Introduction: Experimental Techniques

The Scientific Method

What is science? How does it differ from the other ways we learn the things we believe? Unlike religious dogma or our parent's opinions regarding the "best" political party or pickup truck, science deals only with those things that can be measured.

Scientists employ an efficient and systematic approach called the *scientific method*. The scientific method can be summarized in five basic steps:

1. Observations or controlled measurements are made of some aspect of the phenomenon.

2. A hypothesis is formed on the basis of the observations or measurements.

3. A prediction regarding some unobserved aspect of the phenomenon is made on the basis of the hypothesis.

4. The prediction is tested experimentally. If the prediction fails the experimental test, the hypothesis is modified or a new hypothesis formed, and the process is repeated.

5. The results are published so that other scientists can test them.

All of us occasionally use the scientific method. Suppose you come home from classes and flip the light switch on the back porch. The light doesn't come on. You form a hypothesis that the electricity is off. If your hypothesis is true, then the digital clock on the kitchen range should be out, too. You check and see that it is on. Therefore, your original hypothesis is incorrect. You hypothesize that the bulb is burned out. You remove the bulb and check it with an ohmmeter, and it shows infinite resistance. Your second hypothesis was supported by experiment.

The Fundamental Axiom of Science

A keystone of the scientific approach is the assumption that the universe is "orderly," and that the same basic rules govern natural processes everywhere. For example, astronomers assume that the principles governing gravity and electromagnetism are independent of space and time. This may seem like a big assumption, but it really underlies all human activity. Every time you take some medicine, you are working on the assumption that the rules of biochemistry have not changed. Every time you get on an airplane, you are gambling that the principles of aerodynamics still hold. Without the assumption of an orderly universe, the results of any study would only apply to the very specific time and place when and where the study was conducted.

Formulating Scientific Hypotheses

A hypothesis is an educated guess generated to explain a given phenomenon. Consider these hypotheses:

- Gravity causes objects to fall at the same acceleration regardless of their mass.

- White light is a mixture of multiple colors.
- Babies are delivered by a stork.

These are all *testable* hypotheses. In other words, one can think of observations and/or experiments that would provide evidence to support or refute the hypothesis.

In contrast, the hypothesis “Glenn Miller's music was better than any of this crap they play today.” is not testable, since there is no universally accepted standard to determine what is “better” in music.

The creation vs. evolution debate is a perfect example of misunderstanding of what constitutes science. It is certainly possible that the Biblical account of the origin of life is literally true. However, it is untestable by scientific methods. On the other hand, evolution by natural selection is a process that is observable, and many observations have been made that support it. It is in the realm of science. Questions about the meaning of life, the existence of God, and the number of angels that can dance on the head of a pin, cannot be answered scientifically. They are in the realm of philosophy and religion.

A scientific hypothesis with *universal* application (i.e., “All groundhogs hibernate in the winter.”) can never be absolutely proved (*verified*) because we can’t watch every one of them. Even if we could watch all the ones living now, we couldn’t watch all the ones in the past or future. However, finding just one active groundhog in January would disprove (*falsify)* this hypothesis. An *existential* hypothesis (i.e. "Some extraterrestrial planets support life.") can be verified with an example. It can't be falsified by example, however, because its negative is a universal statement ("No extraterrestrial planets support life.")

What is A Theory?

The scientific use of the word "theory" is very different from its common use meaning an opinion (i.e. "Joe has a theory about why the Royals lost their last 20 games.”). A scientific theory refers to a hypothesis based upon observation or measurement. Examples include atomic theory (matter is composed of atoms) and gravitational theory (objects attract each other with a force that varies directly with the product of their masses and inversely with the square of their distance apart). An accepted theory has withstood years of rigorous scientific testing. Scientists are actually more likely to be wrong about a "fact" than about a theory. For example, it is far more likely that a measurement is in error (a pressure gauge may malfunction) than for a well-established theory (air pressure is directly proportional to the number of air molecules in a given volume provided temperature is constant) to be overturned.

Science depends not only on the forming and testing of hypotheses, but also on the accurate reporting of results. New scientific research builds on work done in the past. Whenever scientists report their results, they must include a detailed description of how they carried out the study. This information allows anyone else—either now or 100 years in the future—to examine, and if they wish, repeat the study to see if they get the same results. Peer review of research is all-important. Thus, in contrast to the stereotype of the scientist working alone in the laboratory, scientific advancements involve the interconnected work of many people.

Exercise – Testable Hypotheses

Read the following statements. Circle "yes" if the statement is a sound scientific hypothesis or "no" if the statement is not a sound scientific hypothesis (whether or not you think it is *true*). Explain your answer.

The cuckoo is a pretty bird.	YES	NO
I will learn a lot in this class.	YES	NO
My mother-in-law weighs a ton	YES	NO
John Elway was the greatest quarterback ever.	YES	NO
The boiling point of water is lower at higher altitude.	YES	NO
Aspirin reduces the risk of heart attacks.	YES	NO
Gremlins are responsible for traffic accidents.	YES	NO

Testing Scientific Hypotheses

Scientists test hypotheses in various ways. One way, an *observational study***,** requires us to study a phenomenon in its "natural" environment. Another, the *experimental study***,** allows us to manipulate the environment. Physicists usually use experimental studies while astronomers – of necessity -- usually use observational studies.

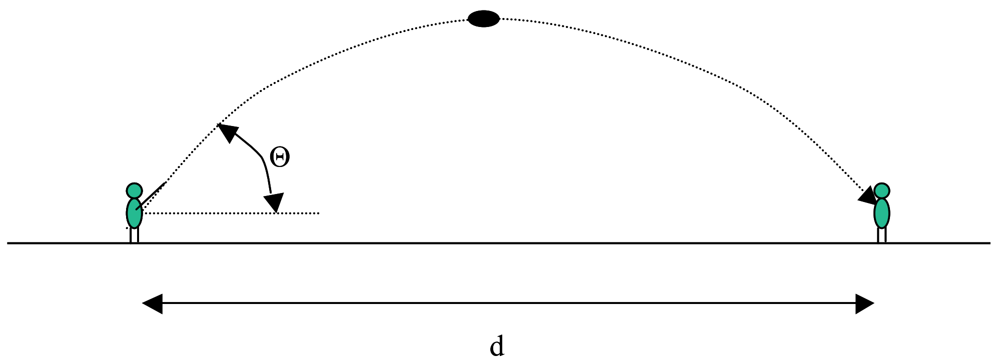
The advantage of the experimental study is that one can control the situation more precisely, which makes results easier to interpret. But, since this is an artificial environment the results sometimes have limited applicability in the "real world." More than one medicine that has killed a virus in a test tube has proven ineffective or dangerous when given to people.

As stated before, we test hypotheses every day, but this testing is usually not as orderly and planned out as testing of scientific hypotheses. Many scientific experiments and observational studies are designed to test how one variable affects another variable. When scientists design an experiment or an observational study, they must pay attention to these factors:

- *Independent variables*
- *Dependent variables*
- *Constants*
- *Confounding variables, artifacts, and bias*
- *Replication*
- *Randomization*
- *Control experiments*

Variables are things that vary within the experiment, like distance, time, force, voltage, etc. The term *independent variable* refers to a quantity controlled or chosen by the scientist. The *dependent variable* changes in response to the independent variable. A well-designed experiment will have only one independent variable. If more than one independent variable is allowed, we have no way of knowing which one produced the observed effect.

For example, let's say we wanted to know the optimum angle Θ to throw a football so that it travels furthest down the field to a receiver (and let's assume the quarterback throws it at the same release speed for any angle).



Here the independent variable is the angle Θ, which could vary from 0 to 90˚. The dependent variable—in this case d—will change as we manipulate values for the independent variable (in the above experiment, other dependent variables could include the time of travel or maximum height of the ball). So, we would throw the football at varying angles Θ, say 10°, 20°, 30°...90˚, and measure the d for each Θ.

Anything kept the same in the experiment we call a *constant*. To really know the effect of the release angle, Θ, on distance traveled, we would have to keep everything constant: speed of throw, wind speed and direction, type of football, amount of spin the football has, etc. If any of these conditions varied while we were varying Θ, then we wouldn't know if the resulting changes in distance were due to Θ or to that other *confounding variable* (also called simply, a "*confound*") When a confounding variable causes an effect on the experiment, we call that effect an *artifact*. Confounding variables are often troublesome and are usually the main hindrance to getting meaningful results. Remember the big news when some scientists "discovered" cold fusion? They were measuring an artifact and didn't know it. But if we know a variable is confounding our experiment, then we can try to account for it. Since we can never account for all confounds in an experiment, we use three techniques to try to eliminate their effects: *replication, randomization, and controls*.

Replication is a way of double-checking an individual result. Let's say that when we threw the football at 90˚(straight up) a huge gust of wind above us carried the football 100 yards down the field. You would probably not believe it, and throw it again to check. Since we never know all the confounds, we generally always replicate trials. Normally, a minimum of 3 to 5 trials is advisable.

Randomization prevents "order effects." Now let's say the quarterback got more and more tired as he kept throwing, and ball speed dropped steadily throughout the day. If the throws were in the order Θ = 0, 10, 20, 30, 40, 50, 60, 70, 80, 90˚, then the ball would travel less far than it should for all those higher angles. One thing to help prevent this artifact is to randomize the order: 40, 80, 0, 30, 10, 70, 50, 20... Then on top of this we replicate it, but in a different random order: 50, 20, 40, 70... The confounding variable of fatigue is still there and will increase the random error in the results, but at least it won't *bias* the results since the effect is spread out instead of concentrated at one end or the other.

A *control* is a special subset of the experiment, identical to the rest, but with one of the constants set at a different value. In this football example we might repeat the experiment with a different thrower throwing at a different speed.

Reporting Results

Professional scientists report their results to the scientific community in a more or less standard format. For example, scientists commonly record data or results in tables or graphs as a means of summarizing a large amount of information.

Tables

Tables are usually a rearranged form of the original data. A table always has a title, and appropriately labeled rows and columns. Below are some hypothetical data from the football throwing experiment. A good table is clear in its presentation, and shows units for each column. The "Average" is one common example of *data reduction*, where the data is condensed to a more usable form. Averaging the data helps eliminate "noise"—random variations in the measurements. However it won't necessarily eliminate the effects of confounds (artifacts and bias).

Table 1: Distance of football throw as a function of throw angle, 3 trials and averages.

	Distance Traveled (meters)			
theta (deg)	trial 1	trial 2	trial 3	Average
0	7.0	9.0	5.0	7.0
10	12.0	20.0	22.0	18.0
20	39.0	37.0	22.0	32.7
30	51.0	45.0	36.0	44.0
40	39.0	51.0	59.0	49.7
50	49.0	48.0	44.0	47.0
60	32.0	33.0	45.0	36.7
70	24.0	33.0	24.0	27.0
80	10.0	18.0	19.0	15.7
90	-3.0	-5.0	5.0	-1.0

Graphs

Graphs are another way of displaying data, and communicate trends better than tables. Here are the rules for a good graph:

- Always plot the independent variable (the one you manipulate) on the horizontal or x-axis, and the dependent variable (the effect you measure) on the vertical or y-axis. This arrangement is referred to as “y *versus* x.”

- Give each figure a descriptive title, centered over the figure.

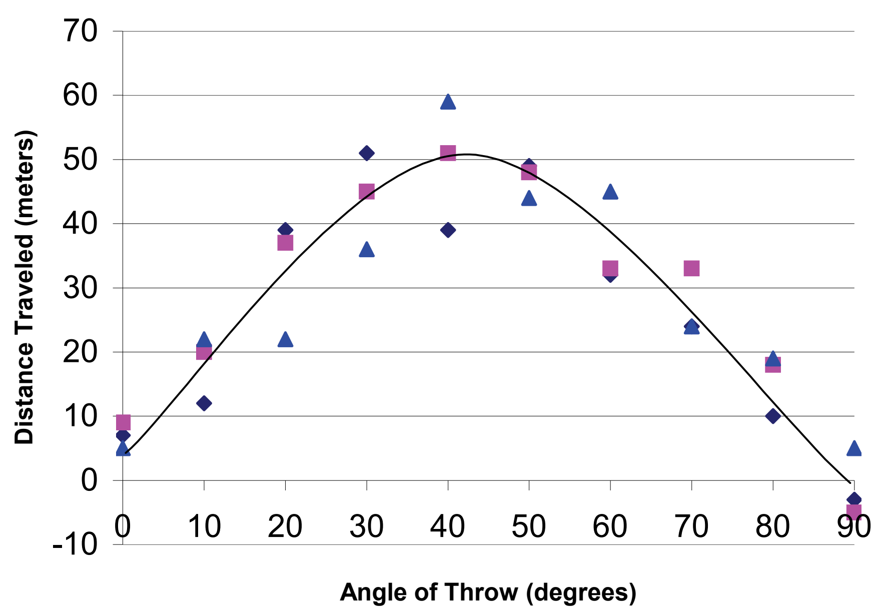
- The x and y axes should have descriptive labels (e.g., "Distance") and units (e.g., "meters").

- Spread the data across most/all of the available graph area (not crammed into 1 corner)

- Plot the raw data (or the averages with *error bars* showing the variation) and draw a *simple, smooth curve* through the points. This curve need not pass through all the points themselves (and might not pass through *any* of them); rather, it should capture the *trend* of the data.

In Figure 1, below, the raw data is shown and a curve is drawn through to best represent the trend. Notice the curve doesn't necessarily go through any particular data point and that it isn't overly complex— straight lines or simple curves like parabolas are predictive of most phenomena, so it is best not to over-interpret the shape. Showing the raw data points allows the reader to see how consistent the data is—i.e., how much random error is occurring and thus how confident we can be in the results. In this case there is quite a bit of random error: see Figure 2 for the line-plots of each individual trial. Figure 2 also shows why it is good to take more than one reading, and why we wouldn't want to draw the lines through each individual data point.

Figure 1: Distance of Football Throw at Varying Throw Angles



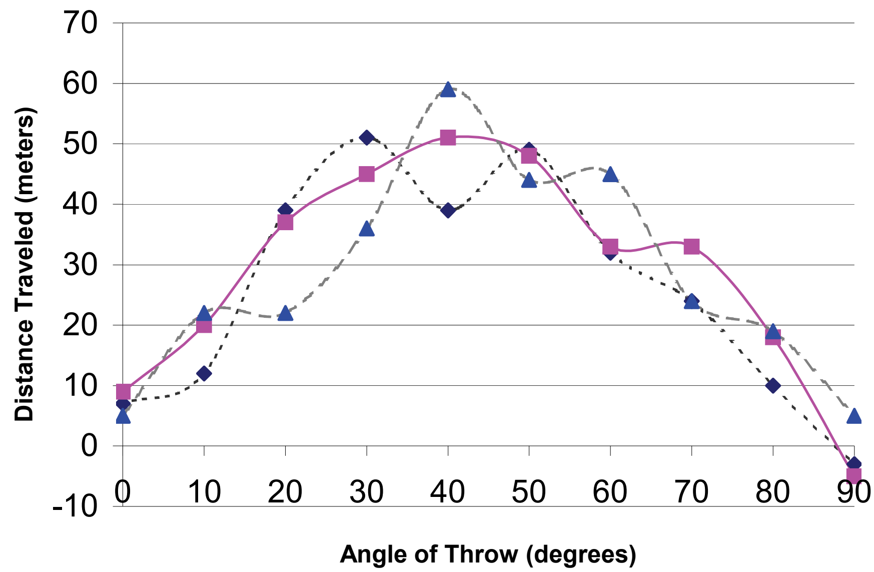
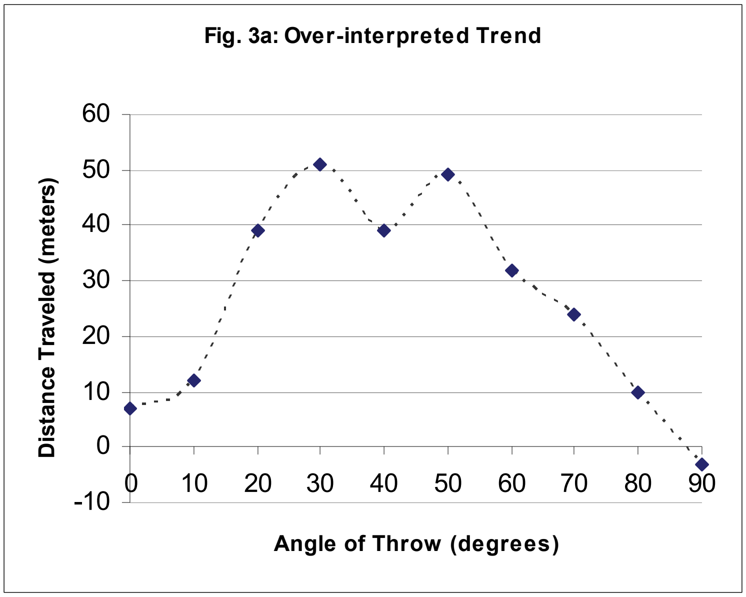


Figure 2: Distance of Football Throw at Varying Throw Angles, by individual trials

Because in this lab we won't always have time to replicate every data point, remember the following:

- Most physical phenomena are best described by straight lines or simple curves.
- All of our measurements are going to have error in them -- hopefully small and random but potentially large and biasing.
- Because of inevitable errors, we wouldn't want to rely on each individual data point for the shape of the curve.

Thus, if we only have 1 trial to work with, we should use a shape that captures the trend but doesn't over-interpret. For examples see Figures 3a (over-interpreted) and 3b (appropriate).



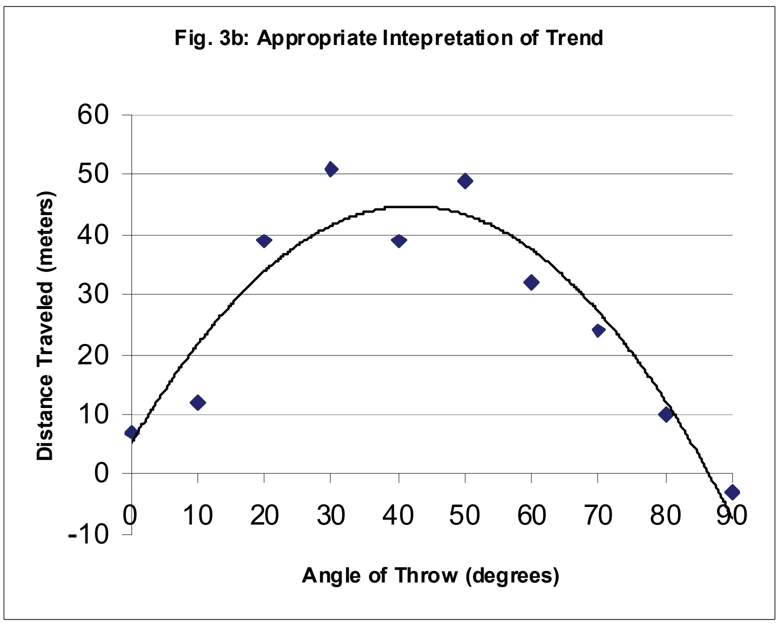


Figure 1 shows the optimum throw angle is between 40° and 50°. It can be shown theoretically that the optimum angle is indeed 45°— assuming no air resistance. With normal air resistance it is less than 45°, although this depends greatly on the mass, size, shape, and speed of the object. For a shot-put, the optimum is only slightly less than 45°, while for a high-powered rifle bullet it is about 30°. To make matters even more interesting, the German army in World War I found that very powerful artillery pieces could fire farther at angles somewhat greater than 45° because the projectiles could be gotten above most of the earth's atmosphere that way. The so-called "Paris gun" was able to shell the French capitol from 75 miles away.

Experiment 1: Measurement of Variables

Units of Measurement

1. Obtain the balance apparatus (meter stick with holes, small cup with holes, hanger, paper clips, and small binder clip), and assemble it so that the meter stick is centered on the hanger.

2. If the meter stick doesn't balance, use the small binder clip to add weight to one side. Explain how you decide when the apparatus is "balanced."

3. Obtain two objects labeled "A" and "B", and either set of hanging masses (wing nuts or lock washers—these will be the "units" of mass for this lab, like grams or pounds).

4. Place paper clip "hangers" in the holes at or near the far ends of the meter stick, equally spaced. Hang OBJECT A from one of the clips. Place one type of unit mass (e.g., lock washers) on the other clip until it balances. What is the mass of OBJECT A in terms this unit of mass? (For instance, the mass of OBJECT A might be "10 lock washers") Note: You may use ½ units if it isn't clear which whole unit is closer.

OBJECT A: ___________________________

5. Remove OBJECT A and replace it with OBJECT B. Use the same type of unit mass. What is the mass of OBJECT B?

OBJECT B: ___________________________

6. Repeat step 4, but this time use the second type of unit mass. What is the mass of OBJECT A this time?

OBJECT A: ___________________________

7. Based on the previous 3 measurements, see if you can calculate the mass of OBJECT B in term of this second type of unit mass. Describe or show your reasoning:

Hypothesis for mass of OBJECT B: ___________________________

8. Now measure the mass of OBJECT B in terms of the second type of unit mass.

Actual mass of OBJECT B: ___________________________

9. Compare your hypothetical and measured mass for OBJECT B. Were they close? Do you think the hypothesis is verified or refuted?

10. Add your data to the class data report.

11. Looking at the entire class data, compare the masses of A and B for both types of hanging masses. What can you conclude about the relative weights of A and B? Does the conclusion depend on the mass unit used?

12. Suppose another lab group has two different objects, C and D. Object C balances with 12 units on the other side of the balance, and object D balances with 15 units (of the same type).

a. What can you say about the masses of C and D?

b. What are the limitations in what you know about the masses of the objects?

Proportionality

1. Collect the following materials

graduated cylinder	eyedropper
aluminum and copper rods	paper towel
aluminum shot	balance
container of water	plastic cups

2. Prediction: The two metal rods are identical in size and shape, but they have different masses. If both are placed into the same amount of water in identical graduated cylinders, how will the resulting water levels compare?
   a. higher for the heavier metal cylinder
   b. higher for the lighter metal cylinder
   c. same level

3. Pour 50 milliliters of water in the graduated cylinder, then slide the aluminum cylinder into the water. What is its volume? Repeat for the copper cylinder. Check your answer in part 2.

4. Now measure the *mass* of the aluminum rod using the equipment from part one and the fact that 1 milliliter of water has a mass of 1 gram.

   Mass of cylinder_________________ (in grams)

5. Measure out an equal mass of aluminum shot. Slide it into the water to find the volume.

   Mass of shot _________________ Volume of shot ___________________

6. Select various amounts of the same shot material (very roughly, 1/4x, 1/2x, 1.5x, 2x, 2.5x or similar). Find 4-5 other masses and volumes for these samples of shot. (These data pairs will be used to make a graph).

Sample:	1	2	3	4	5
Mass:					
Volume:					

7. Make a graph of your data. Put mass on the horizontal axis and volume on the vertical axis. By logic, what volume corresponds to zero mass? Use this as another data point. Review the rules for graphing in the introductory section of the lab manual).

8. Are the volume and mass measurements proportional?   Explain.

10. Describe the graph produced by two measurements that are proportional (Hint: it has *two* features):

    1. ____

    2. ____

11. Describe how you can tell whether two measurements are proportional without using a graph?

Experiment 1: Post-Lab Exercise

State your ideas as clearly as possible.

1. Which 2 of the following sets of numbers are <u>proportional</u>? Explain how you know.

Set 1	Set 2	Set 3	Set 4
4 16	4 2	10 15	4 8
5 20	9 3	6 9	6 10
7 28	25 5	4 6	8 12

2. Sometimes children are introduced to measurement of distance using units like "hands" or "book lengths" instead of standard units. Name an advantage and a disadvantage for this practice, and explain why you would or would not recommend it.

3. Imagine the following scenario:

You have 2 identical containers.
The first is filled exactly ½ -way with water.
The other is filled exactly ½-way with sand.
You pour the sand into the water.

<u>Prediction</u>
Is the container full? Explain.

4. The numbers below show the movement of a beetle crawling across a sidewalk.

distance (centimeters)	**time** (seconds)
0	0
6	2
12	4
15	5
27	9

a) Are the numbers proportional? ___________

b) How do you know?

____

c) Graph the beetle data. (Remember the tips for figures, from the lab manual p. 6-8.)

Experiment 2: Motion With Constant Acceleration

Graphing Motion

All kinds of motion are based on 4 fundamental variables: *position, velocity, acceleration*, and *time*. In this lab we will explore these variables and how they relate to each other.

1. Obtain a marble (or ball bearing), a track, track supports, a meter stick, masking tape, and a stopwatch.

2. Using these materials, set up an apparatus so that the marble appears to travel with *constant speed* over the length of the track, i.e., it is not slowing down or speeding up (once you get it going). Describe how you accomplished this.

3. Describe how you could check to see if speed is constant:

4. Make a hypothesis (an educated guess) about the shape of the graph for distance traveled vs. elapsed time for the marble at *constant speed*. "Distance traveled" means the distance from start to point X, and "elapsed time" means the time from start to that same point X (E.g, "it took 3.2 seconds to travel from 0 to 2.5m"). Sketch the graph below. So we are all consistent, put time on the horizontal axis and distance on the vertical. We will discuss the graph to clarify any questions before we go on.

5. Now angle the track so the marble accelerates. For the acceleration to be constant, the track will need to be as straight as possible. Try for a slope that is gentle enough that you'll be able to time it accurately—at least 4 seconds from start to finish is recommended. Practice until you are sure the motion and your measurements are repeatable.

6. Now make a hypothesis about the shape of the distance vs. time graph for the marble at *constant acceleration*. Draw this graph overlaid on the one in step #4.

7. We will now design an experiment to verify or refute your hypothesis on the shape of the *constant acceleration* graph. Answer these questions to help get you started:

- Is it easier to measure the time at predetermined distances, or vice-versa?

- Given what you decided just above, which variable (distance or time) is the

  independent variable (the one you control):

  dependent variable (the one you measure):

- How many distance-time data points are needed to be reasonably certain about the graph shape (remembering there will be considerable error in every measurement)?

- What factors might be confounding variables in your experiment? And, what can be done to control or minimize these to ensure measurement accuracy?

- What data can you use for the starting point (by logic)? Would this point have error like the other measurements?

8. Before you go on, discuss these questions with your lab partners.

9. Based on steps 7 and 8, develop a procedure to test your hypothesis in step 6. Briefly describe the plan for your experiment:

10. Perform the experiment and make a neat data table of your results. Then plot the data (remember the tips for clear graphs from the Lab Manual). Like step 4, put time on the horizontal axis and distance on the vertical axis. So we are all consistent, use *cm* for distance. Keep your apparatus set up until step 12.

11. Now examine the graph. It will probably have some "rough spots" and/or "holes." As needed, take some more data points to help refine the shape of the graph.

12. Look back to step #5/7 and state whether your hypothesis is supported or not supported. (It is perfectly ok if the hypothesis is not supported!)

13. Think about confounding variables again--what effects do you think they had?

Modeling Motion

One of the goals of science is to be able to describe phenomena with simple, accurate, and usable models. In physics these models often take the form of equations. In this part we are going to try to write the equation for the graph in part one.

Straight-line graphs have the equation

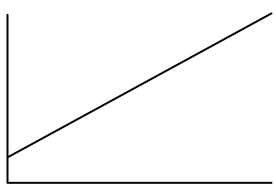
$$y = k(x) + a,$$

where k and a are constants. If a = 0, y is said to be *directly proportional* to x. For example, the distance traveled by a car going 60 miles/hour in a time of 2.5 hours is

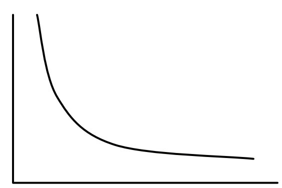
$$d = 60\frac{miles}{hour}(2.5hour) = 150miles.$$

If the graph is a straight line, we can find the *slope*, k, by computing the *rise over run*, and the *y-intercept*, a, by finding the value of y when x is zero. But if the graph is *not* straight, we have to do some figuring to get the equation. There are a few techniques to do this, probably invented by physicists a long time ago to develop the formulas in your textbook. We're going to do the same thing.

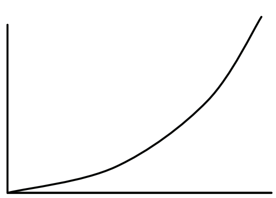
1. Take an educated guess about the form of the equation. Some common ones are shown below. Which do you think is most likely to describe the graph in Lab 2.1?



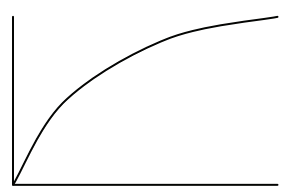
linear: $y = k\,x + a$



inverse: $y = k / x$



quadratic: $y = k\,x^2$



square-root: $y = k\,x^{1/2}$

2. Let's say the equation is $y = k\,x^{1/2}$

3. Now imagine a new variable z which is equal to $x^{1/2}$ $z = x^{1/2}$

4. Then, $y = k\,z$

5. Take all the x values, *find the square root of each* (thus making z values), and plot the data in the form of y versus z. Now the key step: if that graph turns out to be a straight line, we know two things:

i. We were right in our original guess that $y = k\,x^{1/2}$
ii. The "k" in $y = k\,x^{1/2}$ is the slope in the straight line graph $y = k\,z$

If that graph weren't a straight line, then we guessed wrong and we would start over with a different equation, like $y = x^2$.

6. Give this a try with the data from Lab 2.1. Guess an equation-form, manipulate the x data appropriately, plot the new ~straight line graph (or at least *more* straight), and derive the k as the slope of that straight line graph.

7. Now write the final form of the equation in terms of distance and time. Include units (use cm and seconds).

8. Test your equation to see if it works: plug in 3 random times to see if the equation predicts the distance according to the graph (show comparisons):

Experiment 3: Prelab Exercise

State Newton's 3 laws of motion.

1. ____

____

2. ____

____

3. ____

____

Experiment 3: Newton's Laws of Motion

Station 1
1. Place the matchbox car on top of the cart, facing the same direction as the cart.
2. Hold the bare end of the spring with one hand against the end of the cart.
3. Push the cart and spring together, compressing the spring.
4. Release the cart and observe the motion of both the matchbox car and the cart.

Observation:

Which of Newton's laws best explains:

The motion of the cart during release from the spring ___________

The motion of the cart after release from the spring ___________

The motion of the matchbox car (left and right) ___________

Station 2
1. With the spring scale attached to the block, grasp the other end of the spring scale.
2. Bring the block to a comfortable speed and maintain that speed across the table.
3. Observe the amount of force required to maintain a constant speed. Observation:

4. Now try to pull the block with 2x that force. Observation:

5. Now add the weight to the block, and pull with the same 2x force. Observation:

Which of Newton's laws best explains:

The motion of the block in step 3 ?___________

The motion of the block in step 4 ?___________

The motion of the block/weight in step 5 ?___________

Station 3
1. Place a piece of paper on the table and center a wax cup upside down on the paper.
2. Center a marble on top of the wax cup.
3. With a swift motion of your arm, jerk the paper from under the cup as fast as possible.

Observation:

Which of Newton's laws best explains the motion of the marble?___________

Station 4
1. Place the marble at the top of the incline, and then release it. Observation:

Which of Newton's laws best explains the motion of the marble?___________

Station 5
1. Attach one spring scale to a stationary rod, than attach 2 other scales to the first, forming a horizontal chain.
2. Pull horizontally on the unattached spring scale hook. Observation:

Which of Newton's laws best explains the observations?___________

Station 6
There are two pieces of crumpled paper. They are of similar mass, but one is crumpled tightly and the other not. Place them side by side and blow them simultaneously across the table. Repeat. (Note: The force on the paper ball is roughly proportional to its size.) Observations:

Which of Newton's laws best explains the observations?___________

Explain how this law applies to the observations:

Station 7
There are two crumpled pieces of paper. They are of very similar size and shape, but one has more mass than the other. Place them side by side and blow them simultaneously across the table. Repeat. Observations:

Which of Newton's laws best explains the observations?___________

Explain how this law applies to the observations:

Station 8
You are standing or sitting. Gravity is exerting a force on your body downward. Why are you not moving into the floor, since Newton's 2^{nd} law states that $F = ma$?

Experiment 4: Rolling Motion and Newton's Laws

Relationship Between Linear and Rolling Motion

Station One:

Equipment: Wheel, meter stick.

1. Make a hypothesis about how the number of revolutions of the wheel relates to the distance it travels. Write this hypothesis as an equation, including any relevant dimensions of the wheel.

2. Design an experiment to test this hypothesis.
   a) Describe briefly:

   b) What are some confounding factors that could affect your experiment, and how can you prevent them from biasing the results?

3. Discuss your experiment with a neighboring group. Revise your experiment as needed, from what you learn in this discussion.

4. Now perform the experiment and describe your results, comparing your predictions to what you found experimentally. Explain any sources of error.

Rotational Inertia

Station Two:

Equipment: stick with two movable weights, stick with weight at one end.

Begin this exercise by grasping the stick with the movable weights in the center and sliding the two weights close to your hand. Clamp them firmly. Now twist the rod back and forth repeatedly, noting how much torque you must apply to accelerate and decelerate the rod. Repeat the test with the weights clamped at the ends of the rod.

Now try to stand the stick weighted at one end on your finger and keep it balanced there. Decide if it is easier to balance with the weight at the bottom (near your finger) or at the top?

Construct a hypothesis regarding the effect of the location (not the amount) of the mass of an object on the rotational inertia of the object (i.e., how easily it can be accelerated rotationally).

Station Three

Equipment: Inclined plane, solid cylinder, hollow cylinder, solid ball, hollow ball..

On the basis of your hypothesis, predict which of the round objects will roll to the bottom of the inclined plane fastest by numbering them from fastest to slowest.

_____solid cylinder

_____hollow cylinder

_____solid ball

_____hollow ball

Test your prediction. List the experimental results.

Experiment 4: Post-lab Exercise

Measure and record the radius of a car tire.

Measure and record the circumference of the same tire.

Multiply the radius by 2π (π is about 3.14) to check the radius and circumference relationship. Discuss any confounds you notice.

How many times will this tire rotate in 30,000 miles of driving (the average life of a tire)?

In Experiment 3 you identified cases of Newton's 3 laws of motion. The same laws apply to rotating bodies. Identify which of Newton's laws apply in the following cases, and tell what the law predicts.

Picture a <u>frictionless</u> merry-go-round.

1) You set it spinning, then step back. What happens? According to which law?

2) You sit down on the ground and put your feet up so they rub against the edge of the moving merry-go-round. What happens? According to which law?

3) You put another frictionless merry-go-round next to the first. With both of them at rest, you stand on one merry-go-round and push to start the other one spinning. What happens? According to which law?

Experiment 5: Invariant Quantities

Gravitational Potential – Hills

1. A marble rolls down 2 different hills. The hills are identical in surface and height, except one hill is straight the entire way, and the other is steep in the beginning and becomes gradually flatter at the end.

    a. Draw a sketch of the hills overlaid on each other.

    b. Predict how the *time* to reach the bottom of the hill will compare.

    c. Predict how the approximate *final speeds* at the bottom of the hill will compare.

    d. Design an experiment to explore the situation in #1. Describe your procedure including how you will make a quantitative measure of the final speed. Discuss the *average speed* of the two marbles.

    e. Perform this experiment and describe your results.

2. Now imagine a third hill shape, again the same height as the others but it is "S" shaped: fairly flat, then steep, then flat at the end, with gradual changes throughout.

   a. Sketch this hill, overlaid on the sketch in 1a, above.

   b. Predict how the time to reach the bottom of the hill will compare to both hills in #1.

   c. Predict how the speed at the bottom of the hill will compare to both hills in #1.

   d. Test this situation. What were your results?

The Simple Pendulum

There are four basic variables to the pendulum: period, mass, amplitude, and length.

- The *period* is the time it takes to complete one full swing forward and back.
- The *amplitude* is the angle from which the pendulum is released.
- The *length* is measured from the pivot to the center of gravity of the mass.

We're going to look at how the variables of mass, amplitude, and length affect the period.

1. Obtain the following materials: string, paper clip, 3 washers or nuts (heavy in comparison to the paper clip), stopwatch, meter stick

2. Design and perform experiments to investigate the 3 problems given below. For each experiment:

   a. state a hypothesis. (Think about the difference between "hypothesis" and "guess.")
   b. explain your procedure, clearly identifying constants, independent and dependant variables.
   c. produce a data table.
   d. state and explain your conclusion.

3. Before you start:

   a. How can you minimize the effect of stopwatch errors on the measured period?

   b. How can you make sure you are only changing one variable at a time? E.g., Question 1 asks you to find the effect of mass on the period; how do you prevent the variables of amplitude and length from confounding the effect of mass?

Problem 1*:* What is the effect of the mass of a pendulum on its period?

Problem 2: What is the effect of amplitude (or release angle) of a pendulum on its period? Note: Pendulums behave differently when the release angle becomes "large." Keep release angles below 20 degrees from the vertical. (Even a very slight swing of a few degrees is fine.)

Problem 3: What is the effect of length of a pendulum on its period? On this part, take at least 5 readings, over a wide range of lengths (e.g., 10cm to 80cm).

4. Graph the variable that most affected the period versus the period. Remember to put the I.V. on the horizontal axis and the D.V. on the vertical axis.

5. You will probably find this is not a linear relationship. Using the procedure from Lab 2, find what kind of relationship it is (you need not find the "k").

Experiment 5: Post Lab Exploration

1. You are sledding and have your choice of 2 different slopes, both covered by well-packed snow. They have an identical drop of 7 meters vertically. However, one slope is steeper than the other. You notice the sled doesn't even need a nudge to start coasting.

   a. What does the last sentence tell you about friction?

   b. How will the times compare for reaching the bottom of each slope?

   c. How will the speeds compare at the bottom of each slope?

   d. Where do you have the most potential energy?

   e. Where do you have the least potential energy?

   f. Where do you have the most kinetic energy? (Kinetic energy is the energy of motion.)

   g. Where do you have the least kinetic energy?

2. Pendulums were often used for clocks before the electronic age (a slowly falling weight was used to "power" the pendulum, i.e., counteract the small friction that would eventually bring it to a stop.) Why do you think the pendulum was chosen for precise clocks? How would you fine-tune the accuracy of such a clock?

Experiment 6: Conservation of Momentum

Elastic Collisions

1. Obtain a lump of clay, the balance system, and two Hot Wheels cars.

2. Check the cars to make sure they will produce a clean "hit" with the spring between them. Also check that the cars roll about the same. If there is a big mismatch, try a new car.

3. Start with the cars of equal mass. Equalize the masses of the chosen cars by adding a small amount of clay to the lighter one.

4. Think about how Newton's *third* law is at work during the small time of impact (less than 0.1 sec). Is the force applied to the target by the striker the same or different than the force applied to the striker by the target? Use Newton's 3^{rd} law to write an equation relating these forces, using subscripts to keep track of each of the terms.

5. Now think about how Newton's *second* law is at work during the small time of impact, for each car. Write out Newton's second law (as an equation) for each car, using subscripts to keep track of each of the terms.

   Striker:

   Target:

6. From these two laws, what can you predict about the *absolute value of the cars' accelerations (or decelerations)* during the instant of impact: are they equal, or one is greater than the other? Recall Steps 3, 4, and 5 above for this. Show calculations.

   Striker:

   Target:

7. Experiment with running one car into the other, and observe the *change in speed* of *both* cars due to the impact (not due to the rolling friction). Note: the change in a variable always means the final value minus the initial value. Impacts tend to be a bit unpredictable: do at least 3 trials so you can be certain of what is typical. Circle whether the car is decelerating or accelerating. Use your visual judgment to rate the *change in speed* from 0 to 10, with 10 being the speed of the faster car. The acceleration is proportional to the change in speed, since the time of impact is the same for each car: $a = \Delta v / \Delta t$

   Striker: Decelerating or Accelerating ? How much (0-10)? _______

   Target: Decelerating or Accelerating ? How much (0-10)? _______

8. Evaluate your analysis and prediction in step 6 (keeping in mind this is an "eyeball" measurement):

9. Now using additional clay and the balance, make one car twice as massive as the other.

10. Predict the effect of a 2x more massive striker on the *change in speed* (proportional to accelerationl) of both cars. I.e., a 2m striker hits a 1m target. Circle your prediction:

    Predicted change in speed of striker: High Medium Low

    Predicted change in speed of target: High Medium Low

11. Now test your prediction by running a 2m striker into a 1m target, and observe the *change in speed* of both cars.

    Striker: Decelerating or Accelerating ? How much (0-10)? _______

    Target: Decelerating or Accelerating ? How much (0-10)? _______

    Evaluate your prediction in step 10 (keeping in mind this is an "eyeball" measurement):

12. Now reverse the cars so a 1m striker hits a 2m target. First predict like in step 10:

    Predicted change in speed of striker: High Medium Low

    Predicted change in speed of target: High Medium Low

13. Now test your prediction by running a 1m striker into a 2m target, and observe the *change in speed* of both cars.

    Striker: Decelerating or Accelerating ? How much (0-10)? _______

    Target: Decelerating or Accelerating ? How much (0-10)? _______

    Evaluate your prediction in step 12 (keeping in mind this is an "eyeball" measurement):

14. Now go back and apply Newton's second and third laws for these cases: show how the accelerations relate to each other for the two cars (2m and 1m) during the moment of impact. Show calculations using Newton's second and third laws (like step 6):

    2m car:

    1m car:

15. Discuss what you found in step 14 compared to the results in steps 11 and 13:

Inelastic Collisions

Introduction

In the "matchbox car" lab the cars bounced off each other—this is called an "elastic collision," and the cars retain most of their kinetic energy. The same physics principles of Newton's laws and Conservation of Momentum apply to both elastic and inelastic collisions. Momentum is much easier to measure than either forces or accelerations, so this lab will look at momentum..

1. *Conservation of Momentum* says that the total momentum of a system does not change as long as there is no external force on the system. Momentum is defined as **mass × velocity**, *for each mass*. The "system" is defined as both masses. The momentum of the system, before and after, is

Before		After
$m_1 v_1 + m_2 v_2$	=	$m_1 v_1' + m_2 v_2'$

where v_1 **and** v_2 are the velocities of mass 1 and mass 2 before the collision and v_1' and v_2' are the respective velocities after the collision. If mass two is stationary before the collision, then v_2 would be 0. Thus the momentum equation would be simplified:

Before		After
$m_1 v_1$	=	$m_1 v_1' + m_2 v_2'$

In this lab the carts will stick together after the collision, so $v_1' = v_2'$ The momentum equation becomes:

Before		After
$m_1 v_1$	=	$(m_1 + m_2)\ v_1'$

2. Each empty cart has a mass of 1kg and the added masses are also 1kg each. Add 1 mass to each cart, for a total of 2kg per cart (this is the "2/2" case in the Data Table). Place the carts on the track, and set the track slope to just overcome friction (such that either cart will roll at a constant speed).

3. Place the ‘target’ cart (m_2) near the midpoint. Set up the Velcro coupling block on the target so it meets the striker (m_1) cleanly.

4. From the high end of the track, push the striker from its top/rear near the pulley (to prevent it swinging). Practice getting a “clean” collision. In the experiment you will find the speed of the striker cart before the collision, and of the two carts together after collision.

5. For the best data:

1) Choose a relatively small distance so that the cart doesn't slow down very much in the interval. But, too small a distance will amplify stopwatch inaccuracies. Suggestion: select distances for before and after that give a time of about one second.
2) When timing the cart through the distance intervals, be sure to track the same point on the same cart (e.g., the front of the striker).
3) Push the striker with fairly high velocity to minimize friction effects.
4) Do about 3 trials for each case, and use multiple stopwatches.

6. Find the speeds of each cart for the combinations in the table below, and calculate Momentum % Conserved for each combination. *Show units.* Note: *% Conserved = 100 * (Final / Initial).*

7. Evaluate whether Conservation of Momentum seems to hold based on the data, and discuss your results. Recall friction is still present in this experiment, and is a bit unpredictable at the moment of impact. Friction robs the system of momentum, so the Momentum % Conserved of our experiment will be a bit lower than the ideal case.

distance interval for striker pre-collision: _____

distance interval for striker+target post-collision: _____

Mass Striker (kg)	**Mass Target (kg)**	$\Delta\tau$ Pre-coll. (sec)	$\Delta\tau$ Post-coll. (sec)	Velocity Pre-coll. _______	Velocity Post-coll. _______	Momentum Pre-Coll. _______	Momentum Post-Coll. _______	**Momentum % Conserved**
2	**2**							
1	**2**							
2	**1**							

8. In the "matchbox lab" we looked at the *change in velocity* of each car due to the impact. In the next table, examine the cases from today's lab to see how the change in velocity and acceleration are affected by the mass ratios. Since the time of impact is the same for both cars, and acceleration = (change in velocity)/(time of impact), we can calculate the *acceleration ratio* of the two cars:

$$(v_1' - v_1) / (v_1) .$$

That ratio will roughly tell us how the hypothetical occupants of the cars will fare, *relative to each other,* in a crash.

Mass Striker (m_1) (kg)	**Mass Target (m_2) (kg)**	Change in Velocity of Striker (v_1'-v_1)	Change in Velocity of Target (v_1')	Acceleration Ratio of both cars (e.g., 3.2 : 1)
2	2			
1	2			
2	1			

9. Is the data consistent with what you found in the matchbox lab? I.e., ideally, the "1/2" case will be just the inverse of the "2/1" case, with the lighter car experiencing much more acceleration than the heavier one. And, the "2/2" case will have a ~1:1 acceleration ratio. Are the data consistent with predictions and what you found with matchbox cars (allowing for experimental error)?

Elastic Collisions

1. Start with 1 added 1kg mass in each cart (each empty cart is 1kg as well, for a total of 2kg per cart). Place the carts on the track, and set the track slope to just overcome friction, such that either cart will roll at a *constant* speed.

2. Place the ‘target’ cart near the midpoint, and the ‘striker’ cart at one end, with the spring on either cart but between the two.

3. From the high end, push the ‘striker’ cart from it’s top/rear near the pulley (to prevent it swinging). Practice getting a “clean” collision, and finding the speeds (record the time to travel a specified distance) of the striker before and after the collision, and the target after collision. Unlike the last lab, there are generally going to be two objects moving apart after the collision, and you want both of their speeds. Thus, 3 stopwatches are necessary, and probably 3 people per setup. Follow the same general practices you used in the inelastic case.

4. If the target cart jumps off the track (likely only for the 3:1 combination), adjust the location of the spring by moving it <1/8” in the same direction as the jump of the cart.

5. Make a hypothesis about whether Energy and Momentum will be conserved before and after the collision for the carts bouncing apart upon impact (called an “elastic collision”)

   Energy____________________ Momentum ____________________

6. Find the speeds of each cart for the combinations below, and calculate Momentum and Energy for each combination. *Note units for each column.*

7. Note: *% conserved = 100* (Final / Initial)*

Mass Striker (kg)	**Mass Target (kg)**	Δd Striker Pre (m)	Δd Striker Post (m)	Δd Target Post (m)	Δt Striker Pre (sec)	Δt Striker Post (sec)	Δt Target Post (sec)	**Vel. Striker Pre**	**Vel Striker Post**	**Vel. Target Post**
2	2									
2	1									
3	1									

Mass Striker (kg)	**Mass Target (kg)**	Mom. Pre ______	Mom. Post ______	**Mom. % Conserved**	Energy Pre ______	Energy Post ______	**Energy % Conserved**
2	2						
2	1						
3	1						

8. Evaluate your hypotheses based on the above data, and discuss your results.

9. Generally, how do the % Conservation for Momentum compare to the last lab, where the carts stuck together?

10. Think about automobile collisions (which are somewhere in between “inelastic” and “elastic”). Recall that F=ma, and the average acceleration for each car is the (*change in velocity of the car)* / (time of collision). Which combination is most likely to result in an injury, and, is #1 different or the same as #3, from an acceleration standpoint?

1. 2000 lb vs. 2000 lb.
2. 2000 lb vs. 3000 lb.
3. 3000 lb vs. 3000 lb.

Experiment 7: Heat

Phase Changes

Matter has 4 *phases* or *states*: solid, liquid, gas, and plasma. This lab looks at the phase transitions from solid to liquid to gas.

1. Obtain the following materials: 600mL beaker of ice, thermometer, hot plate, timer.

2. Add a very small amount of water to the ice so that air doesn't reach the thermometer bulb.

3. Set the temperature to "Medium" or a little above.

4. Heat the ice/water, stirring regularly (*especially when it is both ice and water*, and just before a temperature reading.)

5. Take temperature readings once a minute, even if nothing seems to be happening. Be sure to keep the thermometer *off the bottom of the beaker* when reading temps. Read question #9 as you take data so you can answer it later. Note the following events in your observations:

    a. All ice is melted.

    b. Visual distortions form in the water due to thermal currents and density changes.

    c. First noticeable steam appears.

    d. Bubbles start. (Well before boiling you will notice very small bubbles on the side of the beaker. These are actually air, not steam, released from the water in which they were dissolved. You can ignore these.)

    e. Bubbles form from the center of the water

6. Keep taking data for at least 3 minutes after a full boil is reached.

Time (min)	Temp (°C)	Observations	Time (min)	Temp (°C)	Observations

7. Graph the data.

8. a) Now note on the graph the points where:

- All the ice is just melted,

- Bubbles form from the center of the water (full boil)

9. As the water first starts to boil, what happens to the bubbles? Explain.

10. There should be two "flat spots" in the graph, where the temperature is steady even though the burner is supplying heat to the ice/water. In each of these flat spots, where does this heat go?

11. After the ice melts, what effect does the heat have on the system?

Calorimetry

The *temperature* of something is a measure of the average kinetic energy of the atoms or molecules that make it up. From a practical standpoint, temperature is "what a thermometer measures."

Scientifically, *heat* is energy transferred between two bodies when their temperatures are different, such as the hot plate and the water. Once the temperatures are the same, heat no longer flows between them even though they may be very hot, such as when the burner is turned off at the end. The units of heat are joules, calories, or kilocalories (the kilocalorie is just called the "calorie" when referring to food).

1. It takes 1 calorie of heat energy to raise the temperature of 1 gram of water by 1°C. Thus the *specific heat* of water is (1cal/gm)/°C. How many calories would it take to raise the temperature of 100 grams of water from 60°C to 61°C? ________

   from 40°C to 50°C? ________

2. In general you can find the energy needed for a temperature change by $Q=mc\Delta T$, where Q is in calories, m is in grams, c is the specific heat of the substance, and ΔT is the temperature change (final minus initial).

3. Obtain 2 styrofoam cups (one large and one small), a plastic cup, a graduated cylinder, and 2 thermometers.

4. Fill the large Styrofoam cup with hot water, and the plastic cup with cold water. These are the "supply" cups. Keep a thermometer in both cups.

5. Record the temperature of the cold water and then measure and add 100g to the small Styrofoam cup (the "mixing" cup).

6. Record the temp of the hot water and then measure and add 20g to the mixing cup.

7. Stir gently with the thermometer. Record the highest temperature reached for the mixture. When the waters mix, the hot water gives up its heat to the cold water: the hot water goes down in temp (to the mixed temp) and the cold water goes up in temp (to the mixed temp). Dispose of the mixed water after recording its temp.

8. Repeat this procedure (steps 5-7) for additions of 40, 60, 80, and 100 grams of hot water. **Use 100g of new cold water each time.** Refill the supply cups as needed.

9. Do the calculations to complete your table. As alluded to in step 7, it might be helpful to think of the cold water and hot water as separate entities, even though they are mixed.

Initial temp of 100-g cold water (°C)	Final temp of hot-cold water mixture (°C)	Temp change of cold water (°C)	*Calculated calories gained by 100-g cold water*	Mass of hot water (g)	Initial temp of hot water (°C)	Final temp of hot-cold water mixture (°C)	Temp change of hot water (°C)	*Calculated calories lost by hot water*
				20				
				40				
				60				
				80				
				100				

10. Compare the *calories gained by the cold water* to the *calories lost by the hot water*, and explain.

Experiment 8: Simple Circuits

1. Obtain a battery, a flashlight bulb, and a short piece of copper wire. Remove the battery and bulb from their holders. Examine them closely, and find two ways to arrange them so the bulb lights. Sketch your arrangements:

2. Examine the 12 bulb/battery sketches attached.

   a) Without testing them, which do you think will cause the bulb to light?

   b) Now test your predictions. Which of them worked? Explain why those worked, but the others did not.

3. Obtain the test objects of steel, plastic, copper, rubber, nichrome wire, paper, and *another* flashlight bulb in a holder. Return the original bulb and battery to their respective holders. Inspect both sides of the battery holder to see how small plastic washers separate the frame of the holder from the terminals on the end.

   Create a circuit of the battery and bulb to check that the bulb lights; call this level of bulb brightness a "5". Now predict the bulb brightness when each test object is inserted into the circuit (between the alligator clip and the battery terminal).   Test each prediction and record your results.

Object	Prediction	Result	Type of material (see below)
Steel			
Plastic			
Copper			
Rubber			
Nichrome wire			
Paper			
2^{nd} Flashlight bulb			

Those materials that allow unrestricted electricity flow are called *conductors* and those that allow none are called *insulators.* Materials allowing limited flow are called *resistors.* Now classify each type of material in the table above.

4. Examine the flashlight bulb holder to see how the parts are arranged to power the bulb. Look on both sides and match up the wires and the contacts. Make a sketch of the socket (as seen from the bulb), noting the conductors and insulators:

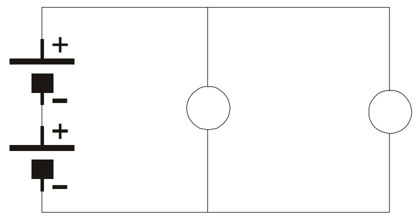
5. Now obtain 3 batteries with holders, 2 identical flashlight bulbs with holders, and some leads (pronounced "leeds") with alligator clips. Place a light bulb in a circuit with a battery. Then compare the effect of adding a second battery, connecting the batteries in tandem (this is called a "series" connection).

6. Predict the effect of connecting 3 batteries in series in various combinations (+ to +, + to -, etc.). Check to see if your predictions are correct.

   Prediction:

   Result:

7. Consider this *schematic diagram* of 2 bulbs in *parallel*, and 2 batteries in series:



8. a) Predict the brightness of the 2 bulbs to each other:

   b) Test your prediction and explain the results:

9. a) Predict the brightness of either of the two bulbs in parallel, as shown, to either of the same two bulbs arranged in series, as in part 3.

   b) Test your predictions and explain the results.

10. Draw a schematic diagram of the circuit of part 9.

11. A *short circuit* occurs when another conductor provides a shortcut for the electricity flow (bypassing the resistors).

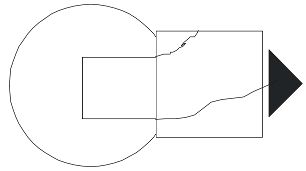
    a) Show what this might be on the schematic (in #7, above). How do you think it would affect the bulb brightness? Check it (very briefly) with a single battery, single bulb, and the copper wire and describe results.

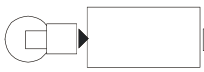
b) Predict what would occur if the copper wire in a) were replaced by a nichrome wire (at least 12" long). Check this and describe results.

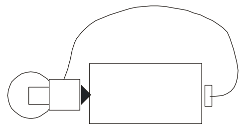
12. Create at least 3 more circuits. Use 2 bulbs and at least 2 batteries each time. Be creative!

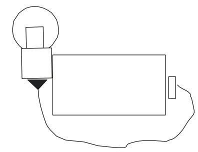
For each circuit:
1. Draw a *schematic* diagram
2. Describe how bulb brightness compares
3. Explain the results

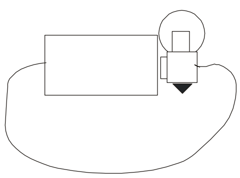
This is how the wires are connected inside the light bulb.

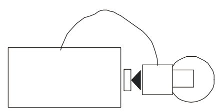


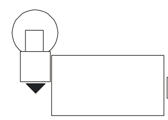
1 

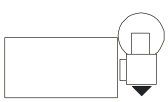
2 

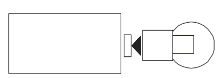
3 

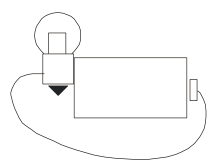
4 

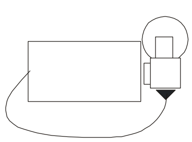
5 

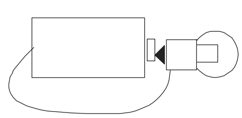
6 

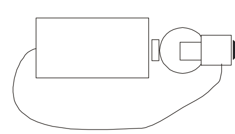
7 

8 

9 

10 

11 

12 

Experiment 9: Electrical Measurements

1. Obtain 3 batteries with holders, 2 identical flashlight bulbs with holders, leads (wires) with alligator clips, and a multimeter.

2. Using the Multimeter

   a. There are 2 probes that fit in the holes near the bottom of the meter. Put the black probe in the COM (Common) hole and the red probe in the VΩmA hole. By convention, black represents the negative side and red represents the positive side. If you mix them on a digital meter it's generally ok; as the meter will just read negative values.

   b. Examine the different Voltage dial settings.   Between the 9:00 position and 12:00 are various "DCV" settings ("V=" on the black meters). These are for measuring Direct Current Voltage (batteries produce direct current; house wiring uses alternating current or "AC"). Each position represents the maximum voltage for that setting. The "2000m" setting means "2000 millivolts" maximum.

   c. Turn the dial through the different settings (600, 200, 20...) and notice what happens to the decimal point. Measure the voltage of a single battery, first using the "600" scale, then progressively lower scales. Notice that if you measure a small voltage with a high setting, you lose precision. E.g., if you want to measure a voltage of 4 volts, you should use the "20" scale to get the maximum precision (although 200 and 600 will work).

3. Put together a simple circuit with 1 battery and 1 bulb, but unscrew the bulb. Measure the voltage (use the 20 DCV scale)

   a) across (i.e, *in parallel with*) the battery terminals: ______

   b) across the ends of the wires at the bulb fixture: ______

4. Now screw-in the bulb and repeat the voltage measurements:

   a) across the battery terminals: ______

   b) across the ends of the wires at the bulb fixture: ______

They should be somewhat lower than before, and very slightly different from each other.

5. Measuring current is more complicated than measuring voltage because all the current must flow through the multimeter. This means the meter must be *in series with* the component who's current is to be measured.

   a) Turn the dial to the 10A setting, and move the red probe to the 10A hole. [FYI, ideally, we would use smaller settings than 10A but the lower ranges available on this meter (covered with masking tape) are too small for our labs: 0.2amps max.]

b) *Disconnect* one of the wires in your circuit, and place the meter into the circuit, so the meter fills the gap made by the broken connection (a series connection). Read the current (in amps): _______

c) Now unscrew the bulb and measure the current: _______

So the presence of voltage does not guarantee that current will flow. There must be a complete circuit.

When a voltage is present, it means electrical energy either has the potential to flow, or is flowing.
When a current is present, it means electrical energy is indeed flowing.

An analogy with water: the water in a pipe has pressure (voltage) whether the faucet is open or closed. But water has flow (current) only when the faucet is open.

6. Rules for Measuring Voltage and Current:
   - Voltage is measured across a circuit element or elements. (in parallel)
   - Current is measured with the meter as part of the circuit. (in series)

7. a) Measure the voltage of two batteries (independently, outside the circuit)

   Battery 1: _____

   Battery 2: _____

   b) Put the two batteries in series, in standard +/- arrangement.

   Predict the voltage measured across both batteries: ______

   Measure this voltage: ______

   c) Put the two batteries in series, this time in the +/+ or -/- arrangement.

   Predict the voltage measured across both batteries: ______

   Measure this voltage: ______

8. Examine the diagram for Circuit #1 on the following page. In the table for Circuit #1, make predictions about what voltages you expect to see between the nodes.

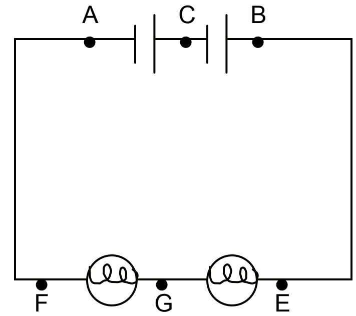
9. Now build circuit #1 and measure those voltages.

10. Measure the current for circuit #1, following the table on the following page.

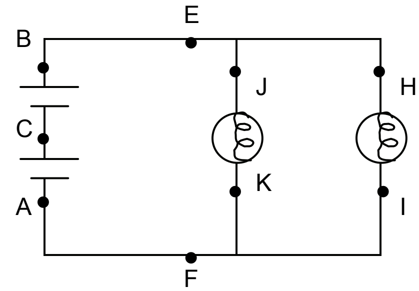
11. Repeat steps 8 – 10 for Circuit #2.

12. Examine your results for both Voltage and Current, and discuss:

Circuit #1

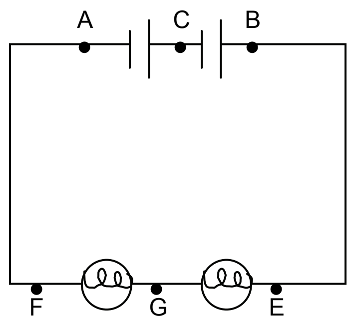


Circuit #2

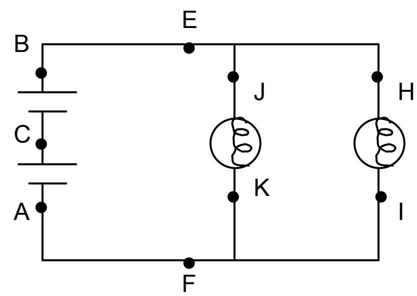


VOLTS	Circuit #1: Predicted	Circuit #1: Actual	Circuit #2: Predicted	Circuit #2: Actual
A – B (all batteries)				
A – C			X	X
C – B			X	X
B – E (battery-bulb)			X	X
F – A (battery-bulb)			X	X
E – F (all bulbs)				
E – G			X	X
G – F			X	X
J – K	X	X		
H - I	X	X		
E - H	X	X		

Circuit #1



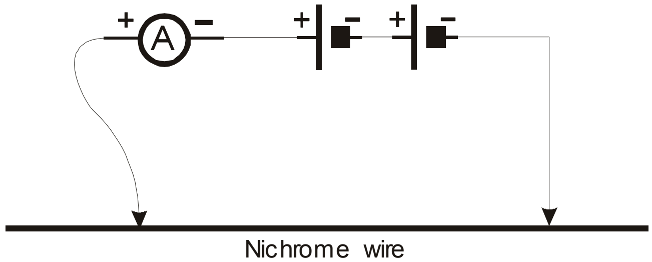
Circuit #2



AMPS	Circuit #1	Circuit #2
A		
B		
C		
E		
F		
G		X
H	X	
I	X	
J	X	

13. Obtain 2 batteries with holder, a meter stick, a length of Nichrome wire, masking tape, leads, and a multimeter. Tape the Nichrome wire to the meter stick.

14. Set up the circuit pictured below, use the multimeter as an ammeter.



15. How do you know that the Nichrome wire between the arrows is part of the circuit, but the part of the Nichrome outside the arrows is NOT part of the circuit?

16. Recall Nichrome wire is a *resistor.* Will the amount of current through the circuit change if you change the length of the Nichrome wire between the arrows? Explain your reasoning.

17. Check to see if the current changes for various lengths of wire in the circuit. Make a data table, recording the length of the wire in the circuit and the current in amps. Be sure to take readings at very short lengths of wire as well as medium and long lengths (this gives the best graph). Then graph the relationship.

18. a) Let's see if we can make sense of this graph. Which of the following does it look like (circle)?

$y=kx$
$y=kx^2$
$y=kx^{1/2}$
$y=k/x$

The longer the Nichrome wire, the more its *resistance.* So the graph above could also be thought of as a plot of current vs. resistance (where length is proportional to resistance). Now write the equation relating current (i) and resistance (R), and discuss:

Experiment 10: Practical Electricity

Many metal surfaces have a very thin layer of rust that can throw off resistance readings (rust is an *insulator*). The red and black probes have sharp metal tips; these are sharp so that you can dig the pointers slightly into the metal to get a better reading.

1. Review: Form a circuit with a small flashlight bulb and a flashlight battery. Use a multimeter to measure the voltage across the light bulb, and the current through the light bulb. Note units.

   Voltage: _________ Current: __________

2. Using the multimeter as an Ohmmeter (the Ω settings), measure the resistance of the both the small flashlight bulb and the large flashlight bulb. Resistance is measured in Ohms (the symbol is Ω).

   Small bulb: _________ Large bulb: __________

3. Based on these resistance measurements, predict the brightness of the large flashlight bulb (in a circuit with 1 battery) compared to the small bulb. Call the small bulb brightness in step 1 a "5".

4. Test your prediction (keep in mind these are ballpark/eyeball "measurements"), and explain why.

5. A household "nightlight" bulb is designed to emit about the same amount of light as these flashlight bulbs, but it runs on 120V instead of 1.5 or 3V.
   a. Predict the resistance of the nightlight bulb compared to the flashlight bulb (circle prediction):

   The resistance of the "nightlight" bulb would be
   much greater
   greater
   about the same
   less
   much less
   than the resistance of the flashlight bulb.

   b. Now test your prediction and explain why.

6. Measure the resistance of these circuit elements (in Ohms):
   a. Large Resistor (blue w/ stripes) __________
   b. Potentiometer: connect to the middle pole, and *either* other pole. Turn knob to see how resistance varies, then record min and max: _______ - _______
   (FYI, whenever you turn a knob on an electrical device, such as the volume on a stereo, you are probably turning a potentiometer.)

7. a. Measure the resistance of two identical medium sized (brown with stripes) resistors:

   Resistor 1 ____________

   Resistor 2 ____________

   These should be pretty close, and for the next part, you can consider them to both be the average of the two measurements.

   b. Predict the *combined resistance* of these two resistors arranged in series and in parallel:

   In series: ______________

   In parallel: _____________

   c. Test your predictions, and explain.

8. Light bulbs are good for getting a feel for voltage, resistance, current, and power, but they aren't so good for exact measurements because their resistance changes as they get hotter. Resistors, on the other hand, have pretty consistent resistance at different temperatures.

   a. In lab 9.2 you showed that current through, resistance of, and voltage across, a component are related by Ohms Law:

   Voltage = Current * Resistance ($V = i R$, so $i = V/R$)

   b. Based on Ohms law, predict and then measure the current that would flow through the large blue resistor with different voltages applied to it. *Show calculations for each*, and take any resistance or voltage measurements that you need to do the prediction. Then measure the current.

With 1 battery:

With 2 batteries in series:

With 3 batteries in series:

With 2 batteries in parallel:

c. Now try predicting and measuring the current flow for a small flashlight bulb instead of a resistor.

With 1 battery:

With 2 batteries in series:

With 3 batteries in series:

Discuss the accuracy of your results, and compare this accuracy to the accuracy in part b, using the resistor. Explain. Is the resistance of the light bulb increasing or decreasing as it gets hotter?

9. Think back to lightbulbs arranged in series and parallel. The brightness of the light increases with the total power delivered to the bulbs.

Power to each bulb = (Voltage across each bulb) * (Current through each bulb).

Or, $P = i V$

Based on step 7 in Lab 10.1, and $V = i R$, would you expect lightbulbs in series or in parallel to deliver more light (brightness)? Explain. Is this due to more voltage applied to each, more current through each, or both? You can either show this mathematically, or setup an experiment, or both.

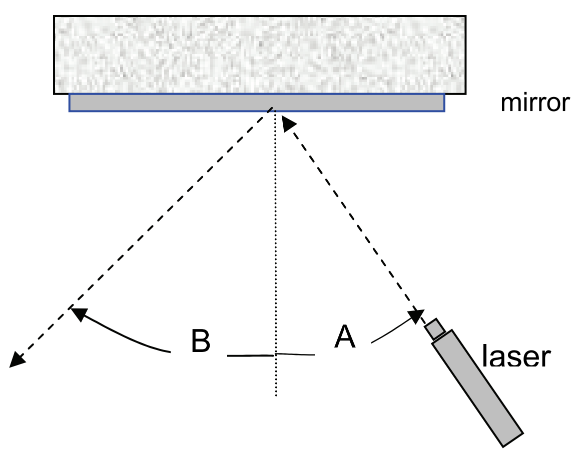
Experiment 11: Reflection and Refraction of Light

CAUTION: **In this exploration you will use a laser beam. Even the weakest laser can harm your eyes. DON'T LOOK INTO THE LASER WHEN IT'S ON. Think about where the beam might go, and avoid having the beam at eye level.**

1. Obtain a beaker, and add warm-hot water until it is 1/2 to 2/3 full. Place the beaker on a white piece of paper. Shine the laser beam into the water, from the top. Repeat this after mixing in a pinch of coffee creamer to the water. Compare your observations of each case. Set the beaker and water aside for later.

2. Obtain a blank piece of paper, a plastic bag, a mirror, and a laser.

   a. Design an experiment to find how the laser reflects off the mirror. Specifically, you are to predict and determine how the angles A (angle of incidence) and B (angle of reflection) are related. You need not use all the materials. Describe your experiment in enough detail that another person could reproduce it. How many different incident angles would be needed to be confident in the relationship between A and B?



   b. Describe your results.

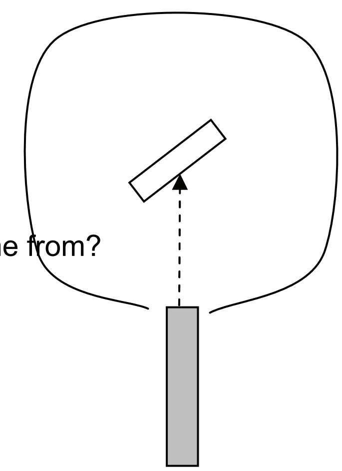
3. Obtain a Lucite (a plastic used for optics) triangle and another piece of paper. Cut the paper lengthwise into 2 pieces and tape it to create a circular screen of about 20cm diameter. Leave a gap for the laser to shine through (see picture, below). Place the triangle in the center of the circle.

a. Predict what would happen to the laser beam if it were shined through the side of the Lucite triangle, as in the sketch below:

Test your prediction and describe the results:

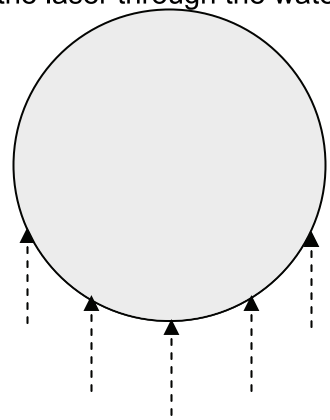
b. Now try rotating the triangle about a vertical axis. Avoid the cases where the laser shines through an edge—these are more complex. You should see three laser "images" on the screen. How do these images move as the triangle is rotated? Hint: examine the one that goes "straight through" very closely.

c. How can you explain these movements and where the three images come from?



d. In #2, above, you found a relationship between the angles of incidence and reflection. Examine the paths of the laser for the Lucite triangle, and draw a picture to show how this law applies.

4. Shine the laser through the side of the beaker and cloudy water, below the water line. Look at the path of the laser from above.
As you change the direction of the laser pointer from the center of the beaker to the edge, examine how the resulting laser beam changes direction in the water.
On the diagram, sketch the path of the laser through the water for each case.



5. Now put the beaker inside the "surround screen." To simulate step 4, you can either aim the laser at different parts of the beaker, or slide the beaker left-right.

   a. What laser projections do you see now? Hint: one of the paths/projections is much fainter than the others, especially through the water.

   b. How can you explain these movements and where the three images come from? Draw a picture (as seen from above) to show how the reflection is occurring.

   c. Now point the laser through the beaker *above the water line*. Is the light bent more or less without the water?

Discussion: Reflection and Refraction

A *reflection* occurs whenever light encounters a surface. The reflection is called *specular* if the surface is smooth (like a mirror) and *diffuse* if it is rough (like a movie screen). Specular reflection isn't all that complicated, as you showed in part 2, except that it can happen at multiple surfaces, leading to more reflections than you might expect.

In binoculars and camera lenses, special coatings are applied to the surfaces of the lenses to minimize reflections, since these reflections reduce light transmission and degrade the image. The usual single coating absorbs the middle of the spectrum of reflected light and only allows red and violet to be reflected; this is why the coatings appear to be purple.

Refraction is the bending of light when it passes between different materials. Fundamentally, light bends because the speed of light varies in different materials: it is fast in air but slower in water, plastic, or glass. The amount of bending (and slowing) of light is described by the *index of refraction*. The higher the index, the more the bending (and slowing):

Medium	**Index of Refraction**
Air	1.00
Water	1.33
Lucite	1.51
Glass (regular)	1.52
Glass (optical)	1.66
"High Index" eyeglass plastic	1.66
Diamond	2.42

When light goes from air to glass it must slow down, and it so happens that it bends towards the perpendicular of the surface when it does so. Conversely, when light goes from glass to air, it speeds up and bends away from the perpendicular.

Question:

In parts 3 and 5 above, explain how refraction affected the path of the laser beam.

Lenses

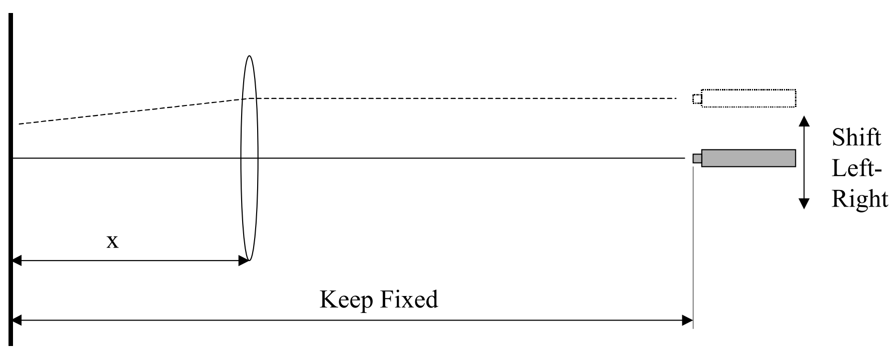
Obtain 3 lenses (marked #1, #2, #3), a laser, a meter stick, and a white screen.

1. a. Look at the surfaces of the three lenses. Two are convex (like the beaker) and one is concave (like a “cave”). You can use the meter stick to see the concave surface better. Look at lenses #1 and #2 from the side. How do the curvatures of the surfaces compare? If you have eyeglasses, check out what kind of lenses they are, too.

b. Experiment with the three lenses to get a feel for their magnification individually and in combination (e.g., #1 and #2 together, etc.). Holding the lenses a few inches off this paper works well. Make predictions and test (e.g., "1 and 2 together will be stronger than lens ___ but weaker than ___")

Combination	**Prediction**	**Result**
1 and 2		
1 and 3		
2 and 3		

2. a. Start with the convex lens #1. Holding the laser horizontally on the table, point the beam through the lens held vertically (see diagram below). Shine the beam on a piece of paper/cardboard about 20 centimeters on the other side of the lens (x=20cm). Keep the laser horizontal and describe what happens to the spot on the paper as you raise the beam; as you lower the beam; as you shift it left or right. Also, keep the distance from the laser to the paper fixed.



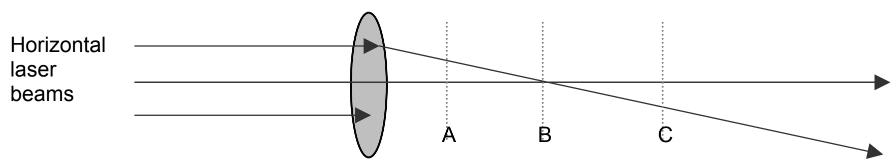
b. Change x to 5cm, and describe what happens.

c. Find the distance, x, where nothing happens as you shift the horizontal beam left and right (try to keep the laser beams parallel to each other). Record this special distance x_f.

d. Now turn the room lights off, and move away from the windows. Allow the window light to shine through the lens and onto a piece of paper/cardboard. Vary the dimension, x, and describe what you see. Record the x_f that produces a clear image. Compare it to that in part c, above.

3. a. Switch to the thinner lens, marked "2", and repeat step d, above. How is the image different?

4. A SCIENTIFIC MODEL:



When the paper is held at C, explain why the dot on the paper moves up and down as the laser moves down and up (opposite).

When the paper is held at B, explain why the dot on the paper doesn't move when the laser moves.

When the paper is held at A, explain why the dot on the paper moves up and down as the laser moves up and down.

5. How is x_f related to:

a. The strength of magnification?

b. The curvature of the lens?

c. The amount the lens bends the laser light?

Experiment 12: Magnetism

Permanent Magnets

1. You need the following materials: several sheets of paper,
   metal bar magnet with poles marked
   unmarked ceramic magnet
   small magnetic compass

2. Place the bar magnet flat in the center of the paper and draw around it. Mark the poles.

3. Place the compass at various positions around the magnet. For each position, draw an arrow showing the direction that the compass pointed. (at least 20 points)

4. Place the magnet on its side in the center of another piece of paper. Draw around it and mark the poles.

5. Repeat #3.

6. Place the ceramic magnet on a piece of paper and repeat #3 and #4.

7. Where are the north and south poles of this magnet. Explain how you know.

   ____

   ____

Electromagnets

1. You need the following materials: battery
   lead wire
   small magnetic compass
   masking tape

2. Wrap the lead wire several times around the compass and tape in place. (You need to be able to see the compass needle.) Connect the lead to the batteries and observe the compass needle. Repeat this 2 more times with the wire wound around the compass in different directions. Start each time with the compass in the same direction.

Observation #1 ____

Observation #2 ____

Observation #3 ____

Note: Your description of the wire winding must clearly show the direction it is wound, the battery polarity of the ends, and the north pole of the magnet.