructor will go over material pertinent to the lab at the beginning of the lab period.

2) **Pre-lab assignments are due at the start time of the class.** All of the pre-labs for this course are electronic, and accessible through Blackboard. The computer will not accept submissions late.

3) **Lab reports are due at the end of the class**; hand it in before you leave the room. They should be written and assembled according to the "**PHYS 123L/124L Lab Report Style Guide**", available separately on Blackboard. Review this document ahead of time, for guidance on the proper format for a lab report.

4) **Copying** from other students, from previous lab reports, or the internet, **is strictly prohibited**. This applies to prelabs, lab reports, and exams. You are NOT allowed to bring in another student's report into the lab. (This includes electronic files, template spreadsheets, capstone files, usb drives etc.) This even applies to reports that you yourself may have written if you have taken the class before; your report is to be a record of the experiment you are doing at the time. **Copying is cheating**; it will be reported to the Dean of Students, and could result in a range of penalties, from a reduced score or zero on an assignment, to a failing grade or dismissal from the class.

5) At the end of the lab period, **straighten up your lab station** ("leave it as you found it, if not better"), and follow any specific clean-up instructions from the manual or your instructor.

6) This lab manual will serve as the **syllabus** for the course.

7) **Lab Exams**: There will be a mid term and final lab exam during the fall and spring semesters. (The summer session will only have a final exam.) The exams will cover lab skills using questions, problems, and hands on activities.

8) **Blackboard:** The course syllabus (which will be the lab manual), course schedule, pre-labs, additional weekly materials, and course announcements will be found on Blackboard. Be sure to check Blackboard weekly for timely announcements that pertain to your lab. Also, be sure to maintain your UAA email account so that mail sent by your instructor can reach you.

Goals and outcomes

1. Instructional Goals

1. To help students understand the basis of knowledge in physics. Instructor will guide students to distinguish between inferences based on theory and on the outcomes of experiments.

2. To reinforce the concepts covered in the PHYS A123 lecture.

3. To provide students with measurement techniques and other experimental skills useful in the study of physical phenomena. The tools to be used include rulers, micrometers, sonic range finders, force sensors, video analysis and computerized data collection equipment. The instructor will provide hands-on supervision of the student's use of these tools in a laboratory setting.

4. To provide the student with data analysis techniques using computers. These include graphing, curve fitting, modeling and statistical analysis. The instructor will provide hands-on supervision of the student's use of these methods in a laboratory setting.

5. To provide the student with an appreciation of uncertainties in measured quantities and uncertainty analysis techniques.

6. To help students develop collaborative learning skills in the investigation of physical phenomena. The instructor will provide hands-on supervision and guidance to students working in small groups in a laboratory setting.

7. To provide opportunities for students to gain familiarity and experience with the equipment and procedures of a college level physics laboratory.

2. Student Outcomes and Assessment Measures

The students in this physics lab course will be able to:

Outcomes	**Measures**
design and conduct experiments and draw inferences from their observations.	Weekly lab reports.
demonstrate competency applying Newton's laws to physical situations.	Weekly lab reports and hands-on midterm and final exams.
demonstrate hands-on competency in using measuring devices.	Performance in a laboratory setting.
Demonstrate the hands-on competency in using computers to analyze data.	Performance in a laboratory setting.
estimate the uncertainty in all physical measurements and will propagate this uncertainty to their final, calculated results.	Weekly lab reports and exams.
collaborate in small groups to set up equipment, take measurements and analyze data.	Performance in a laboratory setting.
describe the equipment and safety procedures of a college level physics laboratory.	Demonstrated compliance with laboratory safety procedures and correct operation of equipment under the direction of physics laboratory personnel.

Lab Safety Guidelines

1. No food or drinks are allowed in lab.
2. Place all books, coats, back packs in a neat organized manner in the entertainment center at the back of the lab.
3. No horseplay or unauthorized experiments are allowed in lab.
4. Read through all lab procedures and ask questions if you have any safety concerns.
5. Pets are not allowed in the lab. Children, friends, or visitors are not allowed in the lab.
6. Appropriate attire is required. No open toed shoes or sandals are allowed.
7. Eye protection must be worn during some laboratory experiments such as launching projectiles. If asked to wear eye protection students must comply.
8. Know the location of the fire extinguisher, the telephone, the building name and room number, fire blanket, safe room and nearest exit. (These items will be pointed out to students on the first lab meeting. If you miss the first lab meeting be sure to ask your instructor where these are when you attend your first lab.)
9. Reports any injuries, incidents or damaged equipment to your laboratory instructor or the lab coordinator.
10. No equipment is to be taken outside of the lab. This especially refers to the strong rare earth metal magnets.
11. During a fire alarm students should exit immediately as a class through the nearest exit and proceed to the parking garage or SSB as needed depending on the weather. Roll will be taken when the class has gathered outside of the building.
    During an earthquake take cover under the bench tops or doorways until the earthquake subsides.
12. If the power should go off the room will become very dark, so stay where you are and listen for instructions from your instructor. There should be a flashlight at the instructor's desk.

Dean's safety letter

August 1, 2012

Dear Science Students,

We join with our faculty in welcoming you to the study of science. As part of our university 's commitment to promote and protect the health and safety of our students, our employees, and the environment, the College of Arts and Sciences has developed rules and policies for laboratory safety. The Chemical Hygiene Plan uses a "Safety First Philosophy" as a requirement for education and also industry. We train for the future.

We expect that you will read the Laboratory Safety Agreement and Procedures carefully and ask questions about those that are unclear. Signing the agreement means that you have read, understand, and agree to follow the rules at all times.

The following sanctions represent the minimum response to violations of the Laboratory Safety Agreement and Procedures:

- First offense – a verbal warning with a written record kept of the warning in the laboratory manager's office. Should the student not violate the rules and procedures again the written record will be removed from the file at the conclusion of the semester.
- Second Offense- a written warning with the rule reviewed and a statement signed by both the student and the instructor stating that the rule is understood and will be followed
- Third Offense – a temporary restriction from attending the lab until a conference is held with the student, the laboratory manager, and the instructor. The student will decide whether he or she will sign an agreement to consistently adhere to the rules and procedures from that point forward. Should the student refuse to sign the agreement, the temporary restriction from being in the laboratory will continue and the student will be referred to the Dean of Students for formal university disciplinary action for violation of the UAA Student Code of Conduct, which may include permanent removal from the course.
- Fourth offense- Should the student sign the agreement upon the third offense and fail to strictly adhere to the rules and procedures, the student will be temporarily restricted from being in the laboratory and referred to the Dean of Students for formal university disciplinary action for violation of the UAA Student Code of Conduct, which may include permanent removal from the course.

Science is an exciting, fun, and safe field of study if one follows the prudent practices outlined in the Laboratory Safety Agreement. Thank you in advance for adopting the "Safety First Philosophy", adhering to the Laboratory Safety Agreement and Procedures and making our labs a safer place for all. We wish you a positive, healthy, and safe learning experience.

Sincerely,
John R. D. Stalvey, Ph.D
Dean, College of Arts and Sciences

How should I prepare for lab?

The lab period is two hours and forty-five minutes long. In that time, you must do the experiment, analyze the data, and write a report on what you did. The labs have been planned in such a way that it is possible to get done with time to spare, but only if you come prepared. In preparing, you should:

Read through the lab write-up before class and try to understand what you will do. Don't spend a lot of time trying to figure out details of the equipment. Rather, determine what physical laws and principles will be examined. If you don't understand a physical principle, look it up in your text and read about it. The labs are not intended to teach you the physical principles from scratch.

PRELAB ASSIGNMENTS are designed to get you thinking about the week's lab ahead of time. All the prelab assignments for this course are electronic, and accessible through Blackboard. Click on the test to see the due date/time, and other specifications about the test. Then click on "Begin" to read and begin the prelab. You can click "Save" at any time to save your work without submitting. Click on "Save and Submit" when the whole prelab is done. These assignments are due promptly at the beginning of class, and the computer will not accept submissions late.

What should I bring to lab?

In addition to this lab manual you will need the following materials in lab:

- Calculator with trig functions (If you are comfortable using computer-based math programs you will not need a calculator)
- Ballpoint or ink pen
- Pencil
- Paper

You need to bring these materials with you to the first experiment.

Significant figures, rounding, and percent difference

I. **Significant figures**: This is a "cheap and easy" way to indicate how precisely you have measured something (the "uncertainties"). The example below is designed as a refresher for significant figures.

How many sigfigs do these numbers have?

number	# of significant figures	explanation
0.000042	2	The zeroes in this case are place holders and are not considered significant.
4.000002	7	Here the zeros are counted as significant between the 4 and the 2.
4.200	4	Here the zeroes are again significant, indicating the quantity is known to the nearest 1/1000.
4×10^2	1	A good way to unambiguously display significant figures is to use scientific notation. In this example, there is just one sigfig.
400	3,2,or 1	It is not clear how well known this quantity is, it may be good to the nearest 100th, 10th, 1.

II. **Rounding:** If a calculation involves several steps, round off to the proper number of significant figures ONLY at the end of the calculation, for the final result. Round up when the first number to be discarded is greater than or equal to five. You should not gain significant figures when performing a calculation.

Example: Finding an area

Correct: Area = 3.7 m x 4.8 m = 18. m^2
Incorrect: 17.760 m^2 ← too many significant figures

Example: Finding a volume

Correct: Volume = 3.7 m x 4.8 m x 5.2 m = 92 m^3
Incorrect: Volume = 18 m x 5.2 = 94 m^3 ← rounded off the "18" too early

III. Percent discrepancy and percent difference

A "quick and easy" way of estimating how good a measurement was, is by comparing it to a second measurement and computing the difference, as a *percentage*. There are two slightly different ways of doing this, depending on the two numbers being compared.

% discrepancy: Use this when comparing YOUR measurement to some KNOWN quantity, for instance, your measurement of "g" to the known value:

$$\% discrepancy = \frac{|known - measured|}{known} \times 100\%$$

Example: $g_{meas} = 8.65\ m/s^2$ $g_{known} = 9.82\ m/s^2$
% discrepancy = $(g_{known} - g_{meas})/g_{known}$ x 100% = 11.9 % Note: This should be rounded to 12%

% difference: Use this when comparing two measurements that are BOTH YOURS (and you don't know which one is "right", or "better"), for instance two different ways of determining an unknown acceleration.

$$\% difference = \frac{|value1 - value2|}{average} \times 100\%$$

Example: $a_1 = 2.35\ m/s^2$ $a_2 = 3.01\ m/s^2$
% difference = $(a_2 - a_1)/[1/2*(a_2+a_1)]*100\%$ = 24.6 % which should be rounded to 25%

First week: Safety Briefing, and Introduction to Spreadsheets

Abstract:
This is a short introductory activity for learning the basics of Microsoft Excel. We'll do this activity the first week of class, after the safety briefing.

Goals:
Learn how to type in simple equations using Excel, copy and paste formulas.

Equipment: None	**Software:** Excel
	Group size: Individual
	What to turn in at the end: Nothing

Procedure:

The goal of this exercise is teach students basic Excel skills. Students will have available to them an Excel template that they will need to complete. The template will be available on blackboard at the start of the semester. Students may practice on the template before coming to class but will have to complete the assignment starting with a blank template once class begins. The instructor will give guidance using Excel individually and with the aide of an overhead projector.

EXPERIMENT # 1: Introduction to Capstone

Abstract:
This introductory lab will introduce the "Capstone Interface" and associated software for taking data using sensors. A motion sensor will be used to explore concepts of position, velocity, and acceleration.

Goals:
Learn how to set up the interface to make measurements, to include adjusting sensor sampling rates, making graphs, and doing fits to the graphs.

<table>
<tr><td rowspan="3">Equipment:
Pasco 850 interface, meter stick, motion sensor</td><td>Software: Capstone</td></tr>
<tr><td>Group size: Individual</td></tr>
<tr><td>What to turn in at the end:
Abbreviated lab report, containing:
-- cover page
-- three motion graphs, and associated calculations for each</td></tr>
</table>

Introduction:
The first thing to accomplish is to become familiar with the locations and names of the various pieces of equipment. Refer to Figure 1.

Figure 1 – Physics Lab Computer and Interface Arrangement

The box resting above the power outlets in Figure 1 is referred to as the Pasco 850 Universal Interface and will be referred to as "the interface" from here on out. The interface connects the computer to the probes/instruments that collect data. The power switch is located on the front of the interface and will display a bluish light when on.

Logging On:
At this point go ahead and turn on the interface, the computer and the monitor. When ready to log on, press (ctrl-alt-delete). Enter the following information.

User id:	UAA student logon id (ex: fmsurname)
Password:	UAA student logon password (the same password used to log onto Blackboard)

Next, click on the Pasco Capstone icon located on the computer desktop. If asked to do a firmware upgrade click yes.

In this lab, we'll experiment with a *motion sensor*. The motion sensor is used to display position, velocity and acceleration vs. time data graphically. To do this the motion sensor sends out ultrasonic sound waves and times how long the waves take to bounce off a target and return. The time taken for the round trip is multiplied by the speed of sound to get the distance for the round trip. The distance to the target is then ½ of the round trip distance. Since the motion sensor uses a sound wave that reflects off of anything it encounters you must pay attention to the direction the motion sensor is pointed and to miscellaneous objects that may be in the path of the sound wave. If your position data is noisy check the aim of the motion sensor and be sure there are no objects (books, arms, hands etc.) in the way that may cause erroneous reflections. You can also adjust the motion sensor to short range or long range when trying to get a better signal. The motion sensor has a minimum and a maximum operating distance. The minimum distance is 15 cm and the maximum distance is 8 meters, however the maximum distance is limited by the sampling rate. For example at a sampling rate of 100 Hz the maximum range is ~ 1.8 m.

Getting Capstone running: This will be done as a group

Plug the yellow and black cords attached to the motion sensors into the digital inputs 1 & 2 on the interface. The yellow plug should be on the left, or digital input channel number 1.

On the left hand side under **tools** click on **Hardware Setup** and then left click on digital input channel 1 and choose the "Motion Sensor II". Click again on the **Hardware Setup** to get rid of the setup window.

Click here to add the sensor.

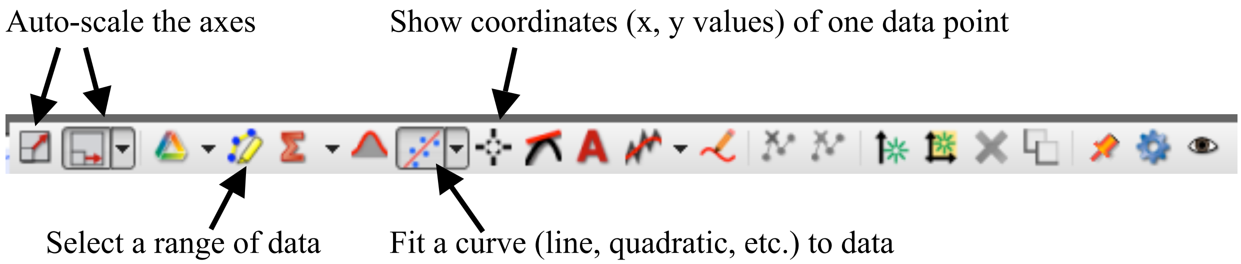
If the interface is communicating successfully with the sensor, it will appear in the "Hardware Setup" window as being connected with green lines. If it shows up connected with red lines, then something is wrong… perhaps the two plugs are backwards?

On the far right side under **Display** double click **graph** to create a single graph. On the vertical axis left click **Select measurement** and then choose **position**. You should now have a position vs. time graph.

Next note that the default sampling rate is set at 20 Hz. This is found on the menu below the graph next to motion sensor. Increase the rate to 50 Hz.

Because this is the first time using the motion sensor, perform a quick sanity check by placing an object a known distance from the motion sensor using a meter stick as the measuring device. A book (with a flat surface) makes a good target. Aim the motion sensor at the target and click record and then stop after about 5 seconds. Check to see that the graph displays the same distance as the meter stick. If the data appears noisy, it may be because the sensor is not aimed properly, or because the object's surface is curved or irregular. Adjust the aim of the sensor. Practice taking data while moving the object back and forth. You can delete practice runs after taking them.

We will be using this Capstone software throughout the semester, and it comes with many tools for analyzing data. Here is a brief summary of the tools we'll use most often. You will become more proficient with these tools as you use them.



Try this: adjust the scaling on the graph so that the data uses up as much of the graph area as possible ("auto-scale" the axes), using this button in the upper left corner of the window: .

Capstone Motion Projects: The following should be done individually.

Your next task will be to create and print out some position vs. time graphs that satisfy a set of conditions. For each plot, make some calculations based on the data you collect (see project details below).

You may find the "coordinates tool":  useful for these projects. Click on it and try it out!

You may discuss with the people at your table how these projects can be accomplished, but each student must create his or her own graph and do their own calculations.

Give each of your three graphs a unique title. Before printing, choose "landscape" under print setup, so that it prints out big and legible. Show all your calculations; you can write them directly on the graph, or on a separate piece of paper, as long as they are neat and the connection to the data on the graphs can be clearly understood by a reader.

Project #1:
Create a graph of motion in which:

- The target is at rest for approximately 5 seconds
- Then, the target moves away from the sensor at a steady speed for approximately 5 seconds
- Then, the target is at rest for approximately 5 more seconds.

Compute:

- The average speed of the target during the entire (approximately) 15 seconds.
- The average speed of the target during the time it was moving (the middle 5 seconds).

Project #2:

Create a graph of motion in which:

- The total time of recording is approximately 30.0 s.
- An overall average *speed* is approximately 5.0 cm/s during that time.
- An average *velocity* is approximately 0 cm/s during that time.

Compute:

- The overall average speed (using your data; it doesn't have to be *exactly* 5.0!)
- The average velocity (using your data; it doesn't have to be *exactly* 0.0!)

Project #3:

Create a graph of motion in which:

- The target is at rest for approximately 5 seconds
- Then, starting from rest, the target moves away from the sensor with a *constant acceleration* until it reaches the end of the table. (Note: this will be difficult to achieve precisely by moving the target by hand. Try to get a graph that looks roughly like a *parabola* and don't worry about getting it perfect.)

Fit the parabola:

- Use the range selection tool  to draw a box around the part of the data which is parabolic. The selected data will get "highlighted" inside the box. Then, use the curve fitting tool  to fit the data to a Quadratic function. Be sure that the three fit coefficients (A, B, and C) are displayed. (No actual calculations here.)

Turn in at the end of the lab: a "cover page" with essential information on it (such as your name, experiment title, date, section, etc.), and the graph and calculations for each of the three motion projects. (No formal lab report.)

EXPERIMENT # 2: Vectors

Using a simple magnetic compass and measuring tape students will collect data needed to calculate the magnitude and direction of an unknown vector: the distance and direction between two trees. Students should become proficient in the following: drawing vectors to scale, breaking vectors into components, writing simple vector equations, adding vectors using the method of components and adding vectors graphically.

<table>
<tr><td rowspan="3">Equipment:
Compass, measuring tape, graph paper, protractor.</td><td>Software: Excel</td></tr>
<tr><td>Group size: Individual, although students will have to pair up to collect the data</td></tr>
<tr><td>What to turn in at the end:
Full lab report.</td></tr>
</table>

Figure 1: Students reviewing the use of their compass before starting the course

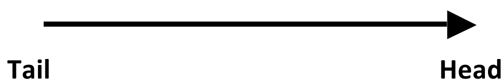
Introduction:
Vectors are quantities which carry information about the magnitude and direction of some physical measurement. In physics and engineering, vectors are indispensable tools and it is crucial that students master their use. This lab experiment makes use of simple measurements of position (including distance and angle) to illustrate the nature of vectors and their addition/subtraction.

Data will be collected outside the building (rain, snow, wind, or sunshine), so students must wear appropriate clothing depending on the weather. Expect to be outside approximately 30 minutes. And as usual here in Anchorage, watch out for moose!

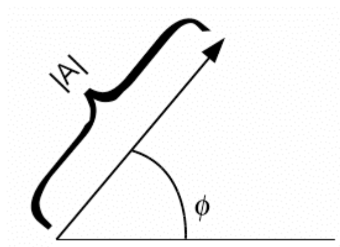
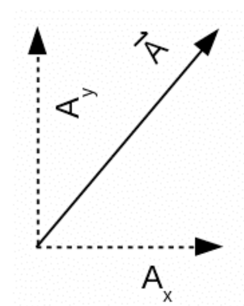
Review graphic vector addition (head to tail) as well as the component method before coming to lab. There is a detailed example at the end of this lab for the student's convenience. The pre lab exercise will aid in the review process and is due at the beginning of the lab. In constructing the lab report, be sure to attach sketches or any other pertinent information to the data tables. Pay attention to **significant figures**.

Review of Vector Theory:

A vector has a head and a tail. The head of a vector has an arrowhead and gives the overall direction or sense of the vector.



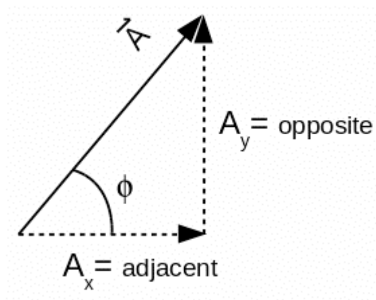
Vectors in general can be described in two ways: with a magnitude and direction, or as a pair of x- and y-components. With either description, two numbers are required to uniquely describe the vector.

Magnitude and direction	*X- and Y-components*
"Vector (A) has a length of 2.00 meters and points 60.0 degrees CCW from the positive x axis"	"Vector (A) points 1.00 meters East and 1.73 meters North"
$\|A\| = 2.00$ m, $\phi = 60.0$ degrees	$\vec{A} = 1.00\hat{i} + 1.73\hat{j}$ using $(\hat{i}, \hat{j})$ notation, or: $A_x = 1.00$ m, $A_y = 1.73$ m
Sketch: Label the vector, indicate the direction. Label the magnitude, and where the angle is measured from. 	Sketch: Label the vector, indicate the direction. Draw the two components, so as to form a right triangle with the vector as the hypotenuse. 

If you know the magnitude and direction, you can compute the x- and y-components using trigonometry:

$$A_x = |A|\cos(\phi)$$
$$A_y = |A|\sin(\phi)$$

(Note: to use these formulas as written, the angle "ϕ" must be defined in the "standard math class way": counter-clockwise from the x-axis, as shown below.)



If you know the x- and y-components, you can compute the magnitude and direction:

$$|A| = \sqrt{A_x^{\,2} + A_y^{\,2}}$$

…because the magnitude is the hypotenuse of a right triangle formed by A_x and A_y on the two sides.

$$\phi = \tan^{-1}\left(A_y / A_x \right)$$

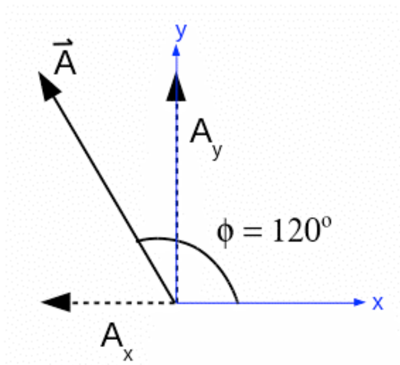
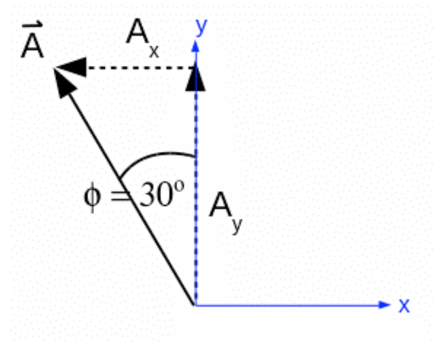
… because the opposite and adjacent sides of the right triangle are related to each other by the tangent of one of the angles of the triangle. *(Note: when computed this way, you get the angle defined in the "standard math class way": counter-clockwise from the +x axis.)*

"What if I want to use an angle that's NOT defined in the "counter-clockwise from the x-axis" way?"

You can! Trigonometry will still allow you to compute x- and y- components from the magnitude and direction, or compute the magnitude and direction from the x- and y-components. But rather than use the formulas above "as-is", you will have to figure out *your own* trigonometry relations, by drawing your triangle carefully (in particular, showing how the angle is measured) and using cosine = adjacent/hypotenuse, and sine = opposite/hypotenuse.

Example: The vector "A" has a magnitude of 2.0, and points 30 degrees West of North. Find its x- and y-components."

You can do this either using "standard math class convention" for angles, or by doing the trigonometry yourself.

Using angles CCW from x (East)	*Using a different angle*
Draw the vector:  	Draw the vector: 
Use standard formulas: $A_x = \lvert A\rvert\cos(\phi) = (2.00)\cos(120^0) = -1.00$ $A_y = \lvert A\rvert\sin(\phi) = (2.00)\sin(120^0) = 1.73$	Use your own trigonometry: $A_x = -\lvert A\rvert\sin(\phi) = -(2.00)\sin(30^0) = -1.00$ $A_y = \lvert A\rvert\cos(\phi) = (2.00)\cos(30^0) = 1.73$ *(Note: you have to see from your picture that A_x should be negative, and put the negative sign in by hand.)*
Going backwards: compute mag/direction (CCW relative to x-axis): $\phi = \tan^{-1}\left(1.73/-1.00\right) = 120^0$ $\lvert A\rvert = \sqrt{(-1.00)^2 + (1.73)^2} = 2.00$	Going backwards: compute mag/direction (relative to North): $\phi = \tan^{-1}\left(1.00/1.73\right) = 30^0$ $\lvert A\rvert = \sqrt{(-1.00)^2 + (1.73)^2} = 2.00$

As you can see, if done correctly, the answer is the same no matter which technique you choose!

Adding and Subtracting Vectors:

<u>*Mathematically, using x- and y-components:*</u>
When performing vector addition, only "like components" of vectors are added to each other. This means that the x components of one vector are added to the x component of the other vector and the y components of one vector are added to y component of the other vector. These two sums form the x and y components of the resultant:

$$\vec{C} = \vec{A} + \vec{B} \Rightarrow \begin{cases} C_x = A_x + B_x \\ C_y = A_y + B_y \end{cases}$$

Keep in mind that these x- and y-components may be positive *or* negative numbers, depending on if they point up or down (in y) and right or left (in x).

So to add two vectors,
1) First, break each vector into its x- and y-components.
2) Add the two x-components to each other. Add the two y-components to each other. These are the x- and y-components of the resultant (or sum) vector.
3) If necessary, recombine these x- and y-components back to a magnitude and a direction.

What about vector *subtraction*? Just as with numbers, "A-B" with vectors is the same thing as "A + (-B)". The negative of a vector has the same magnitude but points in the opposite direction, meaning that both components have the opposite sign. So, the process is similar to vector addition, except you *subtract* the x components instead of adding them, and subtract the y components instead of adding them:

$$\vec{D} = \vec{A} - \vec{B} \Rightarrow \begin{cases} \vec{D}_x = A_x - B_x \\ \vec{D}_y = A_y - B_y \end{cases}$$

A table should be made so that the horizontal and vertical components can be organized and added together as needed. (See the example at the end of this lab.) It is recommended to sketch both the original vectors and their sum (or difference), as a sanity check. This will give the overall sense or direction of the vector, and the magnitude of the vector.

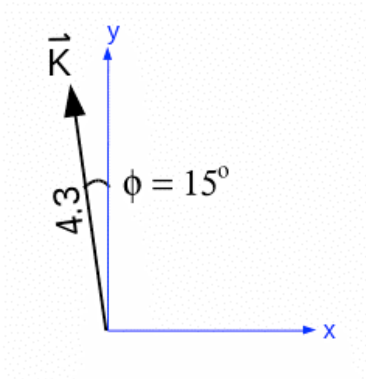
Graphically, using the "Head-to-Tail Method":
One way to quickly get a feel for the magnitude and direction of a sum (or difference) of two vectors is to add/subtract them graphically using the "Head-to-Tail method". Vectors can be "picked up and moved around" on a piece of paper as long as their magnitude and direction are not changed. If the vectors are placed on a piece of graph paper one can easily count the horizontal and vertical squares that make up the components of the vector. The vector can be recreated anywhere on the graph paper by using the components as a guide.

To add two vectors, put the tail of the first vector at the origin. Then, "pick up" the second vector and position it so that its tail starts at the head of the first vector. The resultant vector is drawn with its tail at the tail of the first vector (your starting point) and its head at the head of the second vector added. The order of addition is not important.

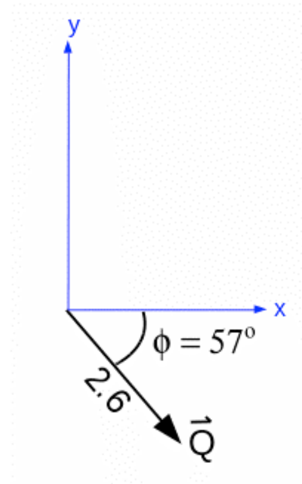
What about vector *subtraction*? Because "A – B" is the same thing as "A + (-B)", one can use the Head-to-Tail method to subtract vectors as well: Add the "A" vector to a version of the "B" vector which is reversed in direction. The order is important: "A – B" points from the head of B to the head of A, while "B – A" points from the head of A to the head of B. See the example below to get a better understanding of this method.

An Example of Vector Addition and Subtraction:

Vector "K":



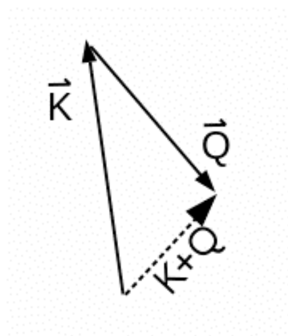
Vector "Q":



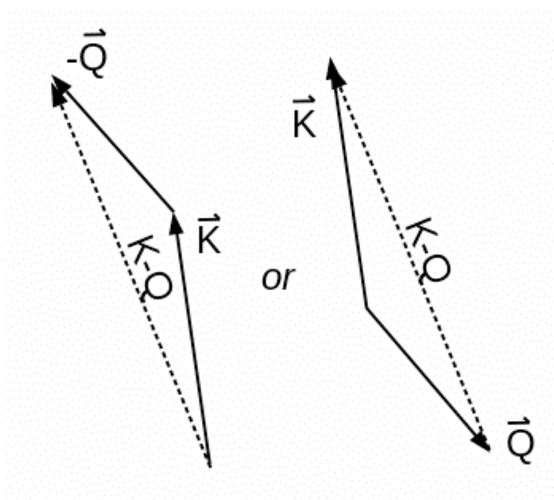
magnitude = 4.3 cm
angle = 105 degrees CCW from East
[or, 15 degrees West from North]

magnitude = 2.6
angle = 303 degrees CCW from East
[or, 57 degrees South from East]

Finding "K + Q" graphically:



Finding "K – Q" graphically:

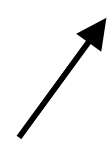


Doing the math:

	x-component	**y-component**
K vector	$K_x = (4.3)\cos(105^0) = -1.113$ $or,\left[K_x = -(4.3)\sin(15^0) = -1.113\right]$	$K_y = (4.3)\sin(105^0) = 4.153$ $or,\left[K_y = +(4.3)\cos(15^0) = 4.153\right]$
Q vector	$Q_x = (2.6)\cos(303^0) = 1.416$ $or,\left[Q_x = +(2.6)\cos(57^0) = 1.416\right]$	$Q_y = (2.6)\sin(303^0) = -2.180$ $or,\left[Q_y = -(2.6)\sin(57^0) = -2.180\right]$
K + Q	(-1.113) + (1.416) = 0.303	(4.153) + (-2.180) = 1.973
K - Q	(-1.113) - (1.416) = -2.529	(4.153) - (-2.180) = 6.333
Magnitude/direction of K+Q	$\lvert K+Q\rvert = \sqrt{(0.303)^2 + (1.973)^2} = 1.996$ $\phi_{K+Q} = \tan^{-1}(1.973/0.303) = 81.3^0$	(angle = CCW from East)
Magnitude/direction of K – Q	$\lvert K-Q\rvert = \sqrt{(-2.529)^2 + (6.333)^2} = 6.819$ $\phi_{K+Q} = \tan^{-1}(6.333/-2.529) = -68.2^0$	(angle = CCW from East)

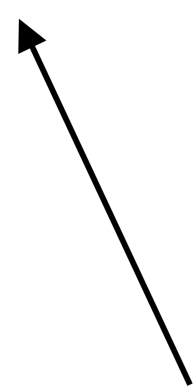
Sanity Checks: Do these numbers match the pictures on the previous page?

Does the sum (K+Q) look like it is about 2 cm long and points about 81 degrees CCW from the x-axis?
(Yes, it does!)



Does the difference (K-Q) look like it is about 7 cm long and points about 70 degrees *below* the x-axis?
(No, it doesn't!)

Why the problem here? Because a vector at (-68.2) degrees, and a vector at (111.8) degrees have the *same tangent*. Your calculator, when you hit the "inverse tangent button", gave you the wrong one of two possible answers. The "real" answer is 111.8 degrees CCW from the x-axis.



Lab Procedure:

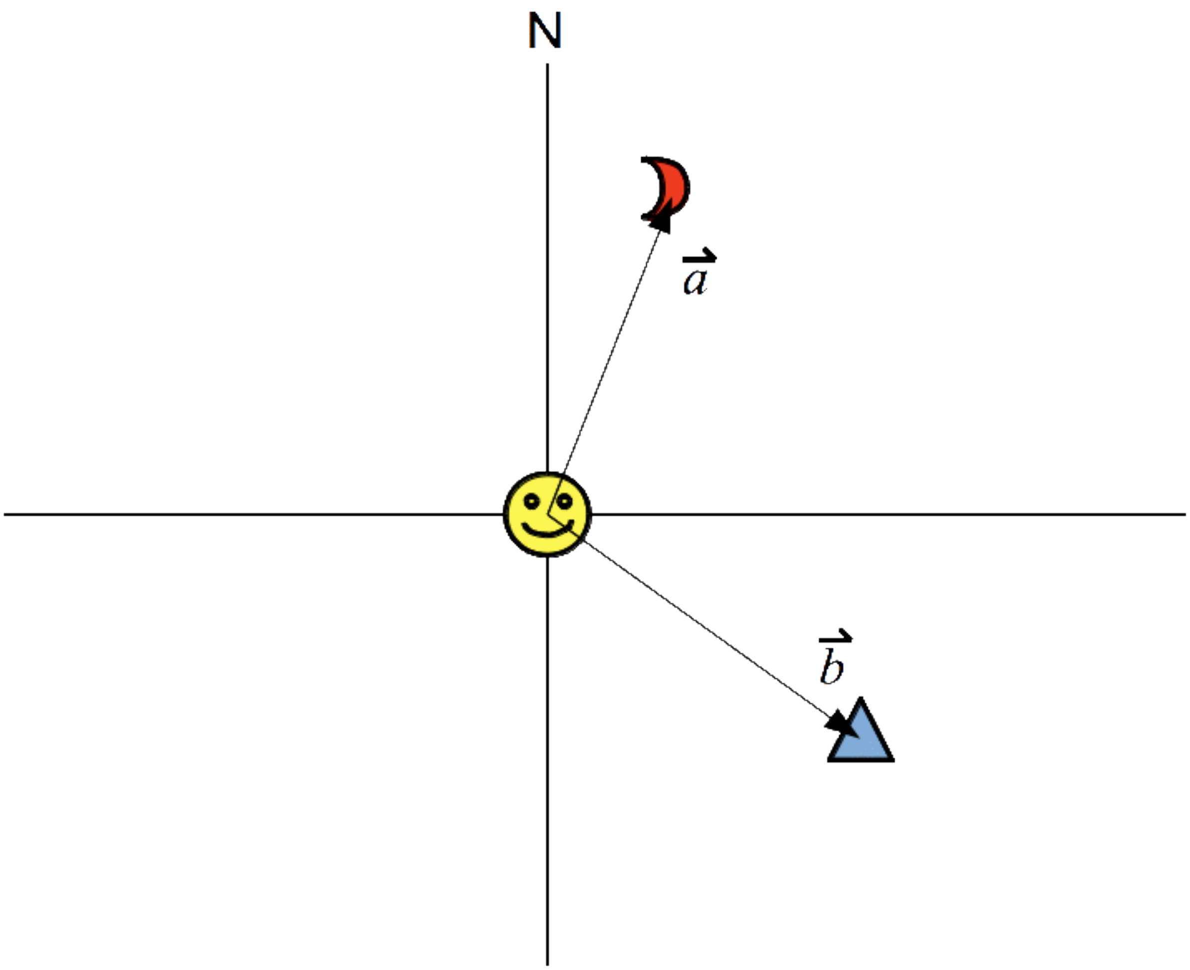
1) Pick a set of "trees" from the instructor.
2) Pick a third point (not a tree) to be the origin point for your measurements. Do *not* pick an origin that sets all three points (the origin and the two trees) along one straight line.
3) For each of the two trees, measure the *distance* from the origin to the tree, and the *angle* between magnetic north and the line from the origin to the tree.
4) On graph paper, make a careful vector graph showing the origin and the two vectors pointing to the two trees. Use a ruler and protractor to make the scale and positioning of the vectors as accurate as you can. Use magnetic north as the "y-axis", making east the "x-axis".
5) Using your measurements, compute the x- and y-components of each of the "tree vectors". Use the Excel template spreadsheet. Because there are different ways of doing this calculation, be sure to *explain* in your lab report *how* you are using angles and trigonometry to calculate these components.
6) Determine the distance between the trees, and the direction which points from the first tree to the second. (Hint: before doing any math, think carefully about this question: Will you need to *add* or *subtract* vectors to find this?) The direction should be expressed as an angle, and you *must* indicate in your report where the angle is measured from (for instance, "counter-clockwise from East" or "West of North", etc.).

Name: ________________________

Scale: ____________ meters per square

Figure and numbers for Pre-lab #2:

Some of the questions on the prelab require this figure (the "smiley-face, moon, and triangle" figure) and associated numbers below. Use this together with Blackboard to complete the prelab:



Vector	Magnitude	Direction (expressed as clockwise from North)	Direction (expressed as CCW from East)
a	5.80	28.0^0	62.0^0
b	6.20	130^0	-40.0^0, or 320^0

EXPERIMENT # 3: 2D Projectile motion challenge

Abstract:
Your overall goal for this lab is to master the kinematic equations of motion in two dimensions in order to predict where to place a ring and a bucket so that a ball launched from a projectile launcher will pass through the ring and land in the bucket. It will be the responsibility of the student to determine what measurements and calculations they will need to make in order to achieve their goal. This will be a two week lab period. The first week will be spent becoming familiar with the equipment and making measurements needed to achieve their goal. The second week will be used to test the student skills at making measurements and calculations.

Goals:
Learn how to make basic measurements using a meter stick and a measuring tape.
Learn how to use the kinematic equations of motion in order to predict height and range of a projectile launched at an angle.

Equipment: Projectile launcher, meter stick, measuring tape, carbon paper, yellow spirit level, blue tape (to hold carbon paper down on floor), plumb bob.	**Software:** Excel as needed. **Group size:** In pairs **What to turn in after the first week:** Nothing. **What to turn in after the second week:** Cover page, and final calculations only.

Procedure:
It will be up to the student/group to determine their own procedure. You may use the first week to experiment, the second week you will graded on the spot based on whether the final shot succeeds or not. There will not be a full lab report due for the lab, but at the end of the second week you should turn in a copy of all the final calculations that you make before taking your shot. There are points for attendance the first week, so be sure to come to both weeks. Plus, if you miss the first week, you will have to work on your own the second week, (no jumping in with another group that came the previous week).

Set up the launcher on a wooden stool as shown in the picture. Use the first week to learn how to determine the initial speed of the projectile and where to place the ring vertically and the bucket horizontally. This will allow you to mover the launcher as needed. Set up a large ~ 16 cm metal ring on a vertical rod attached to a wooden stool.

For the second week you will need to setup your equipment the same as last week and once again make measurements so that the initial speed of the ball as it comes out of the launcher can be determined. Use the long range setting ("three clicks") only. You will be given a launch angle for the projectile launcher and a horizontal distance for the ring. Your goal will be to set the ring and the tub so that the projectile will go through the ring at the given horizontal distance and land in the tub.

The launcher has a point marked on the side, indicating the where the *center* of the ball enters free fall. We have plumb bobs and levels for your use. Remember no matter how good your calculations are, without correct measurements the calculations are of very little use.

Hints:
The student should come to the lab prepared with an idea of how to determine the initial speed of the projectile by making simple height and range measurements of the projectile when launched horizontally. (Hint: Do the pre-lab.) Place a piece of carbon paper on the floor (atop of a piece of white paper) to mark the landing spots of the ball. Once you have a method for determining the launch speed from the height and range set up an Excel spreadsheet to do the speed calculation based solely on the height, range and little “g”. This will save a lot of time when you meet the second week. Once you have determined the launch speed of the projectile (remember to use the long range setting only) come up with a method/procedure to determine the height of the ring based on just the launch angle, the launch speed, and the horizontal distance from the launcher. (Again if you do this in Excel you will save yourself a lot of time and effort.)

The student group will be given one attempt once they set the ring and the plastic tub. Once the group has been given their launch angle they may not try to sight the barrel with the ring for obvious reasons, you must determine the height to set the ring based on your kinematic equations. You may not move the ring (vertically) or the tub (along the horizontal direction) or adjust the angle of the launcher after the first shot. The direction of the launcher (the azimuth) may be changed as needed and a second attempt made as directed by the instructor.

Before getting your angle from the instructor, try some practice shots at an angle. Predict where to put the ring and the bucket for a launch angle of 60 degrees with the ring at a horizontal distance from the launcher of 1.20 meters. If you can correctly place the ring and the bucket for this scenario you will be in great shape for the challenge. If you do not make it on the first shot recheck your measurements first and then recheck your calculations. Remember though, for the challenge, you only get one shot.

EXPERIMENT # 4: Average acceleration of a car on an inclined plane

Abstract:
Using a free body diagram and Newton's Second Law for a rolling cart on an inclined plane with extra friction added, a theoretical expression for little g will be determined without the need to know the coefficient of friction explicitly. The expression $g = \frac{\bar{a}}{\sin(\theta)}$, takes into account the extra friction added to the cart by averaging the acceleration of the cart as it goes up and then down the incline. In the experimental setup the acceleration on the way up will be approximately 30% greater than on the way down, however the percent error between the known value for little g and the experimentally determined value is expected to be less than 5%.

Goals:
Experience with data collection and analysis software using Pasco's Capstone.
Use of Excel to organize and present numerical data and results.
Show how Newton's Second Law and a free body diagram are applied to a cart on an inclined plane to derive an expression for little g.

<table>
<tr><td rowspan="3">Equipment:
Track, Pasco dynamics cart with the friction accessory attached, Table clamp and rod, meter stick, Pasco's 850 interface, angle finder, cleaning cloth to clean track grooves, Motion sensor, track rod clamp, short "spirit" level.</td><td>Software: Excel, Capstone</td></tr>
<tr><td>Group size: Individual</td></tr>
<tr><td>What to turn in at the end:
Full lab report.
.</td></tr>
</table>

Figure 1: Setup for the inclined track and a Pasco cart with the friction accessory.

Theory:
A free body diagram is presented below for a cart moving **up** an incline with friction included but neglecting air resistance.

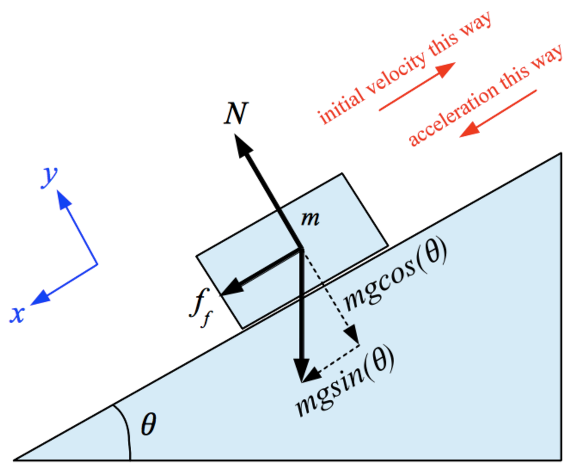


Figure 2: Free Body diagram for the car going up the incline.

g =acceleration due to gravity $\quad m$ = mass of the cart $\quad N$ = Normal force
θ = angle of the incline $\quad a$ = acceleration of the cart $\quad f_f$ = frictional force

Newton's Second Law states that the net force acting on an object is equal to the mass of the object times the acceleration of the object.

$$\sum \vec{F} = m\vec{a} \qquad \textbf{(1)}$$

For the car above with the x,y axis as chosen the acceleration is only along the x axis. Applying Newton's Second Law along each axis gives. (Dropping vector notation)

$$\sum F_x = ma \qquad \sum F_y = 0 \qquad \textbf{(2a,2b)}$$

$$mg\sin(\theta) + f_f = ma \qquad N - mg\cos(\theta) = 0 \qquad \textbf{(3a,3b)}$$

$$f_f = \mu N = \mu mg\cos(\theta) \qquad N = mg\cos(\theta) \qquad \textbf{(4a,4b)}$$

Substituting for N gives

$$mg\sin(\theta) + \mu mg\cos(\theta) = ma \qquad \textbf{(5)}$$

Eliminating m gives

$a_{up} = g[\sin(\theta) + \mu\cos(\theta)]$ Predicted acceleration as the car goes up the incline. **(6)**

With the car going down the incline the frictional force reverses direction and applying Newton's Second Law again results in:

$a_{down} = g[\sin(\theta) - \mu\cos(\theta)]$ Predicted acceleration down the incline **(7)**

Note the acceleration of the car should be greater when the car is going up the incline than when the car is going down the incline. This makes sense because the frictional force and the component of the weight force are in the same direction when the car is on the way up. The two forces are anti-parallel when the car goes down the incline. Both equations predict the acceleration to be $g\sin(\theta)$ in the absence of friction.

Further inspection reveals that the average acceleration of the car averages out the friction effects. The average acceleration for the car up and down is simply:

$$\bar{a} = \frac{a_{up} + a_{down}}{2} = \frac{g[\sin(\theta) + \mu\cos(\theta)] + g[\sin(\theta) - \mu\cos(\theta)]}{2} = g\sin(\theta) \qquad \textbf{(8)}$$

Solving for little g gives:

$$g_{measured} = \frac{\bar{a}}{\sin(\theta)} = \frac{\bar{a}}{\left(h/L\right)} = \bar{a}\frac{L}{h} \qquad \textbf{(9)}$$

(L,h are measured quantities of a length and height of the track that determines the angle of the incline)

An accurate measure of the angle of the incline and the average acceleration will result in an accurate value for little g. The angle of the incline can be determined by measurement of the height and length of the track. The average acceleration will be determined by doing a linear fit to the velocity vs. time graph as the car moves up and then down the incline. The two values of the acceleration a_{up} and a_{down} can be determined separately and then averaged to determine the average value of the acceleration.

To verify that equation 9 averages out frictional effects, extra friction will be added. With care, $g_{measured}$ should agree with g_{known} with less than 1 % error.

Setup Procedure:

1. Open up the Excel template for this lab and use the template to complete your lab.

2. Set up the air track as shown in Figure 1. Clean the grooves of the track with a soft cloth. Inspect the wheels of the car to make sure they spin freely.

3. Add two black bars to the car and then use the 6000 gram electronic balance to measure the combined mass.

4. Measure and record the overall length of the track before setting up the track on an incline since it will be harder to measure the overall length of the track once it is set up.

5. Attach the large table clamp to the table and then place the vertical rod in the clamp. Let one end of the vertical rod rest on the floor for stability. Using the small track rod clamp attach the track to the vertical rod. The angle of the incline should be set to about 10.0 degrees using an angle finder; however you will use the height and length of the track to determine the actual angle using the same method as used for the pre-lab.

6. Using a meter stick and a short level measure the overall height of the track that corresponds to the overall length of the track so that the correct angle of the incline can be determined. Think about whether you should measure to the bottom of the track or to the top of the track. Make a short note describing how you made the height measurement needed to determine the angle of the incline. This is a critical measurement so make sure you get this right.

7. Plug the motion sensor into the interface and then turn on the interface.

8. Open up the Pasco Capstone software and click on **Hardware setup**. Select the motion sensor. Check to make sure the digital channels selected in Capstone are the same as the ones being used by the motion sensor and interface. Increase the sampling rate to 100 Hz.

9. Create a "New Experiment" with "Two Displays". Make each display a "Graph": one of position vs. time, and the other of velocity vs. time.

10. Select the narrow beam on the motion sensor and attach it to the track. It should snap on.

11. Place the car on the track (with the two black bars) and manually push the car up and down the track. Click on record and watch the position vs. time graph to see if the motion sensor tracks the car up and down the track. Adjust the aim of the motion sensor as necessary.

When ready, collect one run of data, which should show the car going up the incline and then back down all in one motion after it has been given a gentle push upwards. At the highest point the car should not get closer than 20 cm to the motion sensor. The point at which it stops is called the turning point. The turning point will be the vertex of the parabola on the x vs. t graph, and will be at $v = 0$ m/s on the v vs. t graph. Concentrate on getting one good run of data without wobbles on the x vs. t graph. Be sure to have the graph auto scaled so that small wobbles will be easily seen. If there are small wobbles in the data they will be magnified in the v vs. t graph. Keep only data that is smooth about the vertex of the parabola. You will only need about (15- 20) cm of data on either side of the vertex. Delete all runs of data other than the one needed for the analysis.

On the velocity vs. time graph use the **select range tool:**  to select the data while the cart is on its way *up* (and slowing down). Choose a linear fit to the selected data, using the curve-fitting tool: , and record the slope of the line, which is the acceleration during this phase of the motion. Now repeat the data selection and fit to get the value of the acceleration of the car on its way *down*. Use the two values of the acceleration to get the average value of the acceleration.

You should print out your two graphs: position-vs-time, and velocity-vs.time. Capstone will only let you display one curve-fit at a time on a graph, so on the v vs. t graph printout, have one of the linear fits displayed, and hand-write the results of the other.

Use your measurements to compute "g". Compare your measurement to the "known" value of g=9.82, by computing the percent difference. Discuss this result as part of your conclusion.

Questions

1. Why is the acceleration greater on the way up than on the way down?

2. Use your measurements of a_{up} and a_{down} to compute the *net force* when it's moving up, and the *net force* when it's moving down.

3. Use your data to compute the coefficient of friction μ_k. [Hint: combine Equation 6 and Equation 7, to find an expression for this coefficient, in terms of a_{up} and a_{down}.]

4. Sketch what the velocity vs. time graph would have looked like if there were *no* friction at all on the track. In this scenario, what would you expect to measure for: a) the acceleration on the way up, b) the acceleration at the highest point, and c) the acceleration on the way down? (Yes, compute an actual number here, using your ramp angle, θ.)

Figure for Pre-lab #4:

You will need this *sample Capstone graph* for some of the questions:

This is a *velocity vs. time* graph.

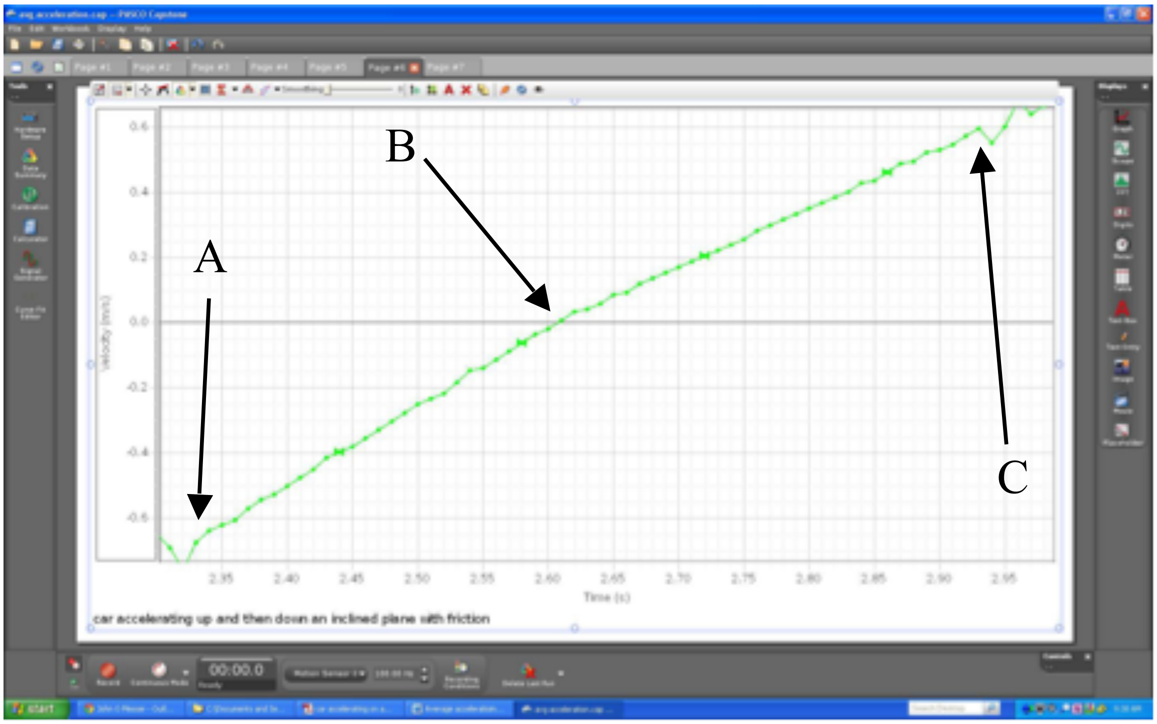


Figure 3: Screen shot of a Capstone graph.

EXPERIMENT # 5: Acceleration of a wooden box

Abstract:
Using a free body diagram and Newton's Second Law for a box being accelerated on a table top by a hanging mass, a theoretical expression for the acceleration due to gravity will be determined. Students will vary the accelerating force on the system while keeping the total mass of the system constant so that a plot of the acceleration vs. the hanging mass can be made. A linear fit will be made to the graph and from the slope and intercept both the acceleration due to gravity and the coefficient of friction will be determined.

Goals:
Experience with data collection and analysis software using Pasco's Capstone.
Use of Excel to organize and present numerical data and results.
Data analysis and curve fitting.

<table>
<tr><td rowspan="3">Equipment:
Friction box, wooden board, mass set, mass hanger, foam cushion, motion sensor, spirit level, C clamp, wooden block for the C-clamp, pulley with table clamp, string, meter stick, Pasco's 850 interface.</td><td>Software: Excel, Capstone</td></tr>
<tr><td>Group size: Individual</td></tr>
<tr><td>What to turn in at the end:
Full lab report.
.</td></tr>
</table>

Figure 1: Setup for acceleration of a box.

Theory:

A free body diagram is presented below for a box being accelerated across a wooden board by a hanging mass.

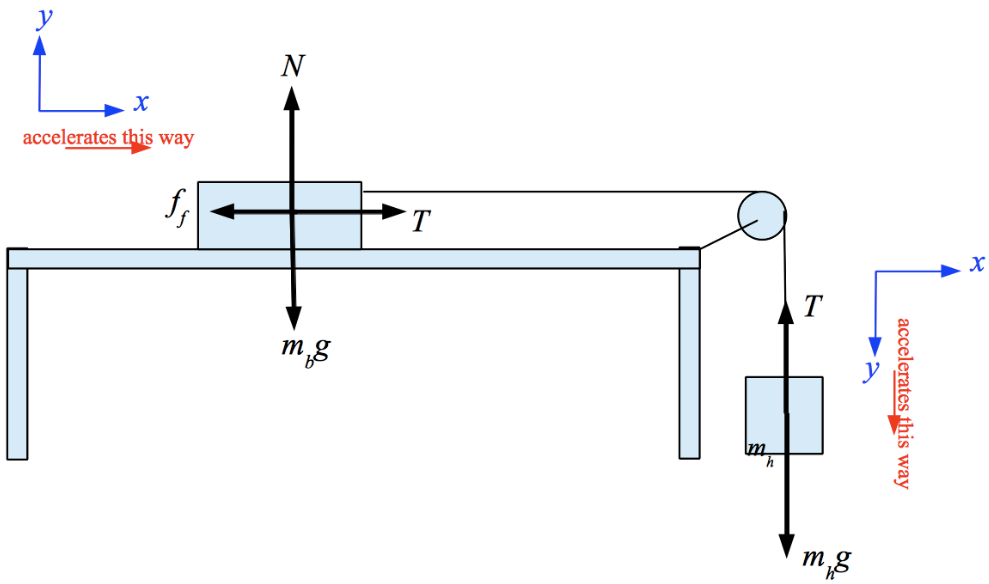


Figure 2: Free body diagram for a box being accelerated by a hanging mass.

m_b = mass of the box, m_h = mass of the hanging mass,
N = Normal force, T = Tension in the string, f_f = frictional force

Applying Newton's Second Law to each object. Solve for the acceleration of the system in terms of m_k, m_h, g, and M_T

Box

$$\sum F = m_b a$$

Hanging mass

$$\sum F = m_h a \qquad \textbf{(1a, 1b)}$$

X axis

$$T - f_f = m_b a \quad \textbf{(2a)}$$

Y axis

$$N - m_b g = 0 \quad \textbf{(2b)}$$

$$m_h g - T = m_h a \qquad \textbf{(2c)}$$

$$f_f = \mu_k N = \mu_k m_b g \qquad \textbf{(2d)}$$

Substituting equation (2d) into (2a) gives $T - \mu_k m_b g = m_b a$ **(3)**

Adding equation (2c) to equation 3 eliminates T and gives

$$m_h g - \mu_k m_b g = m_T a \qquad \text{Where } m_T = m_h + m_b \qquad \textbf{(4)}$$

Solving for the acceleration of the system gives

$$a_T = \frac{m_h g - \mu_k m_b g}{m_T} \quad \textbf{(5)}$$

Notice that the acceleration depends on two variables m_h and m_b. Substituting for m_b by using $m_b = m_T - m_h$ the acceleration can be expressed in terms of one variable and some constants. After a little algebra the acceleration can be expressed as a function of the hanging mass m_h in the form of a linear equation (y = mx +b).

$$a = m_h \left[\frac{g(1+\mu_k)}{m_T} \right] - \mu_k g \quad \textbf{(6)}$$

If a plot of acceleration vs. m_h is made, the acceleration due to gravity can be determined from the slope (*S*) and intercept (*I*) of the graph.

$$S = \left[\frac{g(1+\mu_k)}{m_T} \right] \qquad I = -\mu_k g \quad \textbf{(7a,7b)}$$

Substituting for μ_k in equation (7a) by using equation (7b) gives

$$S = \frac{g - I}{m_T} \quad \textbf{(8)}$$

Equation 8 can be rearranged to solve for g (now call it g_{exp}) in terms of the slope (S) and intercept (I)

$$g_{\exp} = S m_T + I \quad \textbf{(9a)}$$

The coefficient of friction can be determine from equation (7b)

$$\mu_k = -I / g_{\exp} \quad \textbf{(9b)}$$

Setup Procedure:

1. Set up the wooden board on the table top as shown in Figure 1. Attach the motion sensor to both the wooden board and the table top. Clamp down the board to the table with the C-clamp using a small wooden block to prevent damaging the wooden board. Check to see if the board is level using the spirit level and make adjustments with paper shims if needed. Wipe the board clean with your hand and feel for any obvious irregularities in the surface of the board.

2. Attach a loop in each end of the string and adjust the length of the string so that the mass hanger hits the foam cushion on the floor as the box nears the end of the board after being released.

3. Place the (100, 50, 20, 20, 10) masses into the wooden box. These masses are to remain in the wooden box until after you have found the right amount of mass for run number one.

4. Plug the motion sensor into the 850 interface. Open up the Pasco Capstone software and click on **Hardware setup**. Click on plug #1 and select the "Motion Sensor". Increase the sampling rate to 100 Hz. This is found on the bottom menu bar.

5. Create a graph of position vs. time on page one. Click the multicolored triangular icon:  "**allow simultaneous viewing …** " on the graph menu bar to allow multiple runs to be displayed at the same time.

6. To test the setup, manually push the box up and down the wooden board while watching the position vs. time graph.

7. Place about 200 grams onto the mass hanger. **<u>(Leave the loose (100, 50, 20, 20, 10) masses in the wooden box for now.)</u>** Attach the string to the box and mass hanger and adjust the height of the string so that it is parallel to the wooden board. You can vary the height of the pulley to adjust the string height, just be sure to tighten the screw on the pulley so that the pulley does not slip down. Check the height of the string as you increase the hanging mass to make sure the pulley has not dropped lower due to the hanging mass.

Collecting data:

Press "Start" and then release the system from rest to take data. Make a trial run to see if the acceleration is uniform and at least 0.2 m/s^2. If the acceleration is too small, add an extra 20 or 50 gram mass (**<u>get the extra mass from the large tub of loose masses, do not use the masses that are in the box</u>**) to the mass hanger for the initial run. Practice *stopping* data acquisition before the box comes to the end of the board (or the hanger hits the floor), so as to not record "messy" and meaningless data at the end of a run. Once you've gotten some practice, take a series of *five* successive runs.

For each successive run, *increase* the amount on the hanging mass by 40 grams by *transferring* some combination of the masses between the box and the hanger so that the net gain is 40 grams on the hanging mass while keeping the total mass constant. For each run, record the amount of mass that was hanging (*including* the 50 grams of the hanger itself).

It will be convenient (and save paper!) to put all five runs on a single Capstone graph. To do this without all the data "piling up" on top of each other, space them out on the graph by waiting a couple of extra seconds after hitting "Start" before releasing the masses from rest, and increasing this delay with each successive run.

Make quadratic fits to each of the five runs, using this button: . Each time, you'll want to *first* highlight the run by clicking on it in the legend box, and then select an appropriate range of data to fit for that particular run with this tool: . Move all the fit result boxes so that it is clear which fit they are associated with, and so they can all be read without obstructing any data. The five runs, with their five quadratic fits, should look something like Figure 3. Include a printout of this Capstone graph in your lab report.

When you have completed all five runs, place your mass hanger with all the mass on it into the wooden box. Take the box to the electronic balance and measure the total mass of the system, and record this in your Excel template.

Analyzing the data:

For each of the five runs, record the coefficient of the squared term in your Excel template. This is the "A" term in the quadratic fit in Capstone. Determine the acceleration from the A coefficient. (Hint: the coefficient "A" from a quadratic fit is not the same number as the acceleration "a" from kinematics equations! Why not?)

Make a plot of the acceleration vs. m_h. To make the graph, highlight the m_h column first, then hold down the ctrl key on the keyboard and select the acceleration column with the mouse, click on **Insert** on the top menu bar, choose the **scatter option** (the one without any lines) and your graph will appear.

Move and resize the graph so that it will fit in the area on the template set aside for the graph. On the **chart tools** menu click on **design** and choose a design that includes required titles. Rename the titles appropriately and don’t forget to include units.

Click on the horizontal and vertical axis of the graph and manually rescale the graph so that the data fills the graph area. To add a fit line, **left click** any data pair on the graph. Then **right click** and choose **add trendline**. Choose the following: **linear fit**, **display equation on chart**. Check to see if there are any obvious discrepancies in the graph. Make sure you did not enter data incorrectly and if necessary double check quadratic fits for consistency of data selection. You can now use the slope and intercept from the linear fit of (a vs. m_h) to determine the acceleration due to gravity. If you are proficient with Excel don't hesitate to use the slope and intercept function to calculate the slope and intercept so that you won't have to hard type in the values from the fit equation on the graph.

Use your slope and intercept to compute "little g" and the coefficient of kinetic friction μ_k.

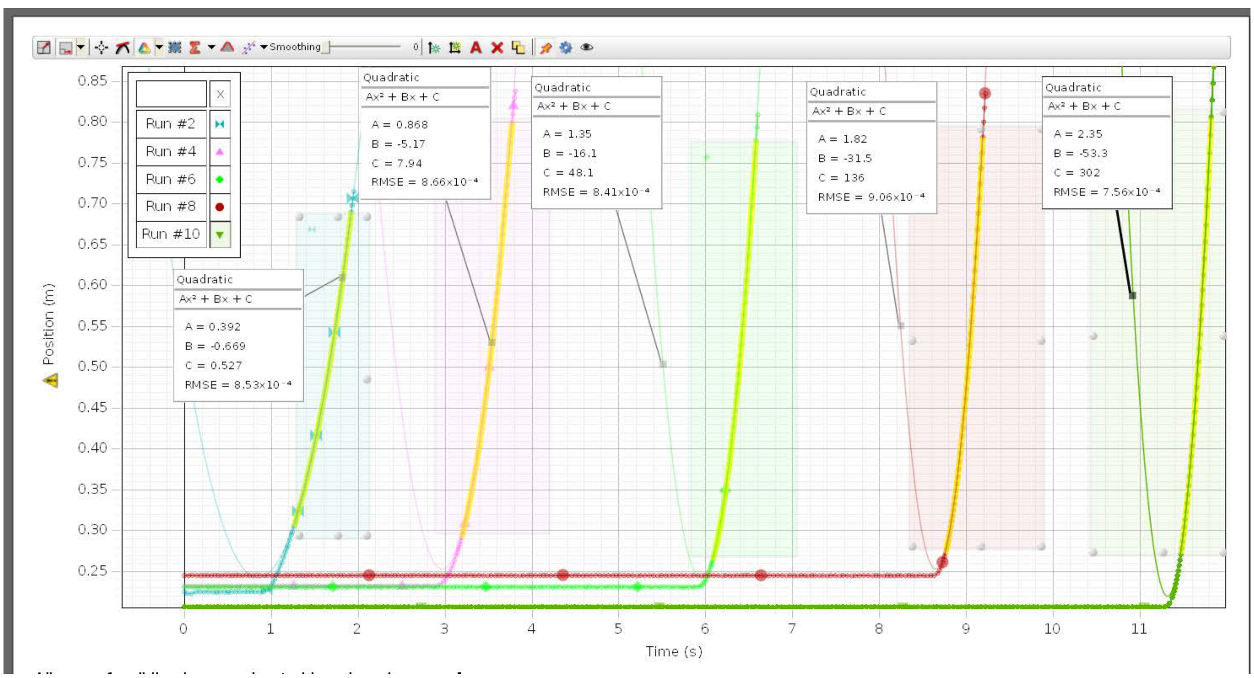


Figure 3: Five Capstone runs, with five fit quadratics.

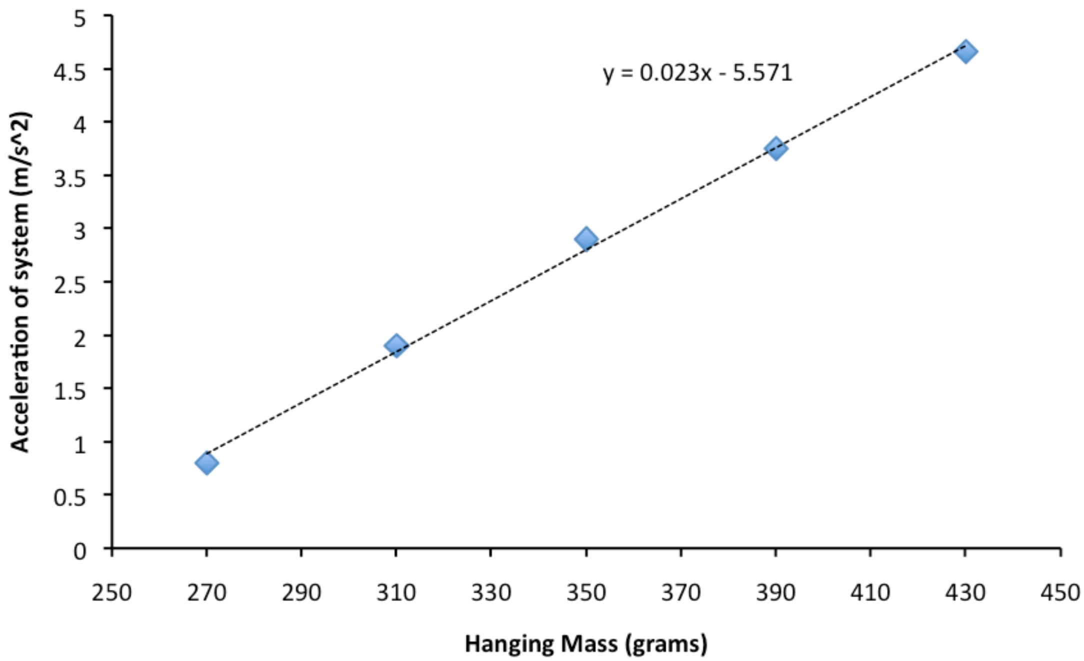
Questions:

1. If the coefficient of friction between the board and the box increased would your measured value of little g be greater, smaller or the about the same? Explain your answer.

2. For this question you will need only the box and the board. Use the angle finder to find the angle at which the box will slide down the board at constant speed. You may need to tap the board to get the box moving, but once it is moving you will need to lower the angle a little. This is a quick and dirty method so do not spend a lot of time trying to get this "perfect". Record this angle in your template and then use that angle to find the coefficient of friction and call it μ_2. $\mu_2 = \tan(\theta)$. Where θ is the angle found from the angle finder. Find the % difference between μ and μ_2. (You can answer this question on the Excel template.)

Figure and numbers for Pre-lab #5:

You will need this *Excel chart* for some of the questions.
This graph was made with a *total mass of the system* of 642 grams.



EXPERIMENT # 6: Collisions in 1-Dimension

Abstract:
Collisions are governed by the law of conservation of momentum. In this lab, one-dimensional collisions are studied by crashing carts into one another on a low-friction track.

Goals: Experience with data collection and analysis using Pasco's Capstone and Excel, and understanding of conservation of momentum and the mechanics of collisions.

Equipment: Two PASCO Smart Carts (one blue, one red), Bluetooth adapter, 2-meter track, bars of extra mass	**Software:** Excel, Capstone
	Group size: 2 students per setup, but individual analysis of data.
	What to turn in at the end: Full lab report.

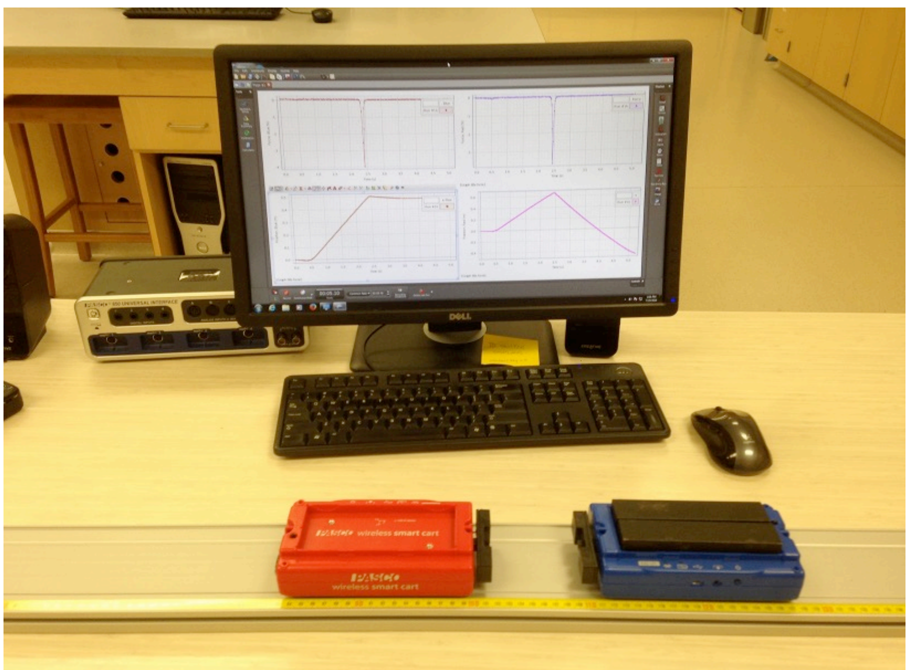


Figure 1 – Carts on the track

Lab **Procedure:**

1. Clean the grooves of your track with a paper towel, to try to get it as frictionless as possible.

2. Plug the Bluetooth Adapter into one of the USB ports on your computer (one on the actual box, not the monitor).

3. Turn on the two Smart Carts. The Battery LED should *not* be blinking red (if it is, this means "Low Power" and the cart needs to be charged.) The Bluetooth LED *should* start blinking red, which means "Ready to Pair".

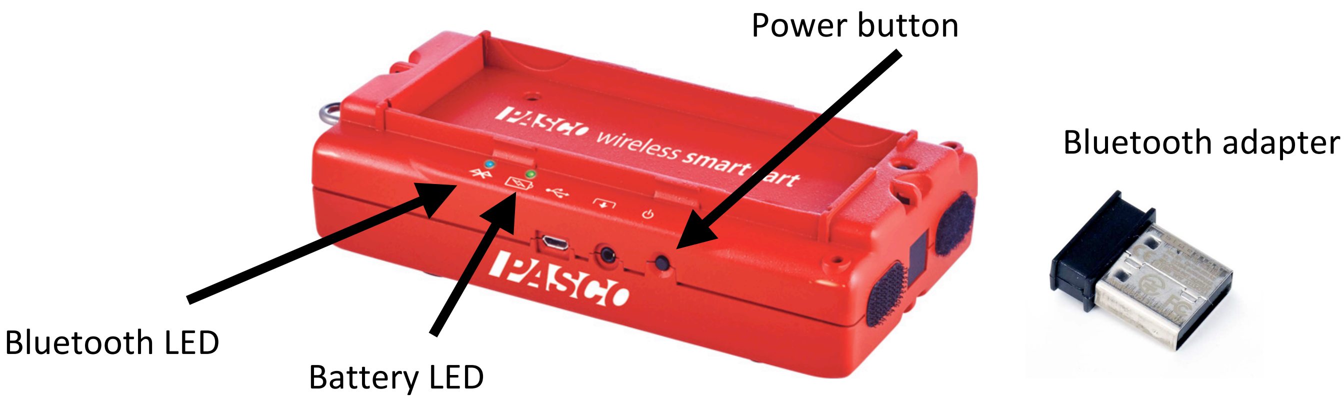
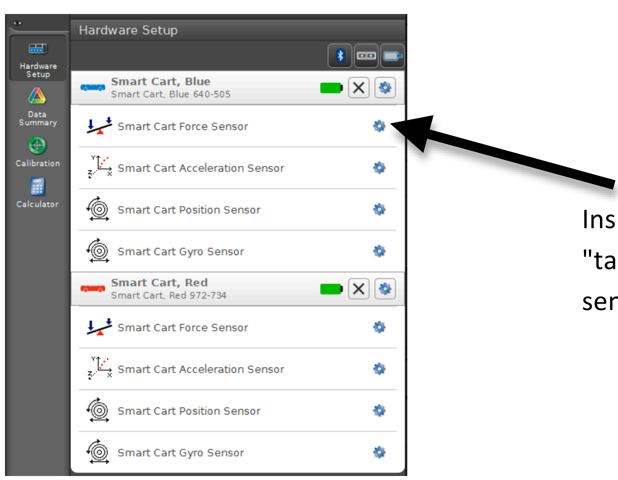


Figure 2: A Smart Cart, and Bluetooth Adapter

4. Launch Capstone, and go to the "Hardware Setup" panel. You should see your two carts listed under "available Bluetooth devices". Find the ones that match yours *by device number* (the six-digits XXX-XXX which are printed on the carts). Click on each one; it should say "Connecting…" and then display some configuration tools for the various sensors onboard the cart, as shown below. The Bluetooth LED on the carts should now be blinking green.



5. At the bottom of the screen, there is a place to set the sampling rate. Choose "Common Rate" from the drop-down menu, and set it to 50 Hz.

6. Configure Capstone to display these FOUR graphs simultaneously:
   - Velocity vs. Time for Cart #1
   - Velocity vs. Time for Cart #2
   - Force for Cart #1
   - Force for Cart #2

7. Orient the carts on the track so that their magnetic bumpers face each other. When the two carts are brought together, the magnets should repel.

8. Start recording data in Capstone. "Gently crash" the two carts into one another (gently enough so that the magnetic bumpers repel each other *without* physically touching). Stop recording when the collision is over and they are moving apart again. Repeat this a few times for different styles of collision, such as:
   a. One cart is at rest, and the other is moving
   b. Carts are launched toward each other from opposite directions
   c. One cart is moving slowly, and the other "comes up from behind" at higher speed

   For each of the runs described above, <u>*qualitatively*</u> *compare the force graphs* of the two carts, and take note in your notebook of what you observe. Include this in your lab report. (Note: If the force sensor data does not start out at zero, "tare" or "zero" the sensors by going into the Settings under "Hardware Setup".)

9. Load up *one* of the two carts with some extra mass, and explore some more collisions, such as:
   a. The heavy one crashes into the light one at rest
   b. The light one crashes into the heavy one at rest
   c. They are launched toward each other from opposite directions at the same speed

   Again, for each of the runs, <u>*qualitatively*</u> *compare the force graphs* of the two carts, and take note of what you observe, for your lab report. If you like, you can try putting one hand on each cart, and pushing them against one another slowly, by hand; how do the force graphs compare?

10. Use the mass scale to find the mass of each cart (including the extra weight on one of them).

11. From the data with one cart heavier than the other, choose *one* run to analyze in more detail. For this collision, use your data to compute the *momentum* of each cart, and the total momentum of the system, *before* the collision. Use whatever Capstone tools you need (fit a curve? take an average?) to do this; you should have enough experience with these tools by now to figure something out. Also, compute the same things for *after* the collision. Organize your work using the spreadsheet template provided.

Note: the computer is using "towards the magnetic bumpers" as the positive axis for each cart. For these calculations, you need to choose *one* direction to be positive for *both* carts. Be sure to document this choice in your sketch of the experiment, and interpret the sign of the computer's numbers accordingly.

Also: this experiment is *not* completely without friction! What effect will friction have on these measurements, and what can you do to get as close as possible to the "correct" velocity measurement? Be sure to address this in your lab report.

12. Turn the two carts around, so that the "Velcro" ends face each other, instead of the magnetic bumpers. You will no longer get any data for the "Force" graphs, so you can remove these from the Capstone display if you want to.

13. Perform some additional collisions, of the same kinds of style as above (one at rest and the other moving, launched at each other from opposite directions, equal mass, unequal mass, etc.)

14. Choose *one* run to analyze in detail: one of the collisions in which the two masses were different. As before, compute the momentum of each cart and the total, both before and after the collision. Re-measure the masses of the carts *if* you need to. Organize your work using the spreadsheet template provided.

15. For both the magnetic bumper collision, and the Velcro collision, compute the *kinetic energy* of each cart, and the total kinetic energy, both before and after the collision. Use the spreadsheet template.

In addition to quoting numerical results, your lab report's conclusion should summarize your general observations about all these collisions. Be sure to address the "force graph" comparisons; what do you conclude about the forces experienced by the two carts in a collision? When discussing the calculations from the spreadsheet, come to a conclusion about whether total momentum is conserved in a collision, and whether total kinetic energy is conserved.

Questions:

1) *What kind* of collision were the ones using the magnetic bumpers? (Elastic, or Inelastic?) What kind of collision were the ones using the Velcro?

2) If there is a collision where kinetic energy is *not* conserved, into what other forms might that energy go?

EXPERIMENT # 7: Ballistic Pendulum

Abstract:
Students will experimentally determine the speed of a small ball launched horizontally using two independent methods. One method will use measure the speed directly using two timing gates. The other method will launch the ball into a ballistic pendulum. By measuring the angular displacement of the pendulum and using conservation of linear momentum and mechanical energy the speed of the ball will be determined. Good agreement for the initial speed between the two methods is expected.

Goals:
Learn how to obtain an average (non-numerically) by observing the spread in data.
To gain an understanding of conservation principles.

Equipment: Ballistic pendulum/Projectile launcher, Steel ball, C-clamp, Safety goggles, Two timing gates and mounting hardware, Electronic balance, Small ruler to balance the pendulum.	**Software:** Excel, Capstone **Group size**: 2 people, one to launch, the other to retrieve the projectile. After the data is collected each student will analyze their data separately. **What to turn in at the end:** Full lab report.

Introduction:
The principle of conservation of mechanical energy demands that the mechanical energy of a system before a process must equal the mechanical energy after the process ($E_i = E_f$). Mechanical Energy is defined as the sum total of the kinetic and potential energy and is conserved in systems where only conservative forces act. Likewise, the principle of conservation of linear momentum requires that the momentum of a system before a process must equal the momentum after the process ($\boldsymbol{p}_i = \boldsymbol{p}_f$). Momentum is always conserved during collisions in the absence of external forces.
The complete ballistic pendulum apparatus used in this experiment consists of a spring-loaded projectile launcher mounted on a sturdy, adjustable support and a specially designed pendulum attached to a low-mass support arm. The pendulum is suspended from a low friction pivot at the top of the launcher mounting frame. The pendulum itself is hollow and is designed to catch and hold a projectile fired by the projectile launcher. With the ball in the launch position, the spring has potential energy. When the spring is released the potential energy is converted to kinetic energy giving the ball an initial speed. The ball is then trapped by the pendulum, causing a small loss in kinetic energy, but the momentum of the ball-pendulum system is conserved during the collision. Immediately after the ball is trapped by the pendulum, the pendulum and ball move

upward in an arc exchanging kinetic energy for gravitational potential energy, conserving mechanical energy.

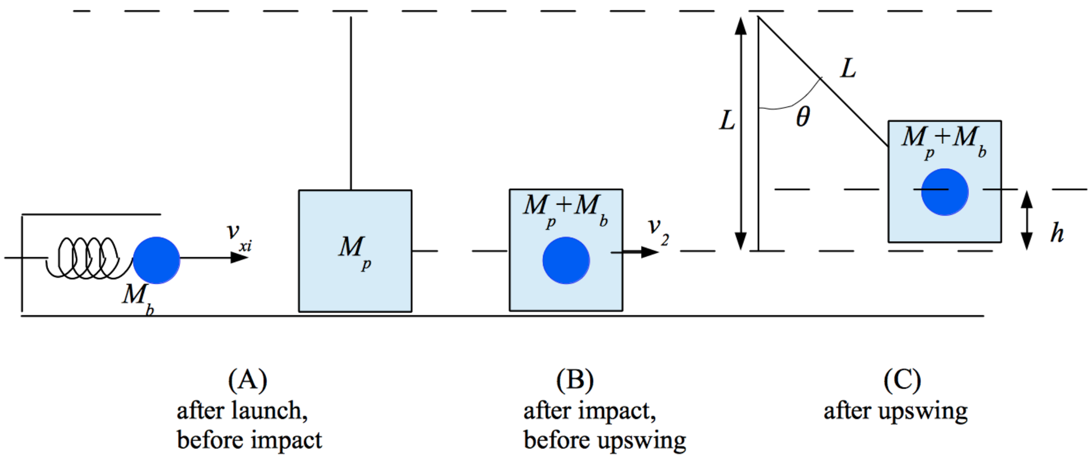


Figure 1- Sketch of Ballistic Pendulum

M_b = mass of the ball, M_p = mass of the pendulum, v_{xi} = initial speed of the ball.
v_2 = speed of the pendulum and ball immediately after the collision
h = the maximum height reached by the pendulum

<u>Before the lab begins: Understanding Conservation of Energy and Momentum</u>

In Figure 1, the ballistic pendulum apparatus is sketched in simple diagrammatic form. In Figure 1A, the projectile (a small ball) is released from the launch tube with an initial speed v_{xi}. In Figure 1B, the pendulum catches and holds the ball as the two masses start to swing upward with a smaller velocity v_2. Linear momentum is conserved during the collision (A-B). In Figure 1C the pendulum with the ball swings up and reaches a maximum height h, while mechanical energy is conserved following the collision (B-C).

Use the schematic of Figure 1, and your knowledge of conservation of momentum and conservation of energy, to *derive* an expression for the "muzzle velocity" of the launcher (v_{xi}), in terms of things you can measure in the lab (M_b, M_p, L, and θ of maximum upswing).

Use the table on the following page to organize this work. Print the page out, complete the table, and include it with your lab report. This does not involve any data, and so it is highly recommended to complete this *ahead of time, as part of your pre-lab assignment*.

PRINT OUT AND COMPLETE THIS PAGE. INCLUDE IT IN YOUR LAB REPORT.

Equation describing the collision A -> B (conservation of momentum):
Equation describing the upswing B -> C (conservation of mechanical energy):
Equation relating the maximum height (*h*) to the maximum angle (θ) of the upswing:
Combine the three equations above to derive the muzzle velocity, as a function of things that are measureable in the lab: $$v_{xi} = \left(\frac{M_b + M_p}{M_b}\right)\sqrt{2gL(1-\cos(\theta))}$$

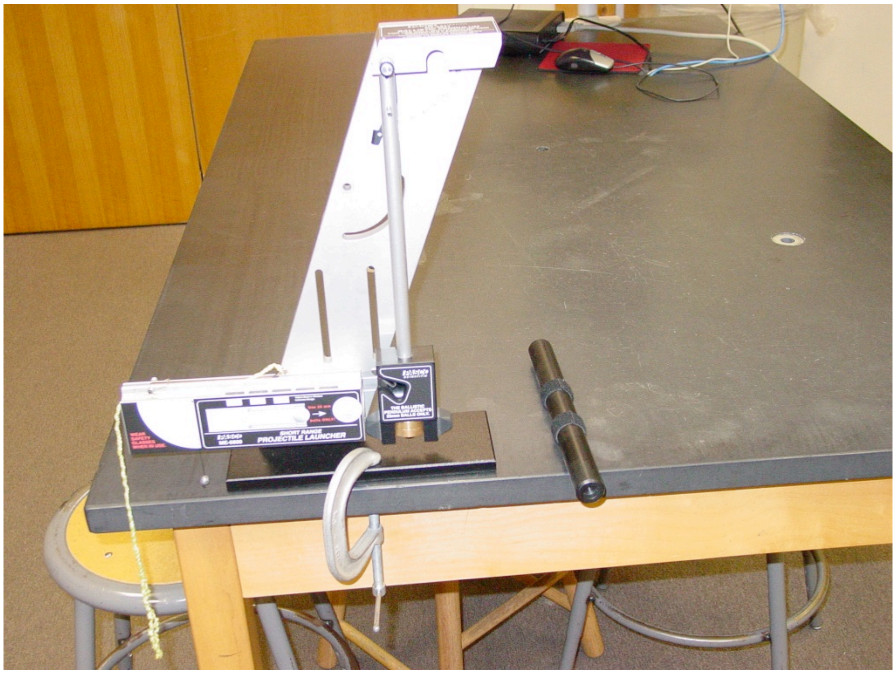


Figure 2 – Typical Experimental Setup of Ballistic Pendulum for Part I.

Safety:
Everyone must wear safety glasses when balls are being launched.
Never look down the barrel of the launcher, treat it like a loaded gun.

Experimental Procedure:
Part I. The Ballistic Pendulum – Finding the initial speed of a ball v_{xi}

1. Measure and record the mass of the ball and the mass of the pendulum.

2. Remove the pendulum from the base support so that the length of pendulum can be recorded. The easiest way to measure the length of the pendulum is to balance the pendulum on a small ruler. Use the distance *from the pivot point to the center of mass* of the ball and pendulum as the "length" of the pendulum.

3. Clamp the pendulum assembly to the table as shown in Figure 2, and make sure the launcher is firmly attached to the pendulum base. (If the experiment can "vibrate", you may get inconsistent deflections.)

4. Record the offset (if any) of the angle marker when it set to the firing position. If the offset is zero, great; if not you will have to adjust the average value of deflection angle to account for this offset.

5. When loading the projectile launcher, brace the launcher with one hand while using the ramrod with the other hand to drive the projectile into the launcher barrel.

The spring has three settings for projectile velocity. Always use the third setting for consistency and best results. Take several measurements of the angle to make sure they are consistent (be sure your lab report includes all of them!), and take the *average* of these measurements for all your subsequent calculations.

Part II. Finding the initial speed of the ball using timing gates.

Use the **same** ball as in Part I, and the same spring setting.

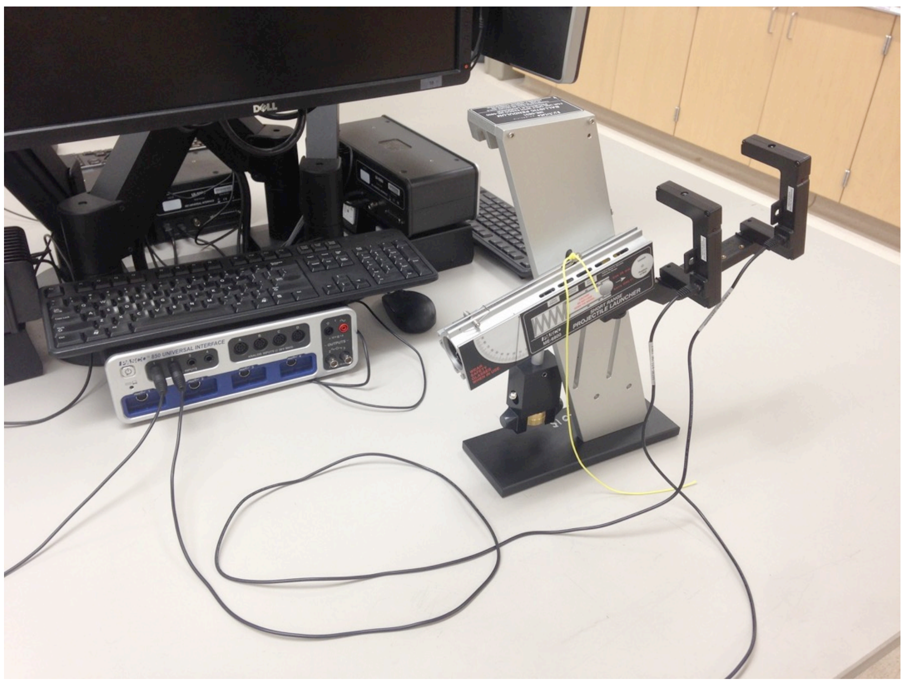
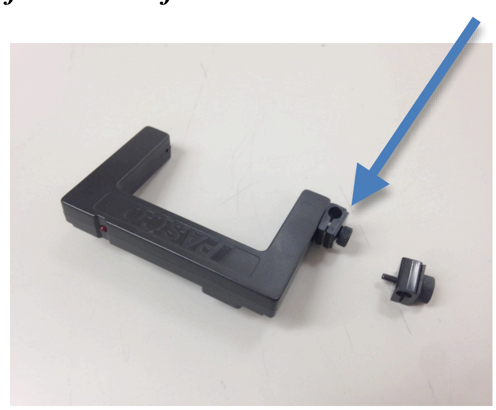


Figure 3 – Typical Experimental Setup of Launcher for Part II.

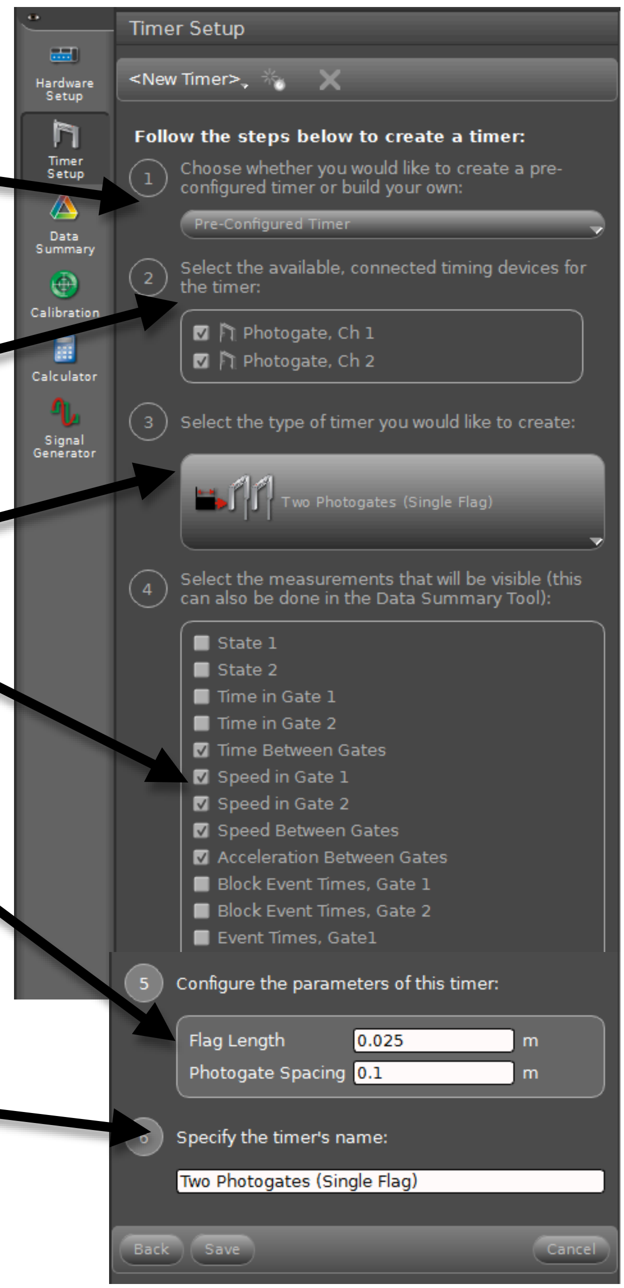


1. Attach the bracket to the launcher.

2. Each of the two photogates has a "stand holder" (a clip held on by a screw) attached to it. Remove these, and set them aside. (Do not lose them!)

3. The mounting bracket contains two screws. Remove these screws from their storage holes, and use them to attach the two photogates. The screws go into the holes left vacant on the photogates when you removed the stand holders. The two photogates should be 10 cm apart.

4. Plug both photogates into the PASCO 850 interface. The photogate *closest to the launcher* should be plugged in to the *first* connector, as shown in Figure 3.



5. In Capstone's "Hardware Setup" tab, connect both sensors as "Photogates".

6. There should now be a "Timer Setup" tab available, underneath the "Hardware Setup" tab. Click on this. Choose the pre-configured timer (the one already selected); hit "next".

7. Make sure both photogates are checked; hit "next".

8. Select “Two Photogates (Single Flag)” (the last one), it may automatically go to the next selection if not; hit "next".

9. Make sure "speed between gates" is selected (among other things); hit "next".

10. Use a set of calipers to measure the diameter of your steel ball. It should be near 0.025 m, but each ball is slightly different. Enter this number as the "flag length" in the Timer Setup. For "photogate spacing", enter the space from the end of one gate to the end of the other, which should be 0.1 m. Hit "next".

11. Name the timer. (The default is fine.) Hit "finish".

12. Create a "Digits" display (instead of a graph), and for the "Measurement", select "Speed between gates".

13. Start recording, and fire the launcher.

Compare the two measurements of initial speed (or "muzzle velocity), by computing the percent difference between then. Discuss this as part of your lab report's conclusion.

When disassembling the experiment, don't forget to return the little "stand holders" (that you unscrewed from the photogates) back to their original places!

Questions:

1) Work done by the spring (inside the launcher) goes into kinetic energy of the steel ball. How much?

2) By the end of the experiment, the ball and pendulum are raised up high, against gravity. How much potential energy does the system have at this moment?

3) If these two numbers are not the same, explain the discrepancy.

EXPERIMENT # 8: Static Equilibrium Mystery Meter Stick

Abstract:
Students will be given the opportunity to demonstrate learned lab skills to determine the unknown mass of a meter stick using the conditions for static equilibrium. This will be an outcome based lab with minimal instructions on how to achieve their overall goal. The students will be shown how to assemble the knife edge clamp onto the meter stick and attach the base to the table with a C-clamp. It will be up to the students to come to lab prepared to make the necessary measurements and calculations to determine the mass of the meter stick.

Goals:
Experience in creating an experiment, collecting data, and analyzing data with minimal instructions to achieve a specific result.

<table>
<tr><td rowspan="3">Equipment:
Meter stick (either the 1m or the 2m meter stick), knife-edge clamp, thread, support stand for the meter stick, C-clamp, mass hangers, Slotted mass set</td><td>Software: Excel</td></tr>
<tr><td>Group size: Individual.</td></tr>
<tr><td>What to turn in at the end:
An abbreviated lab report, with:
-- Cover sheet
-- A clear description and explanation (with sketches!) of the measurements you took, and how you used those measurements to calculate the unknown mass.</td></tr>
</table>

Theory:

The two conditions necessary for static equilibrium are given by:

$$\sum \vec{F} = 0$$

$$\sum \vec{\tau} = 0$$

Procedure:
Your instructor will demonstrate how the knife edge clamp installs onto the meter stick. The rest of the setup will be up to the individual student. Your overall goal is to determine the mass of the meter stick using only the conditions/equations of static equilibrium.

The "knife edge clamp" can be attached to a meterstick anywhere along its length, and can be balanced on a pedestal, as shown below. Use the central edge to read the meterstick position. There will also be a supply of mass hangers, masses, and string; use whatever and as many as you need!

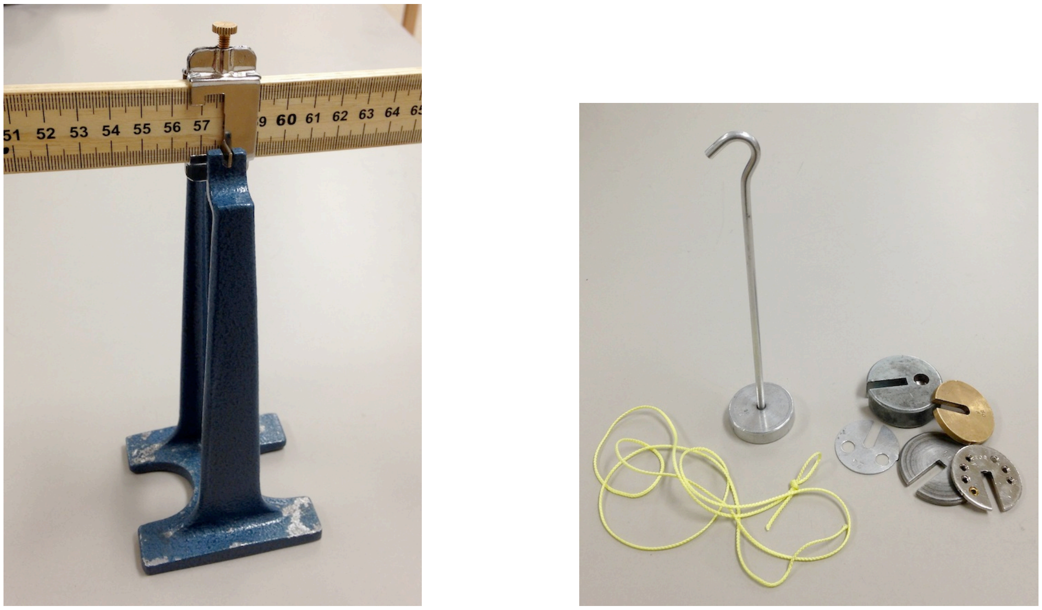


Figure 1: Knife-edge clamp attached to a meterstick, and other available equipment

Write a lab report that clearly explains the measurements you took, and *how* you computed the unknown mass from those measurements. It must include a sketch of the experimental setup. Let g =9.82 m/s^2 for calculations.

When you are ready to turn in your report, bring your meter stick to the instructor's desk and measure its true mass on the electronic balance. Your instructor will record the mass on your cover sheet.

Half your grade will be based on the abbreviated lab report, and the other half will be on the accuracy of your measurement as compared to the true mass, according to the scheme below:

< 1%	5 pts
1% - 3 %	4 pts
3% - 6%	3 pts
6% - 10 %	1 pts
> 10%	0 pts

EXPERIMENT # 9: Mystery Mass on an Atwood machine

Abstract:
Students will be given the opportunity to demonstrate learned lab skills in order to determine the unknown mass at their table using data obtained from graphs of motion of an Atwood machine. This will be an outcome-based lab in which students will be given minimal instructions on how to achieve their overall goal. The only instructions given will be how to set up the smart pulley so that position, velocity and acceleration graphs can be made. It will be up the students to determine the necessary measurements and analysis needed to determine the total mass and they should come prepared to do this. They will know the mass of the pulley and the mass of one of the mass hangers. When the students have completed their lab they may take the unknown mass to the lab instructor and use the electronic balance to determine the mass. No direct measurement of the mass will be made until their lab report is turned in.

Goals:
Experience in setting up an experiment, collecting data, and analyzing data with minimal instructions to achieve a specific result.

<table>
<tr><td rowspan="3">Equipment:
Mass hanger, Unknown mass, smart pulley, table clamp, angle clamp, string, steel rod, foam cushion.</td><td>Software: Excel, Capstone</td></tr>
<tr><td>Group size: Individual</td></tr>
<tr><td>What to turn in at the end:
An abbreviated lab report:
-- Cover sheet
-- Capstone graphs you used
-- A clear description and explanation of the measurements you took, and how you used those measurements to calculate the unknown mass (including algebra).</td></tr>
</table>

Theory:

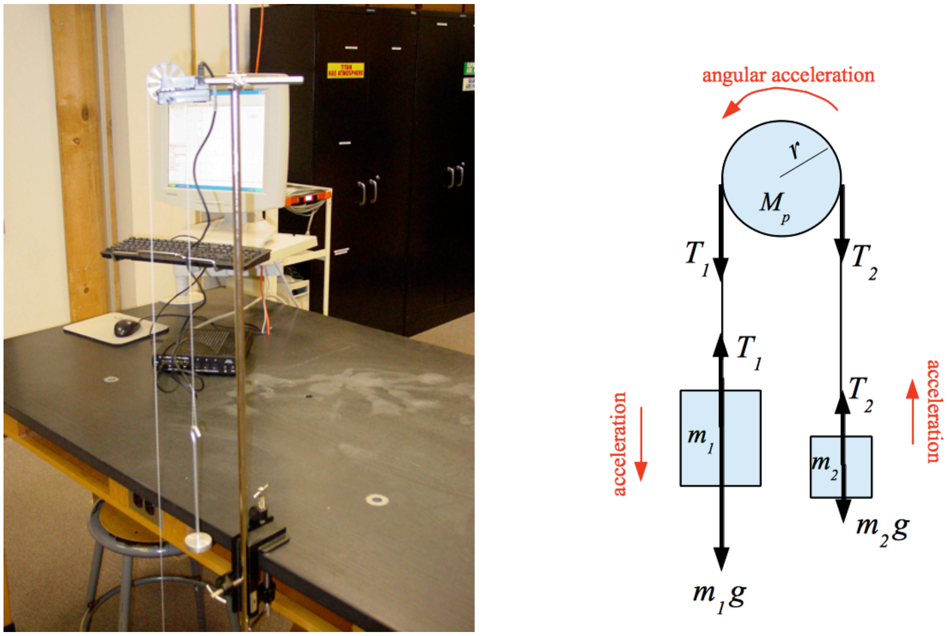


Figure 1: Setup for the Atwood machine using a smart pulley, and sketch of Newton's Second Law

Newton's Second Law, $\sum \vec{F} = m\vec{a}$, for the two masses, $\sum \vec{\tau} = I\vec{\alpha}$ for the pulley gives the following equations.

$$m_1 g - T = m_1 a \qquad \textbf{\textit{(1)}}$$

$$T_2 - m_2 g = m_2 a \qquad \textbf{\textit{(2)}}$$

$$rT_1 - rT_2 = I\alpha \qquad \textbf{\textit{(3)}}$$

Where:

I = the moment of inertia for the pulley and is given by $I = 1/2M_p r^2$, with $M_p = 5.0$ grams being the mass of the pulley. The three equations above can be combined into one equation below.

$$a = \left(\frac{g(m_1 - m_2)}{m_1 + m_2 + \frac{1}{2} m_p} \right) \qquad \textbf{\textit{(4)}}$$

Procedure:

1. Set up a smart pulley as shown in the Figure 1. There will be one smart pulley setup at one of the tables before the lab starts for reference. Be sure to put a cushion on the floor to prevent damage to the floor and/or the suspended masses.
2. Set up the Capstone software for the smart pulley: this sensor is called the "Photogate with Pulley". Once the sensor has been added you can make graphs of x vs. t or v vs. t.
3. Attach the two masses to the pulley with a string. One mass will be the 50.0 gram mass hanger plus any additional mass placed on the hanger[1], the other will be an unknown mass. To prevent the upward accelerating mass from colliding with the smart pulley arrange the height of the pulley so that when one mass is on the floor the other mass should be a minimum of 40 cm below the smart pulley.
4. There will be a mass set at your table that you may use as needed. You can load as much mass as you want opposite the mystery mass, except it must be something *unequal* to the mystery mass, so that the system *accelerates* when released.
5. Take whatever measurements are necessary to calculate the mystery mass, and calculate it! Write a lab report that clearly explains the measurements you took, and *how* you computed the mystery mass from those measurements. Include any Capstone graphs you used. Let g =9.82 m/s^2 for calculations.
6. When you are ready to submit your report, call your instructor and measure the unknown mass on the electronic balance and record the value just below your calculated value. Your instructor will supervise and put a signature. Once this is done, you are not allowed to change the value you calculated. Calculate the percentage difference between the calculated mass and the measured mass, using the measured mass as the known (or true) mass. Based on the grading scheme indicated below, grade yourself out of 5 points.

Half your grade will be based on the abbreviated lab report, and the other half will be on the accuracy of your measurement as compared to the true mass, according to the scheme below:

< 3 %	5 pts
3 % - 4 %	4 pts
4 % - 6 %	3 pts
6 % - 10 %	1 pts
> 10 %	0 pts

1 Hint: Best results are obtained when the acceleration of the system is in the range of (0.5 – 1.5) m/s^2. Therefore adjust the amount of unknown mass so that the acceleration of the system will be in that range.

EXPERIMENT # 10: Friction and Heat

Abstract:
The concept studied in today's lab is work, friction, and heat. Work is done by pulling a mass on a string up from the floor, but most of this work goes into overcoming friction between the string and a metal cylinder. The temperature of the cylinder increases due to work being done by frictional forces between the string and the cylinder. This is what happens when you vigorously rub your hands together. The increase in temperature can be plotted as a function of time. From measuring the work done, and using the equation $Q = mc\Delta T$, the specific heat of the cylinder can be determined.

Goals:
Data collection and analysis.
Comparisons of an experimentally determined constant to theory.

<table>
<tr><td rowspan="3">Equipment:
Friction base apparatus with metal cylinder attached, C-clamp, Thermistor Sensor, yellow string, mass hanger and masses, light table clamp, metal rod, Rotary Motion Sensor, Force Sensor.</td><td>Software: Excel, Capstone</td></tr>
<tr><td>Group size: Collect data in pairs, but analyze data individually</td></tr>
<tr><td>What to turn in at the end:
Full lab report.</td></tr>
</table>

Introduction:

The temperature of an object is a measure of the kinetic energy contained within it in the form of atomic or molecular motion. If two objects of different temperature are put in contact with each other, then **heat** is said to flow from the hot to the cold object until their temperatures equilibrate. Thus, **heat** is defined as **energy** transferred between objects due to a difference in their temperatures.

If mechanical work is converted into heat via some process, a relationship between work and heat can be obtained. In this experiment students will allow a rope to slide on a metal cylinder. The work done by friction between the rope and the cylinder will cause the temperature of the cylinder to increase. By measuring the increase in temperature and the associated amount of work performed, students will be able to determine the specific heat of the cylinder.

Theory:

A sketch of the friction apparatus is shown in Figure 1. The actual apparatus is presented more clearly in Figure 2. In the discussion that follows, refer to both Figures 1 and 2 for better understanding.

The cylinder (of mass m_{cyl}) shown in Figure 1 is constructed of aluminum and designed to have a rope wound around it in several turns. The basic principle is to adjust the rope on the cylinder so that when pulling on the rope to lift a mass, a sufficiently large frictional force is created between the rope and the cylinder so that its temperature rises. This slipping and sliding action of the rope against the cylinder does work and creates a small scale vibration within the aluminum that results in an increase in the molecular kinetic energy within the aluminum, hence, giving rise to an increase in temperature in the aluminum cylinder.

The cylinder's temperature (T) will be measured by a Thermistor Sensor. The force applied by the student (F) will be measured by a Force Sensor. When the mass moves, the distance of travel (Δx) will be measured by a Rotary Motion Sensor (this is a kind of smart pulley, whose radius is known to the computer, and so it can translate rotational motion into linear motion of arc length, as shown in Figure 1.)

The amount of work done by the student is:

$$W = F \cdot \Delta x$$

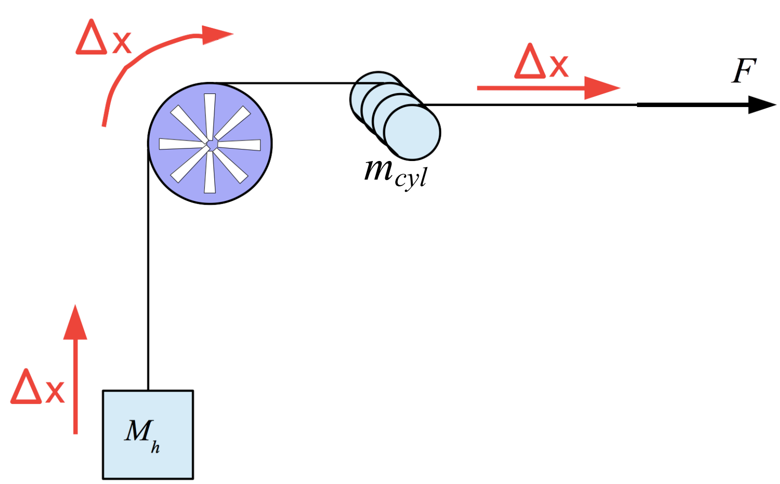


Figure 1 – Sketch of the experiment

This mechanical work results in an increase in cylinder temperature. Such an increase in temperature requires heat to have flowed into the cylinder, from the string sliding over the cylinder. The amount of heat flow required to account for the temperature increase is given by

$$Q = m_{cyl} c \Delta T$$

Where

Q = heat generated;
m_{cyl} = mass of the aluminum (or brass) cylinder;
ΔT = change in temperature;
c = specific heat of aluminum (or brass)

From conservation of energy, we know that:

$$W = Q + \Delta E_{mechanical}$$

… and in this experiment, your goal is to find the "*c*" of the material of the cylinder.

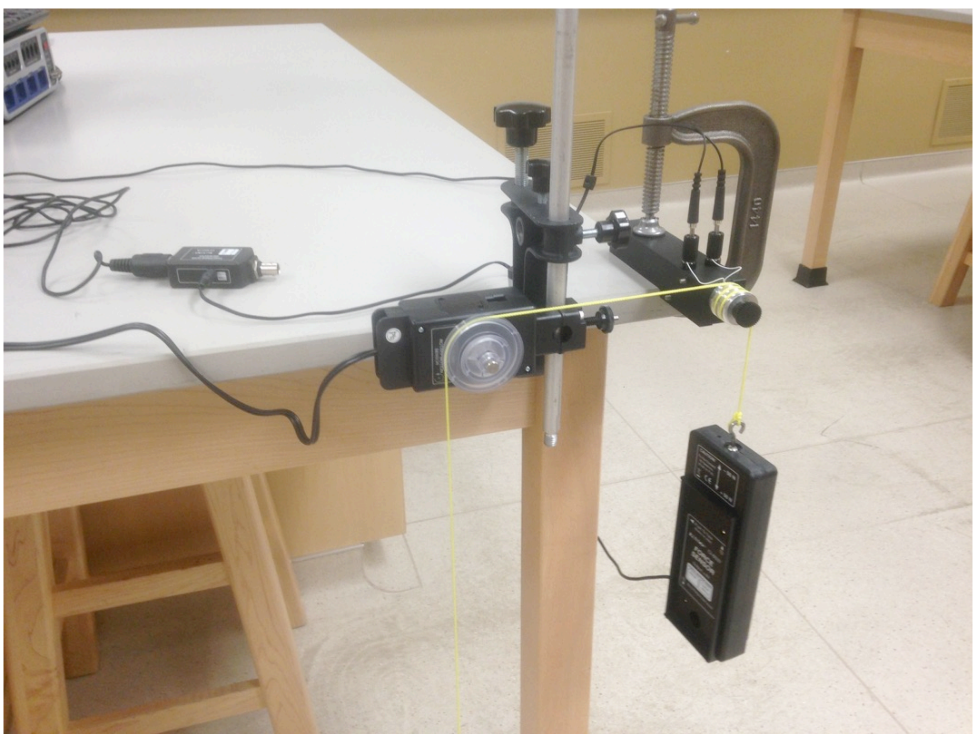


Figure 2 - Friction Apparatus, assembled and ready for data collection

Equipment Setup Procedure:

1. Use a C-Clamp to fasten the Friction Base (that's the rectangular thing that says "ENERGY TRANSFER – FRICTION" on the side) to the corner of the table.

2. If your base has a cylinder already attached, take note of which one it is (aluminum, or brass?) and leave it in place. If not, measure the mass of an aluminum cylinder using an electronic scale, and then install the cylinder on the base (see detailed instructions, at the end of this document).

3. With the cables provided, connect a Thermistor Sensor to the banana jacks on the base. Use the set of cables that plugs into the 3.5 mm stereo plug on the side (not the BNC plug on the end).

4. Use a table clamp and metal rod to mount a Rotary Motion Sensor to the table (see Figure 2).

5. Attach a yellow string to a hanging mass of about 200 grams. Attach the other end of the string to a Force Sensor. Make sure that the string is long enough that the hanging mass can rest on the floor.

6. With one hand, hold the hanging mass while you use the other hand to wind the string over the Rotary Motion Sensor's wheel, and then through the grooves of the aluminum cylinder. It should now look something like Figure 2.

7. Connect all the sensors to the PASCO interface. When connecting the Rotary Motion Sensor, plug the yellow plug into slot 1, and the black plug into slot 2. Use the "Hardware Setup" tab in Capstone to load all three sensors into the software: they are named "Rotary Motion Sensor", "Thermistor Temperature Sensor", and "Force Sensor".

8. While holding the string *slack*, tare (or "zero") the force sensor, by pressing the "TARE" button on the side of the sensor.

9. Set the sample rates of the sensors to 50 Hz. (You have to do this for all three of them separately.)

10. Create three graphs: Force vs. Time, Position vs. Time (from the Rotary Motion Sensor), and Temperature vs. Time.

11. Beginning with the hanging mass resting on the floor, start recording data, and begin to pull with a *steady* force on the force sensor, in order to raise the mass up. Watch the "Force vs. Time" curve to get a sense of whether your force is "steady" or not. When the mass gets close to the tabletop, stop the motion and hold or secure the string so that the mass remains elevated. Once the pulling is over, monitor the "Temperature vs. Time" curve until you see the temperature of the cylinder reaches its peak. Then you can stop recording. (Note: it may take a few "practice runs" before you get a "good" set of data!)

12. Using the Force and Position data from your "best" run, compute the total work done by you when raising the mass up. Use whatever techniques and Capstone tools you find appropriate.

13. Measure the change in temperature of the cylinder, using the coordinates tool. Note: the coordinates tool (by default) will *not* give you enough significant digits to perform this experiment precisely! To get more precise measurements of temperature, you will have to adjust the settings for the coordinates tool:

<u>How to increase the number of temperature digits on the coordinates tool:</u>
-- Right-click on the tool
-- Select "Numerical Format"
-- Select "Vertical Coordinate"
-- Check the "Override default" box
-- Set the number of decimal places, to whatever you need.

14. Use your data to compute the specific heat of the cylinder. [Note that some of the work went into raising the mass up, and some of it went into increasing the temperature of the cylinder.] There is no spreadsheet template for this lab, so be sure to *show and explain* all your calculations clearly in your lab report.

15. Remove the first cylinder (for instance, the aluminum one), and attach the other cylinder (for instance, the brass one). Take another run of data, and similarly compute the specific heat.

16. Compare your answers to the "true" specific heats for aluminum and brass, by computing the percent discrepancy between your measurements and:

Aluminum: $c = 0.896$ J/g ^{o}C
Brass: $c = 0.377$ J/g ^{o}C

Supplementary instructions: To attach a cylinder to the base:

1. Insert the plastic bolt into the cylinder
2. Place the cylinder next to the side of the base that has the hold. Turn the cylinder, such that the indented portion is at the top, with the wires pointing toward the base of the banana jacks.
3. Turn the bolt clockwise to fasten the cylinder to the apparatus.
4. Loosen the knobs on the banana jacks, and insert the stripped portion of the wire in the holds under the jacks (Note: do not kink the wires.) Screw the knobs on the banana jacks to hold the wires in place. Do not overtighten.