1001 LAB MANUAL
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Welcome to Energy and the Environment!

The lab exercises found in this manual focus on the physics that is the basis of issues concerning the generation and use of energy in our technological society. Energy use lies at the center of industrial society, the products of which, from light bulbs to cell phones, are based on our understanding of physics. The generation and the use of energy affect the environment at global, regional, and local levels. Through the exercises in this manual, you will explore the physical principles that govern the production and use of energy. The point is to get an intuitive idea of this abstract concept of energy by using it to make sense of the behavior of real objects.

The lab is where you can apply the physics from the lectures and your textbook to the real world via "hands-on" experience. To do that, some degree of mathematical descriptions and calculations are necessary as tools, and you should feel free to ask your TA for help if you need it. The aim of the lab exercises, and this course as a whole, is to build your ability to think critically about the energy and environmental issues that our society faces.

Before lab each week, read the pertinent sections of the textbook, as indicated for each exercise. Also familiarize yourself with the upcoming lab so that you have a reasonably clear idea of what will happen in the lab. *To do well in lab be prepared before you come.* If you do not come prepared, you will waste time trying to figure out what is going on and will not effectively use the lab time to challenge your ideas about physics and the real world. Use the lab periods to experience the behavior of nature and apply the concepts of this course.

You must have and use a square ruled lab notebook. Keeping a good notebook and answering the prep questions in your lab notebook *before* you come to lab will be part of your lab grade. Your TA will explain what is expected of you. Other details are in the syllabus.

LAB 1
VELOCITY AND ACCELERATION

Our first task in the course is to establish an understanding of how engineers and scientists define and calculate energy in moving objects. When we have done that, the discussion of energy utilization in society and the consequences for the environment can be discussed. The moving objects which we study at first are objects which you can easily see, like cars and baseballs. It turns out that the same concepts are used in much the same way in the study of very small objects like atoms and molecules which you cannot see without very sophisticated equipment. We will need the applications of the concepts of energy to atoms and molecules to understand energy technologies and environmental problems, but we will not discuss those applications for a few weeks, starting instead with the more easily visualized large moving objects

In physics, all motion is ultimately described in terms of the positions of things at successive times. Position can be specified by giving lengths, as when one says that the physics building is about 20 feet straight north of the math building. Notice that to specify that position (even approximately) I had to give a direction as well as a length. By saying 'straight north' I told you that you don't have to go east or west to get there from math, so I also told you the east west position of the building (again approximately.) For buildings, two lengths, say in the north direction and the west direction, are usually enough, but for an airplane position you would also have to give another length, the altitude. Generally, in our world, three lengths are enough to tell anyone where something is. That is what we mean by saying that space has three dimensions. Time requires less discussion: it is what you measure with a clock.

Now a complete description of the motion of an object can be given by stating its position at each moment in time (a kind of history of the positions which the object takes). However it turns out that in order to define and measure the energy of an object and to predict its motion using physics equations, it is useful to use two other quantities which are closely related to this history of the motion and can be obtained from it. These closely related quantities are velocity and acceleration. We discuss them in terms of the motion of a car. You will do experiments on a toy car in this laboratory in order to measure them. A change in from one moment to the next of the position of a car, a baseball or any object means that it has a *velocity*. A change in velocity from one moment to the next means it has an *acceleration*. Notice that acceleration is not the same as velocity because there can be a velocity which is not zero, and as long as the velocity is not changing, the acceleration is zero.

For simplicity we consider only motion along a straight line here, so that position can be specified by just one length. If an object travels along a straight line, as on the track on which the car in the experiments moves, then if it travels a certain time, then its average speed during that time is the distance gone divided by the time elapsed.

If you are driving across Nevada on a very straight freeway, and you go 210 miles in 3 hours then your average speed was 70 miles per hour (210/3). However, your speedometer did not read 70mph the whole time. Sometimes it was higher and sometimes lower. The speedometer measures instantaneous speed which is the average speed averaged over an extremely, immeasurably small, time interval. When you sped up, so that the reading on the speedometer went from 65 mph to 75 mph in 30 seconds then the car had a positive acceleration. To calculate the average acceleration you divide the change in the speed by the time it took. In that case

$$\text{acceleration} = (75\text{mph}-65\text{mph})/(1/120 \text{ hour}) = 1200 \text{ miles per hour per hour.}$$

Here I expressed 30 seconds as 1/120 of an hour. What the average acceleration means is that, if you kept on accelerating like that for one hour your speed would in crease by 1200 mph. (Not possible but fun to think about.) If you slow down, and make a similar calculation of the acceleration, you get a negative number. Negative accelerations correspond to slowing down and are sometimes called decelerations. Just as with velocity, you can also measure an instantaneous acceleration (though the measurement is a little trickier) that corresponds to the average acceleration over an extremely small time interval.

PRE-LAB READING

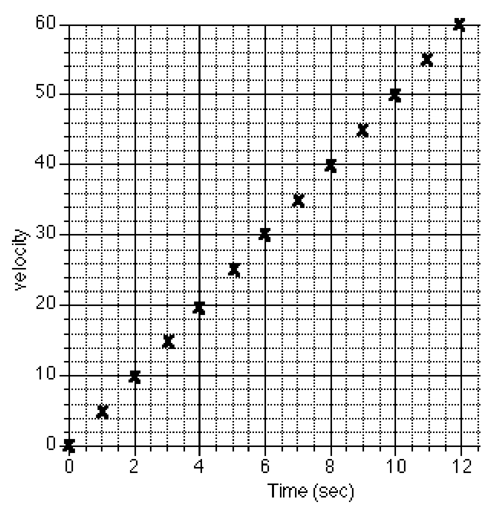
Reading 3.1, 3.4 and 3.5 of Wolfson is suggested.

EQUIPMENT

1 – motorized toy car
1 – aluminum track
1 – wooden block
1 – meter stick
1 – low friction cart
1 – stopwatch
1 – length of string
1 – computer, LabQuest mini interface and Motion sensor using LoggerPro

PREDICTIONS/PRELIMINARY QUESTIONS

1. What does it mean if an object moves with a *constant velocity*? Sketch a graph of velocity vs. time for a car (a motorized toy car in lab) moving with a constant velocity. Put velocity on the vertical axis, and time on the horizontal axis of your graph.
2. In your own words, describe what is meant by *constant acceleration*.
3. Sketch a graph of velocity vs. time for a car that is speeding up with a constant acceleration.
4. Sketch a graph of velocity vs. time for a car that is slowing down.
5. The following graph shows the velocity of a car in meters per second (m/s) measured at several different times. Calculate the acceleration of this car by using the slope of the graph.



6. What happens to the acceleration of a cart as it moves down an inclined track? (Does the acceleration increase, decrease, or remain the same?) Explain your reasoning.

There are two parts to this exercise. The first involves a level track, and the second involves an inclined track.

PART I: LEVEL TRACK, BATTERY CAR

EXPLORATION

Before you start to acquire computer data you need to explore a bit, - to try out the other equipment. This is something you will need to do in each lab; most equipment has a range of operation that is simple and straightforward, but outside that range complicated corrections are needed.

1. Place one of the metal tracks on your lab table and place the motorized toy car on the track. Turn on the car and observe its motion. The battery powered toy car should move at constant velocity on the aluminum track. Do you think it does? Why or why not? You may also want to see if you can get a PASCO cart to travel at constant velocity for taking data.

2. It is often useful to make approximate measurements without using complicated equipment. For example, use your forearm as a unit of distance and count seconds by counting one-thousand-one, one-thousand-two, etc. Then you might measure, with your arm, (don't use a meter stick) three arm lengths along the aluminum track. Let the car run that three arm length distance and measure the time by counting – one-thousand-one, etc. To determine the speed, divide three arm lengths by the time in seconds and obtain the speed in terms of arm-lengths per second. Each person in the group should try this approach at least once.

3. Take some measurements with the meter stick and a stopwatch to calculate the approximate speed of the battery powered car. Explain how you determined its speed (or velocity). Be sure to record the units you are using for each value.

4. How would a graph of horizontal distance vs. time look for the car going at a constant velocity? Sketch this graph in your lab notebook. (You don't need numbers on this graph – just a sketch to show the shape of the motion.) Put distance on the vertical axis and time on the horizontal axis of your graph.

5. Sketch a graph for velocity vs. time for the car going at constant velocity (no numbers are needed - just a sketch.) Put velocity on the vertical axis and time on the horizontal axis.

You should have agreement among your lab partners about the approximate velocity of the car. You should also compare graphs. If you don't agree, continue with the lab knowing that there should be a consensus on the graphs before the end of the lab session.

PROCEDURE

Exploration with LoggerPro - *For instructions about using the interface, LoggerPro data collection software or Motion sensor, refer to the appendices at the end of this lab manual.*

On the computer desktop open the LoggerPro software with the motion detector connected. In the upper left corner, a small icon should show that the interface is connected and that a Motion sensor is plugged in. If you have problems, check your connections and inform your TA.

To collect data you press the Go button along the top menu. Practice collecting data of the motorized toy car. Make certain everyone in your group has a chance to operate the computer. You can adjust the settings in LoggerPro to graph position vs. time, velocity vs. time and/or acceleration vs. time. Please read the appendix on using LoggerPro and take time during lab to make sure you can create all graphs necessary.

If possible, every member of your group should operate the computer.

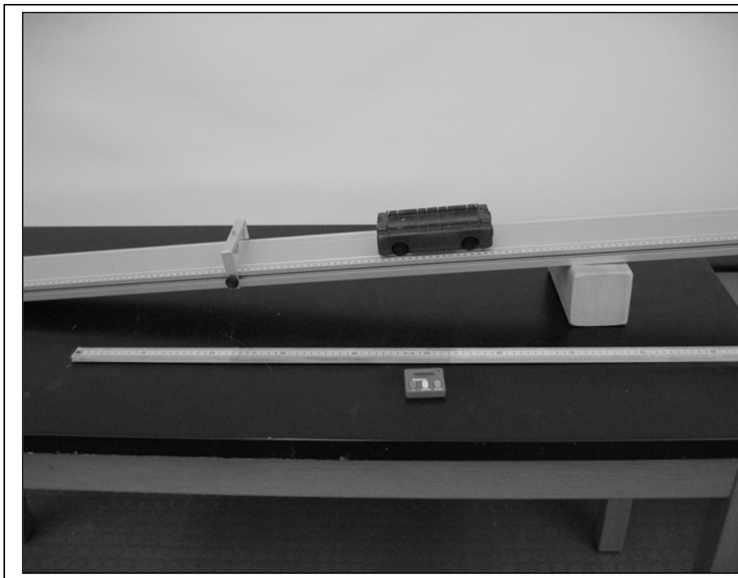
ANALYSIS

1. From the graph of distance vs. time, calculate the slope of the line. How is this slope related to the velocity of the car? LoggerPro allows you to fit curves automatically, read your appendix to find out how.

2. From the velocity vs. time graph, what can you tell about the acceleration of the car? Explain how you can tell this from the graph.

PART II: INCLINED TRACK, CART

Use a low friction PASCO cart – not the battery toy car. Put a wood block under the aluminum track to make the incline. (One block is probably all you need.) **Be certain to catch the cart before it falls on the floor!**



Discuss with your partners and make a prediction: How would you expect a velocity vs. time graph to look for a cart rolling down an incline? Draw a sketch of the graph. Explain what coordinate system you are using

EXPLORATION

1. Use a meter stick and a stopwatch to determine the average velocity of the cart rolling down the incline.
2. Use a meter stick and a stopwatch to record the distance and time for several points along the inclined track when the cart is rolling down the incline. You might need to release the cart more than once.
3. Make a graph of distance vs. time for this measured data.

PROCEDURE

Use the computer to obtain graphs of distance vs. time and velocity vs. time for the cart on the incline. Refer to the proper appendix if you need assistance using the software, interface or sensor.

ANALYSIS

1. How can you obtain the acceleration for the cart from the velocity vs. time graph?
2. What is the acceleration of the cart moving down the incline?
3. Is the acceleration of the cart increasing, decreasing, or constant as it rolls down the incline? How can you tell?
4. How does the value of the acceleration for the cart compare to an object in free fall (9.8 meters per second every second)?

CONCLUSIONS

1. Did either the battery car or the cart have a constant velocity? If so, which one(s)?
2. Did either object have a constant acceleration? If so, which one(s)?
3. Sketch a graph (without numbers) of distance vs. time for an object moving with a <u>constant</u> velocity.
4. Sketch a graph (without numbers) of distance vs. time for an object moving with an <u>increasing</u> velocity.
5. Sketch a graph (without numbers) of velocity vs. time for no acceleration.
6. Sketch a graph (without numbers) of velocity vs. time for constant acceleration.
7. How do your measured graphs compare to your predictions? Can you, in the future, identify motion with a constant velocity and motion with a constant acceleration?
8. Galileo concluded: "A body is said to be uniformly accelerated when, starting from rest, it acquires equal increments of velocity during equal time intervals." Does his definition of constant acceleration agree with your observations?

HISTORICAL NOTES

Galileo held *ignorato motu ignorator natura,* or 'ignorance of motion is ignorance of nature' -- now you and your partners have a start in understanding velocity and acceleration, which will lead to ideas concerning energy and its role in the natural world.

In this exercise, you and your partners analyzed the motion of a motorized car on a horizontal surface (aluminum track) and the motion of a cart on that same surface when tilted. The track and wheels minimized friction. The equipment is not so different from the tilted board used by Galileo in 1608 to study acceleration:

> A piece of wooden moulding or scantling, about 12 cubits [about 7 m] long, half a cubit [about 30 cm] wide and three finger-breadths [about 5 cm] thick, was taken; on its edge was cut a channel a little more than one finger in breadth; having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as

> possible, we rolled along it a hard, smooth, and very round bronze ball (*Discourses on Two New Sciences,* 1638).

Galileo hoped to investigate the motion of falling objects; however, most objects fell too quickly to measure their velocities with the equipment available to him. His solution was to use an inclined plane. He utilized a tilted board with a groove, down which he rolled a metal ball, to test Aristotelian ideas about motion. Galileo's experiments with his inclined plane were revolutionary because he focused on acceleration, a form of motion overlooked by Aristotle and his followers.

LAB 2
VELOCITY, ACCELERATION, AND NEWTON'S SECOND LAW

Now that you have some familiarity with velocity and acceleration, we can introduce the idea of the total force on an object which is in motion. The action of forces is the means by which energy is transferred between objects so it will be very important for our later discussions. We start with a situation in which there is very little friction impeding the motion of the object. For example consider ice skating. Suppose you are standing at the edge of a skating rink and give your little brother (weighs 50 pounds, on skates) a push while holding on to the rail. He goes flying off at some speed. Now suppose you give your sister (100 pounds) an identical push. It turns out that if you measure the final speed of both family members, the little brother will be going twice as fast. We say for a given force on the object (the push which you gave) the acceleration is less if the object has more mass.

Acceleration resulting from a force = (total force on the object)/(mass of the object)

Here we write mass instead of weight. Mass is closely related to weight but it is not quite the same. In the example, the mass or the brother and sister is proportional to the weight. To make a determination of the mass of an object, the most conceptually straightforward way is to use a set of standard masses and a balance. The mass of the object is then the amount of standard mass required for balancing the mass of the object.

Now if you look at the word equation above you see that you know how to measure acceleration (from last week's discussion) and we just discussed how to measure mass, so the only thing left in the equation is the total force. So you can turn the equation around by multiplying by mass to solve for the total force:

total force on the object= (mass of the object)x(acceleration resulting from the force)

This famous equation, often written F=ma, is Newton's second law of motion. So far it basically just defines what we mean by the total force on an object. It becomes useful if we have some additional information about the force. For example consider an object dropped so that it falls straight down. You probably heard that Galileo made experiments with dropping objects and found out that massive balls falling from the top of the leaning tower of Pisa hit the ground at the same time as much less massive ones dropped at the same time. This is interpreted to mean that the acceleration of the balls is the same whether they have a lot of mass or a little mass. Now look at the equation F=ma. The only way it can be true in the case of the falling objects is if the gravitational force on a falling object increases with its mass. Suppose that is true, say that F=mg where g is some constant acceleration due to gravity. Substituting this back in Newton's second law we get:

$$F=mg=ma$$

So a=g, that is the acceleration of falling objects is independent of mass, as Galileo (and many others) observed. So from Newton's second law plus an experiment we learned something about gravitational forces, namely that they are proportional to the mass in the moving object. However, not all forces in nature have this property of being proportional to the mass in the object. For example, the push that you give your sister or brother is not a gravitational force. It is generated by your muscles, which act through what are called electromagnetic forces in physics. That is why, when you push them, the little brother ends up going faster than the sister goes, but if you dropped them off a bridge (of course you would not do that) they would both accelerate the same amount. Most of the time in this course, the forces we consider will be gravitational or electromagnetic in origin. These are two of the four main categories of force known to physicists. At the end of the course, we will consider a third kind of nuclear force.

In applying Newton's second law; it is often important to keep in mind that it refers to the total force on an object and that this total can be the combined result of the action of more than one kind of force. Furthermore, these different forces are not always acting in the same direction and can cancel partially or completely out. As an example, suppose you hold a book out in front of you over the floor. As you hold it there, it is not accelerating so the total force on it is zero by Newton's second law. However, the force of gravity is pulling down on it and you are pushing up on it with your hand (with a force that is electromagnetic in origin). The two forces are exactly equal in magnitude but opposite in direction and cancel each other exactly as long as the book does not fall.

In more complicated cases, forces of friction and air resistance play a role. These more complicated cases (which made the early study of the subject in past centuries difficult) will be discussed later. In this laboratory you will consider cases in which they can be neglected. You and your partners will measure the velocity and the acceleration of an object to understand how it obeys Newton's second law.

PRE-LAB READING

Read 3.1, 3.4 and 3.5 of Wolfson.

EQUIPMENT

1 – aluminum track
1 – motorized toy car
1 – meter stick
1 – mass hanger
1 – mass set
1 – wood block
1 – low friction PASCO cart
1 – piece of string
1 – computer, LabQuest mini interface and Motion sensor using LoggerPro

PREDICTIONS/PRELIMINARY QUESTIONS

1. Sketch a graph of velocity vs. time for a toy car or cart used in lab, moving with a constant velocity.
2. Sketch a graph of velocity vs. time for a low friction cart that is moving down an incline..
3. On the same graph as question #2, sketch a graph of velocity vs time for a cart that is about twice as heavy and is moving on the same incline as the cart in question #2.
4. Sketch a graph of velocity vs. time for a cart moving on a horizontal track being pulled by a weight that is connected by a string over a pulley. (See the sketch in Part III.)
5. Sketch a graph of velocity vs. time for the same cart with extra mass attached (so the total mass of the cart and added mass is about twice the mass of the cart alone). The cart with extra mass is being pulled by the same weight as in question #4. Put the sketch on the same graph as question #4.

PROCEDURE

There are two situations. The first involves an inclined track (part I below), and the second involves a level track with a hanging mass pulling the cart (part II below.) In both exercises below, mass will be added to the low-friction cart for an additional trial.

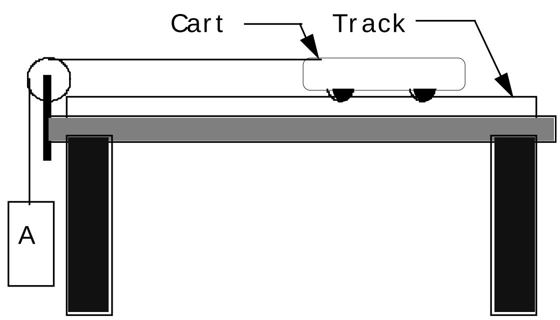
PART I: INCLINED TRACK, CART

Use a low friction PASCO cart – not the battery toy car. Put a wood block under the aluminum track to make the incline.

1. First discuss with your partners and make a prediction: How would you expect a velocity vs time graph to look for a cart on an incline? Draw a sketch of the graph for velocity vs. time.
2. Using a meter stick and stopwatch to determine the **average** velocity of the cart on the incline.
3. Using the computer and motion sensor:
   a) Obtain a distance vs. time graph for the cart on the incline.
   b) Obtain a velocity vs. time graph
   c) How can you obtain the acceleration for the cart from the velocity vs. time graph?
   d) What is the acceleration of the cart?
   e) Is the acceleration increasing, decreasing, or constant? How can you tell?
4. Now add some mass to the cart. Record the approximate mass of the cart and the approximate mass that you add to the cart. Repeat step #3. How does the acceleration this time compare with the acceleration without extra mass? Explain your results.

PART II: TENSION AND LEVEL TRACK

Remove the block from under the track. Attach a string to the cart, hang it over a pulley, and tie a mass hanger with masses to the other end. Now the cart is free to move in the horizontal direction, and the only unbalanced force on it is the tension in the string from the weight hanging off the end. You and your partners will find the cart's acceleration due to this tension.



1. Using the computer and motion sensor:
   a) Obtain a distance vs. time graph for the cart accelerating (before the mass hits the floor.)
   b) Obtain a velocity vs. time graph for the cart.
   c) How can you obtain the acceleration for the cart from the velocity vs. time graph?
   d) What is the acceleration?
   e) Is the acceleration increasing, decreasing, or constant? How can you tell?

2. Now add additional mass to the cart. Repeat your data collection with the more massive cart in order to calculate its acceleration. What is the acceleration of the more massive cart? How does it compare to the earlier acceleration? If you assume that the tension in the string is the

same in the two experiments, what does Newton's second law tell you about what how the two measured accelerations should be related?

CONCLUSIONS

1. a) Did the low-friction cart in Part I accelerate as it moved down the incline? How do you know?
   b) Was the acceleration of the more massive cart greater than, less than, or equal to the acceleration of the cart with no additional mass?
   c) When more **mass** was added to the cart, did the total **force** on the cart change? Did the **acceleration** change? Explain how your observations do or do not agree with Newton's second law of motion.

2. a) Did the low-friction cart in Part II accelerate as it moved down the incline? How do you know?
   b) Was the acceleration of the more massive cart greater than, less than, or equal to the acceleration of the cart with no additional mass?
   c) When more **mass** was added to the cart, did the total **force** on the cart change? Did the **acceleration** change? Explain how your observations do or do not agree with Newton's second law of motion.

3. a) Compare what happened to the **acceleration** in Part I and Part II when more mass was added to the cart (refer to your answers for questions 1b and 2b.)
   b) Compare what happened to the **force** in Part I and Part II when more mass was added to the cart.
   c) If there are differences between Parts I and II, what are they? If there are no differences, how are these trials the same?

Newton's second law of motion is one of the most fundamental relationships of all physics. Together with conservation of energy, it forms the basis of all Newtonian physics. It is hard to exaggerate the importance of Newton's second law when it can be applied in a wide range of topics, from projectile motion to electromagnetic fields. It was the concept of force that was essential to the development of mechanics and all physics. Be certain you can identify the specific forces acting in both parts of this laboratory.

HISTORICAL NOTES

You should not be embarrassed if you find it a little tricky to sort out what is happening in the motion of these simple objects. Though the concepts of acceleration, velocity, force and Newton's second law are quite simple to state, very intelligent people studied these questions for thousands of years before finally getting them right. For example early (more than 2500 years ago) Greek natural philosophers, such as Thales, Anaximander, and Anaximenes, thought that motion was eternal and somehow contained "inside" all things. Aristotle, who wrote a book called 'Physics' that was widely used in Europe during the Middle Ages, thought that rest is the natural condition of objects and that there are two types of motion -- "natural motion" is due to an object's natural tendency towards its proper place where it then rests, and "unnatural motion" is caused by something other than the object itself. It was not until the work of Galileo, who died about 360 years ago, that forces and acceleration started to be correctly understood. A major difference between Galileo and his predecessors is that Galileo did not just think about motion. He did experiments much like the ones you have done in this laboratory.

LAB 3
CONSERVATION OF ENERGY

This week we have enough of the basic concepts to begin a discussion of energy itself. Energy is sometimes introduced as if it is a concept independent of Newton's laws (though related to them). In fact, however, the idea of energy arises directly out of Newton's second law, and Newton's second law actually guarantees a central fact about energy, namely that no energy is ever lost or destroyed, but simply changes form, the so-called law of conservation of energy.

This can be illustrated by the example of the falling ball (You can think of one which Galileo dropped.) The example involves just a little bit of algebra which we use to show how the energy conservation law comes out of Newton's second law. Remember that the gravitational force on the falling ball is the constant mg, where m is the mass of the ball and g is a constant acceleration due to gravity. Therefore Newton's second law takes the form

$$\mathbf{mg=ma}$$

for the falling ball. Now the acceleration is the speed divided by the time elapsed.
In Newton's second law, it should be the instantaneous acceleration, but because the acceleration is a constant for the gravitational force the instantaneous acceleration is the same as the average acceleration. Consider the moment just before the ball hits the ground, supposed to be a time t since it was dropped. If the speed is v then, the acceleration is v/t. Putting this in the previous equation

$$\mathbf{mg=mv/t}$$

Now suppose the ball fell a distance h. To turn the preceding equation into an equation involving energy we multiply both sides of the previous equation by h

$$\mathbf{mgh=(mv/t)h}$$

Now h is the average velocity times t. Here the ball was accelerating so the average velocity is not the final velocity just before it hits the ground but is ½ of that velocity so h=(v/2)t. I substitute this for h in the right hand side of the previous equation and simplify

$$\mathbf{mgh=(mv/t)(v/2)t=(1/2)mv^2}$$

This is an equation which describes how energy is conserved for a falling ball. On the left hand side, the quantity mgh is the force on the ball times its height h above the ground before it was dropped. We call it the gravitational potential energy of the ball before it was dropped. On the right hand side is a quantity $(1/2)mv^2$ which is called the kinetic energy of the ball just before it hits the ground. We interpret the = sign to mean that the gravitational potential energy of the ball before it fell was converted into an exactly equal amount of kinetic energy which it had just before it hit the ground.

To summarize, for a falling ball, two forms of energy, kinetic and gravitational potential, are involved. The sum,

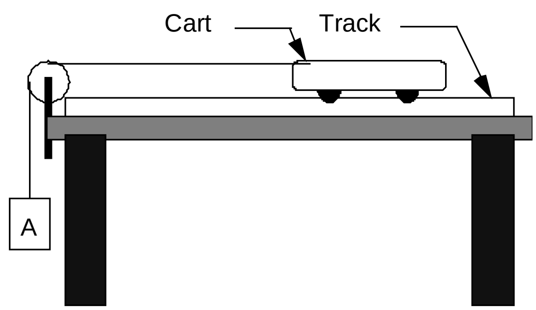
total energy = gravitational potential energy + kinetic energy

stays the same during the motion, but at the beginning of the fall it is all gravitational potential and at the end it is all kinetic. In between, though we did not prove it, the gravitational potential energy gradually decreases while the kinetic energy increases to keep the sum constant. The fact that the sum is unchanged is what we mean by conservation of energy in this case. I showed by algebraic manipulation of Newton's second law that this follows from Newton's second law and is not an independent principle. This conservation law turns out to apply for any system of objects obeying

Newton's equation, though some other forms of potential energy need to be introduced. Though it follows from Newton's equation, the conservation of energy is often easier to apply and think about than the general solution to Newton's equations, so we will often apply conservation of energy considerations to study of complicated situations without worrying much about the underlying Newtonian mechanics.

In this exercise, you and your partners will investigate the law of conservation of energy with an aluminum track and a low-friction cart attached to a hanging mass. You will calculate: (i) the total change in kinetic energy of the cart and hanging mass, (ii) the change in the potential energy of the hanging mass. According to the conservation of energy and the relationship between work and energy, these quantities should be equal.

Figure 1:



Pre-Lab Reading

Reading 3.4 and 3.5 of Wolfson is suggested.

EQUIPMENT

1 – aluminum track
1 – pulley
1 – mass hanger
1 – meter stick
1 – low-friction PASCO cart
1 – piece of string
1 – mass set
1 – stopwatch
1 – computer, LabQuest mini interface and Motion sensor using LoggerPro

PREDICTIONS/PRELIMINARY QUESTIONS

A cart is located on a level air track with a string attached between the cart and a weight. The weight is hanging by the string so it can pull the cart along the track. (See the diagram in figure 1.)

1. When the weight is hanging below the pulley but above the floor, what form of energy could be used to describe the energy of the weight relative to the floor? What quantities would you need to know or measure to calculate this energy?
2. Does the potential energy of the **hanging weight** increase, decrease, or stay the same as it falls to the floor?

3. Does the potential energy of the **cart on the track** increase, decrease, or stay the same as it is pulled by the hanging weight?
4. Suppose the weight falls from a certain height and pulls the cart along the horizontal track. Just before the weight hits the floor, what form of energy does it possess?
5. Using the law of conservation of energy, describe the energy situation just before the hanging weight starts falling compared with the energy situation just before the weight hits the floor.
6. Write an expression for the work done by gravity in pulling the weight from its initial height to the floor. What quantities do you need to measure to calculate the work done on the hanging mass?

PROCEDURE

In this exercise, you and your partners will calculate **:i)** the total change in kinetic energy of the cart and hanging mass and **ii)** the change in potential energy of the hanging mass.

1. The change in kinetic energy of the cart and hanging mass can be calculated. The two objects will both start at rest, so their initial kinetic energies are zero. The cart and the hanging mass will accelerate at the same rate (a string connects them.) The velocity of one object will always be equal to the velocity of the other, as long as the string remains taut.

With the computer data analysis software, you can find the velocity of the cart or hanging mass at any point in time. You and your partners are interested only in the final velocity. (After the weight hits the floor, what happens to the speed of the cart?) The mass of the cart and that of the hanging mass can be determined with a triple-beam balance. Refer to the appendix on using LoggerPro if necessary. With this information, calculate the kinetic energy of each object separately. Recall that kinetic energy is:

$$KE = (1/2)mv^2$$

where m is mass of an object and v is the velocity. Be sure to use the proper SI units: kilograms for mass and meters per second for velocity. To calculate the total change in kinetic energy, you must add the final kinetic energy for both the hanging mass and the cart.

2. There is no change in the gravitational potential energy of the cart – if the track is level, its height off the floor does not change. Only the height of the hanging mass changes. As a result, only the potential energy of the hanging mass changes. Define the floor as the point of zero potential energy. Recall the equation for gravitational potential energy

$$PE = mgh$$

where m is the mass of the object, g is the acceleration of gravity on Earth's surface, and h is the height from the point of zero potential energy. Use this equation and the measured mass of the hanging mass and the distance if fell to calculate the potential energy,

CONCLUSIONS

1. Comment on your values for the total change in kinetic energy of the cart and the hanging mass and the change in potential energy of the hanging mass.

2. a) Do your values support the conservation of energy? Explain.
   b) How can you account for any discrepancies between these values?

Consider the following situation: A physics instructor demonstrates the conservation of energy with a bowling ball attached to the ceiling with a string. It is simply a large pendulum. When the pendulum is pulled back, it has all potential energy, and at the bottom of its swing, it has all kinetic energy. The physics instructor releases the bowling ball from the tip of his nose, and it swings across the room and back toward him. Based on the conservation of energy and your results for this exercise, will this physics instructor get smacked by the bowling ball? Will it touch his nose? Explain. What if he gave the bowling ball a slight push when he let go? Explain your answers. If there is a difference, distinguish between what happens in theory and what happens in the real world.

LAB 4
ENERGY TRANSFER THROUGH WORK

In previous laboratories you have studied the energy of a body or collection of bodies which could be regarded for the purposes of the experiment as isolated. We did not have to consider the transfer of energy from one body to another explicitly. However in energy technology such as the delivery of electricity to your home where it is converted to other forms for your use or the delivery of the chemical energy in gasoline to your car where it is converted through two steps to the kinetic energy of your car, energy transfer from one body to another is of utmost importance. Energy transfer from one body to another takes place through the action of work. To illustrate this, we will turn back to the falling ball discussed in laboratory 2, but this time, suppose that, before the ball was dropped, you picked it up off the floor and lifted it up to height h for dropping. For simplicity we will suppose that it was lifted slowly and steadily so that we can ignore any accelerations and decelerations during the lift. From an energetic point of view, what is happening to the ball is that gravitational potential energy is being added to it. Where did that energy come from? It came from your body, where the energy was stored in the form of chemical energy in your muscles. We want to focus on the mechanism by which the transfer took place: As you lift the ball, a gravitational force mg (mass X gravity) acts down on it and you exert a slightly larger force upward on it with your hand. Since we are ignoring accelerations and decelerations as small we can suppose that this upward force is also of magnitude mg (though it has a completely different origin than the downward force). Now the net energy added to the ball is the gravitational potential energy mgh. Therefore

Energy transferred to the ball during lift = mgh
= (magnitude of the upward force due to your hand X distance through which the force acted)

We say that your hand performed work on the ball equal to the force you exerted on the ball times the distance through which it acted. The conclusion from this example can be generalized: When a body exerts a force on another body and the body moves through a distance, energy is transferred to the other body. The magnitude of the energy transferred is the product of the magnitude of the force times the distance, along the direction of the force, through which the force acts.

When energy transfers of this sort occur, it is often relevant to the engineering application to know how fast they occur. Therefore we introduce the concept of power, which is the rate at which energy is transferred due to the performance of work and is given by the amount of work done divided by the time elapsed.

In this laboratory, you will perform two experiments in which work is done and energy is transferred to a body. The first case is a little tricky because it appears that the body, actually your body, is doing work on itself: You will be running up stairs and measuring the rate at which you add gravitational potential energy to your body. However, one can regard this as a transfer of chemical energy stored in your muscles to the gravitational energy of your body as a whole through the performance of work which is done as you push yourself upstairs with your legs. (If you think about it you will find it a little tricky to analyze how you push yourself upstairs, but it is clear that a net upward force must result.)

In the second experiment, you will turn a crank, which causes a wheel to rub against an aluminum cylinder. In this case, chemical energy is converted ultimately to the thermal energy in the aluminum, manifested as a rise in its temperature. As we will discuss, thermal energy is actually a form of kinetic and potential energy associated with the random motion of the molecules of a substance (aluminum here).

PART 1. TRANSFER OF CHEMICAL ENERGY TO GRAVITATIONAL POTENTIAL ENERGY THROUGH WORK

As you run up stairs, you use over two hundred muscles. When you walk or run, your muscles use energy both to propel your body forward and to move it against gravity. The energy to do this comes from your food. Your muscles convert the chemical energy of adenosine triphosphate (ATP) into mechanical work. In this exercise, you and your lab partners will find your own work and power output when running up a single flight of stairs and then four flights of stairs.

PRE-LAB READING

Read 3.3, 3.4 and 3.5 of Wolfson.

EQUIPMENT

1 – stopwatch
1 – meter stick
1 – bathroom scale

PREDICTIONS/PRELIMINARY QUESTIONS

(Look at the lab procedure and pre-lab reading for help in answering these questions.)

1. Estimate the work you would do in climbing a set of stairs with a vertical height of 4 meters. (Use the weight of a person in kg) If you know the weight of a person how do you find the force of gravity on the person?
2. What is the relationship between the work you do in climbing a set of stairs and the potential energy you gain in going up the stairs?
3. Estimate the time it would take to walk up the set of stairs and use that to determine the power you would develop in climbing those stairs.
4. Estimate the amount of horsepower you develop in climbing those stairs. Note: 746 watts of power are equivalent to one horsepower.
5. If you run up the stairs (instead of walking) will you be developing more horsepower or less? Explain your reasoning.
6. If you walk up several flights of stairs do you think the power you expend would be greater, the same or less than when you walk up only one flight? Explain your reasoning.

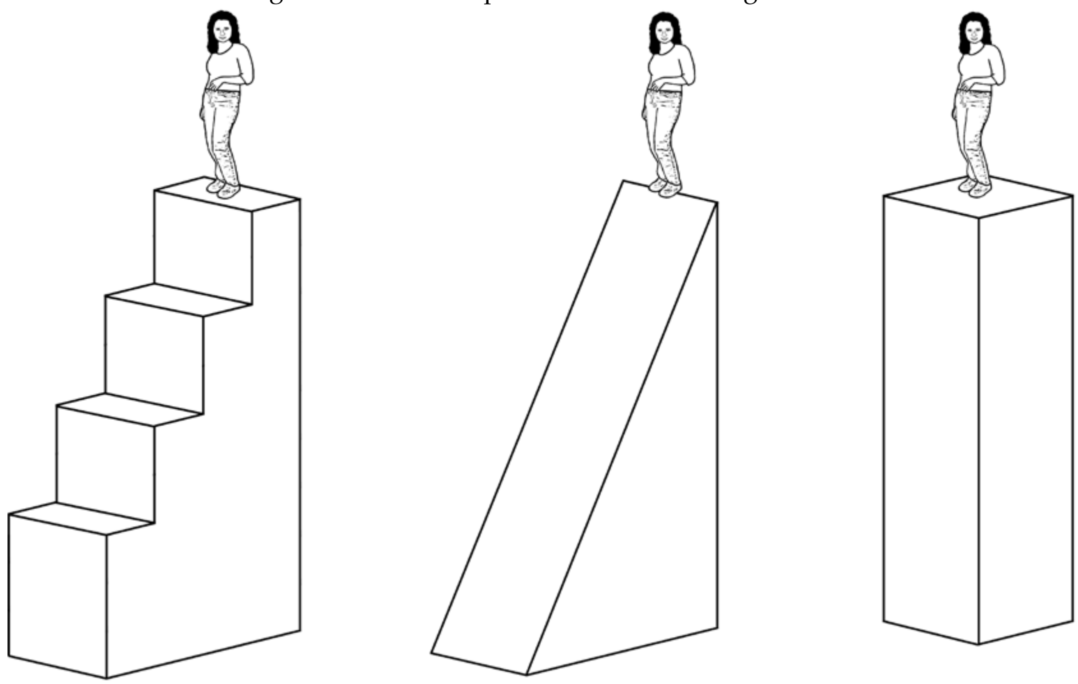
PROCEDURE

In this exercise, you and your partners will calculate your work and maximum power output when climbing stairs. Remember that work is a change in energy. When you climb a flight of stairs, you have increased your potential energy (you now have the potential to fall down the stairs under the influence of gravity). How fast this change in energy occurs will allow you and your partners to determine the power output involved.

This exercise requires physical activity. If you are unable to participate due to an injury or asthma, tell your instructor. Be careful on the stairs so you don't trip or collide with anyone else. Someone acting as a "lookout" is a good idea.

1. To calculate your potential energy, you must know your mass. Measure your weight in pounds on the scale and multiply by 0.45 to find your mass in kilograms.

2. You must also know your change in height to calculate your potential energy. Use the meter stick to determine the height of one flight of stairs and four flights of stairs. Be careful -- the physics building is a little strange. The flights of stairs have different numbers of steps, and some of the flights even have steps with a different height!



In each case, the student has the same gravitational potential energy, and she has done the same amount of work to reach the top because (neglecting friction) she does no work when she moves horizontally. Work is required, though, for her to move against earth's gravity.

3. Each member of your lab group should run up one flight of stairs (from one landing to the next) while someone records the time taken. Next, each group member should run up four flights of stairs (two stories) while someone records the time taken.

4. Calculate the work you did in lifting your body against the gravitational force. The work done is equal to your change in potential energy. To find your power, divide the change in potential energy by the time it took to climb the stairs. Report the results.

CONCLUSIONS

1. Report your leg power in watts (Joules per second). Divide your result by 746 in order to find your power in horsepower. How does your work and power compare to that of your partners? Did anyone do more work than you but used less power? Vice versa? Who did the most work? Who had the greatest power output? The least?

2. As you climb the stairs, you convert food energy into kinetic energy. A major part of this conversion, however, is heat that is lost to the air. In fact, about 75 percent of the energy from food becomes heat. Only 25 percent of the food energy is converted to work. Based on your leg power and the efficiency of converting food energy into work, how long would it take you, climbing stairs, to burn off a Big Mac (570 kilocalories)? How about a Double Whopper with cheese (1010 kilocalories)? One calorie (not Calorie) equals 4.2 Joules.

3. How does your power for a single flight compare to that for four flights of stairs? Read the following article about the Annual Empire State Building Run-Up. Consider the record-holders and the 88-year-old orchestra conductor. Assume that the men -- Paul and Chico -- weigh 170 pounds and that Belinda weighs 130 pounds. Calculate their work and power. Compare to your work and power, and explain the differences. Also consider long distance runners and sprinters. A typical long distance runner has a maximum power of 9 watts/kg body weight, and a typical sprinter has a maximum power of 15 watts/kg body weight.

22nd Annual Empire State Building Run-Up
February 23, 2000

This ain't no party, this ain't no fooling around. This is the 23rd annual Empire State Building Run-Up, "the world's most elevating workout." Organized by the New York Road Runners Club (NYRRC), the race offers 30 minutes of uphill torture.

Starting at 10:30am, beginning in the lobby of the Empire State Building on 34th Street about 150 runners attack flights of stairs in one of the world’s most famous landmarks. According to our abacus, that comes to 1576 steps, for an ascent of 1050 feet – approximately 1/5 of a mile. The stairs themselves are only 40 inches wide – plenty of room for cockroaches, but not much for humans. And the view? There is none, until you reach the top. A ceremony immediately follows on the 86th floor, where the male and female winners each get a trophy.

Why run up all those stairs in the first place? Running from New York's finest muggers and assailants? Hardly. The real reason lies with Fred Lebow, founder of the NYRRC. Twenty years ago Fred lived in a walk-up – a type of apartment building without an elevator – and he figured that if he walked up stairs every day, why not run a race up them? While the idea might seem simple, it has caught on in a big way. Not only is this the NYRRC's 23rd run, but the concept itself has been appropriated by copycats in Chicago, in Toronto, in Moscow, and in Sydney.

If you find yourself inspired to rush over to scale those steps with the other runners, don't bother. You see, this is a special race in a special town. You must apply in writing to the NYRRC for approval and explain in an emotional essay how you've been deprived since birth and why you deserve this type of punishment. If approved, you'll be notified. Don't call them, they will call you. Oh yeah, and you will also sign every medical release known to man.

So who made the cut? Last year, 150 runners from 9 countries and 12 US states crammed their way up those stairs. Ages ranged from 20 to 87, including an optometrist, a nanny, and an air traffic controller. Watch out for the Australians; they hold the record time for the men (Paul Crake made a new record last year, at 10:15 – that's 155.3 steps per minute!) and the women (Belinda Soszyn, 12:19, set in 1996). And look for Chico Scimone, the 88-year-old orchestra conductor from Italy, who has run the race several times, logging last year at 34:21. He'll be running with some family members this year; and, reportedly, he's in even better health than last year! Not bad for 88. Certainly a lot faster than most of you.

Note on Energy Use by the Human Body

ATP is the primary energy source of cells. As its name would suggest, this compound has three phosphate groups, and energy is stored in these chemical bonds in the same way that electrical energy is stored in a battery. With this energy, your muscles produce a force by contracting. When attached to bones by a series of tendons, a contracting muscle can pull two bones together, using the bones as a lever. If you exercise more than a minute or so, then the energy in the ATP in your muscles gets converted to its lower energy form and has to be restored. The slow step in doing the restoration is getting enough oxygen into your blood which is why you start to breath hard if you run for a while. If you are running hard, use up the ATP and your lungs aren't pumping oxygen in fast enough, then your body will switch over to another source, a kind of energy in sugar called glycogen in your blood. The use of glycogen results in an excess of lactic acid in the blood, which can cause cramps and discomfort. The glycogen supply only lasts a few minutes if it's being used at the maximum rate. It's used by athletes in sprints and dashes and the lactic acid results in incapacitation for as much as an hour after such events while the glycogen is restored and the lactic acid is cleared from the blood. If you run at a pace which can be sustained for a long time, because the oxygen is supplied fast enough to keep up with its use, then the glycogen is only involved in a minor way and you can run for hours (as in marathons). For most humans the power production under those conditions is around 1/4 horse power.

PART 2: TRANSFER OF MECHANICAL TO THERMAL ENERGY THROUGH WORK

Thermal energy is central to the operation of many of the energy technologies which we discuss in this course. In most electrical power generation, coal is burned to convert chemical energy to thermal energy which is then converted to mechanical energy in turbines and finally to electrical energy through processes we will discuss later. Most transportation involves conversion of chemical energy to thermal energy which is in turn converted to kinetic energy of the vehicle. So what is thermal energy? Basically, though it took more than a century to establish this, thermal energy is understood to be a form of kinetic and potential energy arising from the random motion of the atoms and molecules in the material, gas or liquid which is heated. Temperature, as measured by a thermometer, is directly related to the amount of kinetic energy in the molecules and atoms. However, because there is also potential energy associated with the forces between the atoms, the temperature alone does not give enough information to calculate the amount of energy added to a material when its temperature rises by a fixed number of degrees. To take account of the added potential energy one needs to know the specific heat c of the material whose temperature is changing. One calculates the added thermal energy through the formula

$$\text{Added thermal energy} = (\text{specific heat } c) \times (\text{change in temperature}) \times (\text{mass of material})$$

In this experiment, you will turn a crank which causes a cable to rub against an aluminum cylinder. The rubbing causes an increase in the random motion of the aluminum atoms in the metal drum, a rise in its temperature and an increase in its thermal energy. You can calculate the work done by multiplying the magnitude of the force by the distance through which it acts and you can calculate the added thermal energy by use of the above equation, knowing the specific heat of aluminum (which is given below) if you measure the temperature rise and the mass of the aluminum. By comparing these two numbers, you can confirm the conservation of energy in this process.

Historically this kind of experiment, which was done very early by some of the people who discovered that thermal energy was a form of mechanical energy, was regarded in a somewhat different way, as establishing the relationship between the units of heat (calories) and the units of mechanical energy (joules). It was eventually found that one calorie equals 4.186 joules.

PRE-LAB READING

Read Chapter 4 of Wolfson.

EQUIPMENT

- 1 – Mechanical Equivalent of Heat apparatus
- 1 – weight on a flat nylon string
- 1 – digital multimeter
- 2 – banana cables

PREDICTIONS/PRELIMINARY QUESTIONS

You and your partners will do work on the aluminum cylinder by turning a crank. A rayon string will be wrapped around the cylinder several times. When you turn the crank, friction between the cylinder and the string will hold up the weight and will heat the drum. Since you are applying force over a distance, you can calculate the work done on the cylinder. You can also measure the cylinder's temperature and will know the specific heat of aluminum, so you can calculate the heat energy produced. The work done depends on the number of times you turn the crank. You will calculate the number of turns needed, in theory, for a specific increase in temperature. You and your partners will compare this theoretical number to your experimental result and consider any differences.

1. Before you do your first trial, you must find the theoretical number of turns of the cylinder needed to raise its temperature by a particular amount. With your lab partners, choose a temperature change of at least 8 degrees Celsius. This will be the temperature increase of the drum that you will use in the so-called heat equation:

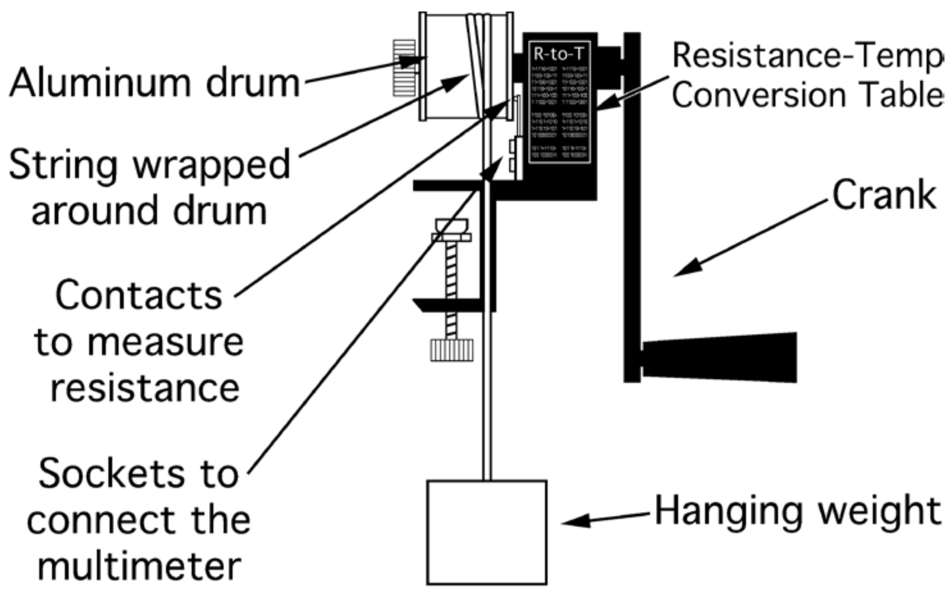
Added thermal energy = (specific heat c) x (change in temperature)x(mass of material)

. The value for the specific heat of aluminum in SI units is 900 joules/kg • degrees C.

2. According to the conservation of energy, the amount of heat transferred *Q* must equal mechanical energy input, or the work you will do on the drum. After you calculate the heat energy, you and your lab partners must consider the work you will do on the drum. Remember that work is a force applied over a distance. The force will equal the pull of gravity on the hanging weight. The distance will equal the drum's circumference times the number of times you turn the drum with the crank. In the form of an equation, the work W done on the aluminum drum will be

$$Work_{gravitational} = \left(m_{weight}\,g\right)\left(\pi D_{cylinder}\right)\left(N\right)$$

where m is the mass of the hanging weight, D is the cylinder diameter, and N is the number of times you turn the crank. With this equation, find the number of turns necessary to increase the heat energy of the drum by the amount you calculated in the first step.



PROCEDURE

With your theoretical number of turns, you are now ready to conduct your trial. Secure the drum apparatus to the table with the clamp. Place your weight on the floor beneath the drum. Wrap the string around the drum two or three times, enough that you hardly need to pull on the string when turning the drum to keep the weight at a constant height off the floor. Practice turning the drum while pulling gently on the string to raise the weight a few centimeters off the floor. As the drum turns and the string slides over it, the friction will heat the drum.

It is a very good idea not to place your feet under the weight. It has a mass of over 8 kilograms and is sufficiently heavy to break your toes if it accidentally falls from a height of several centimeters. Also, never let go of the crank when the weight is off the floor or it will spin rapidly and bruise fingers.

1. You will measure the aluminum cylinder's temperature with a temperature-dependent resistor cleverly called a thermistor. As the temperature of the aluminum increases, the resistance of the thermistor will decrease. The multimeter will be used to measure the resistance of the thermistor. So, set the multimeter to measure resistance (the symbol for which is Ω), and attach it to the apparatus with the wires provided. Record the resistance, and use the conversion table on the apparatus to find the initial temperature. If this resistance is not close to one of the temperatures on the table, grasp the drum with your hand to increase its temperature to a more convenient one. To the initial temperature, add the temperature change on which your group decided in the first step. This will be your final temperature. Use the conversion table to ascertain the resistance of the thermistor when it reaches this final temperature.

2. Choose someone to turn the crank (if the counter is not working, this person must also count the number of turns), someone to hold the end of the string, and someone to monitor the resistance. The person who is monitoring the resistance should watch for the thermistor's resistance to decrease to that which corresponds to the desired final temperature (use the conversion table printed on the apparatus to decide these values beforehand.)

3. Start turning the handle at a rapid pace. Be certain that the apparatus is properly attached to the table so nothing will fall. The hanging weight should stay a constant height off the floor as you turn the handle -- this way the gravitational potential energy of the hanging weight does not change. It is easy for the cord to start wrapping around the cylinder, and it might take some practice to keep this from happening.

4. When the resistance reaches that of your final temperature, stop turning the crank, and record the number of turns. Then compare the number of actual number of drum turns to the number predicted in the second step. Your instructor may ask you to do a second trial with a different change in temperature.

CONCLUSIONS

1. What was the amount of thermal energy transferred to the aluminum cylinder for each trial?

2. Compare the number of actual turns needed to add this amount of thermal energy to the cylinder to the number predicted by your calculations in the second step.
   a) Did you have to turn the crank more times or fewer than predicted?
   b) What are possible explanations for differences between your predicted and measured number of turns?
   c) Is there any source of error or uncertainties in your measurements?

3. Was there any energy lost? How do you know? Are there assumptions in your prediction that account for differences?

4. What could you and your lab partners change to increase the accuracy of the theoretical number of turns? What would you expect if you performed your trials outside instead of indoors? Explain your answers.

5. Using what you have learned about the flow of heat, discuss how the specific heat capacities of aluminum and copper affect the use of these metals in flat-plate solar collectors. (Refer to the Historical Notes below. The specific heat of copper is 387 J/kgC)

HISTORICAL NOTES

Flat-plate solar collectors were invented late in the seventeenth century, but it was not until the 1960s that the collectors were developed and used around the world. The most common types in the world are all-copper solar collectors and copper-aluminum hybrid collectors. In fact, some indigenous communities in the Amazon use collectors described as "an aluminum module with the copper soul" to provide power to their villages. A typical flat-plate collector is comprised of a rectangular surface, called an absorber, with a series of fluid tubes running along it. It is the absorber that is commonly aluminum, copper, or a composite of both.

LAB 5
HEAT AND INSULATION

As a child, you were probably told to turn off the lights when you left a room and to turn off the television when you were not watching it. It definitely makes sense to turn lights and appliances off when they are not in use; however, lights, televisions, computers, and other appliances only account between 10% and 30% of the energy used in an average American home. On the other hand, heating and cooling (collectively known as space conditioning) devour between 50% and 70% of the energy used in most homes. Unfortunately, most houses in the United States are not well insulated, and inadequate insulation is a major cause of energy waste.

When thermal energy is transferred from your house to the outdoors we say that heat is transferred or that there was a flow of heat. Thus we will reserve the word heat for the cases where thermal energy is being transferred from one place to another. We will not speak of the heat "in" a body but only of the thermal energy in a body though we say that energy is transferred as heat from one body to another. This is similar to the way we use the word work. We never speak of the work "in' a body but only of the work done in transferring energy from one body to another.

Insulation decreases heat flow between the outdoors and a house interior by providing a resistance to such flow. There are many different types of insulation: fiberglass blankets, loose mineral fibers and fiber pellets, polyurethane foam, fibrous or plastic boards, plastic fiber made mainly from recycled milk bottles, cement-based foam, adobe (clay), natural fibers such as cotton and straw, and more. Different insulation materials have different degrees of thermal resistance, or resistance to heat transfer.

You and your partners will examine the thermal resistance of four different insulators in an effort to determine the characteristics of an effective insulator. You will measure the temperature change of hot water in a pop (soda) can that is wrapped in an insulator, and this change will be divided by the thickness of the material in order to compare the effectiveness of the different materials.

PRE-LAB READING
Read Chapter 4 of Wolfson.

EQUIPMENT

5 – empty pop cans
5 – alcohol thermometers
Set of various insulators (bubble wrap, felt, can cozies)
1 – digital calipers
hot tap water

PREDICTIONS/PRELIMINARY QUESTIONS

1. Would a substance with **high** thermal resistance be considered a good insulator or a poor insulator?
2. a) Rank the following substances according to their effectiveness as an insulator: aluminum, first aid gauze, foam "cozy" for a pop (soda) can, rubber sheet, and bubble wrap. List the best insulator first. (Note: These comparisons are to be made in terms of effectiveness per the same unit of thickness.)
   b) On what reasoning did you base your decisions about ranking?

PROCEDURE
As previously mentioned, you and your partners will investigate the thermal resistance of four insulators to establish the characteristics of an effective insulator. You will measure the temperature change of hot water in a can that is wrapped in an insulator, and this will be divided by its thickness to compare the effectiveness of the different insulators.

1. Make a table in which to record your group's temperature measurements. You will be measuring the temperatures of the water in five cans each minute for 15 minutes.
2. Determine the mass of each can.
3. Take the five cans to the restroom and fill them with hot water. Be sure each can has the same amount of water -- almost filled to the top -- and bring them back to the lab.
4. Determine the mass of each can when filled with water and record it in your notebook.
5. Leave one can unwrapped. Put one can in the “cozy” and wrap the other cans with a layer of the various insulators: bubble wrap, first aid gauze, and rubber sheet. Secure the insulators around the cans with some tape.
6. Tape a thermometer in each can, so that it does not touch either the sides or bottom of the cans and so there is no heat loss through the hole in the can.
7. Record the temperatures of the water in five cans each minute for 15 minutes.
8. While you are taking your temperature measurements, use the calipers to measure the thickness of the insulator around each can.
9. Determine the temperature in the room with another thermometer and record it in your notebook.

ANALYSIS

For each can for which you have recorded data, graph the temperature minus the room temperature as a function of time. You can put the data for all five cans on the same graph for comparison. Based on your data, rank your materials from “best” insulator to “worst”.

Is the water cooling at the same rate during the entire experiment for one of the cans? If not, when is it cooling fastest? slowest? Can you explain why it cools faster sometimes than others? (Hint: use the expression for rate of heat transfer by conduction on p. 64 of your book.)

Calculate the rate of cooling during the first minute, during the time between the sixth and seventh minute and during the time between the 14th and 15th minute for one of the cans. How much thermal energy left the water in the first minute?

How much thermal energy left the water between the 6th and 7th minute?

(Use the expression: *change in thermal energy=(specific heat)x(mass of water)x(change in temperature)*)

The specific heat of water is 4186 J/kg/^{o}C .)

Now use the expression (p. 66 of your book)

rate of cooling =(1/R) (area of can surface)x(temperature - room temperature)

to calculate the R-value of the insulation around this can. (You need to measure the height and diameter of the can to calculate its surface area A. You need to then solve the above equation for R and use A and the rates of cooling that you determined to get R.) Do this both for the first minute and for the period between the 6th and 7th minute. Are the answers the same? Should they be? Compare the R-value with those in table 4.2 on page 67 of the book. Would this insulation be adequate for a house?

CONCLUSIONS

1. a) What material was the best insulator? The second best? The worst? The second worst? How does your measured ranking compare to your predicted one?

   b) Based on your results, what are the properties of a material that you think will make it a good insulator?

2. Why do most houses in Minnesota have double- or triple-pane windows? Is it the glass that is an efficient insulator, or is something else involved?

3. How can the Inuit construct igloos out of snow and still expect them to remain warm inside? Why do forest animals burrow into snow to find shelter from the winter cold?

4. The following materials (at the stated thicknesses) have the same thermal resistances: 13 cm of polyurethane foam, 58 cm of white pine, 5.5 meters of window glass, and 2.25 km of silver. How does this fit with your results in this exercise?

5. Consider the insulation with which we who live in Minnesota are terribly familiar: winter clothes.

   a) What kind of clothing do people usually wear in winter?

   b) What about these winter clothes makes them better insulators than our summer clothes? Relate your answers to the observations in this exercise.

6. What heat transfer mechanism or mechanisms were involved in this exercise? (Radiation? Conduction? Convection?) Draw an illustration to help explain your answer.

ADDITIONAL NOTES

Research at Oak Ridge National Laboratory, which started in 1943 as a nuclear weapons laboratory, now includes the development of new insulation materials as a part of the Building Envelopes Program. Insulation materials differ and must be chosen to fit several factors: the local climate; the size and construction of the home; the type and efficiency of the heating and cooling systems; and the fuel used. This is because different insulation materials have different degrees of thermal resistance.

In construction, the measurement of thermal resistance is called the R-value. The greater the R-value, the greater the insulation effectiveness. The R-value depends on the type of material and its thickness. The U-value, which is simply the reciprocal of the R-value, is another common measure of thermal resistance. Physicists typically use a quantity called the thermal conductivity to report a material’s resistance to heat transfer.

LAB 6

MECHANICAL FROM THERMAL ENERGY: A SIMPLE THERMAL ENGINE, THE MASS LIFTER AND THE 2nd LAW OF THERMODYNAMICS

Most of the energy which is delivered for use to consumers in our society takes the form of thermal energy at some point before it's used. In automobiles, trucks, buses, airplanes and most railroads, hydrocarbons (storing chemical energy) are burned to produce thermal energy which is then converted back to gravitational potential and kinetic energy of the vehicles. In most electrical power plants (but not nuclear or hydropower ones) hydrocarbons are burned and the resulting thermal energy is converted to mechanical energy in turbines and then to electrical energy which is carried by the power lines to consumers. This week we are considering how the thermal energy is converted to kinetic or gravitational potential energy of large (that is not molecular size) objects in engines. That is the central physical process behind the extraction of energy from fossil fuels discussed in your book and the lectures.

PRE-LAB READING

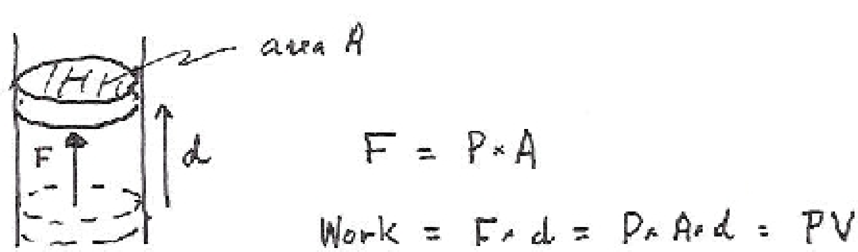
Read 4.7 of Wolfson.

In this laboratory you will make some measurements on a very simple version of a common type of thermal engine, in which a heated gas pushes a piston in order convert the thermal energy in the gas to the large scale mechanical energy of the piston, which can then do things like turn a crankshaft which drives the wheels in your car. Many steam engines are of this type. (Another common form of thermal engine is a turbine, which will be discussed in the lecture.)

The work done on the piston by the gas when the piston moves is easy to compute, and is commonly expressed in terms of the pressure P of the gas in the cylinder containing the piston and the change in the volume of the gas in the piston as the piston moves:

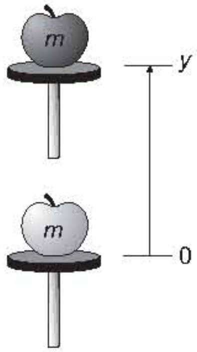
Work done by gas on piston = pressure x change in gas volume.

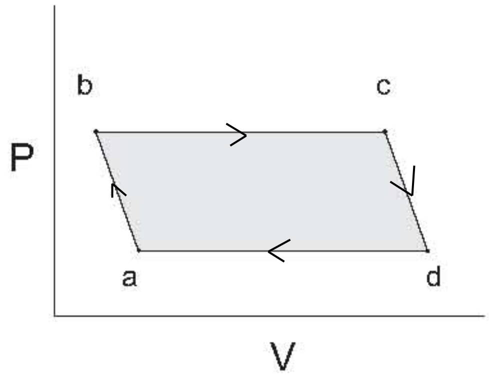
You can understand this formula by recalling that the pressure is the force which the gas exerts on the walls of its container, per unit area of wall. Then refer to this picture



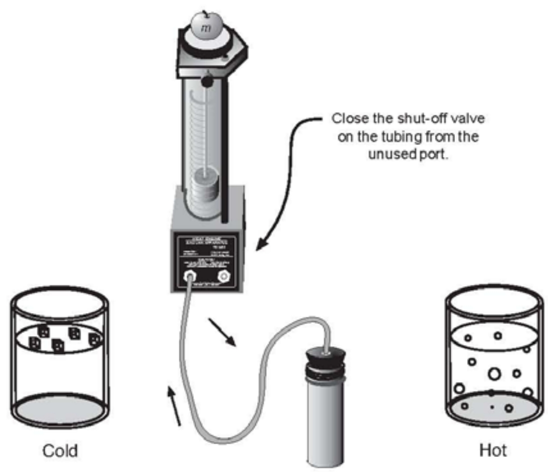
The simple engine you will use uses thermal energy to lift objects. A piston that lifts the objects moves up and down inside of a cylinder filled with air. The air inside the cylinder is connected with a tube to a sealed metal can that can be heated and cooled by placing it in hot or cold water. A cycle is shown in the figure below, in which the 'object' is shown as an apple. In the experiment you will use a weight of known mass instead of an apple. The cycle starts with an object on top of the piston and the can immersed in cold water(point b in the diagram below). The can is then immersed in hot water and the cylinder rises (point c in the diagram). At its highest point you remove the object and the piston rises some more (point d). Next the can is placed into cold water. The piston descends (point a in the diagram). When it stops descending, you put another object of the same mass as the first on it causing it to go lower (to point b again). The gas system is now in its original state, but energy has flowed through it: It raised the gravitational potential energy of the object placed on the cylinder and thermal energy flowed in from the heated can and out through the cold can. Thus this simple engine is converting thermal energy into gravitational potential energy of the lifted objects. A key issue for applications of such engines is their efficiency. The efficiency is defined as the ratio of the work done by the gas divided by the thermal energy which flows in from the hot source. Because some thermal energy always flows out of the gas during the cool, return cycle (d to a to b), this ratio is always less than one. It means that you can never use such an engine to convert all the thermal energy in a hot source into useful mechanical energy. That general rule is one form of the second law of thermodynamics. In this laboratory, you will make some measurements on this engine which permit estimates of its efficiency.

The following figure shows an apple lifted through a height y and a P-V plot showing the pressure and volume of the gas during the cycle that lifts the apple through the height y. Point b on the P-V diagram corresponds to the apple at its lowest point (0 in the picture at left) and point c corresponds to the apple at its highest point (y in the diagram at left). After the apple is removed, and before cooling, the piston rises higher, to point d in the PV diagram. Notice that the gas is still converting thermal to mechanical energy in the c-d part of the cycle, but you might not regard that work as very useful, since it just lifts the piston. Furthermore, in the d-a-b part of the cycle, something must do work ON the gas, to compress it and this reduces the net mechanical energy gained from the thermal energy input. The general statement of the 2nd law of thermodynamics refers to the ratio of the net production of mechanical (here gravitational potential) energy to the total thermal energy input from the hot side. That net production of mechanical energy is related to the shaded area in the PV diagram. That is because during hot, b-c-d part of the cycle, the gas does work on the lifted object and piston, but during the cooling d-a-b part of the cycle, the piston does work on the gas, compressing it. The net work, called the 'thermodynamic work' done on the environment by the gas is the difference. Another way to define efficiency for this engine is to only consider the output of work , called the 'useful work' , done in lifting the object, since the compression of the gas by the piston on the return cycle is done by gravity and would not cost the operator of the engine any effort. You will calculate the efficiency of this engine using both possible definitions of work output.



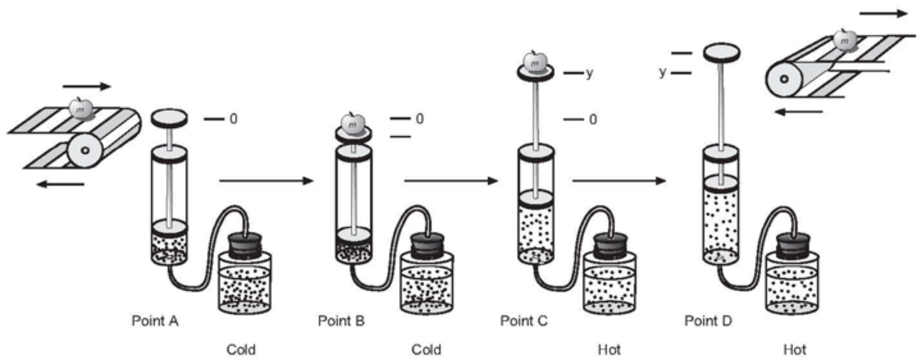


The heat engine we use consists of a hollow cylinder with a graphite piston that can move along the axis of the cylinder with very little friction. The piston has a platform attached to it for lifting masses. A short length of flexible tubing attaches the cylinder to an air chamber (consisting of a small can sealed with a rubber stopper that can be placed alternately in the cold reservoir and the hot reservoir. A diagram of this mass lifter is shown below:



If the temperature of the air trapped inside the cylinder, hose, and can is increased, then its volume will increase, causing the platform to rise. Thus, you can increase the volume of the trapped air by moving the can from the cold to the hot reservoir. Then, when the apple has been raised through a distance y, it can be removed from the platform. The platform should then rise a bit more as the pressure on the cylinder of gas decreases a bit. Finally, the volume of the gas will decrease when the air chamber is returned to the cold reservoir. This causes the piston to descend to its original position once again. Another picture of the various stages of the mass lifter cycle are shown in the next Figure.

Before taking data on the pressure, air volume, and height of lift with the heat engine, you should set it up and run it through a few cycles to get used to its operation. A good way to start is to fill one container with room temperature water and another with hot tap water or preheated water at about 60–70°C. The engine cycle is much easier to describe if you begin with the piston resting above the bottom of the cylinder. Thus, we suggest you raise the piston a few centimeters before inserting the rubber stopper firmly in the can. Also, air does leak out of the cylinder slowly. If a large mass is being lifted, the leakage rate increases, so we suggest that you limit the added mass to something between 100 g and 200 g. After observing a few engine cycles, you should be able to describe each of the points *a*, *b*, *c*, and *d* of a cycle carefully, indicating which of the transitions between points are approximately adiabatic and which are isobaric. You can observe changes in the volume of the gas directly and you can predict how the pressure exerted on the gas by its surroundings ought to change from point to point by using the definition of pressure as force per unit area.



Description of the Engine Cycle

a. Predicted transition *a-b*: Close the system to outside air but leave the can in the cold reservoir. Make sure the rubber stopper is firmly in place in the can. What should happen to the height of the platform when you add a mass? Explain the basis of your prediction.

b. Observed transition *a-b*: What happens when you add the mass to the platform? Is this what you predicted?

c. Predicted transition *b-c*: What do you expect to happen when you place the can in the hot reservoir ?

d. Observed transition *b-c*: Place the can in the hot reservoir and describe what happens to the platform with the added mass on it. Is this what you predicted? (This is the engine power stroke!)

e. Predicted transition *c-d*: Continue to hold the can in the hot reservoir and predict what will happen if the added mass that is now lifted is removed from the platform and moved onto an upper conveyor belt. Explain the reasons for your prediction.

f. Observed transition *c-d*: Remove the added mass and describe what actually happens. Is this what you predicted?

g. Predicted transition *d-a*: What do you predict will happen if you now place the can back in the cold reservoir? Explain the reasons for your prediction.

h. Observed transition *d-a*: Now it's time to complete the cycle by cooling the system down to its original temperature for a minute or two before placing a new mass to be lifted on it. Place the can in the cold reservoir and describe what actually happens to the volume of the trapped air. In particular, how does the volume of the gas actually compare to the original volume of the trapped air at point a at the beginning of the cycle? Is it the same or has some of the air leaked out?

i. Theoretically, the pressure of the gas should be the same once you cool the system back to its original temperature. Why?

Determining Pressures and Volumes for a Cycle

In order to calculate the thermodynamic work done during a cycle of this engine, you will need to be able to plot a *P-V* diagram for the engine based on determinations of the volumes and pressures of the trapped air in the cylinder, tubing, and can at the points *a, b, c*, and *d* in the cycle.

Volume and Pressure Equations

a. What is the equation for the volume of a cylinder that has an inner diameter of d and a length L?

b. Use the definition of pressure to derive the equation for the pressure on a gas being contained by a vertical piston of diameter d if the total mass on the piston including its own mass and any added mass is denoted as M. **Hints:** (1) What is the definition of pressure? (2) What is the equation needed to calculate the gravitational force on a mass, M, close to the surface of the Earth? (3) Don't forget to add in the atmospheric pressure, P_{atm}, acting on the piston and hence the gas.

Now that you have derived the basic equations you need, you should be able to take your engine through another cycle and make the measurements necessary for calculating both the volume and the pressure of the air and determining a *P-V* diagram for your heat engine. Instead of calculating the pressures, if you have the optional equipment available, you might want to measure the pressures with a barometer or a barometer sensor attached to a computer-based laboratory system.

Determining Volume and Pressure

a. Take any measurements needed to determine the volume and pressure of air in the system at all four points in the engine cycle. You should do this rapidly to avoid air leakages around the piston and summarize the measurements with units in the space below. You should also record the temperature Th of the hot water and Tc of the cold water for use in calculating the thermal input during the cycle later.

b. Next you can use your measurements to calculate the pressure and volume of the system at point *a*. Show your equations and calculations in the space below and summarize your results with units. Don't forget to take the volume of the air in the tubing and can into account!

$P_a =$

$V_a =$

c. Use the measurements at point *b* to calculate the total volume and pressure of the air in the system at that point in the cycle. Show your equations and calculations in the space below and summarize your results with units.

$P_b =$

$V_b =$

d. What is the height, *y*, through which the added mass is lifted in the transition from *b* to *c*?

e. Use the measurements at point *c* to calculate the total volume and pressure of the air in the system at that point in the cycle. Show your equations and calculations in the following space and summarize your results with units.

$P_c =$

$V_c =$

f. Remove the added mass and make any measurements needed to calculate the volume and pressure of air in the system at point *d* in the cycle. Show your equations and calculations in the space below and summarize your results with units.

$P_d =$

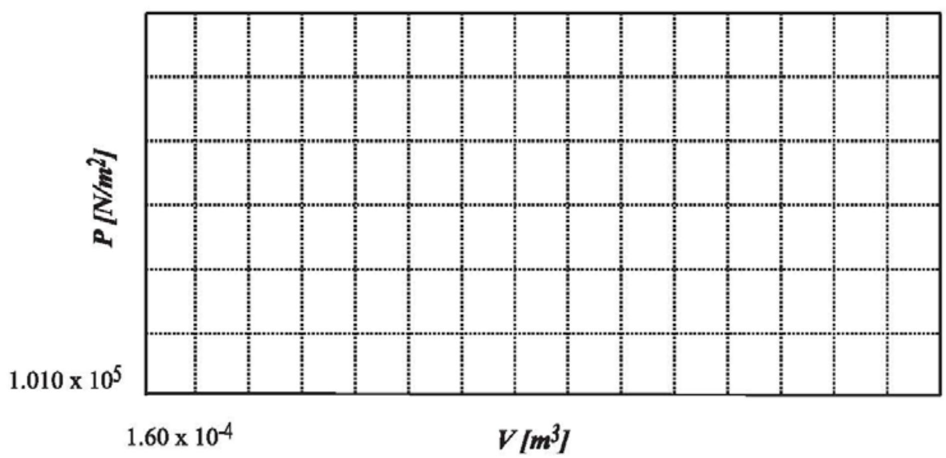
$V_d =$

g. You should have found that the transitions from *b-c* and from *d-a* are "isobaric" which means that the pressure does not change during those parts of the cycle. Explain why this is the case.

Finding Thermodynamic Work from the Diagram
In the next activity you should draw a *P- V* diagram for your cycle and determine the thermodynamic work for your engine.

Plotting and Interpreting a P-V Diagram

a. Fill in the appropriate numbers on the scale on the graph frame that follows and plot the *P-V* diagram for your engine cycle. Alternatively, generate your own graph using a computer graphing routine and affix the result in the space below.



b. On the graph in part a, label each of the points on the cycle (*a*, *b*, *c*, and *d*). Indicate on the graph which of the transitions (*a-b*, *b-c*, etc.) are adiabatic and which are isobaric.

Next you need to find a way to determine the area enclosed by the *P- V* diagram. The enclosed area doesn't change very much if you assume that *P* is approximately a linear function of *V* in the ab and cd legs of the cycle. By making this approximation, the figure is almost a parallelogram so you can obtain the enclosed area using one of several methods. Three of the many possibilities are listed below. *Creative students have come up with even better methods than these, so you should think about your method of analysis carefully*.

Method I
Since the pressure doesn't change from point *b* to point *c,* you can take the pressure of those two points as a constant pressure between points. The same holds for the transition from *d* to *a.* This gives you a figure that is approximately a parallelogram with two sets of parallel sides. You can look up and properly apply the appropriate equation to determine the net thermodynamic work performed.

Method II
Display your graph with a grid and count the boxes in the area enclosed by the lines connecting points *a*, *b*, *c*, and *d*. Then multiply by the number of joules each box represents. You will need to make careful estimates of fractions of a box when a "leg" of a cycle cuts through a box.

Comparing the Thermodynamic and Useful Mechanical Work

a. Choose a method for computing the thermodynamic work in joules, describe it in the space below, and show the necessary calculations. Report the result in joules.

b. What is the equation you need to use to calculate the useful mechanical work done in lifting the mass from one level to another?

c. Use the result for the height that the mass is lifted in the power stroke of the engine to calculate the useful mechanical work performed by the heat engine.

d. How does the thermodynamic work compare to the useful mechanical work? Please use the correct number of significant figures in your comparison (as you have been doing all along, right?)

Calculating the efficiency:

To calculate the efficiency by the two definitions described above, you need to determine the denominator in the definition of efficiency, which is the thermal energy input to the gas during the heating, b-c-d part of the cycle. You will estimate this quantity from your data on the volume of the gas at point a, the temperature Th of the hot and Tc of the cold source (in absolute degrees K) and the pressures of the gas during the b-c and d-a parts of the cycle. The details of the formula for determining the thermal energy input from these quantities are a little beyond the scope of this course, so we have provided a simple 'calculator' for you to use in determining it, using these data. Basically, the calculator uses a formula of a form which should be familiar to you, namely, thermal energy = (specific heat)x(mass)x(temperature change) for the b-c part of the cycle, though there are some details about the determination of the factors which we will not go into here. The determination of the thermal energy input during the c-d part of the cycle depends on whether it occurs at constant temperature or not and this is difficult to determine with certainty from the data available in this experiment. The calculator assumes that c-d occurs at constant temperature. The results do not depend very much on this assumption.

When you have used the calculator and your data to determine the thermal energy input per cycle to the engine then you can calculate the two efficiencies

thermodynamic efficiency =(thermodynamic work)/thermal energy input)

useful energy efficiency= (useful work)/(thermal energy input)

Do that.

Finally compare the calculated efficiencies with the maximum thermodynamic efficiency for this engine which is (1-Tc/Th).

Discussion of Approximations and Uncertainties

Understanding the stages of the engine cycle on a *P-V* diagram is reasonably straightforward. However, the thermal input calculator made some assumptions which cannot be fully justified. These include the assumption that air is a so-called ideal gas and the assumption that the temperature is constant during legs ab and cd of the cycle. However the errors arising from these assumptions can be shown not to be very large. More serious problems can arise in this experiment because the cylinder is not perfectly insulated, either to the flow of heat through its walls or to the flow of gas through leaks between the piston and the walls. The leakage of heat through the walls will affect the assumptions made in the calculation of thermal input and the leakage of air through the seals between the piston and the wall results in a smaller mass of air at the end of the cycle than was present at the beginning. You can observe the last effect, which is largest when lifting large masses, by noting that in the transition from point *d* to point *a,* the piston can end up in a lower position than it had at the beginning of the previous cycle. Nevertheless, this mass lifter engine does help us understand typical stages of operation of one type of practical heat engine, of which your car engine is an example. And your calculations can give reasonable, if approximate, values for its efficiency. The experiment correctly illustrates the main take-home message, which is that heat engines always have efficiencies less than 1 (100%) and that, in practice, the efficiencies are usually much less than even the ideal thermodynamic efficiency of (1-Tc/Th).

Lab 7
Half-life and Radioactive Waste Storage

In southeast New Mexico, more than 650 meters beneath the surface, is the Department of Energy's Waste Isolation Pilot Plant (WIPP). Carved out of the ancient salt beds, the WIPP is the model for safe and environmentally sound radioactive waste disposal. It is designed to be a permanent disposal facility for only low-level radioactive waste. Here, plutonium-contaminated clothes, gloves, tools, rags, glassware, and other debris will be harbored until its radioactivity dwindles to safe levels. Congress specified that the WIPP should remain undisturbed for 10,000 years. This period was chosen to allow sufficient time to pass for the radioactivity of the debris to drop to safe levels -- ^{239}Pu has a half-life of 24,000 years, and ^{240}Pu has a half-life of 6500 years. The problem is warning future generations of the danger. No human-made monument has lasted for 10,000 years. The Egyptian pyramids are only half that old. Those pyramids that survived were plundered, and their inscriptions remained unreadable for centuries. Archaeologists and linguists were consulted to devise ways for the WIPP to warn future generations over the next ten millennia. Their final plan includes immense earthworks, granite perimeter monuments, hundreds of buried warning markers, subterranean rooms, a central information structure, and information about the WIPP in archives around the world. Visit the WIPP website at http://www.wipp.energy.gov/ for more information about the project.

Unfortunately, not all nuclear waste is 'low-level'. The waste from nuclear power plants as well as from some military operations cannot be safely stored at WIPP and is currently in various temporary repositories in the US. The general plan is to store this high level waste in a repository in Yucca Mountain, Nevada, although planning and controversy around this repository have continued for almost 20 years and it has still not accepted any waste for storage. One aspect of the controversy concerns the length of time for which the facility should be designed to safely store waste. If you look at the table and graph on p. 458 of your book you will see that radioactivity will continue for up to a million years, which is of the order of the half life of ^{237}Np which is the longest-lived nuclide in the table on p. 458. The target life time for the facility was originally set at 10,000 years, but a court recently ruled that this was too short a time. It is very unclear whether engineers can reliably design a facility to last even 10,000 years.

Not all low-level waste is produced by the defense industry and power industries.. Nuclear medicine uses radioactive isotopes to diagnose and treat cancers and other diseases. Because certain radioisotopes are attracted to specific organs, their emissions can provide information about a particular disease or cancer. Nuclear techniques can provide data about the function of organs, not just their structure. One consequence of nuclear medicine is a plethora of contaminated waste: syringes, glass, gloves, and vials of radioactive pharmaceuticals. Unlike defense-related waste, most refuse from nuclear medicine won't be radioactive for millennia. For example, one radioactive isotope of indium, ^{111}In, is used as a "tracer" to identify tumors and has a half-life of 2.8 days, much shorter than that of plutonium. In this exercise, you and your partners will find the half-life of Ba-137m, a very short lived isotope.

PREPARATION: Try the simulation “The Radioactive Dating Game” at http://phet.colorado.edu/.

Pre-Lab Reading

Read Chapter 7 of Wolfson.

EQUIPMENT

1 – Radiation Monitor; contains a Geiger-Mueller tube (GM tube)
1 – LabPro data collection interface
1 – Isotope Generator Kit (Barium-137 m)
1 – wooden block or other support (for keeping the radiation source in the correct location)

This Cs-137/Ba-137m Isotope Generator is used to demonstrate the properties of radioactive decay. Based on the original Union Carbide patented design, it offers exceptional performance, ease-of-use and safe operation.

Each generator contains 10 μCi of Cs-137, which represents one Exempt Quantity, making it free from specific State and Federal licensing. The generator can produce up to 1000 small aliquotes of the short lived Ba-137m isotope with a half-life of 2.6 minutes.

Each generator is supplied with 250 mL of eluting solution (0.9% NaCl). The parent isotope Cs-137 with a half-life of 30.1 years beta decays (94.6%) to the metastable state of Ba-137m. This further decays by gamma emission (662 keV) with a half-life of 2.6 min. to the stable Ba-137 element. During elution, the Ba-137m is selectively "milked" from the generator, leaving behind the Cs-137 parent. Regeneration of the Ba-137m occurs as the Cs-137 continues to decay, re-establishing equilibrium in less than 1 hour.

Approximately 30 minutes after elution, the residual activity of the Ba-137m sample has decayed to

PROCEDURE

You will use a radiation monitor. The monitor contains a Geiger-Mueller tube (GM tube) that detects the radiation. The GM tube consists of a cylindrical tube held at a negative potential and a middle wire held at a positive potential. The tube is filled with methane and argon gas that become ionized when radiation passes through the tube. Ionization is the removal of electrons from the gas molecules. These electrons, having a negative charge, are attracted to the positive central wire. These electrons are rapidly accelerated, and the result is a pulse of current that can be detected to indicate a radioactive event. The radioactive events are indicated by a blinking light, an audio sound (if you set it on “audio”), and the scale on the monitor.

1. The radiation monitor is battery powered and will operate without being attached to anything. (For taking data we will connect it to the computer for ease of use.) Turn on the monitor before it is attached to anything and do a little exploring to check on background radiation. You might need to use the “x 10” scale for most of your measurements but if the meter starts to go “off scale” use the “x 100” setting. (The “x1” setting is an option if radioactivity level is not very high.)

After checking out the radiation monitor you can make the necessary connections and investigate the half life of the Barium isotope.

2. Connect the LabPro interface to the computer using the USB connector. Plug the interface transformer into the power strip. Connect the cable from the radiation monitor to the “dig/sonic 1” digital channel on the LabPro interface.

3. On the computer open Logger Pro

Under file, click “open”; open the folder “probes and sensors” next open the folder “radiation monitor”, next open “counts vs time”

4. After opening "counts vs time" you may get a "sensor confirmation" dialog box. Just click OK. Next you need to make some "setting" adjustments. On the menu, near the top of the screen, under experiment choose 'data collection.' In the dialog box adjust the settings for length and sample rate that are appropriate.

5. When you are ready to take data click on the green "collect" button near the top of the screen. 1st you should take a set of readings to determine the background radiation. It is OK to take about three to six minutes of readings. (The computer should give you the time and the radiation count for each minute. Find the average for one minute so you can subtract the background from the radiation due to the barium sample.) Press the red "stop" button near the top of the screen when you have enough data. After your measurements of background radiation, you and your partners are ready to measure the decay of the generated isotope. The instructor will use the kit to create your sample.

6. Place the barium sample as close to the screen of the radiation monitor as possible. Do not move the sample until you have completed taking data.

7. When you and your partners have finished taking measurements, you must ascertain how many radioactive events occurred in each one-minute interval. To do this, subtract the background radioactivity in the lab for each one-minute interval.

ANALYSIS

1. Plot your results on a graph of counts vs. time. Using Microsoft Excel for these graphs is recommended. (See Appendix II.) You should discover that, as you took your measurements, the radioactivity of the indium decreased. Also make a graph of (*ln* counts) vs. time. You and your lab partners should find that the data points form a fairly straight line. The slope of this line is the decay constant, usually represented by the letter *k*. Record this value. Is the value of this slope positive or negative?

2. Radioactive decay is an exponential process. The exponential decay equation is:

$$N = N_O\, e^{-kt}$$

in which N_O is the initial number present, N is the number present at time t, k is still the decay constant and e is the number .2.7182818.. Remember that the half-life ⊚ is the time required for half of the nuclei present to decay. If the above equation is solved for the time at which N is one half of N_O, the result is:

$$\tau = \frac{\ln 2}{k} \quad \text{or} \quad \tau = \frac{0.693}{k}$$

You and your partners can use the above equation to calculate the half-life of ^{116}In by substituting the slope of your natural-log graph in the place of *k*.

CONCLUSIONS

Report the value for the half-life of Barium-137 m. How certain are you of the result? What is the uncertainty in your measurements and analysis? How does the half-life of this isotope of barium compare to radioisotopes of indium in the table below?

What does the half-life of Barium-137m imply for its disposal?

indium-110	1.15 hours
indium-111	2.8 days
indium-112	14.4 minutes
indium-114	1.12 minutes
indium-115	6×10^{14} years
indium-116	5 minutes
indium-117	43 minutes
indium-118	5 seconds
indium-119	2.4 minutes
indium-120	44 seconds
indium-121	23 seconds

1. Some environmentalists have objected that research facilities, such as Lawrence Berkeley National Laboratory, contribute too much to the amount of radioactive waste produced in this country. Most of the waste from Lawrence Berkeley Laboratory, for instance, comes from the chemical science and life science branches of the lab. The waste consists largely of radioactive pharmaceuticals and tracers, such as indium-116. Based on your results in this exercise, what would you say to those environmentalists who contend that Lawrence Berkeley National Laboratory, by storing such waste, is “creating an unsafe environment for Berkeley citizens and the region” (Janice Thomas, the Committee to Minimize Toxic Waste, “Lab Plans Waste Storage Expansion,” *The Daily Californian,* 12 Oct 95)? There is no “correct” answer; however, you must support your arguments with your results from this exercise and information from your textbook.

LAB 8
HEAT, THE SOLAR INPUT, AND EARTH'S AVAILABLE ENERGY

Note: This exercise must be done on a clear day and/or during a 20-minuteperiod when there are no clouds. Heat lamps will be provided to simulate the lab, but if possible you should try and get outside. You can get surprising results even in the winter with a clear sky.

Almost all of the Earth's available energy comes from the sun (geothermal and nuclear energy do not). Fossil fuels such as oil and coal are a result of ancient photosynthesis. Renewable biomass fuel, as well as our food supply, is also a product of photosynthesis. Wind and waves are driven by heat from the sun, and solar panels directly collect the sun's radiant energy. Consequently, the planet's available energy and our food supply are both restricted by the amount of energy received from the sun. Humans and other animals depend on the plant kingdom for food, which is completely dependent on solar radiation.

In this exercise, you and your partners will investigate how much radiant energy the earth receives from the sun at the earth's surface. From this and some additional information you will be able to draw conclusions. Such as, how much of this energy is used in photosynthesis? How much of total solar energy is used by plants humans can eat. How many people the earth could support if all we did was feed them? Is enough solar energy to run our economy in the United States, and how much of the solar energy coming from the sun gets all the way to the earth's surface. To measure the energy coming from the sun you and your partners will determine the amount of the sun's energy that is absorbed by a solar collector as the sun heats it.

PRE-LAB READING

Read Chapter 9 of Wolfson.

EQUIPMENT

1 – stopwatch
1 - rectangular solar collector (aluminum plate w/ leads)
1 – DMM (digital multimeter)

PREDICTIONS/PRELIMINARY QUESTIONS

1. To determine how much solar energy reaches the earth's surface you can let sunlight heat a metal plate, then calculate how much heat has been gained by the substance and from that obtain an estimate of the amount of solar energy reaching the earth. Suppose the substance you are heating is aluminum.
   a) What would you need to measure to be able to determine the radiant heat absorbed by the aluminum?
   b) How would you calculate the amount of heat gained?

2. a) To determine the power supplied by the sun what must you measure in addition to the heat gained?
   b) After measuring the quantity needed in part a) how do you calculate the power supplied by the sun?

3. a) To determine the power supplied by the sun per square meter what must you measure?
   b) After measuring the quantity in part a) how do you calculate the power per square meter?

4. Once you know the power supplied by the sun per square meter how would you calculate the power supplied to the whole earth?

PROCEDURE

In this exercise, you will put a solar collector outside parallel to the sun. It will change temperature over time, eventually leveling off. Based on the increase in the heat energy of the aluminum plate, you will find how much energy Earth receives from the sun. From this calculation, you and your partners can estimate how much of this energy is used in photosynthesis; how much of that is used by plants we can eat; and how large a human population Earth can support.

1. Determine the cross-sectional area of the solar collector. In other words, if you look at the box head-on, what is the apparent area of the square you see?
2. You should determine the mass of the aluminum plate within the collector. Take care to remove the plate, keeping track of all the loose parts. (Make sure the box is 100% assembled when you are finished with lab!)
3. Find a location outside that has direct sunlight and little or no wind. If the wind picks up, shield the set-up as best as you can, **but don't block any sunlight!**
4. Be sure to aim your collector directly at the sun. The white plastic post will not cast a shadow on the black aluminum plate when alignment is correct. Be very careful about this, you might even have to adjust the collector during the time it is receiving solar energy. Also be sure that you shield the collector from the sunlight until you start the stopwatch.
5. Record the initial temperature of the aluminum plate. It might be helpful to cool the plate 10°C to 20°C below the outside ambient (shade) temperature before starting. Record the resistance (temperature) every half minute until the temperature is 10°C to 20°C above the outside temperature. You will be provided with a conversion chart to change resistance to temperature. Be careful -- the metal plate might become very hot. Gather your equipment and return to the lab.

ANALYSIS

The "solar input" is the amount of power that an area receives from the sun when directly overhead. Using your measurements, you and your partners can determine the heat energy absorbed by the solar collector based on the temperature increase of the aluminum plate. We will assume the collector is a perfect insulator, meaning that it gains no heat from nor loses any to the environment. Computation of the solar input involves solving an equation that equates the thermal energy gained by the aluminum plate to the radiant energy received from the sun.

1. You and your partners should have already calculated the cross-sectional area of the collector. As stated previously, the solar input is the amount of power that an area receives when the sun is directly overhead. When the sun is at an angle (which is always true in Minnesota and all places outside the Tropics of Capricorn and Cancer), an area receives a fraction of the full energy. Since you aimed the mirror directly at the sun, we do not need to make a correction for this.

2. Next, you and your lab partners should determine the thermal energy gained by the aluminum plate due to the solar input. Use the equation:

   thermal energy transferred=(mass of aluminum plate)x(specific heat of aluminum)x change in temperature

   The change in the temperature is the final temperature of the aluminum plate minus the initial temperature. The specific heat of aluminum in SI units is 900 Joules/kg • degrees C.

3. You and your partners can now determine the value of the solar input. As mentioned already, you can find the solar input by setting the thermal energy gained by the aluminum plate equal to the radiant energy which came in from the sun:

   Energy received from sun = thermal energy gained by the aluminum plate

Remember, however, that the solar input is a measure of the sun's power, not energy. Since power is energy over time, we should change our equation to:

$$\text{Power from the sun} = \frac{\text{thermal energy added to aluminum plate}}{\text{Time in the sun}}$$

4. Power from the sun for the collector:

$$\text{Solar input} = \frac{\text{Power from the Sun}}{\text{Area receiving sunlight (in square meters)}}$$

$$= \frac{\text{thermal energy added to aluminum plate}}{(\text{collector cross-sectional Area})\cdot(\text{Time})} = \frac{mc\,\Delta T}{(\text{collector cross-sectional Area})\cdot(\text{Time in Sun})}$$

The solar input is the amount of power that an area receives from the sun when it is directly over that area. If you used only SI units, your result for the solar input is the amount of power (in watts) received by one square meter.

5. To determine the total solar power received by Earth, you and your partners should multiply your result for the solar input by Earth's cross-sectional area. (Use the radius of Earth, 6.38×10^6 m, to calculate its cross-sectional area.)

$$\text{solar power received by Earth} = (\text{Solar Input})\cdot(\text{Earth's cross-sectional Area})$$

6. Determine the solar power used in photosynthesis. It has been estimated that about 0.0757% of the solar power that reaches the Earth is captured by plants and utilized in the photosynthesis process. Knowing this, how much solar power is used by plants to make their food?

7. Now you can estimate the amount of food could be produced with this much sunlight, if it were all used to produce food. In *The Hungry Planet,* George Borgstrom, a professor of Food Science and Geography at Michigan State University, states that 10% of the solar power used by plants in photosynthesis can be used by humans as food. Determine how many watts of power this equals.

8. Knowing that one watt equals 0.24 cal/sec and one food Calorie equals 1000 calories, calculate how many food Calories could be produced on the Earth in one day.

9. Lastly, estimate the maximum population of Earth. The current opinion is that the normal food requirement of a full-grown person is about 3,000 food Calories per day. Since most humans eat animal products as well as plants, their intake includes the energy needed to feed the animal products they consume. So, although the normal food requirement is about 3,000 food Calories per day, this figure increases to about 10,000 food Calories a day when the conversion of plants to animal products is taken into account. If you use a 10,000-Calorie intake as a standard, what is the theoretical maximum number of humans that Earth can support?

10. The amount of solar radiant energy reaching the top of the earth's atmosphere from space was first measured by the first space satellites in the middle of the last century and is about 1360 W/m^2. How does this number compare with the radiant power per meter squared which you measured? Do you expect it to be bigger or smaller? Explain the factors which would lead it to be different.

11. In the US economy, you can deduce from Figure 1.15 of your book that energy usage is about 10 kilowatts per person on average. If the solar energy were coming in to the surface of the earth at the rate which you measured, assuming that the US population is 300 million, and assuming that 1/5 of the solar energy could be converted to an easily used form such as electrical energy, how much area of the surface of the US would be needed to collect enough solar energy to power the economy?

CONCLUSIONS

1. In the experiment, you assumed that all the energy in the sunlight which was incident on the collector was transformed into thermal energy in the aluminum plate. What effects might make this assumption invalid? Which of them is the most important? Can you make any quantitative estimate of how big they might be and how much they could affect the result? Do you expect these effects will make your result for the energy coming in from the sun too big or too small? How could you alter the experiment to make the effects less important?

2. How does your result compare with the current population of Earth, approximately six billion? Based on current rates of growth, the global population has a doubling time of about 40 years. What are the implications of that figure based on your results? In how many years will the number of humans reach your maximum population estimate?

3. What if all humans became vegetarian? Go back to the final step of your analysis, and assume that all our food came from photosynthesis. This would mean that each person would need about 3,000 food Calories per day, not 10,000 Calories. If everyone was a vegetarian, how many people could inhabit the planet? How does this compare to your previous result? In about how many years will the population reach your new estimate?

4. Check the website http://www.oksolar.com/images/daily_solar_radiation1.gif about energy from the sun. It discusses the sun input and shows a map of the minimum solar energy received in the United States per day. How does your result compare with the website values? Redo steps 5 through 9 using the numbers form the website. What are your new answers?

LAB 9
ENERGY AND ATOMIC SPECTRA

It turns out that the principles which govern the operation of generators and motors also allow for the existence of waves of electrical and magnetic fields propagating in space and carrying energy. When this was first discovered in the nineteenth century (by Maxwell on the theoretical side and by Hertz experimentally) people realized for the first time that the light by which we see is an electromagnetic wave. From the point of view of energy technologies, light is important as a source of energy for solar energy devices and from the point of view of climate change, it is important in understanding the temperature of the earth's surface which is determined by a balance of energy flows of which the incoming electromagnetic wave flow from the sun and the outgoing infrared radiation are dominant.

The use of solar radiation to generate useful energy proceeds by three major pathways. One is direct conversion to thermal energy, which has been discussed earlier. Another is the use of solar radiation to produce electrical energy in photovoltaic cells (as in solar powered calculators) and the third is in the conversion of the energy of solar radiation to chemical energy in plants. The conversion of solar electromagnetic radiation to chemical energy in plants is not only the source of the energy in food and bio-fuel but is also the source of energy in fossil fuels, which store the energy converted in this way by plants which lived millions of years ago. Of course electromagnetic waves are also central to many information technologies, such as radio, TV, and cell phones.

To understand more fully how these various conversions of solar radiation to other forms work, one has to introduce the idea of the spectrum of light and to discuss the nature of waves in a little more detail. A wave is a disturbance in a medium or the vacuum of space which is characterized by a propagation speed, a frequency and a wavelength. In a traveling wave (the kind we will mainly consider) the speed is the speed at which the bumps in the wave move in the direction of travel. The wavelength is the distance between the bumps on the top of the wave and the frequency is one over the time that passes between the moments when successive bumps pass some fixed point in space. The three quantities are related by (see pg. 10, the section on Electromagnetic Radiation)

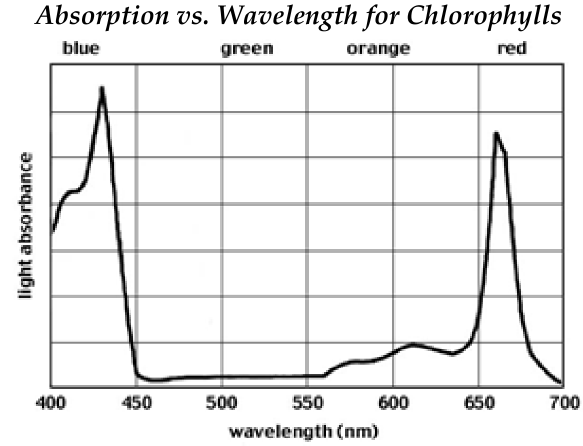
$$\text{speed} = \text{wavelength} \times \text{frequency}$$

Wave speed is characteristic of the type of wave and the medium in which it is propagating. It does not depend on the wavelength or the frequency. Therefore, from the previous equation, for a given medium and type of wave, once you know the wavelength you know the frequency and vice versa. The other important feature of a wave is the amplitude of the wave, which is the height of the bumps, and which determines how much energy the wave is carrying. Solar radiation consists of electromagnetic waves, which travel in vacuum at a universal (and very high) speed of $3\text{x}10^8$ m/s. It is a mixture of waves at different frequencies and wavelengths however. The color which we see in lighted objects arises because our eyes distinguish between electromagnetic radiation of different wavelengths. We see longer wavelengths of light as red and shorter ones as blue with the other colors appearing as yellow, green, purple, etc. depending on wavelength. We can't see all the electromagnetic radiation which exists with our eyes however. The waves which carry cell phone, TV and radio signals are of longer wavelength and our eyes do not detect them and we also can't see ultraviolet and X-ray radiation which are electromagnetic waves of shorter wavelengths than we can see. You can be convinced that solar radiation is a mixture of different wavelengths by using a prism to split the light into a rainbow of different colors, an experiment first done by Newton. In a more quantitative experiment, one can use an instrument to measure how bright the light at each color (that is, how much energy is coming in at each color). Making a graph of this measurement as a function of wavelength gives the quantitative 'spectrum' of the light. Looking more closely at such spectra, one finds that they consist of two different types of features. There is a smoothly varying background as well as some sharp peaks. The shape of the smooth background tells you the temperature of the source (a very high 6300 kelvin degrees for the sun) and the peaks tell you characteristic of the atoms present in the sun. These so-called 'line spectra' were first discovered about 100years ago. They serve as a fingerprint of the chemical composition of any light source and have been used to learn the composition of the stars by astronomers. In this laboratory, you will observe the spectra of sources made of various elements in the periodic table. Your observations should give you an idea how the spectra vary depending on the chemical composition of the source.

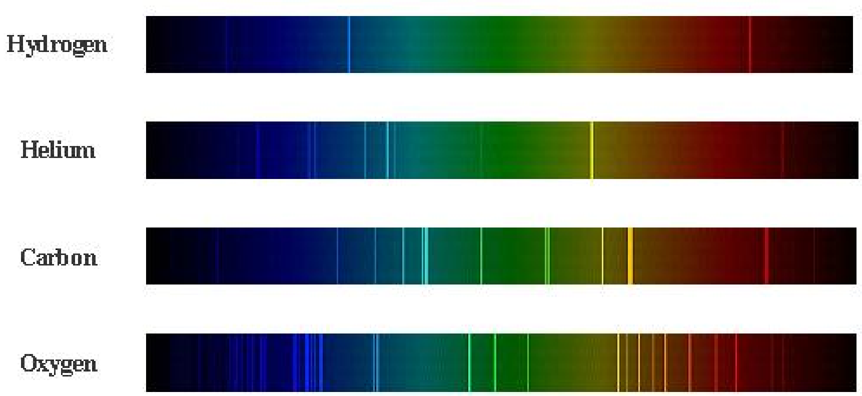
The reason why atoms give out line spectral is because the electrons which move around the heavy nuclei of the atoms can only move in certain ways. When they jump from one mode of motion to another, they emit radiation characteristic of the difference between the rates at which they orbit the nucleus in the two modes.

Just as some materials which are emitting electromagnetic energy do so only at certain well defined wavelengths, materials can only absorb electromagnetic radiation at certain wavelengths as well. Thus, with the proper equipment, one can also observe absorption spectra, which tells you which wavelengths failed to get through the material. The absorption spectrum of chlorophyll, which is the material in plants which harvests sunlight for conversion to chemical energy, is shown below. Chlorophylls absorb only certain portions of the visible spectrum: the blue-violet range (420-460 nm) and the red range (630-660 nm). The other colors, particularly green, are not absorbed by the chlorophylls and are reflected. Because plants therefore reflect green light to our eyes, we see them as green in color.

Absorption vs. Wavelength for Chlorophylls



Examples of atomic spectra (visible light only):



You and your partners will view the atomic spectra of several different elements. You will record the characteristic spectrum for each element. Using the periodic table and your observations, you and your lab partners will get some understanding of the role of electron energy levels in creating atomic spectra.

Once you and your partners have taken time to view the atomic spectra of various elements, you will Investigate the effect of a varying light spectrum on solar cell output using a bright light source and colored acetate filters. The acetate filters are used to change the color of light that will strike the solar cells.

PRE-LAB READING

Read Chapter 9 of Wolfson.

EQUIPMENT

1 - handheld quantitative spectrometer (per student)
1 – high-voltage power supply
1 – set of spark tubes filled with different gases

1 - solar cell
1 – incandescent heat lamp
1 – set of colored filters
1 – rod, table clamp and three prong clamp
2 – banana cables
1 - DMM

PREDICTIONS AND PRELIMINARY QUESTIONS

Use the **PHYS2000 websites Science Trek** http://physics.bk.psu.edu/teaching/Phys2000/ to help gain some understanding of the topics in this lab and answer these questions. Also check the website www.webelements.com for a periodic table.

1. What are electromagnetic waves? What is electromagnetic radiation?
2. What do we suggest an electron, within an atom, does when the atom produces a certain color in the spectrum?
3. In terms of **electrons** what is a difference between atoms of one element and atoms of another element that produce spectra that are very different? Compare for example an atom with a complex emission spectrum and an atom with a spectrum having only a few lines in its spectrum.
4. Think about the energy of different wavelengths of light. If you had a light source that emitted the exact same quantity of light, but at different wavelengths, which color of light, red or blue, would have more energy?

PROCEDURE

Part 1: You and the rest of the class will first observe and record the spectra emitted from a series of different elements. The spectra are your data for this exercise. From your observations, you will get some insight into the role of electron energy levels in creating spectra.

1. The elements you will observe first are gaseous and are contained in spark tubes. The spark tubes will allow us to excite the electrons of these gases. The electrons in a gas can be excited by running an electric current through the gas. The electricity will be supplied by a high-voltage power supply; it is similar to the equipment that is used in "neon" signs. A spark tube is placed within an electric circuit, and an electric current is run through the circuit. The gas within the tube is excited, and as a result, light of specific wavelengths is emitted. The lab instructor will handle the spark tubes as they are fragile and involve high voltage.
2. Instead of using a prism to spread out the emitted light, you will use a spectrometer with a thin piece of plastic called a diffraction grating. It is essentially a plastic slide with a large number of evenly spaced parallel grooves. The grooves are very fine, with 4000 to 8000 lines per centimeter. When you hold the spectrometer in front of your eye, you will see the light from the windows and the overhead lights spread out into a rainbow. The scale indicates the wavelengths of the light you see. To cut out this extraneous light, the shades will be pulled down and the lights turned off.
3. Your instructor will put spark tubes with different gases in the power supply. **Observe the spectrum of each and record it as accurately as possible. Note the color, brightness, spacing, and number of the lines.**
4. To use the blue spectrometer, hold it with the writing up and point the rectangular opening (located on the right side) toward the light source. Look through the eyepiece in the smaller end. There is a note about calibration, on the spectrometer, close to the eyepiece: Point the rectangular opening toward a fluorescent light and rotate the small plastic eyepiece until the green line is aligned with the mark at 546 nm. Then it should be ready to use if you don't adjust the eyepiece any more.
5. Observe the spectra and try to identify the elements. Open "The Elements Spectra" (located in the Physics folder on the desktop) to obtain the spectra of the elements. Click on one of the elements in the periodic table to see the spectrum. The program shows both the absorption spectrum and the emission spectrum that you see looking through the spectrometer. The most noticeable or significant lines in the absorption spectrum are probably the easiest see in an emission spectrum.
6. Examine a periodic table of the elements. Use www.webelements.com, **the PHYS2000 website** http://physics.bk.psu.edu/teaching/Phys2000/science_trek.html, or other sources you have found**. Read the sections on Electromagnetic Waves, Quantum Atom, and the Periodic Table in the the PHYS2000 website.** Use this information to help answer the questions in the conclusion.

Part 2: Now that you have a good idea of what different colors of light mean, use the broad spectrum lamp, filters and solar cells to investigate the effect on the current output of a solar cell under a light source using various color filters. The filters absorb certain wavelengths of color and transmitting the other wavelengths. The color filters we use will let through only the color of the filter and absorb all other colors.

1. Setup a simple circuit with a solar cell hooked to a DMM set to read mA.

2. Use the rods and clamps to setup the lamp at a distance of 25-35cm from the solar cell.
3. Measure the current with the source only, then take measurements with each color filter. Record your results.
4. What happens to the current produced by the solar cell if you add an additional layer of the colored filter between the cell and the light source? How about 3 layers?

CONCLUSIONS

1. Describe why light emitted by a particular *electron* would have only a *specific* set of energies.

   Which of the elements had the fewest spectral lines? Which element had the most?

   What causes the complexity of the spectra? Explain in detail. (Remember that if there are more protons in the nucleus of an atom, there are more electrons and therefore more available levels for the electrons to populate.)

2. The power supply and gas discharge light sources used in this exercise is very similar to that used in "neon" signs. Use your knowledge of atomic theory and explain how you think all of the different colors in "neon" signs are made -- feel free to look up more information on the web to answer this one.

3. Identification of elements by spectra lines is often employed in environmental science. In particular, it is used in the fields of environmental contaminants, atmospheric chemistry, hydrology, waste management, soil chemistry, and various others. In addition, it used by other scientists. For instance, astronomers use spectra to investigate stars, and geologists use them to investigate microscopic variations in minerals. Can you think of some other applications of atomic spectra? Explain your answers.

4. The color filters used in Part 2 pass the same color of light as the filters. Does the filter pass all of the light? Explain your answer.

5. Did the result you measured in Part 2 match your expectations? Which color had the highest current output? Does this make sense based on what you know about energies of various wavelengths of light across the spectrum?

LAB 10
CONVERSION OF GRAVITATIONAL POTENTIAL AND WIND ENERGY TO ELECTRICAL POWER: HYDRO AND WIND POWER

Now that you have some familiarity with the way an electrical generator works, you will use a somewhat more sophisticated generator to study how effectively it converts the gravitational potential energy of water lifted above the earth's surface (in applications, above sea level) to electrical energy. As discussed in your book, this source supplies about 3 % of the US electricity supply (using the water stored behind dams to drive turbines which turn generators.) It is ultimately a form of solar energy because the water gets into the rivers and flows into the dams through the collection of rain and snow falling on mountains and other highlands. The rain, in turn arises because the heating of the ocean surface by the sun evaporates water which rises as vapor to the clouds and is dropped as rain on the mountains. Unfortunately most of the promising sites for hydropower plants are already developed in the United States, and constructing new dams has some negative environmental consequences, so there are not prospects for strong growth in this energy sector in the United States.

You will use the same generator to study the effectiveness of the generation of electrical energy from the wind. Wind energy is also partly due to solar heating of the atmosphere, but the wind is partly extracting energy from the kinetic energy of the earth's rotation. Wind energy generation is a rapidly growing industry in the United States and Europe and can supply a significant portion of electrical energy needs in the future (10% or more and 8% in the near future in Minnesota).

PRE-LAB READING

Read Chapter 10 of Wolfson.

EQUIPMENT

1. Generator Assembly
2. Pulley, three-step
3. Resistor Plug (1),100 ohm (1)
4. LED plug (1)
5. Spool of thread (1)
6. Turbine
7. Windmill

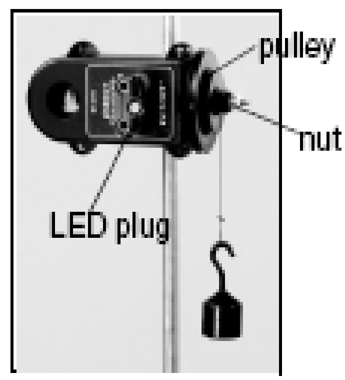


Figure 1a: Mounting the Generator to a rod stand

PREDICTIONS/PRELIMINARY QUESTIONS

If you have 500 cubic centimeters of water an average height of 0.5 meters above the turbine, what is the maximum energy which you can generate with the available energy? If there is a 100 ohm resistor across the output terminals of the generator, and the water takes a minute to run through the turbine, what is the average voltage which you expect to see across the output terminals of the generator?

PROCEDURE

Part 1. Electrical Energy from Gravitational: Potential Energy of a Weight.

First use the generator to convert the gravitational potential energy of a weight to electrical energy. You will do one qualitative experiment in which the electrical energy is converted to light and a second experiment in which you measure the output energy quantitatively. :

1.Use the rod clamp on the side of the generator to mount the generator to a rod stand.

2. Insert the LED plug into the jacks on the generator (Figure 1a).

3.To attach the pulley, align the indent marks on the pulley with the indented portion of the black shaft on the generator; then slide the pulley onto the shaft. Fasten the nut tight over the screw to hold the pulley in place.

4. Cut a small piece of no-bounce foam, and place the foam underneath the hanging mass .

5. Cut a piece of string to tie to the hanging mass and pulley (Figure 1b).

6. Tie a double knot in the string and hook the knot in the slot on the pulley.

7. Attach the other end of the string to the hanging mass.

8. Wind the string up on the smallest pulley, such that the string falls out when the mass reaches the bottom of the foam pad.

9. Adjust the position of the hanging mass or the height of the generator so that the knot slips out just as the mass reaches the foam.)

10. Now wind up the string and let the mass fall, observing the light emitted by the light emitting diode. You will see it changing from green to red and back, corresponding to current flowing in one direction and then in the opposite direction. What does this tell you about this generator? In particular, does it have a commutator, as the one illustrated in Figure 11.11 does? Does the rate at which the light changes from green to red and back change as the weight falls? Note the answer in

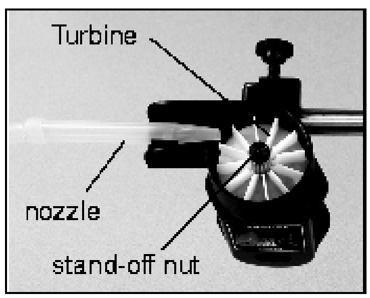


Figure 7a:
Turbine in Housing

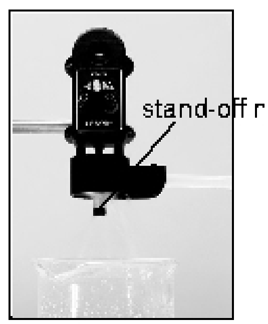


Figure 7b:
Hydro Housing
on Generator

your notebook, together with a brief discussion of the possible reason for any changes.

11. Now for the quantitative measurement, remove the LED plug and insert the resistor plug into the jacks on the generator. Your instructor will show you how to attach a voltage probe to the resistor jacks and to the computer and to use the software LoggerPro to make a graph of the power coming out of the generator at each moment in time. The instructor will also explain how to get the total electrical energy produced during the fall from the power data plotted on the screen. Note the total energy in your notebook and make a sketch of the graph of power versus time.

12. Measure the distance which the weight fell and note it in your notebook and weigh the weight to determine its mass (if it is not marked on the weight) and make a note of it.

Part 2. Electrical Energy from Gravitational Potential Energy of Water

1. Attach the ET-Hydro accessory housing to the molded case of the generator using the two captured screws and the supplied screwdriver

2. Insert the pointed end of a plastic nozzle into the spring clip underneath the housing

3. Connect the nozzle to a piece of tubing connected to an external water supply.(figure on next page). Have a beaker or container below the housing to collect water exiting the turbine.

4. Run the water supply through the nozzle of the turbine and watch the turbine spin.

5. Shut off the water with the valve and refill the water container. Measure the vertical distance from the center of the cylinder to the turbine and the diameter of the cylinder. Plug the resistance into the generator and connect the voltage detector to the resistance and the computer as before in order to measure energy output as you did in Part 1.

6. To start taking power data, open the valve and let the water run out through the turbine. Determine and record the energy output in your notebook.

Part 3. Electrical Energy from Wind Energy

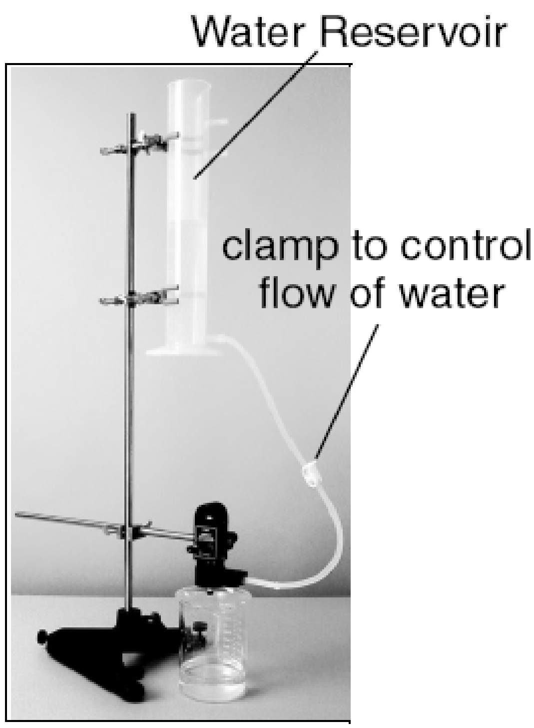
1. Remove the turbine from the generator and attach the windmill assembly.

2. Turn on the fan and point it toward the windmill. Observe the windmill turning

3. Use both the Hall wind device and/or the anemometer provided to measure the velocity of the air as it hits the windmill. Which is more accurate? Does it matter?

4. Turn off the fan and measure the diameter of the windmill.

5. Now turn the fan back on and measure the power output.



ANALYSIS

1. Calculate the efficiency of conversion for each of the three experiments.

a. For the weight, divide the total electrical energy output by the change in gravitational potential energy during the drop of the weight.

b. For the hydro experiment, similarly divide the total electrical energy output by the gravitational potential energy change of the water. To calculate the change in gravitational potential energy of the water, you need its mass, which is given by the volume of water times the mass density of water which is close to 10^3 kg/m^3.

c. For the wind experiment, calculate the input power from the wind as

(1/2) x(mass density of air)x (air speed)^{3}x (cross-sectional area of the windmill)

Calculate the efficiency of the wind generator by dividing the measured electrical power by the input power of the wind. The density of air is approximately .094 kg/m^3

CONCLUSIONS

Compare the efficiencies of the three conversions you have determined. Discuss the reasons for the differences.

LAB 11
ELECTRICAL CIRCUITS

To understand how energy in electrical form as generated for example in power plants and flashlights is transmitted from one place to another through the electrical grid and inside devices, it is essential to understand the fundamental characteristics of electrical circuits. In thinking about circuits there are two principles to bear in mind. The first principle is that energy is conserved during their operation, though the energy involved does not all stay inside the circuit. The second principle is that the electrical charge is conserved, which means that no electrical charge is created or destroyed during the operation of the circuit. Unlike energy, in most circuits electrical charge does not escape from the circuit. That is the reason that we have circuits at all. The charge must have a way to go both in and out of a device (which is why electrical cords consist of two wires). In a flashlight, for example, charge flows from a battery through a wire to a bulb. When the charge moves through the filament of the bulb, some energy is transferred to the filament. As a result, the filament heats up and radiates energy as light. The charge then flows back to the other side of the battery to close the circuit. The rate of charge flow is called *current.* One can only have charge flow (current) for an extended period of time, as in the flashlight, if the charge has a closed circuit, or path, to flow around. This is because electrical charge can never be created or destroyed. If the charge starts to flow and there is not a closed circuit, then it starts to build up somewhere, where the path it is following ends. The pileup of charge is accompanied by a buildup of stored energy and eventually the charge escapes by arcing, often destructively. The fact that charge never disappears in nature is another of the great conservation laws of physics. In this class we will be concerned with both the charge flow and the energy flow in circuits.

The closed circuits to be considered in this experiment involve charges leaving the positive terminal of a battery, passing through the wires or light bulbs, and returning to the negative terminal of the battery. The bulb acts as a *resistor* because it "resists" the flow of charges. The bulb's resistance causes the filament inside to increase in temperature and start to glow. Your battery separates positive charges from negative charges within its structure. The work that is done to separate these charges increases their electrostatic potential energy and a *voltage* difference is created. Something very similar occurs in the electrical power system of the whole country: The power plants play the role of the batteries in the simple circuits considered here and the many devices which use the electrical energy transmitted over the grid play the role of the light bulbs in the circuits considered here. However not all the devices which are connected to the electrical grid obey Ohm's law, which is characteristic of some types of devices such as light bulbs.

The simplest circuit involves a resistor and battery connected in a single current path. When the battery's voltage is increased and the resistance is held constant, the current increases. If the voltage is held constant and the resistance is decreased, the current should again increase because the flow of charges is not "resisted" as much as before. These relationships can be written as $V = IR$, in which V is voltage, I is current, and R is resistance. This is Ohm's Law. It holds for the resistors you will study in this laboratory, but it not for all possible circuit elements. In this exercise, you and your lab partners will investigate Ohm's Law by measuring voltage, current, and resistance in a simple closed circuit.

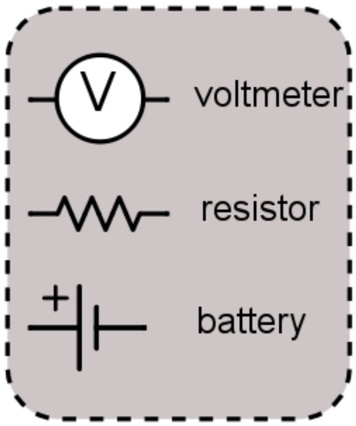
PRE-LAB READING

Read Chapter 11 of Wolfson.

EQUIPMENT

1 – six-volt battery
2 – digital multimeters
1 – light bulb
3 – resistors
1 – set of wires

PREDICTIONS/PRELIMINARY QUESTIONS



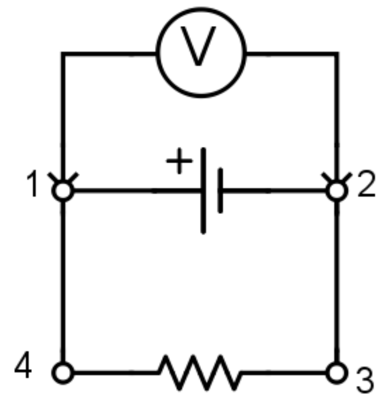
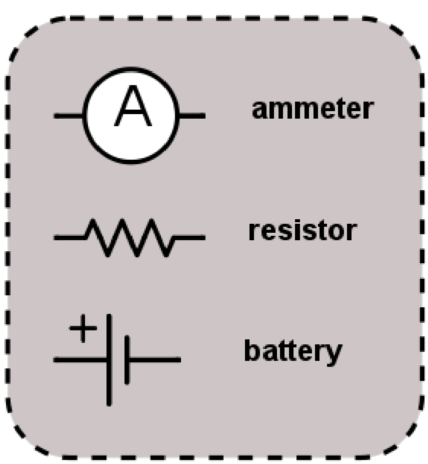


Figure 1

1. Suppose a voltmeter were connected across a battery to measure the voltage from point 1 to point 2. (See figure 1.) Suppose you moved the voltmeter and connected it from point 3 to point 4. Compare the **voltage** reading at the new location with the reading at the first location. Explain your reasoning.
2. Compare the **current** reading, in amps, on an ammeter connected between point 2 and point 3 with the reading on the ammeter if it were connected between points 1 and 4. (The ammeter is connected between the points so all the current runs through it. See figure 2.) Explain your reasoning.
3. If you were to double the voltage (for example, using two batteries) what would happen to the amount of **current** in the circuit if the resistance in the circuit stayed the same? (See figure 2)
4. If the resistor in the circuit were replaced with a resistor with twice the resistance, what would happen to the current in the circuit assuming you used the same battery with the same voltage?



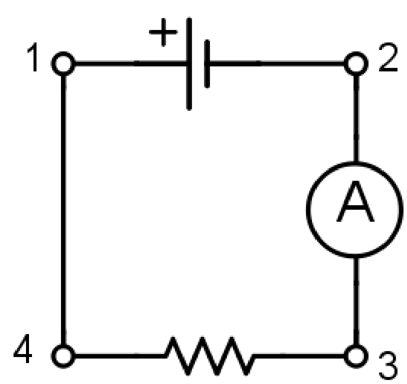


Figure 2

PROCEDURE

The first part of this exercise is to become familiarized with two quantities: voltage (known also as potential difference; measured in volts) and current (measured in amps). Voltage is the work done transferring one coulomb of charge from one place to another; you do not need a complete circuit to measure a potential difference.

The digital multimeter (DMM) has various settings to measure voltage. It also allows you to measure the current (Amps) by turning the switch to the "amps" or "milliamps" settings. Furthermore, you can measure resistance by turning the switch to the "ohms" settings. See Appendix I for a more thorough description of how to use the DMM.

When you set up a circuit in the lab with the necessary wires, meters, and resistors, etc. make the circuit look as simple as possible. Do not let the wires cross unless necessary. Keep the wires as straight as possible and as short as possible. Make the circuit so you can easily tell which objects are connected to each other.

1. First, set the digital multimeter to measure volts and connect it across the terminals of the battery. Observe what happens as you change the range settings on the meter. Observe what happens when you reverse the connection. The meter adds a minus sign if the potential difference is reversed and indicates (by a blank screen) if the potential difference is too large to be measured. Choose a range where the most digits are displayed so that you will have the greatest precision in your measurements.

2. You can leave the multimeter connected across the battery terminals, but to measure the current through the circuit another meter must be connected in series with the resistor and the battery. Connect a complete circuit from the positive terminal of the battery, through a second multimeter (set to measure the current through the resistor), and back to the battery. The second multimeter is now able to measure current. Record the current and the voltage across the battery.

3. Disconnect the circuit. Set a multimeter to measure resistance, and connect it across the terminals of the resistor. Record the value of your resistor in ohms. Why must you disconnect the circuit before trying to measure the resistance of the resistor?

4. Repeat these steps several times, using a different resistor in the circuit each time. Also take measurements using a light bulb as the resistor. Be sure to take measurements of the resistance, voltage, and current for each circuit.

ANALYSIS

Record the values that you measured using the multimeter in a data table, similar to the one shown below. Also calculate theoretical resistances using your measurements for voltage and current (R=V/I) and then record your calculations. Tabulate your experimental and theoretical resistances for all the resistors and the bulb. Explain the values that you have obtained.

	Measured Voltage (in Volts)	Measured Current (in Amps)	Measured Resistance (in Ohms)	Calculated Resistance (R = V/I)
Resistor 1				
Resistor 2				
Resistor 3				
…				
Light Bulb				

You can confirm that the resistors are generating heat by (cautiously), touching them when the battery is connected. For a given battery strength (voltage), do you expect more heat generation for a small resistor or a large one? Make a prediction and then check by doing the experiment.

PARALLEL AND SERIES CIRCUITS

Replace the single resistor in the circuit you used above by

a. Two resistors in series

and then by

b. Two resistors in parallel.

Before you carry out the experiments to determine the resistance of the combined resistors in each of the two cases, make predictions: In which circuit will the current be largest? And what will the value of the combined resistance in each case be?

Then make the measurements and compare the results with your predictions.

CONCLUSIONS

1. Compare the measured and calculated resistance values in your data table. How close are they? If there are differences, what are some possible reasons for these differences?
2. Discuss the flow of energy in these circuits, describing the forms of energy involved and where they enter and leave the circuit.
3. Superconductors are materials which, when cooled sufficiently, offer almost no resistance to electrical current. The copper wires in your circuits do, however, add to the total resistance.
    a) What if the wires used in the circuit with the light bulb were replaced with superconducting wires and the resistance became almost nothing? Would the current in the circuit change, or the does voltage change, or both?
    b) What would happen to the light bulb? Explain your answer using Ohm's law.

LAB 12
MAGNETS AND MOVING CHARGES

The interaction of magnetism and electric charges underlies how motors and generators function. Motors and generators look very similar inside and are mechanically very similar. They work by closely related, but different principles. In this laboratory you will study the principle by which motors work in Part 1 and the principle by which generators work in part 2. Magnetic fields arise from magnetic materials and also from moving charges in the currents running in circuits or beams of electrically charged particles. The picture in most television sets used to be made by such beams (of electrons) which moved from the back of the picture tube to the screen where they hit the screen and excited phosphors which made the light which you see. (Actually, the magnetic fields arising from magnets can be regarded as arising from moving microscopic currents inside the material.) If one has a magnetic field produced by one of these means (a magnet, a current carrying wire (often wound in a coil or a charged beam) then if other moving electrical charges move through this magnetic field, the moving charges will experience a force. This force is what makes the rotor of an electric motor go around. To get an idea how that works you should study Figure 11.7 of your book. The rotor (the thing that goes round and round) in the motor has a wire in it that carries a current. The rotor moves in a magnetic field provided by two "pole magnets" labeled N and S in the figure. Because the charges in the wire in the rotor are moving, they feel a force which pulls on the rotor and makes it turn. What is strange about this force is its direction: It is not in the direction of the magnetic field and it is not in the direction of the velocity of the moving charges but is perpendicular to both those directions as illustrated in Figure 11.4 of the book. In part 1 of this laboratory, you will do some experiments using a magnet and the currents in a cathode ray tube (a simplified TV tube) to help you to understand this peculiar directional aspect of magnetic forces better.

Whereas in a motor, electrical energy is being converted into mechanical energy through the action of the forces arising from the motion of charges through magnetic fields, in a generator, mechanical energy is turned into electrical energy. That is possible because of a different principle illustrated in Figure 11.10 of the book, Notice that Figures 11.10 and 11.7 look very similar. You should make sure you understand how they are different. In 11.10, illustrating a generator, the wire, which does not have a current being forced through it by an external battery, is being mechanically forced to turn by forces exerted on some kind of a handle on the shaft. As a result, the magnetic field through the coil is changing. The new principle is that a changing magnetic field through a coil will cause a voltage in the coil to develop and then a current will flow. (This principle is a form of what physicists call Faraday's law.) In part 2 of this laboratory, you will explore this principle by moving a magnet around a coil of wire and observing the resulting currents. Then you will construct and measure aspects of the operation of a simple generator.

PRE-LAB READING

Read 3.2 of Wolfson.

PART 1. THE PRINCIPLE BY WHICH MOTORS WORK: THE EFFECT OF A MAGNETIC FIELD ON A MOVING CHARGE

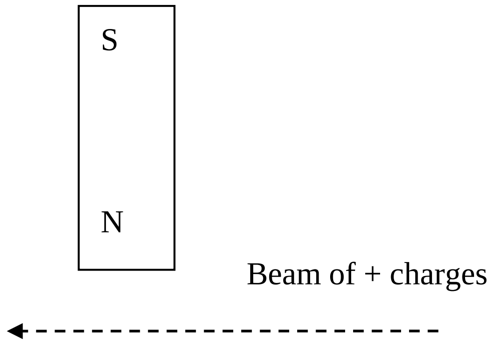
EQUIPMENT

1 – cathode ray tube (CRT)
1 – high-voltage (CENCO) power supply
3 – bar magnets
1 – compass

PREDICTIONS/PRELIMINARY QUESTIONS

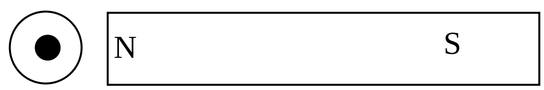
1. If a beam of positively charged particles moves from right to left as shown in the figure below what would be the effect of a bar magnet on the beam if it were located as shown in the

diagram? (Would the beam move up? down? Out of the paper? Into the paper? Or, would there be no effect?)



2. If the beam of particles, in the above diagram, were electrons (negative charges) what would be the effect of the magnet on the beam? (Would the beam move up? Down? Out of the paper? Into the paper? Or, would there be no effect?)

3. If a beam of positive charges were coming out of the paper what would be the effect of the magnet on the beam? (The black dot represents the beam coming out of the paper.) Would the beam move up? down? Out of the paper? Into the paper? Left? Right? Or, would there be no effect?)



PROCEDURE

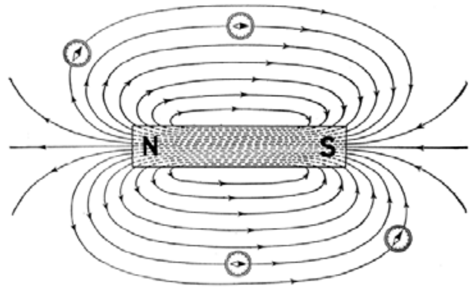
A cathode ray tube (CRT) produces an electron beam that can be seen as a glowing spot when it hits a phosphorescent surface inside the tube. Holding a magnet close to the CRT produces a magnetic field in the tube and causes the electron beam to deflect, which will make the spot on the phosphorescent screen move. The lab instructor will show you how to connect the CRT to the high-voltage power supply properly.

You and your partners will work with equipment that produces large voltages, and improper use can cause injury. To avoid danger, the power should be off and you should wait at least one minute before any wires are connected to or disconnected from the power supply. Do not grasp a wire by its metal ends.

1. How do you think the electron beam will be deflected in the presence of a magnetic field? Record your predictions in your notebook.

2. Connect the CRT and the power supply. Consult with your instructor about the ideal accelerating voltage with which to start the exercise. Record this value. Also record the location of the non-deflected beam spot on the screen.

3. Use your compass to determine which pole on your bar magnet is the north magnetic pole. Below is the magnetic field that is produced by a bar magnet:



Based on this, describe what the magnetic field will be like within the CRT.

4. Place the magnet at the side of the CRT. In what direction does the beam deflect? Does the deflection of the beam match your prediction? Why or why not? Repeat the procedure for the south pole. Should there be a difference? Why or why not?

5. If you position a bar magnet at the front of the screen of the CRT, do you see any deflection? What does the right hand rule predict? Try this with both poles of the bar magnet. What are the results? Are they what you expected? Can you orient the bar magnet so that it attracts or repels the electron beam?

6. Place the north pole of your magnet a fixed distance from the side of the CRT screen. Record the initial deflection of the beam. Increase the electrons' speed by increasing the accelerating voltage as much as possible.

CAUTION: Always turn off the power supply and wait a 10 seconds before removing and reconnecting wires, or you could get a dangerous shock! Never grasp a wire by its metal end.

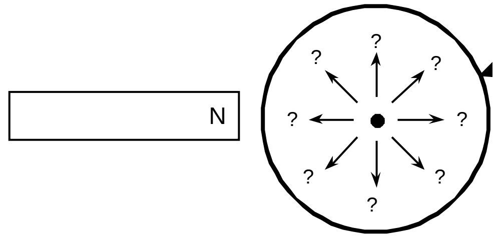
How much does the deflection change? Try with both poles of the magnet. Were the results what you anticipated?

7. Place the north pole of the bar magnet a fixed distance from the side of the CRT near the screen. Record the initial deflection. Increase the magnetic field by adding more magnets. Also try the south poles. Was the result what you would expect?

8. What effect does Earth's magnetic field have on the CRT electron beam? What is the direction of Earth's magnetic field in your lab room? Based on your earlier findings, orient the CRT to see the maximum effect. Also orient it for the minimum effect. Is there also an effect on the beam from Earth's gravitational field?

CONCLUSIONS

1. When you bring the north end of a bar magnet near the side of the CRT:



   a) in what direction is the electron beam deflected?
   b) Does the beam deflection increase or decrease as your magnet is moved closer to the CRT?
   c) Does the beam deflection increase or decrease as the magnetic field strength increases? How can you tell?
   d) Is the direction different for the south end of the magnet?

2. The electron beam in a television is "steered" with magnetic fields.
   a) What is the direction of the field that pushes the electrons up and down? (Draw a sketch and use words to explain it.)
   b) What is the direction of the field that pushes the electrons left and right? (Draw a sketch and use words to explain it.)

3. In the future, the use of superconductors will allow construction of smaller, lighter, and more efficient generators and motors. In a superconductor, there is no resistance to the flow of electrons. This has two effects: (1) no energy is lost in the form of heat, and (2) the velocity of the electrons would be greater.
   a) Does the deflection of an electron beam in a magnetic field depend on the speed of the electrons?
   b) Discuss what effects a higher electron velocity in the wires of a generator and a motor would have.

PART 2. THE PRINCIPLE BY WHICH GENERATORS WORK: THE EFFECT OF A CHANGING MAGNETIC FIELD ON THE VOLTAGE IN A COIL

In the previous part of this laboratory you studied the way in which forces are exerted on moving charges, either in a beam or in a wire, when they move through a magnetic field. That is the principle by which motors work. (The magnetic force is sometimes called the Lorentz force.) In this part of the laboratory you will study how a changing magnetic field can cause the charges in a wire which has no current flowing in it to start moving, thus producing a current, as a result of the changing magnetic field. This principle is a version of Faraday's law. In generators it is used to produce a current by mechanically forcing a wire coil to move through a stationary magnetic field (as in Figure 11.10 of your book) or by magnetically causing a magnet to move in and out of a coil (as in the simple generator you will build in the laboratory.)

In the first part of the exercise, you and your lab partners will investigate the currents and voltages which are induced in wire coils when the magnetic fields around them change in time. Then you will construct a simple generator using which uses Faraday's law to convert mechanical to electrical energy.

EQUIPMENT

1 – long wire solenoid
1 – short wire solenoid
1 – digital multimeter
3 – neodymium magnets
1 – roll of masking tape
1 – pencil or wood dowel to affix magnet to
1 – compass

PREDICTIONS/PRELIMINARY QUESTIONS

1. What, if anything, happens to the charges inside a coil of wire when a magnet moves through the coil? What happens to the charges if the magnet is close to the coil but not moving?
2. Does the same thing happen to the charges if you move the North end of a magnet toward a coil of wire as when you move the South end toward the coil? Explain your reasoning. Does the speed at which the magnet moves make a difference?
3. What happens to charges in the wire if you hold the permanent magnet stationary and move the coil?

PROCEDURE

In this exercise, you and your partners will use a permanent magnet to produce changing magnetic fields. This causes an electric field to be produced, which you will detect using a solenoid (a spool of wire) connected to a multimeter. The electric field drives electrons around the solenoid, producing a current that can be detected by the multimeter. Consult Appendix I at the back of this manual for information about the use of your multimeter. If you still have difficulties, ask your instructor for assistance.

1. Use a compass to determine which ends of the magnets are north and which are south. Keep in mind a compass needle is a lightweight magnet balanced on a pivot point, but the end labeled as north points to Earth's magnetic north pole.

2. Start with the longer wire solenoid -- it has more loops of wire than the other one. Do you detect any current with your digital multimeter when a magnet is simply placed at rest inside the solenoid? Try the lowest setting to measure current.

3. Do you detect any current when you move the magnet or wiggle it inside the solenoid or near it? What happens if you change the speed at which you move the magnet? If you reverse the direction of the magnet's poles, what happens?

4. What happens if you hold the magnet still and move the solenoid? What happens if you change the speed at which you move the solenoid? What happens if you reverse the direction of the magnet's poles?

5. What happens when you repeat the above steps with second magnets? With three?

6. Now you and your partners will construct a generator. Tape a magnet securely to the end of a pencil so that its looks like the head of a hammer. Mark the north and south poles of the magnet (if not marked already) for later reference. Rotate the pencil near the solenoid and observe the induced current with the digital multimeter. Change the orientation of the pencil and note its effect on the current. Which orientation induces the largest current? The smallest current?

7. If you change the speed at which you rotate the pencil near the solenoid, does it have any effect on the "amplitude" of the induced current?

8. Use the second wire solenoid with the same diameter but fewer loops. Compare the strength of the induced current in the two solenoids.

9. How does the current produced by your generator change with the distance of the bar magnet?

CONCLUSIONS:
1.What factors affect the induced current in the wires?

2.In this exercise, you and your partners used a magnetic field to induce a current. In the previous exercise, you and your partners used magnetic field to move an electron. How do the factors that affected the electrons in the previous exercise compare to the factors in this exercise?

3.Based on your experience in this exercise and the previous one:

a. describe how an electric generator works. (What basic components are needed? What needs to happen with these components?)

b. Describe how this happens for each of the following sources of electricity: solar, geothermal, hydroelectric, tidal, wind, and nuclear power.

4.Based on what you know about generators and motors, how could you convert your generator in this exercise into a motor?

Lab 13

GREENHOUSE EFFECT

Every day the Earth receives energy from the Sun. On a daily basis the Earth reflects about 1/4th of the incoming solar radiation. The remainder is absorbed and contributes to warming the land, atmosphere and oceans. For the Earth's temperature to be steady and not rapidly heating or cooling, this absorbed energy must be very nearly balanced by energy radiated back to space in the infrared wavelengths. Luckily the amount radiated out in as infrared energy increases with the temperature of the earth, allowing us to reach steady states without overheating. The average temperature of the earth's surface, and our climate, is therefore determined by how effectively the infrared radiation coming from the warm surface of the earth can be reradiated into space. The reason that scientists are concerned about global warming at this time is because some human activities are making this re-radiation less effective. These human activities release molecules into the atmosphere which cause the radiated infrared radiation to reflect back down to the earth's surface, rather than escaping into space. Thus the atmosphere acts like the window on the ceiling of a greenhouse, which also causes infrared radiation coming from the plants inside to be trapped inside the greenhouse, keeping it warm in (mild) winters. So the effect of certain gases in the atmosphere which trap infrared radiation and cause the earth's surface to be warmer than it would otherwise be is called the greenhouse effect. Greenhouse gases are molecules such as carbon dioxide and water, which absorb and reradiate infrared radiation as the atoms in them vibrate against each other. The human activity which is having the biggest effect on this balance is the burning of fossil fuels which is releasing much more carbon dioxide into the atmosphere than was released in pre-industrial times. Measurements confirm that the amount of carbon dioxide in the atmosphere is steadily rising and that the average temperature of the earth's surface is also rising. Because the climate is complicated and because other things can also cause the temperature to change there has been some discussion about whether the temperature rise is caused by the carbon dioxide increase. However, in the last few years as a result of many measurements as well as extensive computational modeling, a very wide scientific consensus has emerged which attributes much of the observed temperature increase to the human activities leading to increased carbon dioxide in the atmosphere.

In this laboratory you will investigate the effects of increased carbon dioxide in a simple system. You will measure the temperature near the bottom surface of an aquarium as energy is applied using a heat lamp. Data is taken both with and without additional carbon dioxide. Additional trials will investigate if changing the bottom material of the aquarium has an effect.

Trial 1: Aquarium
Trial 2: Aquarium with CO2
Trial 3: Aquarium with black paper on bottom
Trial 4: Aquarium with CO2 and black paper on bottom

PRE-LAB READING

Read Chapter 12 of Wolfson.

EQUIPMENT

- 5 gallon aquarium
- Tank of compressed CO2
- Black Paper cut to fit bottom of aquarium
- Heat Lamp
- Table clamp, rod, three prong clamp, rod to rod clamp
- SaranWrap to cover aquarium
- Vernier LoggerPro interface, temperature sensor and computer

PREDICTION

Given the four Trials, predict possible outcomes for each of the systems; rank in order of highest to lowest equilibrium temperatures.

Do you think the aquarium with only C02 will have a higher equilibrium temperature than the aquarium with only black paper on the bottom?

WARM-UP QUESTIONS

1. What effect is the black paper going to have on the model system?
2. From your knowledge of CO2, what effect might it have on the system?
3. Do you think that the effects of the black paper and CO2 gas will be additive? If so, why? If not, why?
4. Which of the four trials do you believe will have the hottest equilibrium temperature?

EXPLORATION

Familiarize yourself with the apparatus. When adding CO2 to the aquarium you will experience a slight cooling, how can you minimize the effect on your data? It is useful to know that CO2 is heavier than air, so it will sit in the aquarium like water in a bathtub if not disturbed too much? The Saran Wrap is necessary to keep convection to a minimum during each trial.

How much effect do you think the position of the lamp in relation to the aquarium will have on your results? How can you ensure this position is the "same" between Trials? You might want to mark the location of the aquarium using tape and make sure the lamp is setup and located so it is not moved.

How important is the temperature probe positioning? If the lamp directly shines on the probe, does this affect your measurements? It is best to place the probe near the bottom of the aquarium with the tip covered from direct light using a Styrofoam cup.

Make a plan that determines a good amount of time to collect data. How can you tell if your system has reached equilibrium?

MEASUREMENT

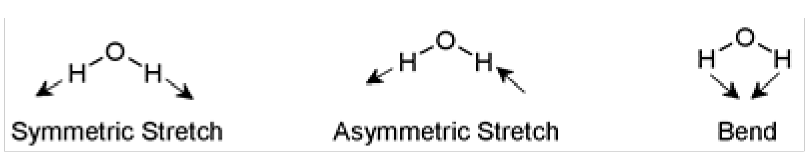
Run the trials and collect temperature data for each.

ANALYSIS

List the equilibrium temperatures for each group and compare.

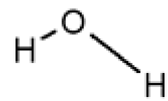
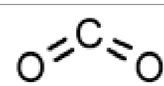
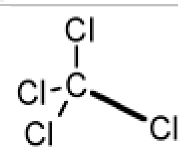
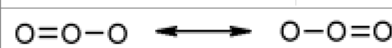
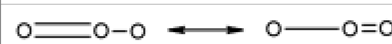
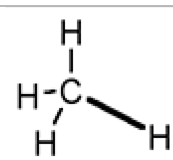
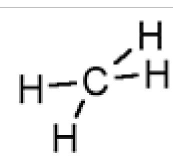
CONCLUSION

Changes in the vibrational and rotational motions of molecules are the main reason for the absorption of IR energy The direct absorption of infrared radiation occurs **only** if there is a **change in the dipole moment** of the molecule.



Consider the dipole moment as the molecule undergoes each of these motions. The vibrations will result in an absorption in the infrared region. Infrared absorption frequencies for several atmospheric gases are given in Table 1.

Table 1: Principal IR Absorptions for Various Atmospheric Gases

Type of Gas	**Absorption Ranges** (in cm^{-1}) [Look for **one** peak within the following ranges.]	**Type of bond causing absorption**	
Water (H_20)	3800-3600		**Asymmetric Stretch**
	1600-1400		**Bend**
Carbon Dioxide (CO_2)	2400-2200		**Asymmetric Stretch**
	800-600		**Bend**
Nitrous Oxide (N_20)	2400-2200	 [2 resonance forms]	**Symmetric Stretch**
	1400-1200	 [2 resonance forms]	**Asymmetric Stretch**
Carbon Tetrachloride (CCl_4)	1000-600		**Asymmetric Stretch**
Ozone (O_3)	2400-2200	 [2 resonance forms]	**Symmetric Stretch**
	1200-1000	 [2 resonance forms]	**Asymmetric Stretch**
Methane (CH_4)	3200-3000		**Asymmetric Stretch**
	1400-1200		**Bend**
Nitric Oxide (NO)	2000-1800		**Stretch**

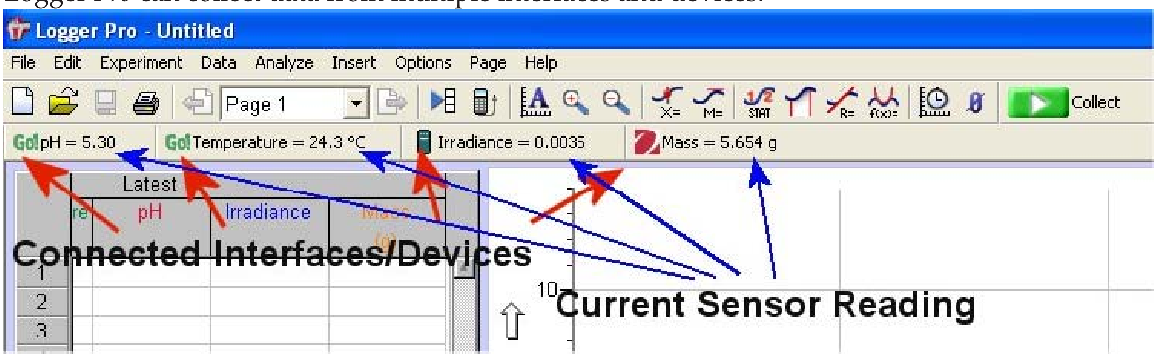
Appendix A: LoggerPro data acquisition software:

Before launching, you should:

- Power the LabPro using the AC power supply or AA batteries.
- Connect a sensor to LabPro.
- Connect the USB or serial cable to LabPro.
- Attach the other end of the interface cable to any unused serial port or USB port on your computer.

Start Logger *Pro*

Locate the Logger *Pro* icon and double-click on it.
Logger *Pro* can collect data from multiple interfaces and devices.



In the figure above, a Go!Link, Go!Temp, LabPro and Ohaus balance are connected to the computer.
Logger *Pro* is a program that allows you to collect and analyze data from Vernier LabPro. Among its many features, data may be manually entered from the keyboard, pasted from the clipboard, or retrieved from a file saved on disk. Logger *Pro* is also a document creator, with the ability to include several pages in one document.
With Logger *Pro* you can also:

- Perform data analysis, such as statistical analysis, curve fitting, and calculated columns.
- Add pictures to lab reports.
- Add movies and synchronize movies with data collection.
- Manually enter data.
- Export data to Excel® or other spreadsheets.
- Have students draw a prediction on a graph and see how well the experimental data matches it.

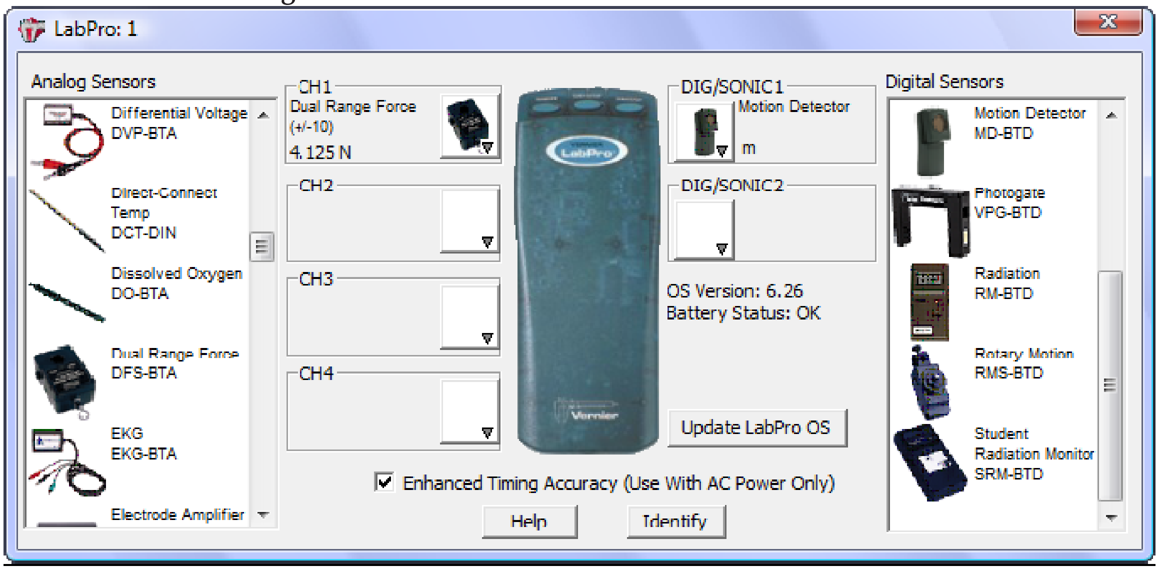
AcquiringData

Configure Logger *Pro* for Your Experiment

There are several ways to set up Logger *Pro* for an experiment. Most often you will just start Logger *Pro* with auto-ID Sensors connected.

- **Auto-ID Sensors** With auto-ID sensors, all you need to do is connect the sensor to one of the LabPro channels and start Logger *Pro* software. The sensor will be identified, and default data-collection parameters loaded for that sensor. You are ready to click the button and begin data collection!
- **Probes & sensors experiment files** If you are using an older Vernier sensor that is not auto-ID, or if you want to use some other specially configured file, you will need the Probes & Sensors folder. Choose Open from the File menu, and open the Probes & Sensor folder. There you will find a folder for each of the Vernier sensors. Open up a file with a name that best fits the data collection you want to perform.

- **Sensor dialog**



This dialog, called up by clicking the LabPro icon in the upper left side. It shows your sensor information, the units and current readings. The details of the dialog vary, depending on the specific interface used. Use the scroll bars in the Sensor Catalogs to view all sensors.

By clicking in a Channel box with a displayed sensor, you may be able to:

- **Calibrate a sensor:** Perform a new calibration.
- **Get sensor information:** Includes collection details and calibration information
- **Zero a sensor:** Sets the current reading of a sensor to zero.
- **Choose sensor:** Select another sensor for the channel.
- **Change the current settings:** Select the available units or calibration settings.
- **Analog out (CH 4 only):** This channel can be used as a function generator.
- **Remove sensor:** Clears the channel of the sensor.

Collect Data

Click the green GO button. Logger *Pro* will begin plotting data in the graph window. Tip: Normally, the data collection stops at the time indicated on the time axis. You can stop the data collection early by clicking the stop button. If you discover you want the data collection to go even longer, you can add additional time by choosing Extend Collection from the Experiment menu.

Now that you have collected data, there are many things you can do with it. Keep reading for descriptions of some of the most commonly-used Logger Pro features.

Store Data

The Store Latest Run option in the Experiment menu saves the most recently collected data in memory, allowing you to do another collection while keeping the first one.

The run labeled "Latest" always contains the most recently collected data, and is overwritten when you collect more data. When you store the latest run, a new data set named Run 1, Run 2, etc, is created and the values of the latest data set are copied to it. Columns in the latest data set are drawn with thick lines on the graph, while other columns are drawn with thin lines.

Note: *Using Store Latest Run does not save data on disk, nor will it preserve your data between sessions or when you turn off your computer. You must select Save As from the File menu to save your session (data and analysis) to disk.*

Data Collection and Modes

You are not limited to time-based data collection. Choose Data Collection from the Experiment menu to modify data collection parameters for your experiment. See Logger *Pro*'s Help for information about your choices.

- **Time Based** Set the data collection rate as a function of time.
- **Events With Entry** A data point is recorded whenever the Keep button is clicked. You are then prompted to enter values for a new data column.
- **Selected Events** A data point is recorded whenever the Keep button is clicked.
- **Digital Events** You can set data collection to run continuously (until the Stop button is clicked) or at a certain number of events.

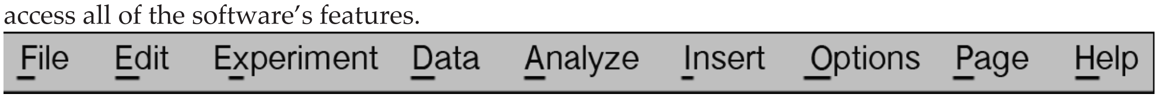
Manually Enter Data

You can type data directly into the data table from the keyboard. To manually enter data, disconnect all interfaces, and start Logger *Pro*. Click on a cell and type in a number. You can use the mouse or the Enter/Return key to move and edit within the table. Your values will also be plotted on the graph.

Logger *Pro* Screen and Toolbar

Toolbar The toolbar contains buttons for the most commonly used features of Logger *Pro*. All of the features in the toolbar are also available in the menus. As you move the pointer across a button, you are given a short description of each feature.

Menu bar Logger *Pro* has a menu bar across the top of the main window. Use the menu bar to access all of the software's features.



Click	To
	Create a new document.
	Open an existing document.
	Save the active document or template with its current name.
	Print the screen as displayed on your monitor.
	Scroll between pages.
	Bring up the previous page of the current document.
	Bring up the next page of the current document.
	Bring up the Data Browser Window.
	Import data from the Texas Instruments calculator.
	Automatically scale the graph to include all data points.
	Zoom in to the selected region of the graph.
	Zoom out by a factor of two in both x- and y-directions.
	Enter Examine mode.
	Enter Tangent Line mode.
	Integrate selected data range.
	Calculate statistics on selected data.
	Make a linear fit to the selected range.
	Perform general curve fits.
	Set data-collection parameters.
	Begin collecting data.
(The following icons only appear when collecting data or if is relevant.)	
	Stops collecting data or stops a replay.
	Tells the heat pulser to generate a pulse.
	Click this button to keep a data point.
	Click the Zero button to set the current value of a sensor to zero.
	Create a new Graph Match.

Manage Your Page and Data

There are numerous ways that you can customize the presentation of your data.

Move Objects Select the object by clicking on it once. Move the cursor over the edge of the selected object until the cursor turns into a hand, then hold down the mouse button while grabbing and moving the object.

Resize Objects Single-click on an object to select it. When an object is selected, its border becomes visible, along with eight resizing handles.
Clicking and dragging a resize handle will resize the object in the appropriate direction.

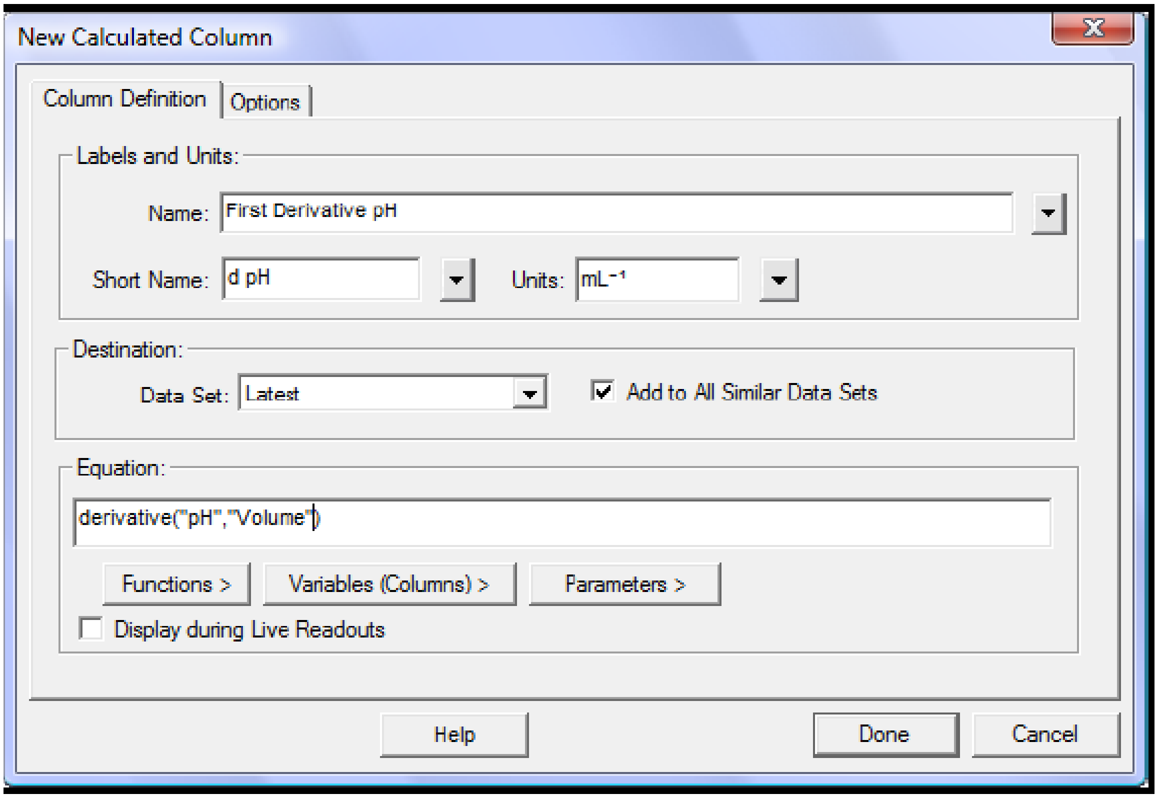
Graph Axes Customize your graph by changing the columns that are displayed.

1. Position the mouse over the X-axis or Y-axis label and click. A list of available columns will appear.
2. Select the column you want displayed. If you want more than one column displayed, select More and check the boxes next to the desired columns.

Graph Options Double-click on the graph or select Graph Options from the Options menu to call up the Graph Options dialog. This allows you to change the graph object appearance, including point protectors, legend, line style, and other graph features. Click the Axis Options Tab to adjust scaling and select what columns are plotted or add a Y axis to the right-hand side of the graph.

Create a Column

You can create a new column that is manually entered or that consists of calculations based on other data in Logger *Pro*. Create a new column by selecting New Manual Column or New Calculated Column from the Data menu.



Select and Edit Cells in a Data Table

Manually-entered data and data collected using the Events with Entry mode can be edited.

- To edit a single cell in a table, single-click in the cell.
- To select a single cell in a table, click and drag the selection within that cell.
- You can select entire columns by clicking on the title of the column.
- You can select an entire row of data by clicking on the row numbers.

The Data Browser

The Data Browser is a container for all data in a Logger *Pro* file. In contrast, a given Data Table will not necessarily show all data columns.

Data Browser Features

Drag and drop from the Data Browser to objects such as tables and graphs. Drag a column to a y- or x-axis to plot it there.

When the Data Browser is selected, edit menu items like Cut, Copy, Paste, etc. will apply to the selected items within the Data Browser.

Analyze Data

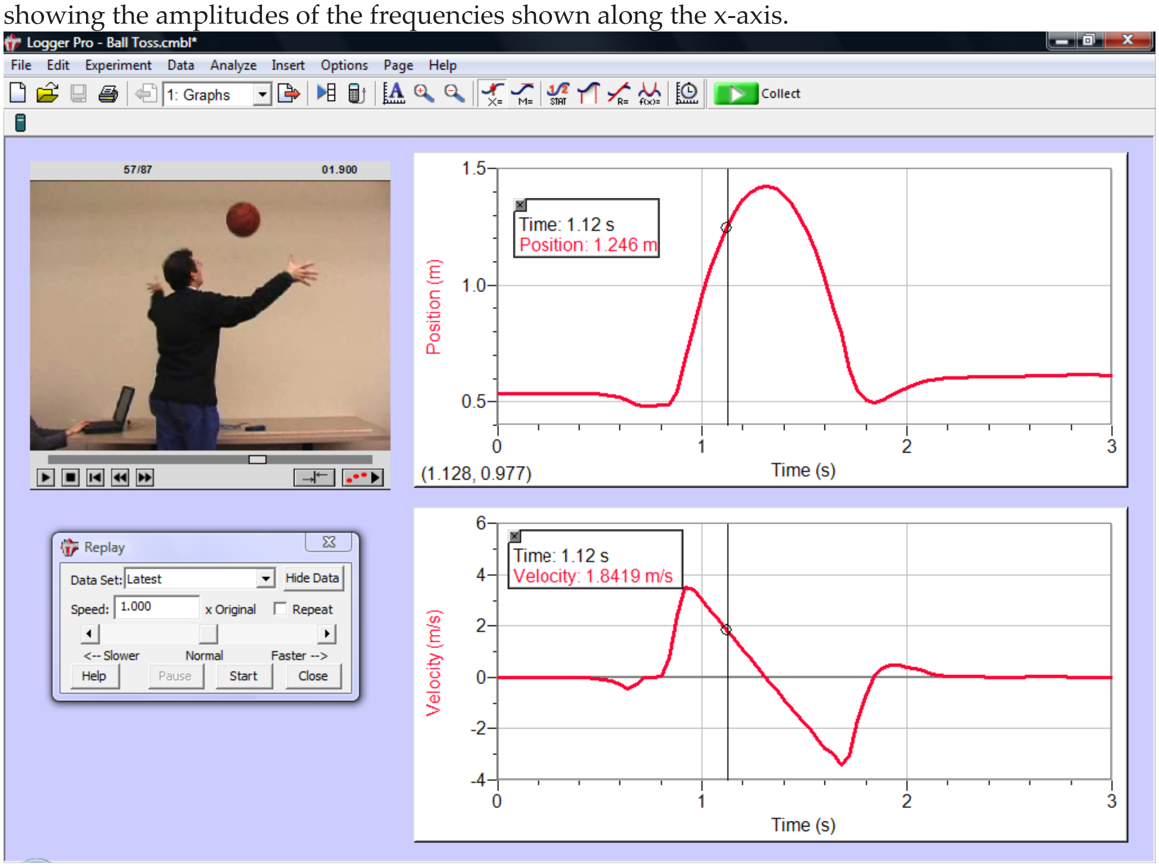
The Analyze menu contains functions for examining and analyzing your data. A few of the most commonly used analysis functions include:

- **Examine:** Shows the x- and y-values of the data point closest to the mouse pointer.
- **Statistics:** Calculates the minimum, maximum, mean, and standard deviation.
- **Curve Fit:** Fits a selected or user-defined function over the data.
- **Draw Prediction:** Sketch a prediction on a graph using the mouse.

Several of the analysis features are available from the Toolbar.

Additional Analysis Features

Movie: You can synchronize data collection and a movie of the experiment so that as you Replay the movie, the data are replayed on the graph.
Video Analysis: You can create a graphical representation of the motion you see in a movie.
Model: Perform a manual curve fit of your data.
Histogram: Displays the distribution of values for a data set in bar graph format.
Strip Chart: Each new collected data point gets added to the right most edge of the graph.
FFT: Gives the amplitudes of the frequency components of a data series, and displays a bar graph showing the amplitudes of the frequencies shown along the x-axis.



Set Preferences

The Preferences dialog box contains several options that pertain to the general operation of the software. These preferences will apply every time Logger *Pro* is launched.

In Windows, choose Preferences from the File menu. In Mac OS X, choose Preferences from the Logger *Pro* menu.

Printing

Print Graphs and Data

1. Arrange the objects on the screen as you want them to appear on the paper. If you choose, you can print several graphs and data tables at once.
2. Select Print from the File menu or click on the toolbar.
3. When the printer is ready, click in the Print dialog box.

You can print the graphs and data tables individually by selecting Print Graph or Print Data Table from the File menu.

Where to Next?

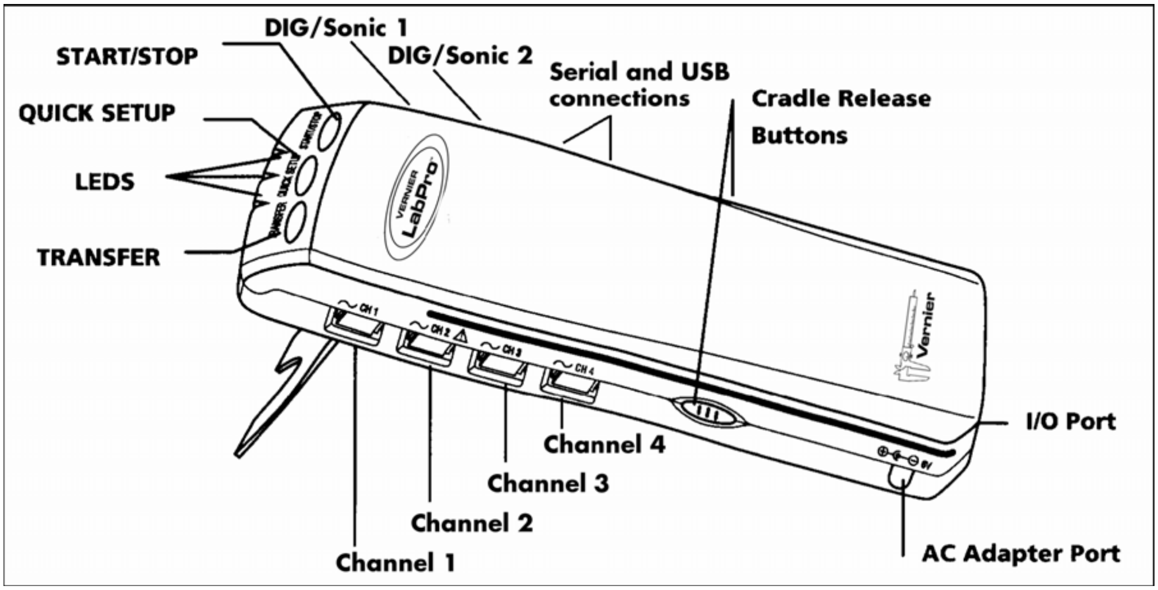
The extensive Help system in Logger *Pro* provides detailed instructions for these and other features.

Also available are the Logger *Pro* Tutorials. Choose Open from the File menu to access them. These short tutorials are suitable for reference or for use in your classes. First-time users should work through one introductory tutorial and the advanced tutorials as needed.

If you have questions as you are using our software, call or e-mail us. We will be happy to help!

Appendix B: LabPro Computer Interface

The LabPro interface has three buttons, three LEDs, four analog channels (CH 1, CH 2, CH 3, and CH 4), two digital channels (DIG/SONIC 1 and DIG/SONIC 2), a serial computer connection, a USB computer connection, a piezo speaker, and a calculator I/O port.



Buttons: The three buttons on the top of LabPro are used for the following purposes:

- TRANSFER begins transfer of calculator programs or applications (apps) between LabPro and an attached TI graphing calculator.
- QUICK SET-UP clears any data stored in LabPro's memory, then polls all channels for auto-ID sensors and sets them up to collect data. QUICK SET-UP is used when neither a computer nor a calculator is attached to LabPro and works only with auto-ID sensors.
- START/STOP begins sampling for Quick Set-Up. Sampling continues until the default number of samples is collected or you press START/STOP again. This button also acts as a manual trigger for certain data-collection modes.

Lights

LabPro has three lights that indicate the LabPro status.

- Red indicates an error condition.
- Yellow indicates that LabPro is ready to collect data samples.
- Green indicates LabPro is collecting data.

Beeps

LabPro has a piezo speaker that makes four kinds of sounds or "beeps."

- A "good" beep is a medium tone followed by a high tone.
- A "caution" beep is a medium tone followed by another medium tone.
- A "bad" beep is a medium tone followed by a low tone.
- A "tick" sound is made when a key is pressed.

Connecting Sensors

Sensors can be divided into two basic types—analog and digital. Examples of analog sensors are Temperature Probes, pH Sensors, Force Sensors, Oxygen Gas Sensors, etc. Up to four analog sensors can be connected to LabPro. Four jacks for the analog sensors (CH1-CH-4) are located on the same side as the AC Adapter Port. The analog ports accept British Telecom-style plugs with a right-hand connector. Examples of digital sensors are Motion Detectors, Radiation Monitors, Photogates, and Rotary Motion Sensors. Up to two digital sensors can be connected to LabPro. The digital ports (DIG/SONIC), which accept British Telecom-style plugs with a left-hand connector, are located on the same side as the serial and USB computer connections. Connect the sensor to the appropriate port. An important feature of LabPro is its ability to detect auto-ID sensors, and automatically set up an experiment. If you are not using sensors with the auto-ID ability, you can easily set them up with the experiments provided with the Logger*Pro* software.

Attaching LabPro to a Computer

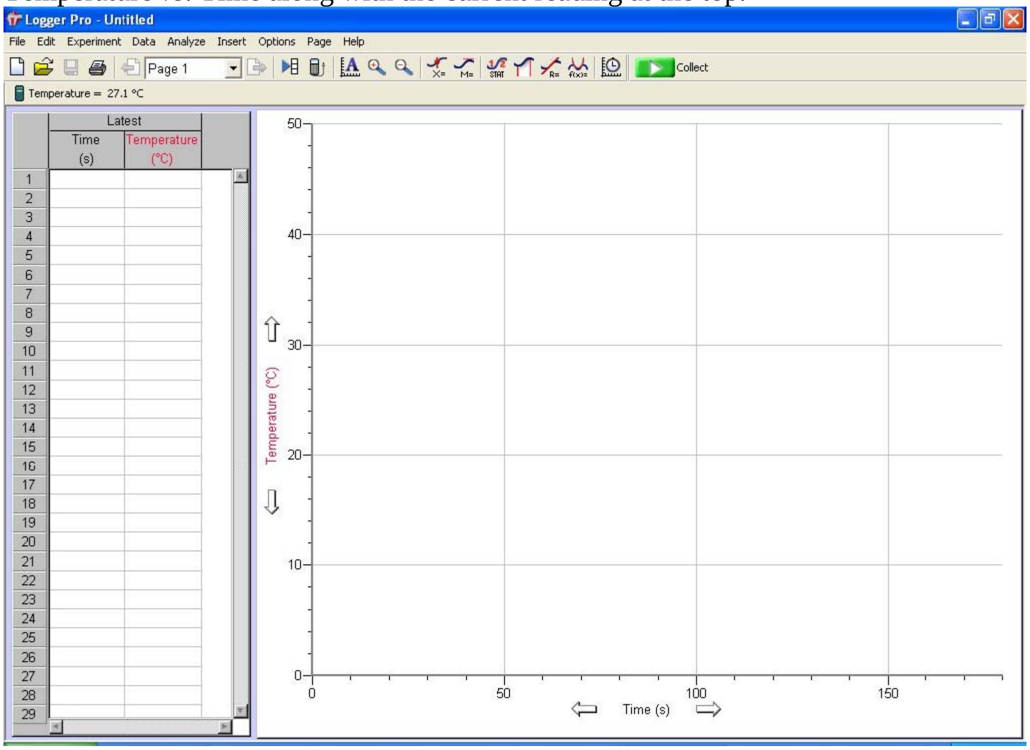
The LabPro computer connection is located on the right side of the interface. The sliding door found there can be moved left to reveal the serial port or to the right to reveal the USB port.

Serial Port and Digital Channels (USB Port is behind the sliding door)

Starting Logger *Pro* Software and Preparing to Collect Data

Locate the Logger *Pro* icon on your computer and double-click on it. An important feature of LabPro is its ability to detect auto-ID sensors, and automatically set up an experiment.[3] If Logger Pro does not detect your LabPro and/or a sensor is not connected, the Collect button will be faded. Choose Connect Interface from the Experiment menu. The computer will attempt to communicate with LabPro. If you see the following message[4], then Logger *Pro* is having trouble communicating with LabPro. Select the correct port or check your current port and click OK.

If you have connected a Stainless-Steel Temperature Probe and the computer has detected the LabPro interface, for example, you will see the following screen, which shows a graph of Temperature *vs*. Time along with the current reading at the top.



Notice how the program automatically identified the temperature probe (an auto-ID sensor). The current temperature reading is displayed in the status bar at the top of the screen. The default data collection mode is time graph. In this example, you have a Temperature Probe, reading in Celsius, and collecting data as a function of time for 120 seconds. If you now disconnect the Temperature Probe, connect a different auto-ID sensor, and choose New from the File menu, Logger *Pro* will set up a new experiment for the new sensor.

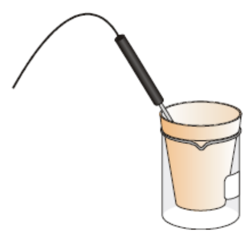
Tutorial: Temperature Measurement with Logger *Pro*

A good way to get acquainted with LabPro is by performing a simple experiment. Using this tutorial, you will take measurements using a temperature sensor. Follow the simple steps and you are well on your way to collecting and analyzing data with a computer.

MATERIALS

Computer & LabPro interface
Vernier Stainless-Steel Temperature Probe
One 250-mL beaker or cup
100 mL hot water

PROCEDURE



1. Place about 100 mL of hot water into a 250-mL beaker or a cup.

2. Plug the Stainless-Steel Temperature Probe into channel CH 1 on LabPro, and lay the temperature probe on the tabletop.

3. Start the Logger *Pro* software. Logger *Pro* will detect the auto-ID sensor, set the data collection parameters, and computer display. In this case, collection parameters are 1.0 sample per second and 120 samples. The program displays a graph and data table on the computer. The vertical axis of the graph will have temperature scaled from 0 to 100°C. The horizontal axis will have time scaled from 0 to 120 seconds. You are ready to collect data.

4. Click GO to begin data collection.

5. Wait about 10 seconds and place the Temperature Probe into the cup of hot water, as shown above. Allow Logger *Pro* to complete data collection.

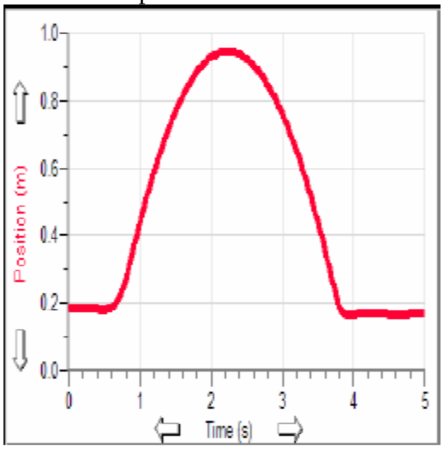
6. Notice that the sensor does not read the new temperature instantly; it takes a moment to respond.

7. Now that the run is complete, pull down the Analyze menu and choose Examine. The cursor will become a vertical line. As you move the cursor across the screen, temperature and time values corresponding to the cursor position will be displayed. Move the cursor to the point when the probe was first placed in the hot water. Record that time. Move the cursor to find the highest temperature, and record that time. How long did it take for the temperature sensor to stabilize at the water's temperature? This tutorial is an example of how easy it is to collect and analyze data with LabPro and a computer. The auto-ID Stainless-Steel Temperature Probe simplified the experiment setup, but the use of non auto-ID sensors is almost as easy. All you have to do is connect the sensor or sensors, and open up an appropriate experiment file. Logger Pro software has over 500 experiment files. This set of files is also includes experiments in our lab books.

Appendix C: Motion Detector

The Motion Detector is used to collect position, velocity and acceleration data of moving objects. Students can study a variety of motions with the Motion Detector.

This is a sample of motion data collected with Logger *Pro*® and a computer.



How the Motion Detector Works

This Motion Detector emits short bursts of ultrasonic sound waves from the gold foil of the transducer. These waves fill a cone-shaped area about 15 to 20° off the axis of the centerline of the beam. The Motion Detector then "listens" for the echo of these ultrasonic waves returning to it. The equipment measures how long it takes for the ultrasonic waves to make the trip from the Motion Detector to an object and back. Using this time and the speed of sound in air, the distance to the nearest object is determined.

Note that the Motion Detector will report the distance to the closest object that produces a sufficiently strong echo. The Motion Detector can pick up objects such as chairs and tables in the cone of ultrasound. The sensitivity of the echo detection circuitry automatically increases, in steps, every few milliseconds as the ultrasound travels out and back. This is to allow for echoes being weaker from distant objects.

Features of the Motion Detector

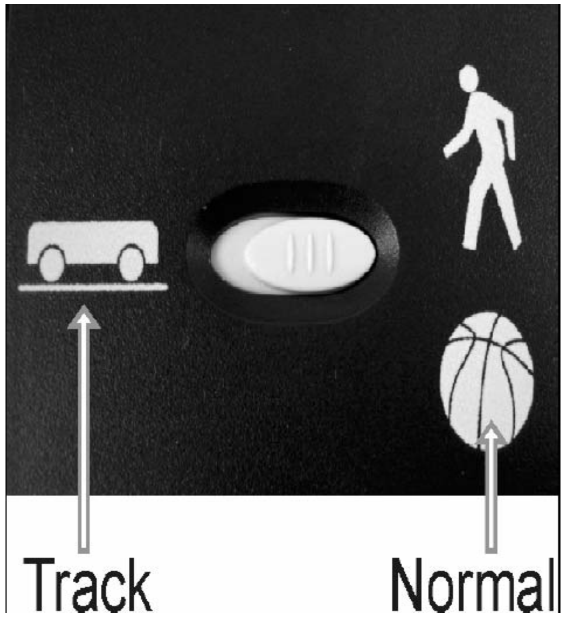
- The Motion Detector is capable of measuring objects as close as 0.15 m and as far away as 6 m. The short minimum target distance (new to this version of the Motion Detector) allows objects to get close to the detector, which reduces stray reflections.
- The Motion Detector has a pivoting head, which helps you aim the sensor accurately. For example, if you wanted to measure the motion of a small toy car on an inclined plane, you can lay the Motion Detector on its back and pivot the Motion Detector head so that it is perpendicular to the plane.
- The Motion Detector has a Sensitivity Switch, which is located under the pivoting Motion Detector head. To access it, simply rotate the detector head away from the detector body.

Connecting the Motion Detector to a LoggerPro Interface

To use the Motion Detector with LabPro, the Motion Detector is connected to the interface with the included cable. Plug the cable into the DIG/SONIC port on the right side of the Motion Detector. Plug the other end of the cable into the interface.

Using the Sensitivity Switch

Slide the Sensitivity Switch to the right to set the switch to the "normal" setting. This setting is best used for experiments such as studying the motion of a person walking back and forth in front of the Motion Detector, a ball being tossed in the air, pendulum motion, and any other motion involving relatively large distances or with objects that are poor reflectors, e.g., coffee filters. The other sensitivity setting, which we call "Track", works well when studying motion of carts on tracks like the Vernier Dynamics System, or motions in which you want to eliminate stray reflections from object near to the sensor beam.


Track
Normal

Appendix D: Voltage Probe

The Differential Voltage Probe is designed for exploring the basic principles of electricity. Use this probe to measure currents in low voltage AC and DC circuits. With a range ±6.0 V, this system is ideal for use in "battery and bulb" circuits. Use it with the Current Probe to explore Ohm's law, phase relationships in reactive components and much more. This differs from the Voltage Probe that comes with your interface in that neither clip is connected to ground. Use multiple sensors to explore series and parallel circuits. This sensor has the same characteristics as the Voltage Probe from the Vernier Current and Voltage Probe System.

Using the Voltage Probe with a Computer

1. Connect the Differential Voltage Probe to any of the analog ports on LabPro (in most cases, Channel 1 is used)
2. Start the Logger *Pro*® software on the computer.
3. You are now ready to collect data. Logger *Pro* will identify the Differential Voltage Probe and load a calibration. Click on Collect and begin collecting data.

Specifications

Differential Voltage Probe input voltage range: ± 6.0V
Max. voltage on any input: ±10 V
Input Impedance (to ground): 10 M∧
Linearity: 0.01%
Resolution (using LabPro): 3.1 mV
Supply voltage: 5 VDC
Supply current (typical): 9 mA
Output voltage range: 0 - 5 V
Transfer function : $V_o = \updownarrow 0.4 (V_+ \updownarrow V_-) + 2.5$

How the Differential Voltage Probe Works

The Differential Voltage Probe measures the potential difference between the V_+clip (red) and the V_- clip (black). The voltage probes have differential inputs. The voltage measured is with respect to the black clip and not circuit ground. This allows you to measure directly across circuit elements without the constraints of common grounding. The voltage probes can be used to measure negative potentials, as well as positive potentials. This is a nice improvement for people using one of our 0 to 5 volt interfaces. The voltage probes are designed to be used like voltmeter leads. They should be placed across a circuit element. The differential input range is ↕6 volts to +6 volts. Over-voltage protection is provided so that slightly higher voltages will not damage the sensor. You should NEVER use high voltages or household AC with these probes.

Do I Need to Calibrate the Differential Voltage Probe? "No"

You should not have to perform a new calibration when using the Differential Voltage Probe in the classroom. We have set the sensor to match our stored calibration before shipping it. You can simply use the appropriate calibration file that is stored in your data-collection program from Vernier in any of these ways: 1. If you are using the Differential Voltage Probe with a LabPro, then a calibration is automatically loaded when the Differential Voltage Probe is detected. 2. If you manually load an experiment or calibration file, choose the Current & Voltage Probe system. The calibration for the Differential Voltage Probe is the same as for the Voltage Probe in this older system.

The output of this system is linear with respect to the measurement it is making. As mentioned before, the amplifier allows you to measure positive and negative voltages on any of our interfaces. Since many lab interfaces can read voltages only in the range of 0 to 5 volts, the amplifier offsets and amplifies the incoming signal so that the output is always in the range of 0 to 5 volts. If an input is zero volts, for example, the amplifier will produce an output of 2.5 volts. The output varies from this 2.5 volt level, depending on the input. To collect data as differential current, use either the calibration supplied with your program, or calibrate the unit using known voltages. A standard, two-point calibration is done, as with any Vernier sensor. Another option to consider instead of calibrating is "zeroing" the sensor. This is done by shorting out the leads of the sensor, then choosing the Zero option in the data-collection software. This option adjusts the calibration offset but does not adjust the calibration gain.

The default calibration slopes and intercepts for these sensors are:

Potential in volts:

Slope: −2.5 V/V Intercept: 6.25 V

Appendix E: Microphone

The Microphone can be used for a variety of activities with sound waves:

- Demonstrate how the wave pattern changes when frequency and amplitude are changed
- Compare the waveforms from various musical instruments
- Have students capture the waveform of the sound of a tuning fork and model the sine wave using a function
- Measure the speed of sound by using reflected sound waves in a tube
- Demonstrate beat patterns
- Determine the period and then the frequency of a sound by measuring the time between peaks on the waveform
- Display the fast Fourier transform (FFT) of a sound

Collecting Data with the Microphone

This sensor is used with the Vernier LabPro® with a computer. Here is the general procedure to follow when using the Microphone:
1. Connect the Microphone Probe to the interface.
2. Start the data-collection software.
3. The software will identify the Microphone and load a default data-collection setup. You are now ready to collect data.

Specifications

Frequency range approximately 20 Hz to 16,000 Hz
Maximum frequency
LabQuest 10,000 Hz
LabPro, SensorDAQ, or CBL 2 5,000 Hz
Power 7.5 mA @ 5 VDC
Stored calibration Slope 1 Intercept 0 (arbitrary units)
Note: The maximum data collection rate of the interface affects the maximum frequency you can effectively sample.

How the Microphone Works

The Microphone uses an electret microphone that has a frequency response covering essentially the range of the human ear. An op-amp circuit amplifies the signal and sends it to the British Telecom connector. Actually the signal is sent to the interface on two different lines. A signal centered at 2.5 volts is on the Vin-low line and a signal centered at 0 volts is on Vin. More information about the input lines on LabPro a is available in appendix B. The best sound sources to use with the microphone are tuning forks, but you may want to investigate a human voice or a whistle, electronic keyboards, and other musical instruments. Try comparing the wave pattern for different sound sources. Try playing two sounds of nearly the same frequency to produce beat patterns. Make sure the sound level is in the correct range to produce good wave patterns. If the sound is too loud, the wave pattern will be "clipped off" at the top or bottom. Move the microphone further from the sound source, or turn down the volume of the sound.

Appendix F: The Energy Transfer Generator

Used for demonstrating the conversion of stored gravitational potential energy into electrical energy. The generator includes a 3/4 inch neodymium magnet, which spins between two 400-turn coils, and is visible inside a semi-clear, plastic housing. A plastic rod clamp is molded to the generator for attaching the housing to a rod stand. Two plug attachments, an LED (light-emitting diode) plug and 100-ohm resistor plug are included. Both the LED and resistor plug insert into the banana jack outputs on the generator's housing. Each plug contains two jacks for connecting a voltage sensor to the generator for collecting data with a computer. The LED plug allows the user to visually see the electrical effects of turning the shaft on the generator. As the student rotates the generator, the LED emits light. The resistor plug is recommended for use with sensors, so the student can measure the effects of generator rotation on power, voltage, and energy. A three-step pulley keys into the shaft on the side of the housing and is removable.

Basic Setup

Note: The basic setup uses a pulley and hanging mass. If you have purchased accessories for the ET-Generator, see "Attaching Accessories to the Generator" on pages 6-9 of this manual.

Attaching a Pulley with Hanging Mass to the ET-Generator

1. Use the rod clamp on the side of the ET-Generator to mount the generator to a rod stand.

2. Insert the LED plug into the jacks on the generator (Figure 1a).

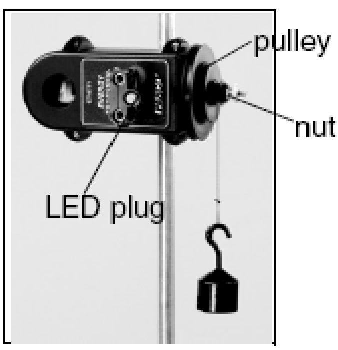


Figure 1a: Mounting the Generator to a rod stand

3. To attach the pulley, align the indent marks on the pulley with the indented portion of the black shaft on the generator; then slide the pulley onto the shaft. Fasten the nut tight over the screw to hold the pulley in place.

4. Cut a small piece of no-bounce foam, and place the foam underneath the hanging mass (Figure 1b).

5. Cut a piece of string to tie to the hanging

mass and pulley (Figure 1b).

6. Tie a double knot in the string and hook

the knot in the slot on the pulley.

Collecting Data with the ET-Generator

Note: For real-time data collection, a computer interface is required.

1. Insert the resistor plug into the jacks on the generator. **Note:** For electrical studies, use the resistor plug and a Voltage Probe.

2. Connect a Voltage Probe to the LabPro interface

3. With the Voltage Probe, connect the black banana plug to the black jack and red banana plug to the red jack on the ET-Generator.

4. Setup your experiment in LoggerPro.

5. In LoggerPro, click the **Start** button. Let the mass fall, and record the power or other measurement.

Attaching the ET-Hydro Accessory (ET-8772) to the ET-Generator

1. Attach the ET-Hydro Accessory housing to the molded case of the ET-Generator using the two captured screws and the supplied screwdriver (Figures 6-7)

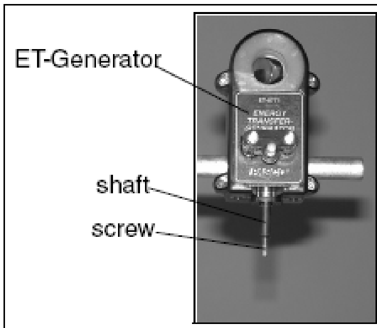


Figure 6: Shaft on ET-Generator

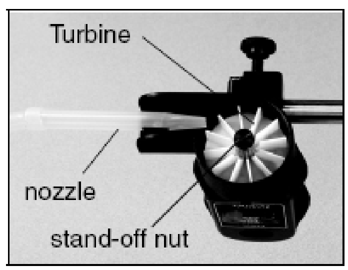


Figure 7a:
Turbine in Housing

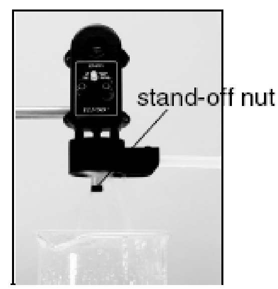


Figure 7b:
Hydro Housing
on Generator

2. Attach the turbine blade and tighten the standoff nut over the shaft screw. Keep your fingers in the recess of the housing and hold the shaft to keep the turbine from spinning (Figure 7a).

3. Insert the pointed end of a plastic nozzle into the spring clip underneath the housing (Figure 7a). **Note:** The clip is spring-loaded and can turn to adjust where the water stream hits the turbine. To increase the water flow, cut (trim) the nozzle end.

4. Connect the nozzle to a piece of tubing connected to an external water supply. **Note:** Have a beaker or container below the housing to collect water exiting the turbine.

5. Run the water supply through the nozzle of the turbine and watch the turbine spin. **Note:** To collect data, insert the 100-ohm resistor plug into the banana jacks, connect banana plugs from a Voltage Probe into the resistor plug, and click the **Start** button in LoggerPro. when water is running through.

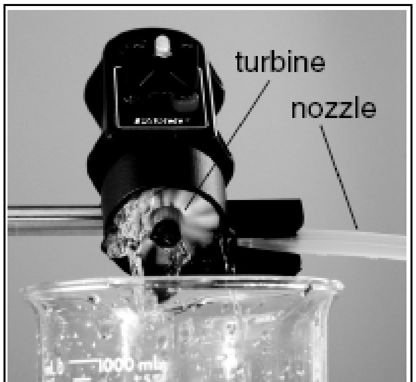
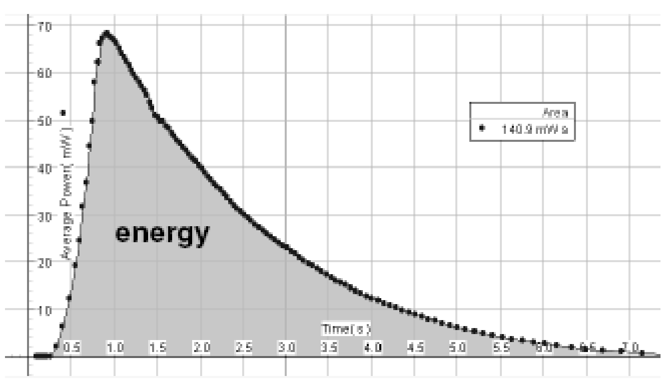


Figure 8: Nozzle Clipped in Turbine Housing

Sample Results

a) This graph is of average power, and for each turn of the magnet, it shows the average power generated for that small time. The area under the curve is energy (notice almost the same value as the energy for instantaneous power) but should be easier to comprehend for the beginner.

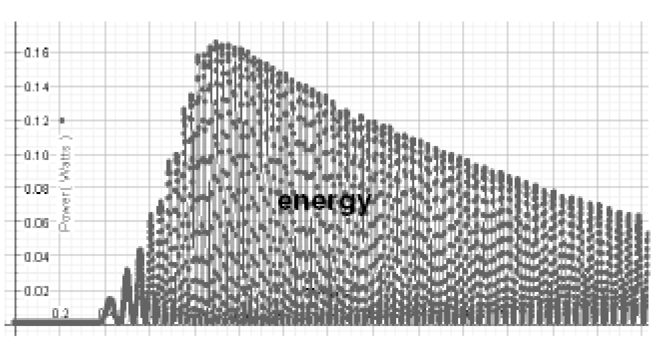
Sample Data: Average Power (mW) Per Second



Note: This graph is recommended for beginning physics students.

b) The graph below is the actual instantaneous power, and the area under the curve is energy. For beginning students, this graph would be hard to understand. They might ask, why is it going up and down?

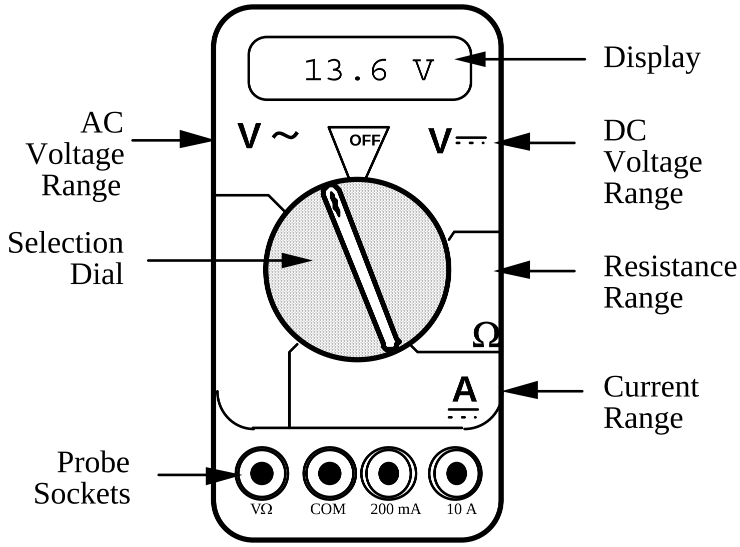
Sample Data: Instantaneous Power (Watts) Per Second



Note: This graph is recommended for advanced physics students.

Appendix I – The Digital Multimeter (DMM)

The digital multimeter is a piece of equipment that can be used to measure a number of electrical quantities, most often current, resistance, and potential. The DMMs that you will be using are capable of measuring both direct current (DC) and alternating current (AC) circuits. Be careful about knowing which type of measurement you need to make, then set your DMM accordingly. The layout of some DMMs might be slightly different from the one pictured to the right.

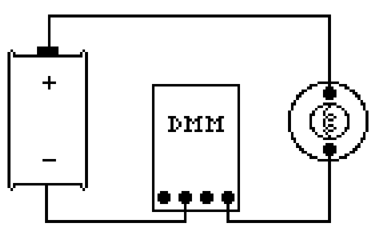


The DMM can measure currents from 10 amps to one microamp (10^{-6} amps). This versatility makes the DMM fragile, since measuring a large current while the DMM is prepared to measure a small one will certainly harm the DMM. For instance, measuring a 1-ampere current while the DMM is on the 2-milliamp scale will blow a fuse. If this happens, the TA may be able to change the fuse. However, if you damage the DMM beyond repair, you will have to finish the lab without it.

Measuring Current:

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

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



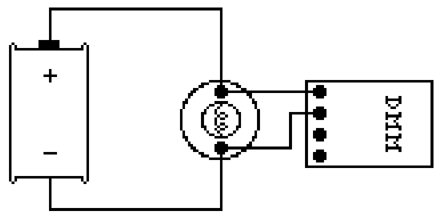
To measure current, the DMM must be placed in the circuit so that all the current you want to measure goes **through** the DMM.

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

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

Measuring Voltage:

1. Set the DMM selection dial to read DC volts. Insert one wire into the socket labeled 'V?' and a second wire into the socket labeled 'COM'.
2. Set the selection dial of the DMM to the highest voltage measurement setting. Connect the two wires from the DMM to the two points between which you want to measure the voltage, as shown below.



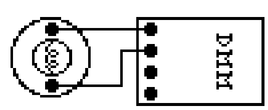
   To measure voltage, the DMM must be placed in a circuit so that the potential difference across the circuit element you want to measure is across the DMM.

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

Measuring Resistance:

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

1. Set the DMM selection dial to measure ohms (Ω). Insert one wire into the socket labeled 'VΩ' and a second wire into the socket labeled 'COM'.
2. Make sure that the circuit element whose resistance you wish to measure is free of any currents.
3. Attach the wires across the circuit element, as shown in the example below:



4. If no number appears, try a different scale. Use a method that covers all the scales, such as beginning at the largest scale (20 MΩ) and working your way down.

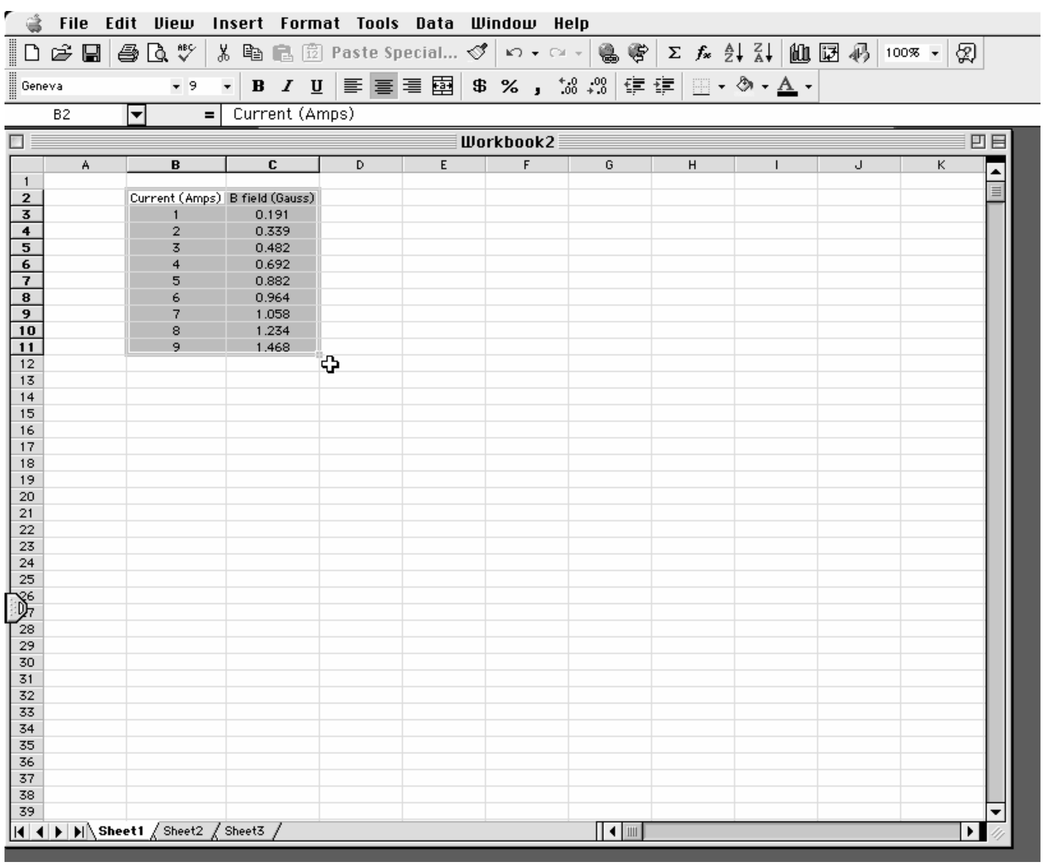
Appendix II – Graphing with Microsoft Excel

You will find that numerous exercises in this manual will require graphs. Microsoft Excel is a spreadsheet program that can create fourteen types of graphs, each of which have from two to ten different formats. This results in a maze of possibilities. There are help screens in Excel; however, this overview is covers the type of graph you should include in your lab reports. This is meant to be a brief introduction to the use of Microsoft Excel for graphing scientific data. If you are acquainted with Excel already, you should still skim through this appendix to learn about the type of graph to include in reports.

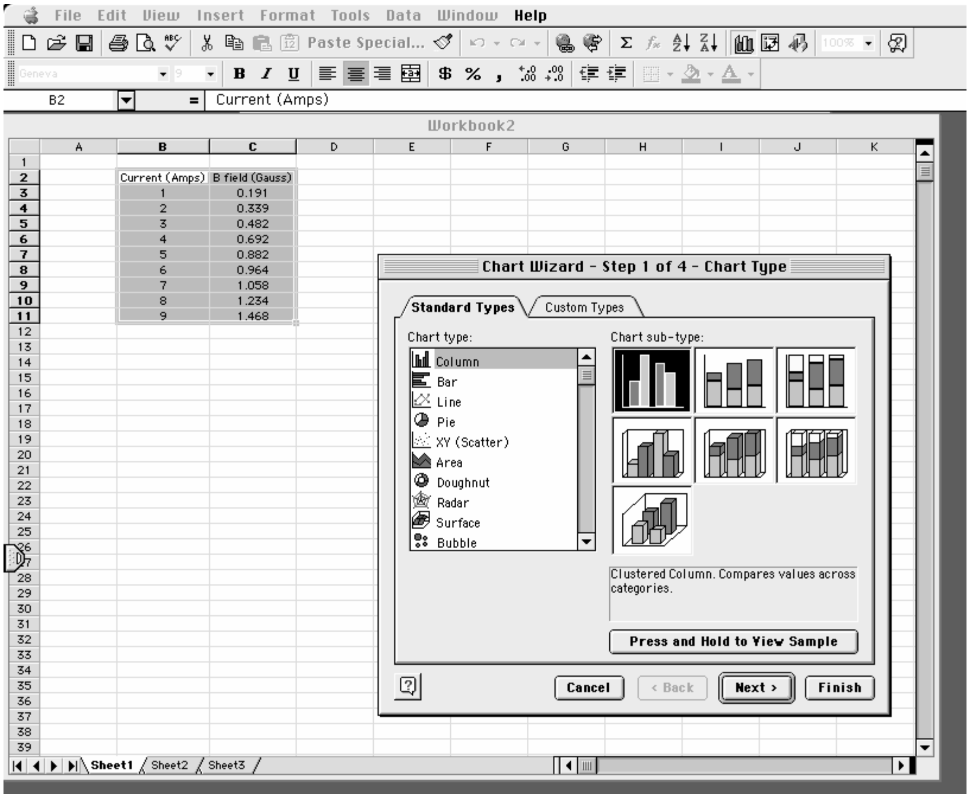
Microsoft Excel is available to all students on the computers in the University labs:

East Bank:	Eddy Hall Annex 54 Elliott Hall 121 Folwell Hall 14 Walter Library 103
West Bank:	HHH Center 50
St. Paul:	Classroom Office Building 135 Classroom Office Building 17 Magrath Library B50 McNeal Hall 305

Step 1. Input your measurements and highlight the data using your cursor.

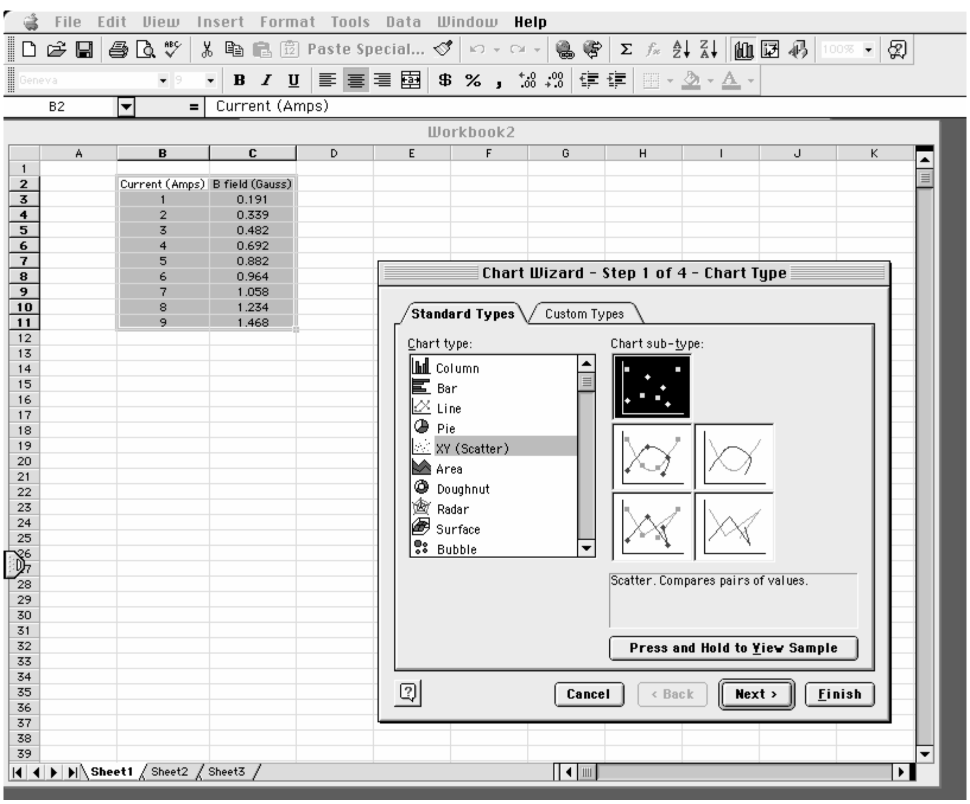


Step 2. Click on the “Chart Wizard” on the toolbar.



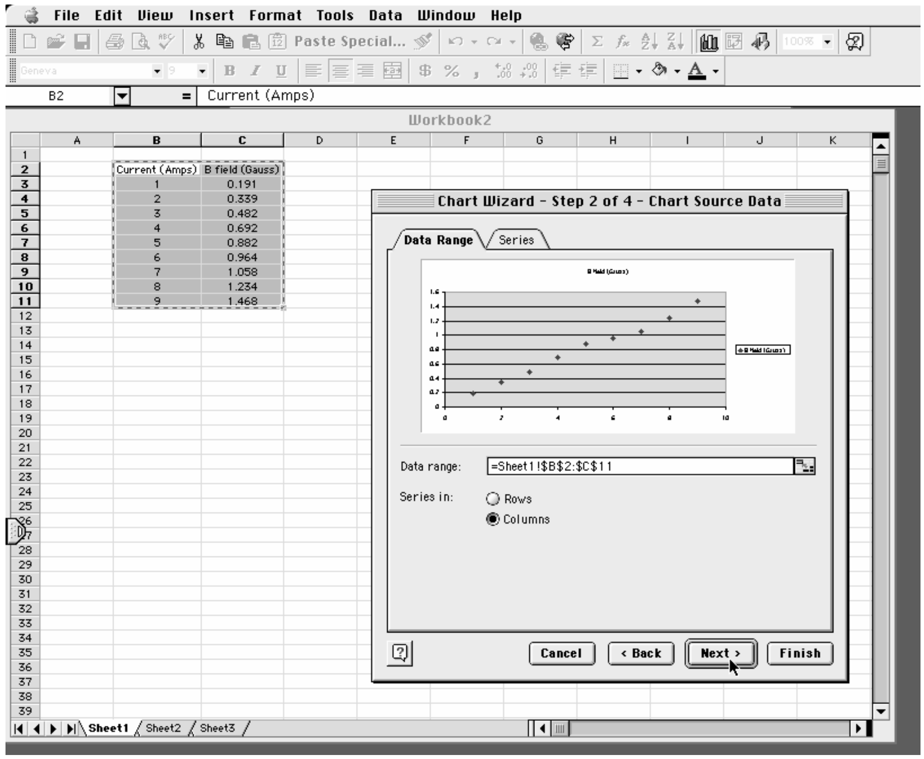
Step 3.

Choose XY Scatter, not Line, from the list and click the “Next” button.

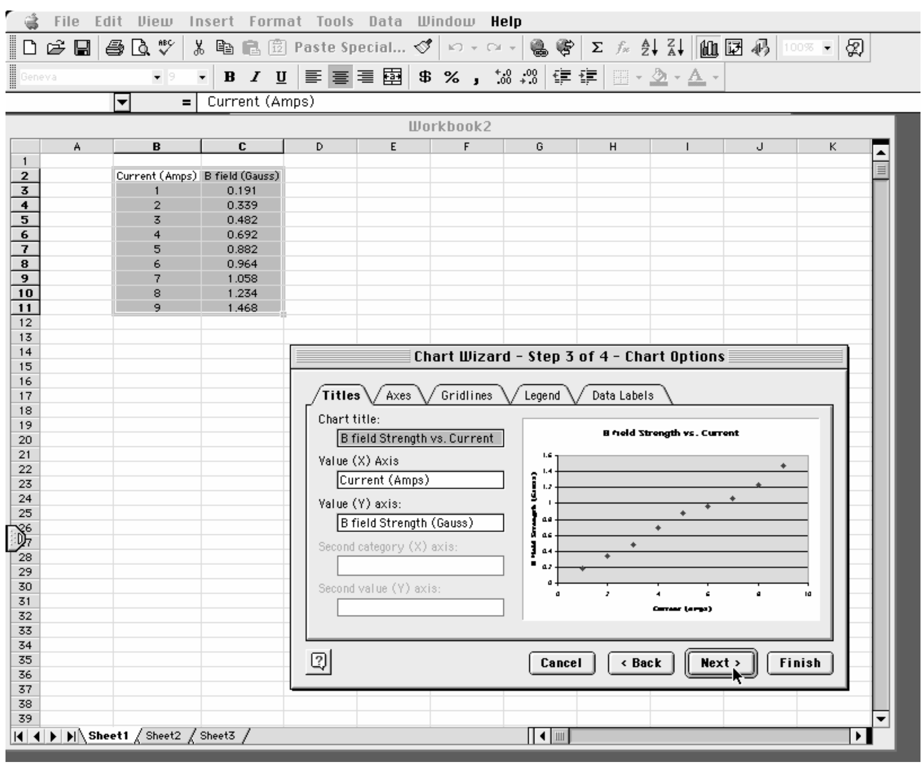


Step 4.
Select the

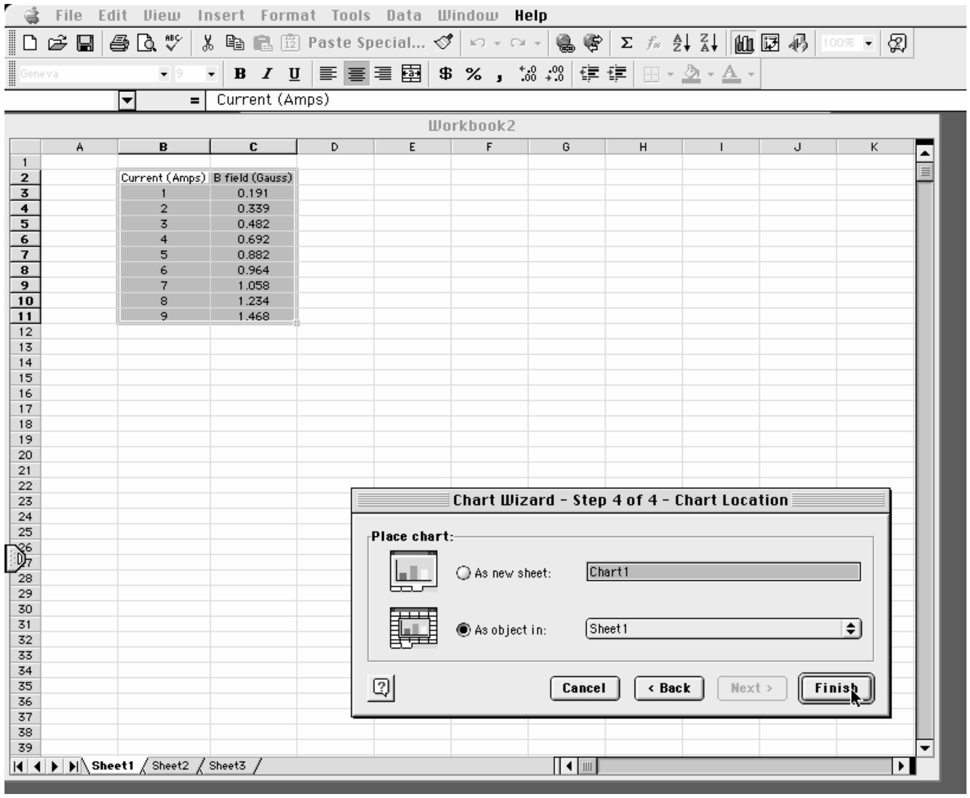
“Series in: Columns” option and click the “Next” button.



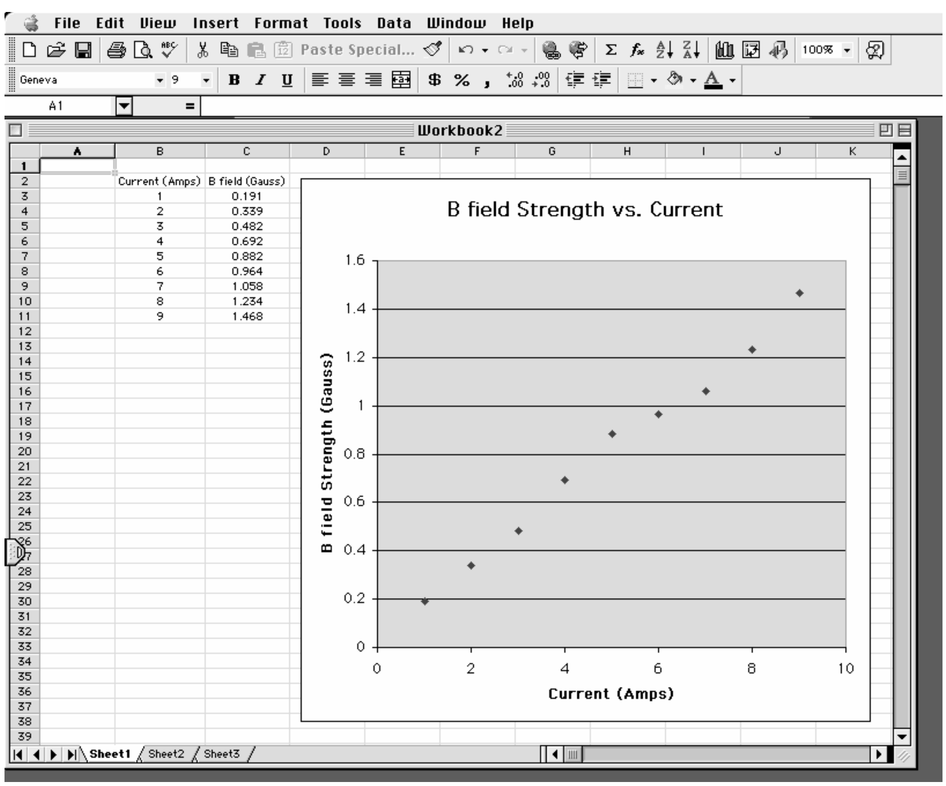
Step 5. Fill in the chart title and axis labels, and click the “Next” button.



Step 6. Click the “Finish” button.

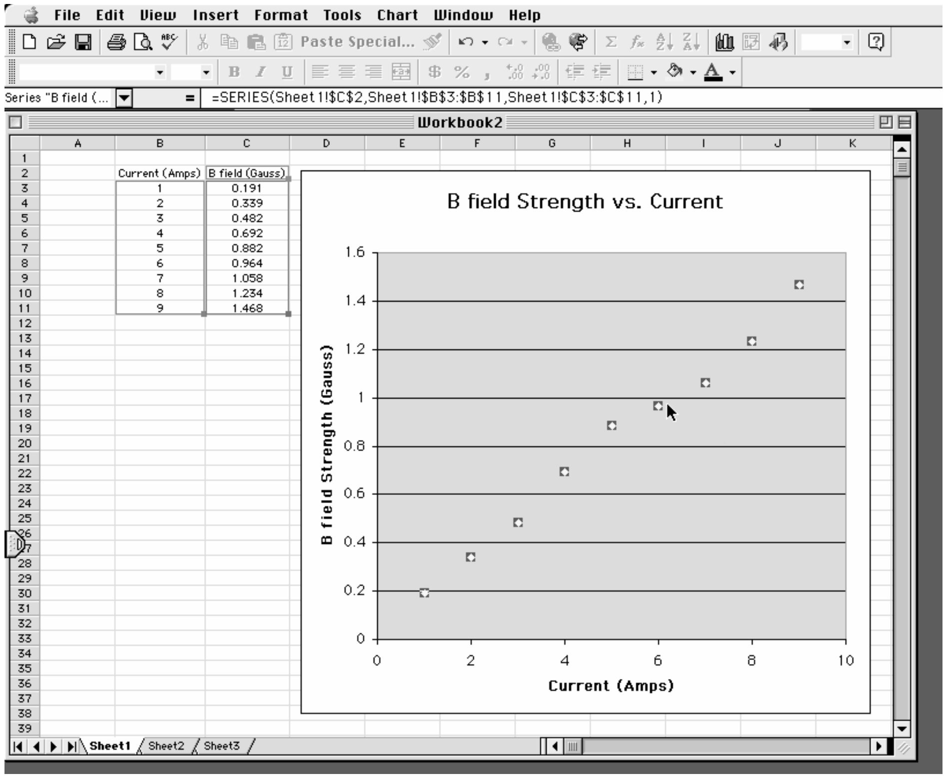


Step 7. Your graph will appear on the worksheet.

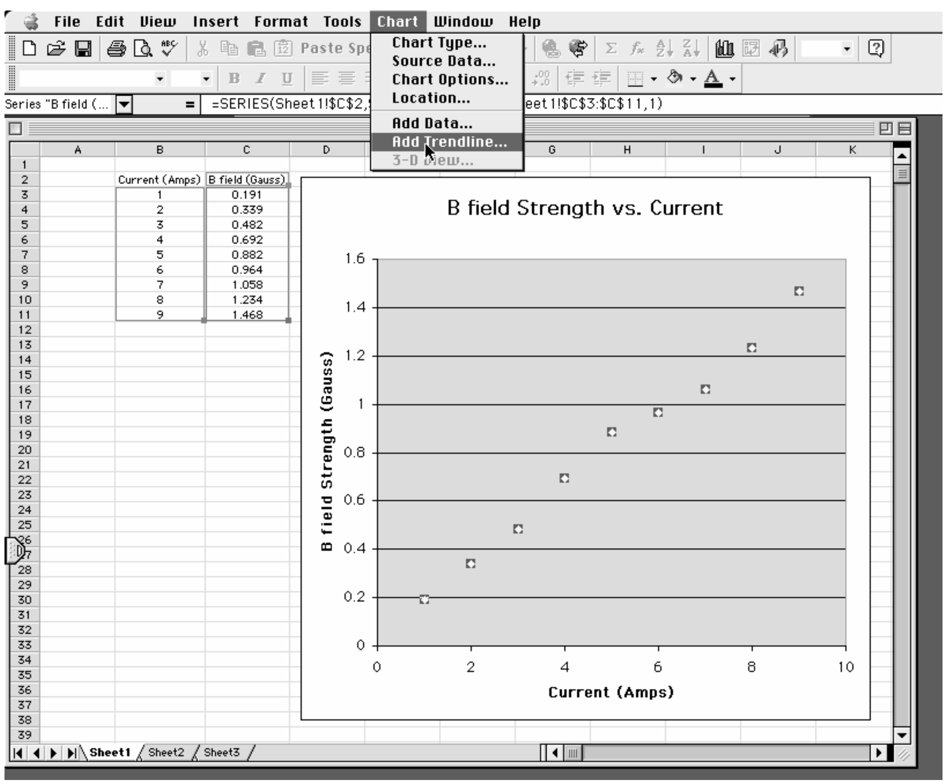


Step 8. Click on the data points to highlight

them.

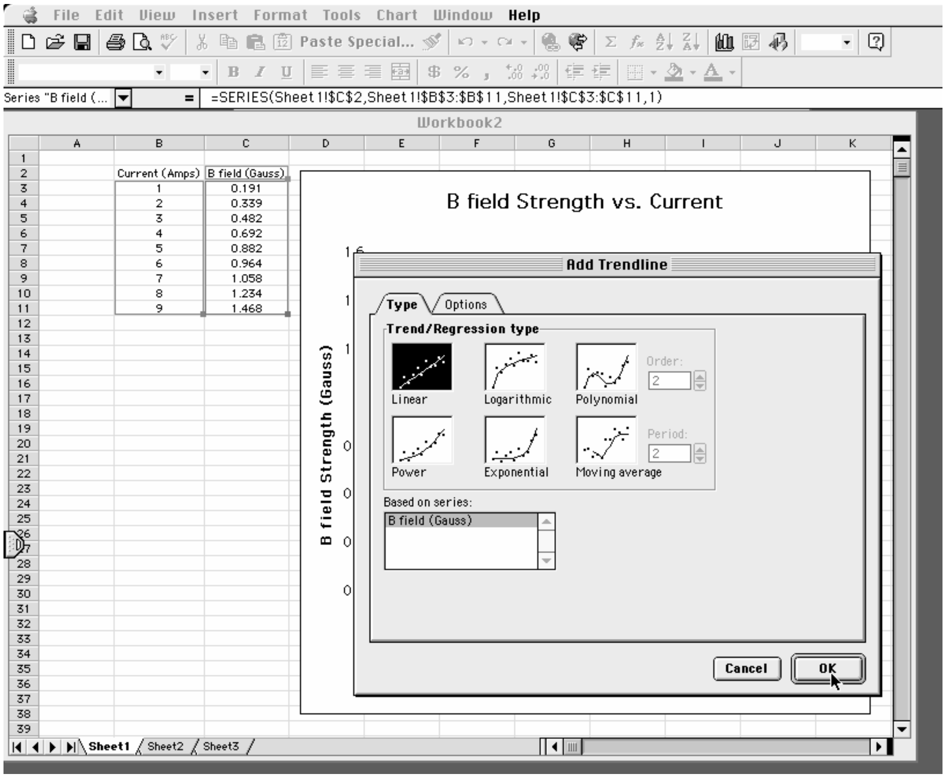


Step 9. Select "Add a Trendline" from the "Chart" menu.

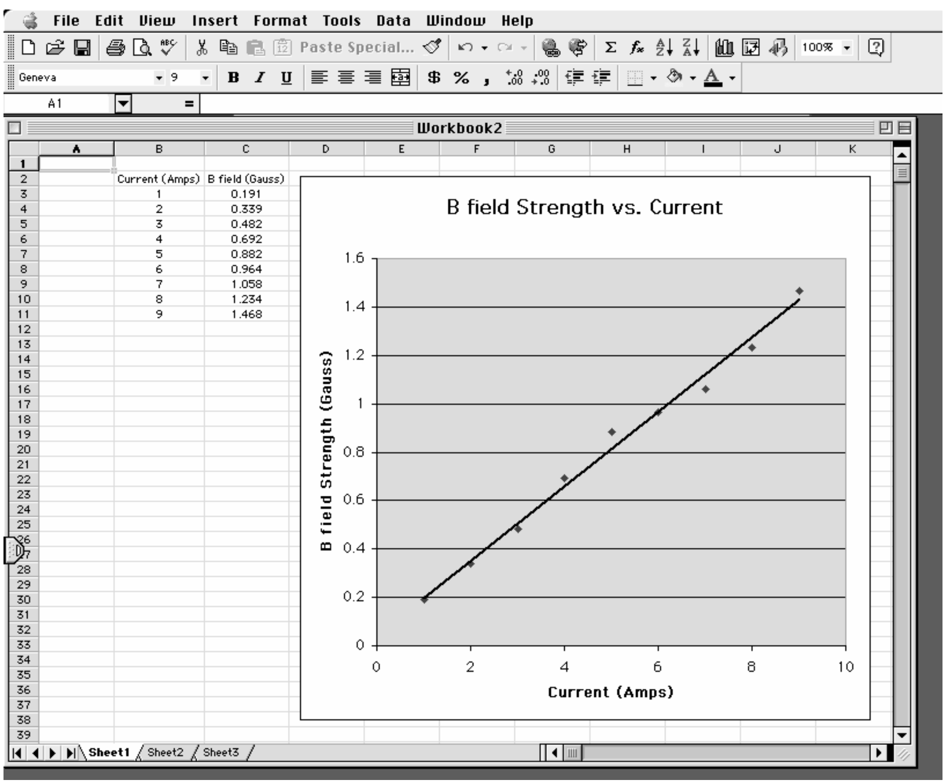


Step 10. Choose the best

type of trend line for your data.



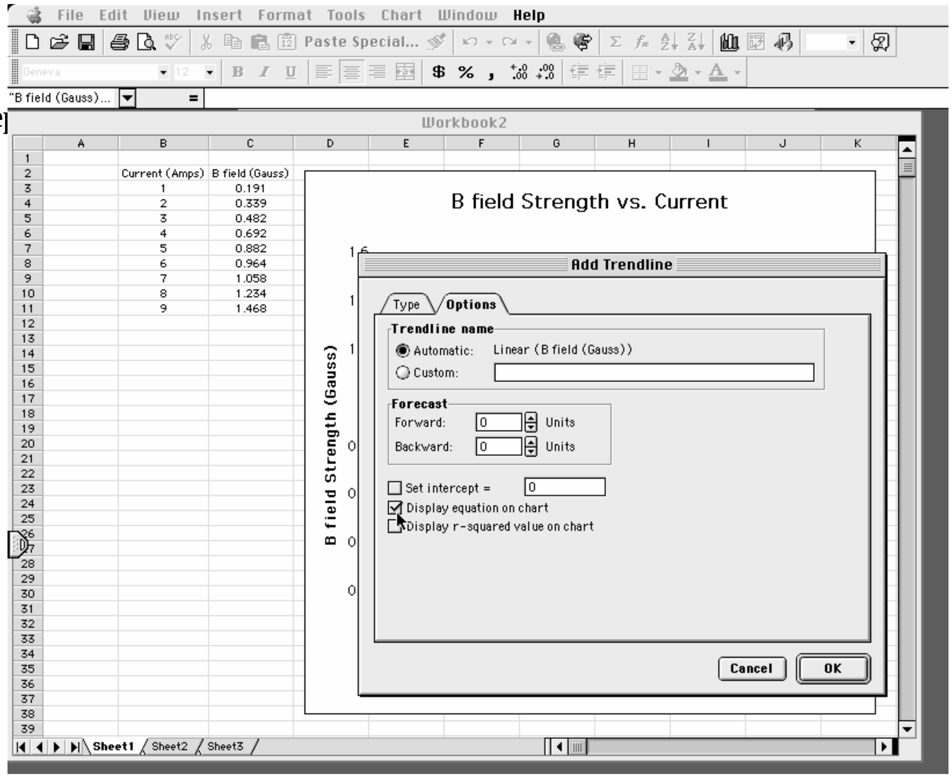
Step 11. The trend line will appear – is it a good fit to your data?

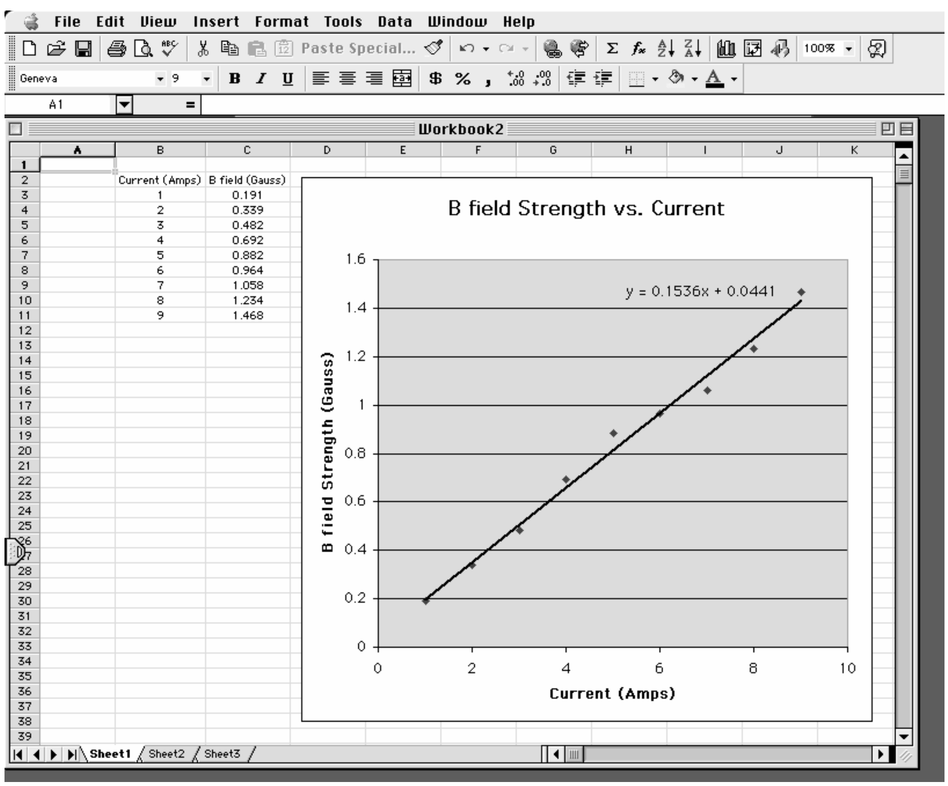


Step 12. If the equation of the line is

needed, choose "Display equation on chart."

Ste

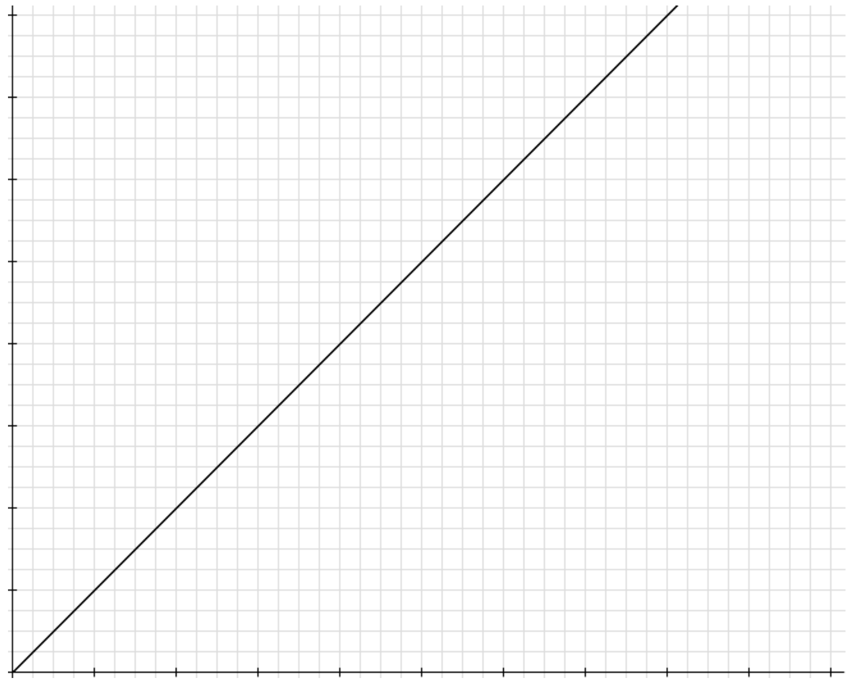




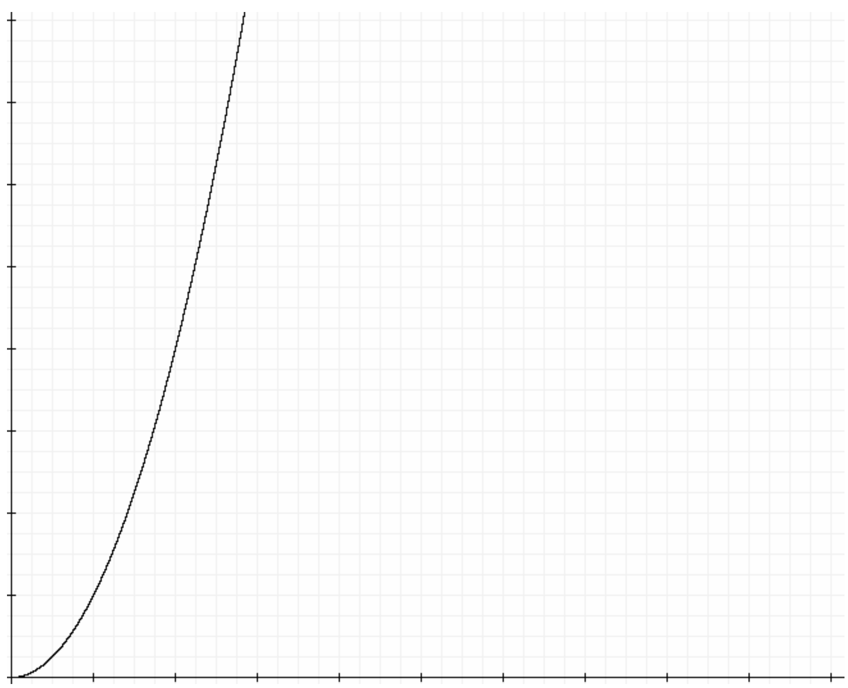
Appendix III – Graphed Proportions

You will find that numerous exercises in this lab manual will require you to determine the relationship between two variables. This section includes graphs of common proportions that you may encounter in these exercises.

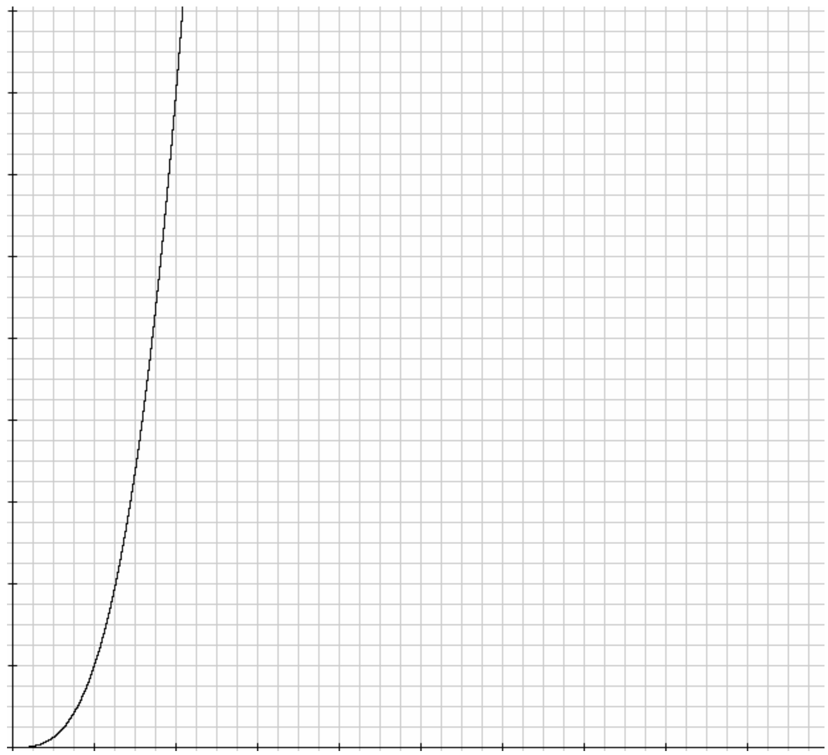
y α x (x and y are directly proportional)



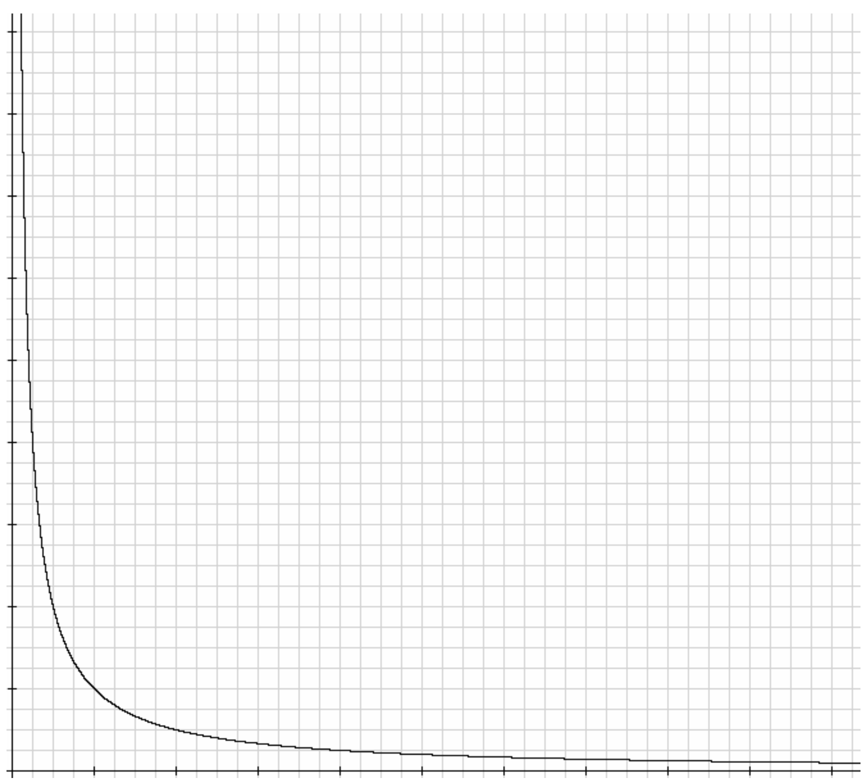
y α x^2 (y is proportional to x squared)



$y \propto x^3$ (y is proportional to x cubed)

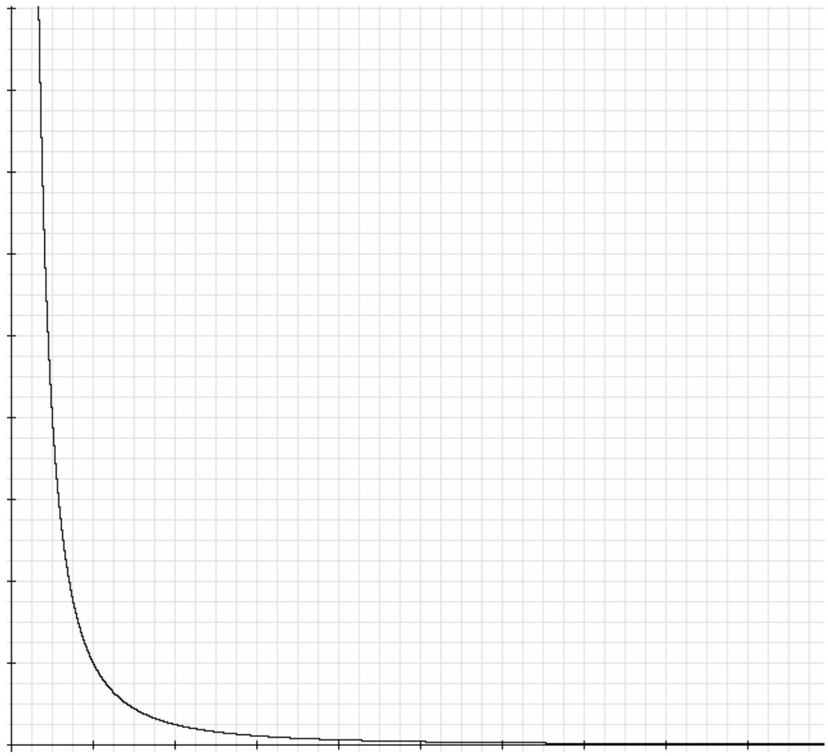


$y \propto \frac{1}{x}$ (x and y are inversely proportional)



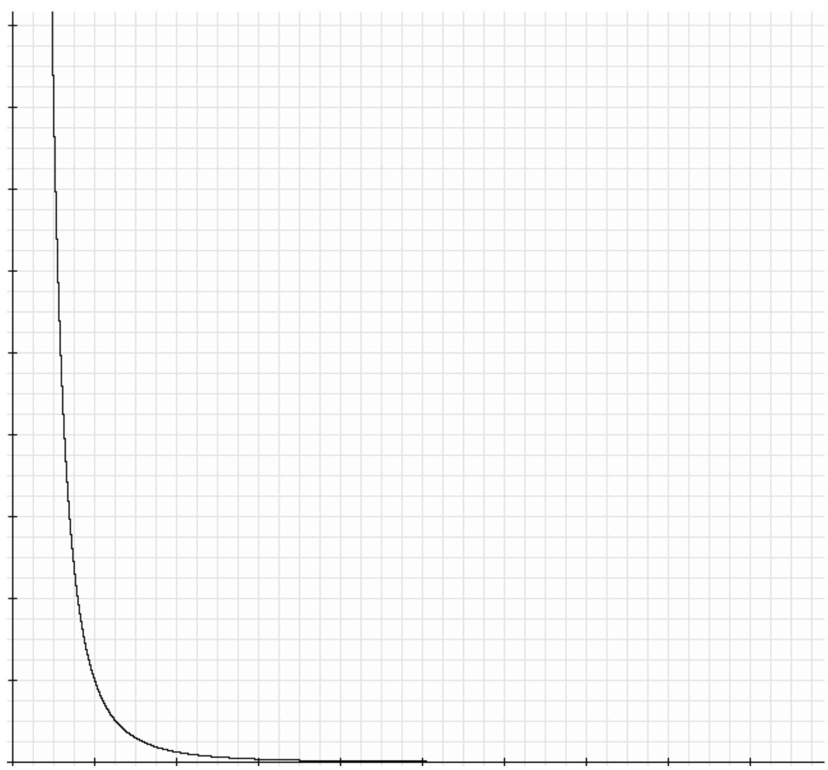
$y \propto \frac{1}{x^2}$ **(y is**

inversely proportional to x squared)



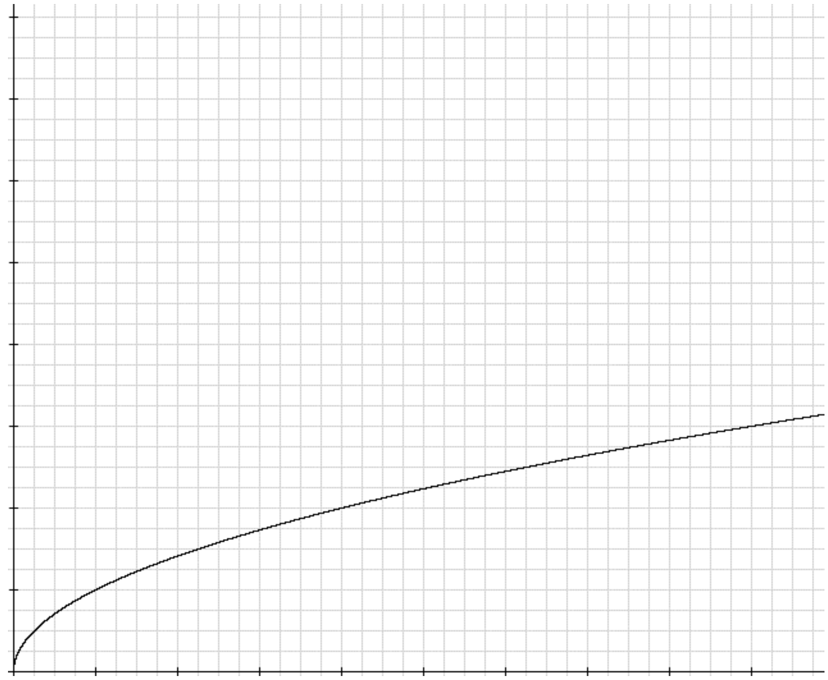
y α $\frac{1}{x^3}$ **(y is**

inversely proportional to x cubed)



y α $\sqrt{x}$ **(y is**

proportional to the square root of x)



$y \propto \frac{1}{\sqrt{x}}$ (y is inversely proportional to the square root of x)