ISLE labs for Physics 9

The inspiration for these labs comes from the PAER group at Rutgers

General Information:

There are 3 types of Investigative Science Learning Environment (ISLE) labs: observation experiments, testing experiments, and application experiments.

Observation experiments are intended for students to learn skills such as changing one variable at a time, clearly recording and representing observations, and making accurate observations without mixing them with explanations. This is the first step of the experimental cycle, and allows you to observe phenomena, look for patterns in data, and start to devise explanations (once observations are carefully completed).

The next step, once explanations have been devised, is to do testing experiments, which is an independent test students design that will test a hypothesis *based on* a specific explanation or rule. This helps you practice the skill of making predictions about the outcome of an experiment based on an explanation/rule/relationship. For a testing experiment, you can't just do the experiment and record what happens – they must have a predicted outcome based on some explanation – and if the outcome of the experiment agrees with the prediction it gives confidence that the explanation may be correct, but if it disagrees, then you know the explanation is incorrect. In order to make this judgment, you also need to apply basic uncertainty calculations. (A guide for understanding uncertainty is included in this packet.)

The third type of experiment is the application experiment, where you apply some explanation/rule/relationship that you have tested enough that you think it is 'good', and you apply it to understand a new situation. Some application experiments require that you determine some unknown quantity multiple ways – in order to determine if the methods are consistent, it is necessary to apply basic uncertainty analysis.

By performing this sequence of experiments, it is possible to explore and devise a physics relationship, test it, and when you are convinced it is good, apply it to understand a new situation – providing you with a complete understanding of the basic physics relationships (equations). By designing your own experiments, it gives you creative control, and assures that you understand the steps that you perform, as they are done by your conscious choice, and not by following instructions or 'playing around.'

Lab write-ups:

There is one lab write-up per group, each group member must put their name at the top of the write-up in order to obtain credit. Since the ISLE labs are labs you design yourself, and are intended to help you learn specific skills such as justifying your conclusions, comparing results, and understanding how uncertainty comes into play, it is important that you explain your work carefully in the form of a lab write-up. The lab write-up is done *in the lab*, there is nothing for you to do after the lab period. The write-up is not formal, but does need to be clear. Your lab may have specific questions for you to answer, or specific statements of tasks to complete, in which case you need to answer and document those things in your write-up. The lab will include a general set of bullet points that always need to be addressed within your write-up. Those general bullet points are specific to the type of experiment: observation, testing, or application. Abide by the bullet guidelines as closely as possible, and by all means read ahead and/or make preliminary tests of the equipment if it helps to abide by them. However, if something you do or observe seems more appropriately addressed in a different bullet, it is okay. Just don't skip anything.

Do not make the mistake of writing too much in your lab reports. Your information does not need to be presented in paragraph form, or often, even in complete sentences. You can use equations instead of trying to write the math out in words. Your reports should have a few sentences or bullet points, equations and/or diagrams where appropriate. You should address the required points succinctly and clearly. Your reports should not be lengthy or wordy. This is good practice in science writing and will also save both you and the grader valuable time.

Grading:

If you do not pass the lab, you do not pass the course. Your TA will grade your lab write-up based on some subset of the items you are asked to include. Each item will be graded out of a possible of 3 points. 0 points means the item is not included in the report. 1 point means the item is included, but incompletely, or incorrectly. 2 points means the item is included, but with some small mistake, or it isn't completely explained. 3 points means it is correct and complete. Roughly 5-9 items will be chosen for grading each week. There is a set of "rubrics" for you and for the TA to use to evaluate your work. You are strongly encouraged to check your write-up with the rubrics while you are doing the lab. They are not just used for grading, but are also intended to help you fully understand the skills you are to develop and demonstrate, and to help you assess and improve the quality of your work. You TA will further discuss grading policies.

Conclusion:

Lab is not for testing your knowledge, but is a place for developing it. Take advantage of the time to explore the physics relationships to your own satisfaction, make sure your work makes sense to you, and use your TA as a resource to make sure you leave the lab with a good understanding of the material.

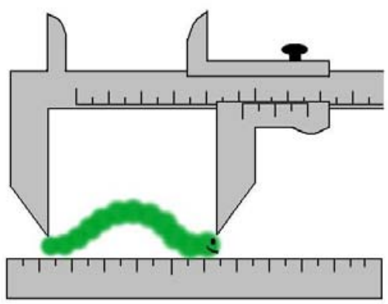
EXPERIMENTAL UNCERTAINTIES

No physical quantity can be measured exactly. One can only know its value with a certain range of uncertainty. This fact can be expressed in the standard form $X \pm \Delta X$. This expresses the experimenter's judgment that the "true" value of X lies between $X - \Delta X$ and $X + \Delta X$.

Uncertainties of measurements

1. Instrumental uncertainties

Every measuring instrument has an inherent uncertainty that is determined by the *precision of the instrument.* Usually this value is taken as a half of the smallest increment of the instrument scale. That is 0.5 millimeter is precision of a ruler, 0.5 sec is precision of a watches etc.



Instrumental uncertainties are the easiest one to estimate, but unfortunately they are not the only source of the uncertainty in your measured value.
You must be a very skillful and lucky experimentalist to get rid off all other sources and to have the measurement uncertainty equal to the instrumental one.

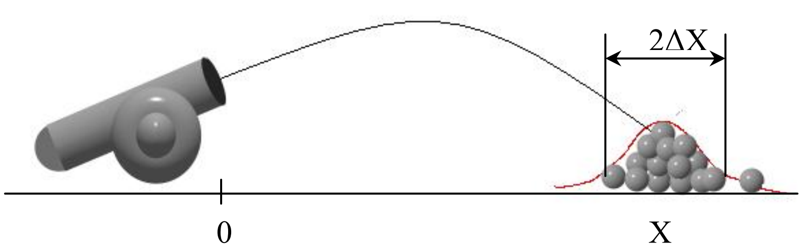
2. Random uncertainties

Sometimes when you measure the same quantity you can get different results each time you measure it. That happens because different incontrollable factors affect your results randomly. This type of uncertainty, ***random uncertainty,*** can be estimated only by repeating the same measurement several times. For example if you measure the distance at which cannonball hits the ground, you could get different distances every time you repeat the same experiment. For example, say you took three measurements and obtained 50 m, 51 m, and 49 meters. To estimate the ***absolute value of the random uncertainty*** you first find the average of your measurements:

$X = (50\text{m} + 51\text{m} + 49\text{m}) / 3 = 50$ m.

You then *estimate approximately* how much the values are spread with respect to this average – in this case we have a spread of about $\Delta X = 1$ m. That is, our measurement of the distance was

$X = 50$ m $\pm$ 1 m.

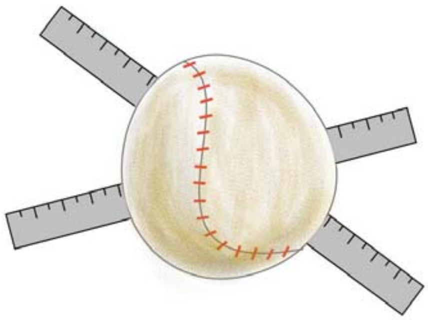


Most cannonballs will get into the range from $X-\Delta X$ to $X+\Delta X$.

Thus multiple trials allow you to find the average value and to estimate the uncertainty range.

3. Effect of assumptions

Assumptions inherent in your model may also contribute to the uncertainty of the desired quantity. For example, you wish to find the speed of the ball moving on the floor. You are assuming that a ball moves along a straight line while in fact the surface of the floor in bumpy and the bumps contribute significantly to the distance that the ball covers and thus decrease the speed that that you calculate. Repeating the measurement will not let you get rid off the bumpiness of the floor and will contribute to the uncertainty with which you will determine the value of the speed. This type of uncertainties is not so easy to recognize and to evaluate. First of all, you have to determine the sign of the effect, i.e. whether the assumption increases the value of the quantity, decreases it or affects it randomly. Then try to estimate the size of the effect.



For example, you measure the diameter of the baseball assuming it is perfect sphere. However, the real size of the ball may differ by 1÷2mm if you measure in different dimensions. This difference will determine the uncertainty of your measurement.

It is difficult to give strict rules and instructions on how to estimate uncertainties in general. Each case is unique and requires thoughtful approach. Be ingenious and reasonable.

Comparison uncertainties

If you are comparing the uncertainties in the values of two quantities then by analyzing the absolute uncertainty ranges you cannot tell which of the measurements is more accurate because the units of the measured quantities are different. How can we decide then which quantity has a larger uncertainty? Here we need to compare **relative uncertainties**, the ratio of the **absolute** uncertainty and the quantity itself $\Delta X / X$. This may be expressed as a fraction or as a percentage by multiplying the ratio by 100%.

The sizes of the circles at the picture are determined with different accuracy.

The absolute size of the soft edge (9 units) is the same for both blue circles. However the large blue circle (90 units) looks sharper than the small one (30units). That happens because we compare **relative** uncertainties, which are 10% for the large circle and 30% for the small one.

Note: Common sense and good judgment must be used in representing the uncertainties when stating a result. Consider a temperature measurement with a thermometer known to be reliable to ± 0.5 degree Celsius. Would it make sense to say that this causes a 0.5% uncertainty in measuring the boiling point of water (100 degrees) but a whopping 10% in the measurement of cold water at a temperature of 5 degrees? Of course not! (And what if the temperatures were expressed in degrees Kelvin? That would seem to reduce the relative uncertainty to insignificance!). However in most calorimetry tasks value of interest is not temperature itself but only the change of the temperature or the temperature difference.

Reducing uncertainties

The example with the circles shows a way to reduce the relative uncertainty in your measurement. The same absolute uncertainty yields the smaller relative uncertainty if the measured value is larger.

Suppose you have a bob attached to a spring and want to measure time for it to oscillate up and down, back to its starting position. If you are using a watch to measure some time interval, the absolute uncertainty of the measurement will be 0.5 s. If you now measure the time needed for the bob to go up and down one, you get 5 s. This means that you have a relative uncertainty of 10% in the time measurement. What if you measured the time for 5 oscillations instead? Say you measure the time for 5 oscillations and get 25 s. The instrumental uncertainty is *still* 0.5 s! The ***relative uncertainty*** in your measurement of the time interval is now: time relative uncertainty = (0.5 s/25 s) *100% = 2%

By measuring the time for a longer time period, you have managed to reduce the uncertainty in your time measurement by a factor of 5!

Of course you should not forget about the obvious way of reducing relative uncertainties by minimizing absolute uncertainty with better design, decreasing effect of assumptions or increasing the accuracy of instrument if it is possible.

Uncertainty in calculated value

It is important to estimate data uncertainties because uncertainties propagate through the calculations to produce uncertainty in results.

Consider now the following example. Suppose you know the average mass of one apple m with the uncertainty Δm. If you want now to calculate the mass of the basket of the 100 apples you will get the value $M \pm \Delta M = 100m \pm 100\Delta m$. It means that ***relative*** uncertainty of calculated value M remains the same as the relative uncertainty of the single measured parameter m

$\Delta M / M = \Delta m / m$.

If you have more than one measured parameter, estimating uncertainty of the result may be more complicated. However, if one of your sources of uncertainty is **much larger** than the others (comparing ***relative*** uncertainties!) then you can neglect other sources and use the **weakest link rule.**

Weakest link rule

The percent uncertainty in the calculated value of some quantity is at least as great as the greatest percentage uncertainty of the values used to make calculation.

Thus to estimate uncertainty in you calculated value you have to:

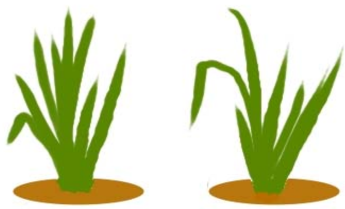
1. Estimate the ***absolute uncertainty*** in <u>each</u> measured quantity used to find calculated quantity.
2. Calculate the ***relative percentage uncertainty*** in each measured quantity.
3. Pick out the largest percentage uncertainty. This will be the percent uncertainty in your calculated quantity.

Comparable uncertainties

In case you have measured values with comparable uncertainties the rules are more complicated: they depend on the type of the mathematical relationship you use for calculation. In the most frequent case of multiplying two values their relative uncertainties add. One of the consequences of this rule is that the raising to the second power doubles the relative uncertainty and the raising to the third power triples it. Thus, in the example above, the relative uncertainty in the calculated volume of the baseball will be three times larger then the relative uncertainty in the measured radius.

Why do you need to know uncertainty?

Is the measured value in agreement with the prediction? Do the data fit the physical model? Are two measured values the same? You cannot answer these questions without considering the uncertainties of your measurements. Indeed, how can you compare two values if the difference between them is smaller than the uncertainty in their measurement?



Which bunch of grass is higher? You cannot tell this because their heights are determined with the uncertainty larger than the height difference. If you cannot tell which of two values are larger you can claim them the same.

Thus to make judgment about two values X and Y you have to find the ranges where these values lie. If the ranges $X \pm \Delta X$ and $Y \pm \Delta Y$ overlap you can claim the values X and Y the same within your experimental uncertainty.

Summary

When you are doing a lab and measuring some quantities to determine an unknown quantity:

- Decide which factors affect your result most.
- Wherever possible try to reduce effects of these factors.
- Wherever possible, try to reduce uncertainties by measuring longer distances or times etc.
- Decide what the absolute uncertainties of each measurement are.
- Then find the relative uncertainties of each measurement.
- If one uncertainty is much larger than the others you can ignore all other sources and use this uncertainty to write the value of the uncertainty of the quantity that you are calculating.
- Find the range where your result lies. Make a judgment about your results taking into the account the uncertainty.

Ability to design and conduct an observational experiment					
Scientific Ability		**Missing**	**Inadequate**	**Needs some improvement**	**Adequate**
1	**Is able to identify the phenomenon to be investigated**	No mention is made of the phenomenon to be investigated.	An attempt is made to identify the phenomenon to be investigated but is described in a confusing manner.	The phenomenon to be investi-gated is described but there are minor omissions or vague details.	The phenomenon to be investigated is clearly stated.
2	**Is able to design a reliable experiment that investigates the phenomenon**	The experiment does not investigate the phenomenon.	The experiment involves the phenomenon but due to the nature of the design it is likely the data will not contain any interesting patterns.	The experiment investigates the phenomenon and it is likely the data will contain interesting patterns, but due to the nature of the design some features of the patterns will not be observable.	The experiment investigates the phenomenon and there is a high likelihood the data will contain interesting patterns. All features of the patterns have a high likelihood of being observable.
3	**Is able to decide what is to be measured and identify independent and dependent variables**	The chosen measurements will not produce data that can be used to achieve the goals of the experiment.	The chosen measurements will produce data that can be used at best to partially achieve the goals of the experiment.	The chosen measurements will produce data that can be used to achieve the goals of the experi-ment. However, independent and dependent variables are not clearly distinguished.	The chosen measurements will produce data that can be used to achieve the goals of the experiment. Independent and dependent variables are clearly distinguished.
4	**Is able to use available equipment to make measurements**	At least one of the chosen measurements cannot be made with the available equipment.	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.
5	**Is able to describe what is observed without trying to explain, both in words and by means of a picture of the experimental set-up.**	No description is mentioned.	A description is mentioned but it is incomplete. No picture is present. Or, most of the observations are mentioned in the context of prior knowledge.	A description exists, but it is mixed up with explanations or other elements of the experiment. A labeled picture is present. Or some observations are mentioned in the context of prior knowledge.	Clearly describes what happens in the experiments both verbally and by means of a labeled picture.
6	**Is able to identify the shortcomings in an experimental design and suggest improvements**	No attempt is made to identify any shortcomings of the experimental design.	An attempt is made to identify shortcomings, but they are descri-bed vaguely and no suggestions for improvements are made.	Some shortcomings are identified and some improvements are suggested, but not all aspects of the design are considered.	All major shortcomings of the experiment are identified and specific suggestions for improvement are made.
Ability to construct, modify, and apply relationships or explanations					
7	**Is able to construct a mathematical (if applicable) relationship that represents a trend in data**	No attempt is made to construct a relationship that represents a trend in the data.	An attempt is made, but the relationship does not represent the trend.	The relationship represents the trend but no analysis of how well it agrees with the data is included (if applicable), or some features of the relationship are missing.	The relationship represents the trend accurately and completely and an analysis of how well it agrees with the data is included (if applicable).
8	**Is able to devise an explanation for an observed relationship**	No attempt is made to explain the observed relationship.	An explanation is made but it is vague, not testable, or contradicts the observations.	An explanation is made and is based on simplifying the pheno-menon but uses flawed reasoning.	A reasonable explanation is made and is based on simplifying the phenomenon.
9	**Is able to identify the assumptions made in devising the explanation**	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	Most assumptions are correctly identified.	All assumptions are correctly identified.

Rubric B

Ability to design and conduct a testing experiment (testing an idea/hypothesis/explanation or mathematical relation)					
	Scientific Ability	**Missing**	**Inadequate**	**Needs some improvement**	**Adequate**
1	**Is able to identify the hypothesis to be tested**	No mention is made of a hypothesis.	An attempt is made to identify the hypothesis to be tested but is described in a confusing manner.	The hypothesis to be tested is described but there are minor omissions or vague details.	The hypothesis is clearly stated.
2	**Is able to design a reliable experiment that tests the hypothesis**	The experiment does not test the hypothesis.	The experiment tests the hypothesis, but due to the nature of the design it is likely the data will lead to an incorrect judgment.	The experiment tests the hypothesis, but due to the nature of the design there is a moderate chance the data will lead to an inconclusive judgment.	The experiment tests the hypothesis and has a high likelihood of producing data that will lead to a conclusive judgment.
3	**Is able to distinguish between a hypothesis and a prediction**	No prediction is made. The experiment is not treated as a testing experiment.	A prediction is made but it is identical to the hypothesis.	A prediction is made and is distinct from the hypothesis but does not describe the outcome of the designed experiment.	A prediction is made, is distinct from the hypothesis, and describes the outcome of the designed experiment
4	**Is able to make a reasonable prediction based on a hypothesis**	No attempt to make a prediction is made.	A prediction is made that is distinct from the hypothesis but is not based on it.	A prediction is made that follows from the hypothesis but does not incorporate assumptions	A prediction is made that follows from the hypothesis and incorporates assumptions.
5	**Is able to identify the assumptions made in making the prediction**	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but the assumptions are irrelevant or are confused with the hypothesis.	Relevant assumptions are identified but are not significant for making the prediction.	All assumptions are correctly identified.
6	**Is able to determine specifically the way in which assumptions might affect the prediction**	No attempt is made to determine the effects of assumptions.	The effects of assumptions are mentioned but are described vaguely.	The effects of assumptions are determined, but no attempt is made to validate them.	The effects of the assumptions are determined and the assumptions are validated.
7	**Is able to decide whether the prediction and the outcome agree/disagree**	No mention of whether the prediction and outcome agree/disagree.	A decision about the agreement/disagreement is made but is not consistent with the outcome of the experiment.	A reasonable decision about the agreement/disagreement is made but experimental uncertainty is not taken into account.	A reasonable decision about the agreement/disagreement is made and experimental uncertainty is taken into account.
8	**Is able to make a reasonable judgment about the hypothesis**	No judgment is made about the hypothesis.	A judgment is made but is not consistent with the outcome of the experiment.	A judgment is made and is consistent with the outcome of the experiment but assumptions are not taken into account.	A reasonable judgment is made and assumptions are taken into account.
9	**Is able to revise the hypothesis when necessary**	A revision is necessary but none is made.	A revision is made but the new hypothesis is not consistent with the results of the experiment.	A revision is made and is consistent with the results of the experiment but other relevant evidence is not taken into account.	A revision is made and is consistent with all relevant evidence.

Rubric C

	Scientific Ability	Missing	Inadequate	Needs some improvement	Adequate
	Ability to design and conduct an application experiment				
1	**Is able to identify the problem to be solved**	No mention is made of the problem to be solved.	An attempt is made to identify the problem to be solved but it is described in a confusing manner.	The problem to be solved is described but there are minor omissions or vague details.	The problem to be solved is clearly stated.
2	**Is able to design a reliable experiment that solves the problem**	The experiment does not solve the problem.	The experiment attempts to solve the problem but due to the nature of the design the data will not lead to a reliable solution.	The experiment attempts to solve the problem but due to the nature of the design there is a moderate chance the data will not lead to a reliable solution.	The experiment solves the problem and has a high likelihood of producing data that will lead to a reliable solution.
3	**Is able to use available equipment to make measurements**	At least one of the chosen measurements cannot be made with the available equipment.	All of the chosen measurements can be made, but no details are given about how it is done.	All of the chosen measurements can be made, but the details about how they are done are vague or incomplete.	All of the chosen measurements can be made and all details about how they are done are provided and clear.
4	**Is able to make a judgment about the results of the experiment**	No discussion is presented about the results of the experiment	A judgment is made about the results, but it is not reasonable or coherent.	An acceptable judgment is made about the result, but the reasoning is flawed or incomplete.	An acceptable judgment is made about the result, with clear reasoning. The effects of assumptions and experimental uncertainties are considered.
5	**Is able to evaluate the results by means of an independent method**	No attempt is made to evaluate the consistency of the result using an independent method.	A second independent method is used to evaluate the results. However there is little or no discussion about the differences in the results due to the two methods.	A second independent method is used to evaluate the results. Some discussion about the differences in the results is present, but there is little or no discussion of the possible reasons for the differences.	A second independent method is used to evaluate the results. The discrepancy between the results of the two methods, and possible reasons are discussed. A percentage difference is calculated in quantitative problems.
6	**Is able to identify the shortcomings in an experimental design and suggest specific improvements**	No attempt is made to identify any shortcomings of the experimental design.	An attempt is made to identify shortcomings, but they are described vaguely and no specific suggestions for improvements are made.	Some shortcomings are identified and some improvements are suggested, but not all aspects of the design are considered.	All major shortcomings of the experiment are identified and specific suggestions for improvement are made.
	Ability to construct, modify, and apply relationships or explanations				
7	**Is able to choose a productive mathematical procedure for solving the experimental problem**	Mathematical procedure is either missing, or the equations written down are irrelevant to the design.	A mathematical procedure is described, but it is incomplete, due to which the final answer cannot be calculated.	Correct and complete mathematical procedure is described but an error is made in the calculations.	Mathematical procedure is fully consistent with the design. All quantities are calculated correctly. Final answer is meaningful.
8	**Is able to identify the assumptions made in using the mathematical procedure**	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	Most assumptions are correctly identified.	All assumptions are correctly identified.
9	**Is able to determine specifically the way in which assumptions might affect the results**	No attempt is made to determine the effects of assumptions.	An attempt is made to determine the effects of some assumptions, but most are missing, described vaguely, or incorrect.	The effects of most assumptions are determined correctly, though a few contain errors, inconsistencies, or omissions.	The effects of all assumptions are correctly determined.

Rubric D

Physics 9C Lab Schedule

	Mon	Tue	Wed	Thu	Fri
Jan 4-8	Lab 1	Lab 1	Lab 1	Lab 1	Lab 1
Jan 11-15	Lab 2	Lab 2	Lab 2	Lab 2	Lab 2
Jan 18-22					
Jan 25-29	Lab 3	Lab 3	Lab 3	Lab 3	Lab 3
Feb 1-5	Lab 4	Lab 4	Lab 4	Lab 4	Lab 4
Feb 8-12	Lab 5	Lab 5	Lab 5	Lab 5	Lab 5
Feb 15-19					
Feb 22-26	Lab 6	Lab 6	Lab 6	Lab 6	Lab 6
Feb 1-Mar 4	Lab 7	Lab 7	Lab 7	Lab 7	Lab 7
Mar 7-11	Lab 8	Lab 8	Lab 8	Lab 8	Lab 8

Physics 9C Lab 1: Charge

I. Observation Experiment: Sign of Charge

Some bullets have a parenthetical indicator, for example (O2), which refers to ***O***bservation experiment ability 2 in the guidelines you have for Observational, Testing, and Application experiments. All bullets, whether so designated or not, must be addressed in your lab write-up, and a random subset will be graded. *Don't forget this; it applies to all labs this quarter.*

It is known that an acrylic (clear plastic) rod rubbed with cloth is positively charged. Using this information, design experiments to determine if the following objects are uncharged, positively charged or negatively charged. When you conduct your experiments, be careful that the objects you are touching are isolated from other objects.

Styrofoam board rubbed with cloth.

Piece of scotch tape that is first stuck to the tabletop and then pulled off.

Piece of scotch tape stuck atop a second piece stuck to the table, then the top one pulled off.

At least one other nonmetallic object (2 liter bottle, PVC rod) rubbed with cloth.

Include the following in your report:

a. (O4) Briefly describe how you will make use of the available equipment to make your observations.

Perform the experiments.

b. (O5) Describe what is observed (without trying to explain). Include a data table.
c. (O7) Using your data, state any trends you found in your observations.
d. (O8) Devise an explanation for your observed trends.
e. (O9) Identify any assumptions made in devising the explanation.
f. If your observations raise questions you haven't yet addressed and can be fairly easily tested, proceed with tests and report the findings. Did they confirm your previous observations or did you need to make corrections?
g. (O6) Identify shortcomings of your experimental design by listing the sources of experimental uncertainty. Describe improvements you could and/or did make to minimize them.

Please: Remove any tape from the table when you're done in today's lab.

II. Testing Experiment: Charge in a Conductor

A textbook says that metallic objects such as aluminum cans have electrically charged particles that can freely move inside, and that insulating objects such as plastic bottles do not have freely moving charged particles. Design an experiment to test this using any equipment at your table: cans, plastic bottles, tape, foil, and/or any objects from experiment 1.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

Include the following in your report:

a. (T1) Identify the hypothesis (rule) to be tested.
b. (T2) Design a reliable experiment that tests the hypothesis including a brief description of your procedure.
c. Draw a labeled sketch of the experimental set-up.
d. (T4) Make a prediction about the outcome of the experiment based on the hypothesis.
e. (T5) Identify the assumptions made in making the prediction. What assumptions about the objects, interactions, and processes you need to make to solve the problem?

Perform the experiment.

f. Clearly record the outcome of your experiment.
g. (T7) Decide whether the prediction and the outcome agree/disagree.
h. (T8) Make a reasonable judgment about the hypothesis based on your experimental outcomes and the assumptions you made.
i. Fill out a table with the arguments and evidence for testing your hypothesis Look at the example provided below.

    Explanation/ Hypothesis : If …

    Experiment design : and I do this…

    Predicted outcome : then …

    Observed outcome : And I saw/But I saw …

    Conclusion (hypothesis supported or not) : Therefore …

III. Observation Experiment: Forces on a Pith Ball

Hang a very small wad of tin foil (tape the string's top to the horizontal rod) within 1 cm of a smooth, charged, metal object, such as the side of your soda can. (Make sure the metal object is isolated.) Put your finger within 1 cm on the other side of the wad. Let the wad touch the metal, then try to get it oscillating between the metal and your finger, without you physically swinging/pushing it.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (O4) Briefly describe how you will make use of the available equipment to make your observations

Perform the experiment.

b. (O5) Describe what is observed, without trying to explain.
c. (O8) Devise an explanation for your observations.
d. What evidence do you have to support whether or not your finger is a conductor?
e. (O9) Identify any assumptions made in devising the explanation.

Physics 9C Lab 2: Electric Potential and Field

Most relevant text references: Chapters 22&23.

I. Background Information: The relationship between potential and field

A "field" can have different values at each point in space. For a "vector field," that value is a vector, and for a "scalar field" it is a scalar. Electrostatics deals with a vector field $\vec{E}(x,y,z)$ called electric field, measured in N/C, and a scalar field $V(x,y,z)$ called electric potential, measured in J/C (Volts), *and they are intimately related—one can be found from the other.*

$$\vec{E} = -\vec{\nabla} V$$

To understand the relationship, it's worthwhile to consider a familiar case that's quite similar: gravity. There, the vector field is gravitational field $\vec{g}(x,y,z)$, in N/kg (aka m/s^2), and the corresponding scalar field is gravitational potential energy per unit mass $V_g(x,y,z)$, in J/kg. The corresponding relationship is

$$\vec{g} = -\vec{\nabla} V_g$$

In the simplest example, near Earth's surface, we know that the gravitational energy per unit mass is $V_g = mgy / m = gy$. The gradient of this increasing function of *y* has a direction upward, and its magnitude is $d(gy) / dy = g$, so we would conclude from the relationship above that the corresponding vector field has magnitude g and is downward, which is of course correct. Your TA will discuss the idea further, with an additional example or two.

Two important questions

1: If you had an "equipotential surface", i.e., a curve or surface where the value of *V* (either gravitational or electrostatic) is constant, could you say what angle the field would make with that surface? The answer is in the above formulas.

2: For a vector field, "field lines" represent the field not with arrows, but continuous lines (which never cross) that would pass through those arrows. Is there a relationship between the spacing of field lines and the field's strength? Think of a planet's gravitational field.

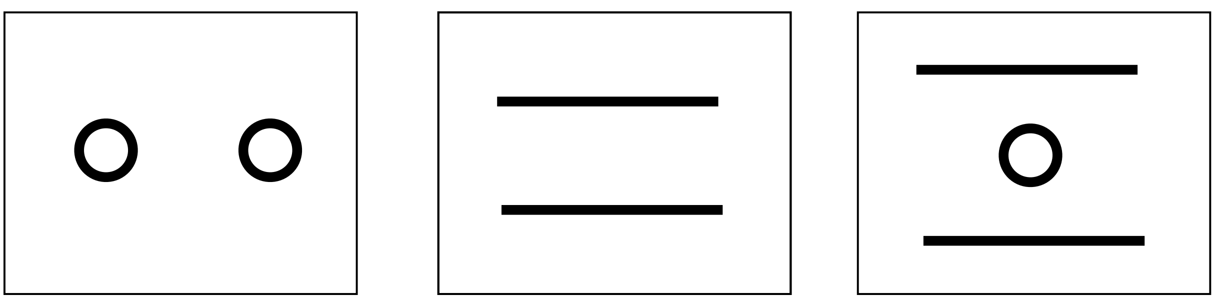
II. Observation Experiment: Potential and Field, Various Cases

You have a plastic tray, water to pour in a fairly thin layer (~1/2") in the tray, and straight and round electrodes. When a potential difference Δ*V* is established across the electrodes, an electric field is established in the water. Since water is a conductor (if a poor one), while air and glass are not, and the electric current is always parallel to the electric field, the electric field lines will be strictly in the two-dimensional plane of the water. In this experiment you are to map equipotential curves in the water, and from these explore the relationship between electric potential and electric field.

You'll map equipotentials with a multitester and graph paper, which you can print from a file on the lab computers. The graph paper should be placed underneath the tray. Actually, it's probably best to print *multiple* copies, and while one lab partner finds points of different potential on the under-tray graph paper, another can transcribe the readings to another/"external" piece.

In preparation, open the computer file "Field and Potential 5V RMS," which when "ON" is selected sends a 5V rms signal to Ouput 1 of the Pasco Universal Interface. Set the rotary dial on your multitester to 20(V) in the ~V (meaning AC volts) sector. (Note: This lab uses AC, not DC, to avoid some asymmetries as well as electroplating of our electrodes. It's a sinewave of 7.07V amplitude and thus a 5V "rms voltage," which is what the multitester reads. For the purposes of drawing conclusions today, you can treat it as DC.)

Consider the geometries shown below. Arrange electrodes as shown, then connect two "leads" (wires), one from each Output 1 jack to an electrode via alligators clips. *Don't let the electrodes touch, or otherwise "short out" the Output!* Connect another lead from the multitester COM jack to the power supply's negative/black jack, and a somewhat pointier lead, which we call a "probe," in the multitester VΩ jack. This way, *the probe will indicate the potential at any chosen point relative to "ground"* (the power supply negative). Your setup makes the electrodes 0V and 5V equipotentials, and you are to map others. Find sufficient points in the water layer at 1V to enable you to sketch a smooth 1V equipotential through them on your external graph paper. Then move to 2V, 3V, and 4V. Also make sure to indicate on your graph paper where the electrodes themselves are.



~12-15cm apart | ~10cm apart | electrodes ~15cm apart, isolated cylinder between

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (O3) Decide what is to be measured and identify independent and dependent variables.

Perform the experiments, each with new "external" graph paper.

b. From your equipotentials, sketch out representative electric field lines. Explain how the relationship between potential and field is involved.
c. Describe the shape of the electric field, and explain why it should have this shape.

d. For the “point charges” geometry, identify regions of higher and lower electric field, and explain how you know.
e. For the “parallel plates” geometry, devise a mathematical relationship for both the potential and the electric field between the plates (not near the edges).
f. (O6) Identify shortcomings and sources of experimental uncertainty in the experiment. Describe improvements you could and/or did make to minimize them.

III. Application Experiment: The field between concentric cylinders

A controversy has arisen: whether the electric field in a thin conductive layer between a small circular electrode and a larger concentric one would be proportional to $1/r^2$ or to $1/r$ when a potential difference (voltage) is applied between them. Design an experiment to address the controversy. You have the equipment from before, plus a large metal ring.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

Include the following in your report:

a. (A1) Identify the problem to be solved.
b. (A2&A3) Design a reliable experiment that solves the problem and discuss how you will use the available equipment to make the measurements.
c. Draw and label appropriately a sketch of your experimental design.
d. (A7) Describe the mathematical procedures you will use.
e. (A8) Identify the assumptions made in using the mathematical procedure.
f. What are the possible sources of experimental uncertainty? How could you minimize them?

Perform the experiment.

g. Record the outcome of your experiment. [Note: The spreadsheet “Simple Plot and Trendline” is on the computer. Use it as you wish. As an example, though unlikely, if you suspected $V(r)$ to be proportional to r^3, then a plot of $V(r)$ versus r^3 should be a straight line, and this would imply that the electric *field* would behave how?]
h. (A4) Make a judgment about the results of your experiment.
i. (A6) Identify any shortcomings in the experiment and suggest specific improvements.

Physics 9C Lab 3: Capacitors

Most relevant text references: Chapter 24.

I. Testing Experiment: Capacitance

Capacitance has a definition. Design an experiment that tests whether that relationship seems to hold for capacitors *in series*. You have a multitester, a 9V "battery" (actually, it's a small black box with red and black jacks, connected to a plug-in power supply, but behaves like a battery that doesn't run down), a capacitor of one value and another whose capacitance is 0.47 times as large, but neither of which is known to better than about 15%. The two capacitors are mounted adjacent to each other in one corner of a "component board" and have red and black jacks. (Don't use the larger capacitor with red and black jacks in a different corner.) All capacitors in this lab are "electrolytic," meaning that they contain an electrolyte. Though capacitors usually behave the same way independent of the polarity, an electrolytic works properly only when positive charge goes in its positive "terminal" and negative charge in the other. For each, make sure its negative terminal, with the black jack, "points" only toward the negative of the "battery" and its positive/red terminal only toward battery positive. You'll measure voltage in this experiment, so make sure the multitester leads are in the correct jacks and set it to 20V in the **DC Voltage** scale. Among other things, you'll want to measure the battery voltage, for it won't be exactly 9V. Ask your TA if you are unsure about capacitor polarity or use of the multitester.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (T1) Identify the hypothesis (rule) to be tested.
b. (T2) Design a reliable experiment that tests the hypothesis including a brief description of your procedure.
c. Make a sketch of your design.
d. (T4) Devise the mathematical procedure that you will use, and make a prediction about the outcome of the experiment based on the hypothesis.
e. (T5) Identify the assumptions made in making the prediction.
f. What are experimental uncertainties in this experiment?

Perform the experiment.

g. Record the outcome of your experiment.
h. (T7) Decide whether the prediction and the outcome agree/disagree.
i. Decide whether your assumptions and experimental uncertainties can account for any discrepancy between the predicted and measured value.
j. (T8) Make a reasonable judgment about the hypothesis based on your experimental outcomes, the assumptions you made, and the estimated uncertainty.

II. Application Experiment: An Unknown Capacitance

The larger of your two previous capacitors was 1000μF. You have a multitester to measure voltage, a ~9V power supply, and several free unknown capacitors. Choose one of the unknown capacitors, and design at least two experiments involving the known 1000μF capacitor to determine the unknown capacitance. One of your experiments should involve charging only one of your two capacitors (either the 1000μF or the unknown), disconnecting it from the power supply, and connecting it to the other capacitor, previously uncharged. *Observe proper polarity. On all the unknown capacitors, the positive terminal is the **longer** lead.*

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (A2&A3) Design experiments to solve the problem.
b. (A7) Describe the mathematical procedures you will use.
c. What are the sources of experimental uncertainty?

Perform the experiments.

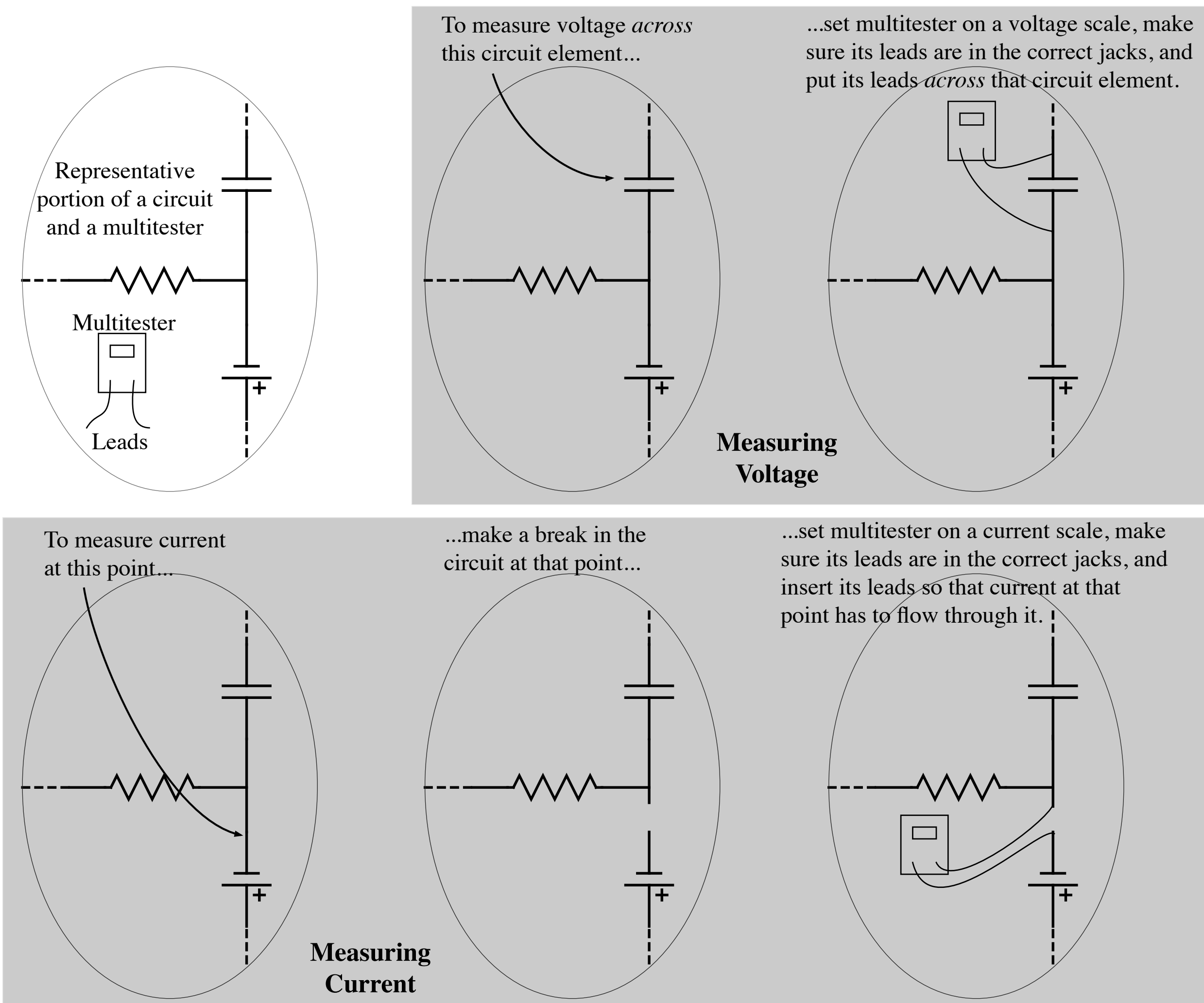
d. Record the outcome of your experiments in an appropriate format.
e. (A5) Compare the two values you obtained, keeping possible uncertainties in mind. If they are different, discuss possible reasons for the difference.

Physics 9C Lab 4: DC Circuits

Most relevant text references: Secs. 25.1-26.2.

I. Background Information: Measuring voltage and current

Today you'll be measuring, separately, resistance, voltage and current, with the multitester. For the latter two, use the figure below as a guide, and don't hesitate to ask your TA if you need help. Fewer meters are blown by students who ask than by those who *think* they know what they're doing.



Your TA will give a brief demonstration.

II. Observation Experiment: Resistance

At your table, you have strips of conductive paper. (Again, this paper is delicate, and we reuse it, so please be careful with it.) You also have two straight metal electrodes that stick pretty well to a metal base, a multitester, and wires. By placing the electrodes across the strips of paper, you can measure the resistance of the paper with the multitester. Devise an experiment(s) to determine the relationship between the resistance of the paper and the geometry of the paper. Note: Binder paper may also be helpful; you don't want to measure the resistance of the base! Hint: The conductive paper is essentially 2 dimensional, so how many parameters will you need to test? (Note: Once you've established a relationship to a given dimension, don't spend time reconfirming it while considering a different dimension; the time would be better spent on other tasks.)

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (O2) Design a reliable experiment that will investigate the phenomenon.
b. (O3) Decide what is to be measured and identify independent and dependent variables.

Perform the experiment

c. (O5) Describe what is observed without trying to explain, both in words and by means a data table. You will need to make several measurements in order to find a mathematical relationship between the parameters.
d. Represent the data graphically. You'll need one graph for each parameter you varied. (Recall that "Simple Plot and Trendline" can reveal a linear relationship, y vs. x, or an inverse one, y vs. 1/x, or …)
e. (O7) Using your graph(s), determine the mathematical relationship between all of the parameters. What parameters does the resistance depend on, and how did you arrive at this conclusion?
f. (O8) Devise an explanation for your observed relationship(s).
g. (O6) Identify shortcomings of your experimental design by listing the sources of experimental uncertainty. Describe improvements you could and/or did make to minimize them.

III. Testing Experiment: Kirchhoff's Rules

Design an experiment to test whether Kirchhoff's junction rule and loop rule work. The junction rule states that the sum of the currents entering any junction must be equal to the sum of the currents leaving that junction. The loop rule states that the algebraic sum of the changes in potential encountered in a complete traversal of any loop of a circuit must be zero. Your circuit must have two batteries, at least two different loops, and at least 4 resistors. *Also, each battery must have a resistor immediately in series with it,* either on its plus or minus side (or both). This ensures that batteries will never be completely shorted out or somehow just connected to each other, which would cause problems! Equipment: Resistors (all those on the side of the component board that has only black jacks), "batteries" (as before, the black box with red and black jacks), and a multitester. Note: When measuring current, it's probably safest to start on the 200m scale, and move to the 20m scale only if your currents all seem to be less than 200mA.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (T1) Identify the hypothesis (rule) to be tested.
b. (T2) Design a reliable experiment that tests the hypothesis, including a brief description of your procedure.
c. Draw a labeled sketch of the experimental set-up including a circuit diagram.
d. (T4) Make a prediction about the outcome of the experiment (including both current at various points in the circuit and voltages across various circuit elements) based on the hypothesis.
e. What are experimental uncertainties in this experiment?

Perform the experiments

f. Clearly record the outcome of your experiment.
g. (T7) Decide whether the prediction and the outcome agree/disagree.
h. Decide whether your experimental uncertainties can account for any discrepancy between the predicted and measured value.
i. ((T8) Make a reasonable judgment about the hypothesis based on your experimental outcomes and the estimated uncertainty.

Physics 9C Lab 5: RC Circuits

Most relevant text references: Chapter 26.

I. Observation Experiment: Capacitor charging and discharging

Devise an experiment for determining the direction and variation (qualitatively) with time of current flow in a circuit while a capacitor is charging and discharging. You have wires, a 15V "battery" (actually, like last time, one that gets its energy from the power outlet), and, at adjacent places on the component board, a 3300μF capacitor and a special light bulb (with green and yellow jacks). Note: The capacitor is again an electrolytic, so make sure its plus side (red jack) never "points" to the negative side of the battery. If it gets hot, you've got it wired wrong!

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. Draw clearly labeled circuit diagrams of your experimental set-up for when the capacitor is charging and when it is discharging.

Perform the experiment

b. (O5) Describe what you observed without trying to explain.
c. Explain specifically how you are finding the direction of the current from your data.
d. (O8) Devise an explanation for your observed current flow.

II. Observation Experiment: The Oscilloscope

At your table is a device extremely useful for understanding circuits, especially those in which voltages are changing with time. It has approximately one million controls and switches. Most of them you *won't* need today, and they should be set as follows. Those in the "Trigger" section tell the scope which part of a signal to use as the starting point (trigger) when plotting a varying voltage. Leave the slide switches there at P-P AUTO, LINE, and CH1. There are three prominent dials (horizontally aligned) across most of the panel, and in the middle of each is a little knob, labeled "cal", that should be fully clockwise. Everything in the CH2 part of the VERTICAL section can be ignored. In the HORIZONTAL section set the slide switch at X1, and in the CH1 part of the VERTICAL section set the top slide switch at CH 1 and the bottom at DC. You definitely *will* need to play around with the voltage and time scale controls (surrounding the "cal" knobs) in, respectively, the CH1 part of the VERTICAL section and in the HORIZONTAL section. You will probably also wish to get a feel for their respective Position controls.

Now, turn on the oscilloscope, and once you see its "trace," set the voltage in the CH1 part of the VERTICAL section to 5 volts per division (we use 1x, so ignore the 10x), and set the time scale in the HORIZONTAL section around the middle of its settings. Then place the oscilloscope leads across your 15V “battery,” black to black and red to red. While watching carefully, temporarily move the bottom slide switch in the CH1 part of the VERTICAL section to GND (essentially making the input zero) then back to DC. This should tell you something about the positioning of the beam.

Next, open the computer file “Scope Testing,” and click the ON button in the Signal Generator window. Place the scope leads across the Output 1 signal generator outputs, black to ⏚ and red to ∿. Play around with the onscreen Waveform, Frequency and Amplitude settings (in the interest of efficiency, 2 or 3 waveforms should be plenty), and scope Volts/Div, Sec/Div, and Position controls. Note: The defaults obscured under Offset and Limits are chosen to protect our equipment–don’t change them.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

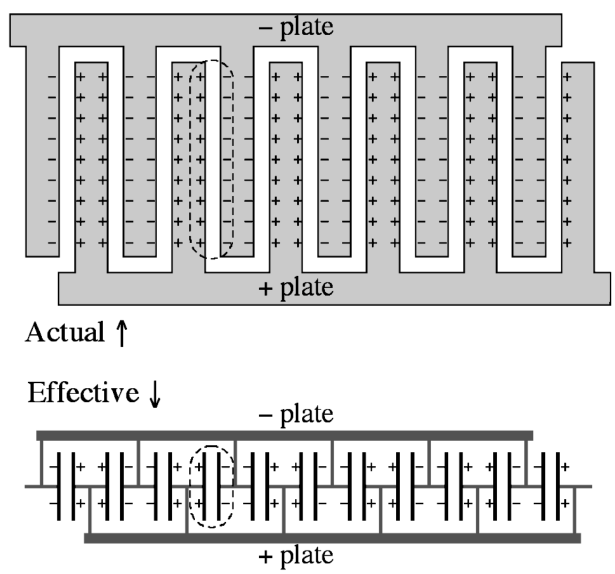
Include the following in your report:

Perform the experiment

a. (O5) Describe what you observed (with at least some quantitative detail).
b. Summarize what an oscilloscope is designed to show, including how one obtains *numerical* values from it. Note: This is very important. You will need to know how to use the oscilloscope in Phy 9C lab, *and this is where you are expected to learn*.

III. Application Experiment: Capacitance of a variable capacitor

The device with the little interleaving plates is a variable capacitor. It is in a protective plastic house because it is *very delicate*. Its plates are close together and easily bent. If they are bent, they’ll touch, and the capacitor will be ruined, becoming just another simple, yet essentially worthless conductor. *Never touch the plates*! As shown, every other little plate is connected together by internal conductors to form the overall capacitor’s “– plate”, and the other half of the plates are connected together to form its “+ plate”. It is effectively a combination of many little capacitors; the fourth “little capacitor” from the left, for instance, is set apart in a dashed box, with the “connecting wires” shown in gray.



Devise two methods to determine the capacitance of the variable capacitor with its knob set to give a maximum value. For one method, assume that the capacitor's plates have a diameter of about 3.2cm and when interleaved are separated by about 0.25mm. Again, *never touch the plates*! Another method should involve the capacitor in series with a 100kΩ resistor (the small blue component with purple jacks, near the "special light bulb") and the signal generator, set as follows: In the "Scope Testing" file, choose the "Square" under Waveform, then set the frequency to 1000Hz and the amplitude to 2.5V, then click the "Offset and Limits" button below it and change the offset from 0 to 2.5V. This causes the signal generator to produce a simple 5V ON–OFF–5V ON–OFF, etc. The oscilloscope should be across either the capacitor or the resistor, and it would probably be helpful during your experiment to rotate the capacitor knob. By the way, if you don't know what "across" means, please ask your TA. Also, if the product of resistance and capacitance doesn't ring a bell, it would be a good idea to peruse the text section on RC circuits. *Important Equipment Note*: The oscilloscope won't read voltage properly unless its black lead is effectively attached to the signal generator's ⏚ jack, i.e., either to that jack or to a wire going there. So pay attention to the order in which you wire the resistor and capacitor in series; if you want to "look" at the capacitor voltage, make sure *it* has one lead going to the signal generator's ⏚ jack, and if you want to "look" at the resistor, make sure it has one lead going there. In a series circuit, they can't *both* go there.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

Include the following in your report:

a. (A1) Identify the problem to be solved.
b. (A2&A3) Design experiments that solve the problem and discuss how you will use the available equipment to make the measurements.
c. Make a labeled sketch of your experiment involving the RC circuit.
d. (A7) Describe the mathematical procedures you will use.
e. (A8) Identify the assumptions made in using the mathematical procedure.
f. What are the possible sources of experimental uncertainty?

Perform the experiment.

g. Record the outcome of your experiments in an appropriate format. Include experimental uncertainties via the weakest link rule.
h. (A4) Make a judgment about the results of your experiments.
i. (A5) Compare the two values you obtained, keeping your uncertainties in mind. If they are different, discuss possible reasons for the difference.
j. (A6) Identify any shortcomings in the experiment and suggest specific improvements.

Physics 9C Lab 6: Magnetic Effects and Fields

Most relevant text references: Chapters 27&28.

I. Observation Experiment: The Compass

Design an experiment to determine whether the oscillation frequency of a compass needle depends on the strength of the magnetic field it experiences. You have a stopwatch, a compass, the earth, and a stack of four ceramic magnets, which can be used individually or collectively. *Warning*: You should be careful, for compasses are delicate, and fields too strong can damage them. In fact, even suffering some shock in the vicinity of a magnetic field that doesn't seem that strong can sometimes cause their polarity to reverse(!), obviously complicating conclusions. Also: The slinky isn't used here, but *don't bring magnets near it*.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (O4) Briefly describe how you will make use of the available equipment to make your observations.

Perform the experiment

b. (O5) Describe what you observed without trying to explain.
c. (O8) Devise an explanation for your observations.
d. (O9) Identify any assumptions made in devising the explanation.

II. Testing Experiment: Magnetic Force

Design at least two experiments to test the right hand rule as used to find the direction of the force that a magnetic field exerts on a moving charge/current. The equation describing this is $\vec{F} = q\,\vec{v} \times \vec{B}$. You again have a stack of four ceramic magnets and the earth, a power supply and a large flexible wire loop, and a "cathode ray tube" (with its own special power supply). Your experiments should not all involve the cathode ray tube.

A few important notes: The cathode ray tube contains a beam of electrons moving toward the screen, which produces a green dot when it hits. It is very fragile—*Don't jar it*! Also, it does take a minute or so to warm up. The flexible loop is very simple, so you can easily see what the current is doing, but it is also accordingly rather delicate, so be careful. Also, one of the wires you use to connect the flexible wire loop to the power supply ***must be a special green one***. It has an inline device to prevent too much current from flowing ("opening" the circuit till a minute or so after the excess is reduced). The loop should carry around 1.3A. It can't take much more, and you should *connect a multitester* in the series circuit, *using the 10A setting and corresponding jack*, to make doubly sure that the current doesn't significantly exceed this limit.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (T2) Design reliable experiments that test the hypothesis including a brief description of your procedures.
b. Draw labeled sketches of the experimental set-ups.
c. (T4) Make a prediction about the outcome of the experiments based on the hypothesis.

Perform the experiment.

d. Record the outcome of your experiments in an appropriate format.
e. (T7) Decide whether the prediction and the outcome agree/disagree.
f. (T8) Make a reasonable judgment about the hypothesis based on your experimental outcomes.

III. Application Experiment: Magnetic Field Character

Design experiments to reveal the variation in the magnitude (at least qualitatively) and direction of the magnetic field produced by (i) a bar magnet, (ii) a straight wire, and (iii) a slinky carrying a current. (You aren't asked to contrast the three, but to characterize each independently.) *In the case of the bar magnet, you should make a fairly accurate drawing of the field lines.* You have a bar magnet (ceramic stack), a power supply and a flexible wire loop (a portion of which can serve as a straight wire), a slinky with a frame to hold it in place, and a compass. (You may find it convenient to tape the compass to a nonmagnetic stick.) Note: For *both* the slinky and the flexible wire loop, one of the wires connecting them to the power supply ***must be a special green one***, and, as before, you should be monitoring the current with a multitester. Don't exceed about 1.3A for either.

Special note on the slinky: Some variation in coil separation is inevitable in a slinky that has been used repeatedly, and it won't significantly affect your experiment. However, please don't play with it, for if it gets tangled, it will be ruined. Also, you may wish to bring the compass near the slinky, and/or any other ferrous metal, with *no current* flowing through it, to give you some baseline for conclusions. *Don't bring magnets near the slinky.*

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (A2&A3) Design experiments that solve the problem and discuss how you will use the available equipment to make the measurements.
b. Make a labeled sketch of a representative experiment.
c. What are the possible sources of experimental uncertainty?

Perform the experiment.

d. Record the outcome of your experiments in an appropriate format.
e. (A4) Make a judgment about the results of your experiments.
f. (A6) Identify any shortcomings in the experiment and suggest specific improvements.

Physics 9C Lab 7: Electromagnetic Induction

Most relevant text references: Chapter 29.

I. Observation Experiment: Producing an EMF

Design an experiment to demonstrate what happens, mostly qualitatively, when a coil or coils of wire move in the vicinity of a magnet. You have: a magnet atop a thin pedestal, protected by a Plexiglas tube; a plastic spool, probably astride the Plexiglas, with two more or less identical 25-turn wire coils wrapped around it, one in red insulation and one in black; and a voltage sensor cable, to insert in Port A of the Pasco box, which will produce a plot of voltage versus time. The file is "Electromagnetic Induction". You may find the coordinate and/or area tools useful, in combination with the data-highlighting tool. Note: There are two coils so that you can compare a single one with two in series. Check with your TA to see whether you should actually test them in series *multiple* ways.

Include the following in your report:

a. (O2) Design a reliable experiment that will investigate the phenomenon.
b. (O4) Briefly describe how you will make use of the available equipment to make your observations.

Perform the experiments.

c. (O5) Describe what you observed (without trying to explain). Report your data in an appropriate format.
d. (O8) Devise an explanation for your observed trends.
e. (O9) Identify any assumptions made in devising the explanation.
f. (O6) Identify shortcomings of your experimental design by listing the sources of experimental uncertainty. Describe improvements you could and/or did make to minimize them.

II. Testing Experiment: Faraday's Law

Design an experiment to test *quantitatively* Faraday's Law (but not Lenz's). You have a large coil, of 15.7cm radius and 100 turns, and a small coil, of 1.3cm radius and 1000 turns, an oscilloscope, and the Pasco Box signal generator Output 1, black and red, with which you should apply a sinusoidal signal to the large coil. The file to control it is "S.G. Control." It may help to play with the equipment a bit before deciding exactly how your experiment will proceed. Note: It won't be useful to exceed about 1.5V on the supply, for with the small resistance connected to it, it wouldn't be able to supply the corresponding large current anyway.

Defaults on the Oscilloscope: Leave the slide switches in the Trigger section at P-P AUTO, LINE, and CH1. There are three prominent dials (horizontally aligned) across most of the panel, and in the middle of each is a little knob, labeled "cal", that should be fully clockwise. Everything in the CH2 part of the VERTICAL section can be ignored. In the HORIZONTAL section set the slide switch at X1, and in the CH1 part of the VERTICAL section set the top slide switch at CH 1 and the bottom at DC.

All bullets must be addressed in your lab write-up, and a random subset will be graded.

a. (T1) Identify the hypothesis to be tested.
b. (T2) Design a reliable experiment that tests the hypothesis including a brief description of your procedure.
c. Draw a labeled sketch of the experimental set-up.
d. (T4) Make a prediction about the outcome of the experiment based on the mathematical application of the hypothesis.
e. (T5) Identify the assumptions made in making the prediction. What assumptions about the objects, interactions, and processes you need to make to solve the problem?
f. (T6) Determine specifically in which way assumptions might affect the prediction.
g. What are experimental uncertainties in this experiment?

Perform the experiment.

h. Record the outcome of your experiment in an appropriate format.
i. (T7) Decide whether the prediction and the outcome agree/disagree.
j. Decide whether your assumptions and experimental uncertainties can account for any discrepancy between the predicted and measured value.
k. (T8) Make a reasonable judgment about the hypothesis based on your experimental outcomes, the assumptions you made, and the estimated uncertainty.

Physics 9C Lab 8: Topics in E&M

I. Observation Experiment: The Inductor

You have an inductor (yellow with blue jacks on your component board) and a ~220Ω resistor (at one corner, with red/red/brown painted bands and perhaps another band), *both* of whose resistances you should measure. You also have a battery, a multitester, and a voltage sensor cable, to insert in Pasco box Port A, producing a voltage versus time plot—the file is "Inductor Testing". Carry out an experiment in which you connect the resistor across the inductor, and also connect the battery across the inductor, and lastly the voltage sensor across the inductor (you might say everything is in parallel), then quickly disconnect (only) the battery from the circuit. Note that the computer file automatically stops recording after one second (to save data-storage space), so you need to disconnect the battery rather quickly, though not instantly, after you start recording.

Include the following in your report:

a. (O1) Identify the phenomenon being investigated here.
b. Sketch an appropriately labeled circuit diagram.

Perform the experiments.

c. (O5) Describe what is observed (without trying to explain). Include your data.
d. (O8) Devise a *quantitative* explanation for your observations, including all aspects of the voltage changes and meanwhile determining the inductance.
e. (O9) Identify any assumptions made in devising the explanation.
f. (O6) Identify shortcomings of your experimental design by listing the sources of experimental uncertainty. Describe improvements you could and/or did make to minimize them.

II. Application Experiment: Putting it to Use

Build a speaker or motor or microphone. You have the signal generator, with outputs on the Pasco Box and controlled via "S.G. Control", an oscilloscope, coils, magnets, a battery, wire, tape, cups, bendable paper clips, plastic wrap, etc. *Report on and explain your experiment appropriately as you have learned in Physics 9 lab.* Also, make sure to demonstrate your device to your TA.

As a start, and given the freedom that your physics understanding should allow for simplification/improvisation, you might wish to view one of these links.

http://cse.ssl.berkeley.edu/lessons/indiv/regan/piepanlab.html
http://www.wikihow.com/Build-a-Simple-Electric-Motor

Note: The seemingly bare " magnet wire" has very thin insulation that can be removed with the edge of anything reasonably sharp (scissors, key, nail clippers, etc.), exposing the somewhat lighter colored copper. Also, *importantly*, despite what you hopefully know about the relationship between a speaker and microphone, if you think about the related efficiencies, or inefficiencies, the microphone is a lot harder to do than the others. Should you choose to give it a try, thin wire and the lightest vibrating materials are vital.