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INTRODUCTION

Traditionally, the second semester of introductory physics is much more difficult than the first for the students. Grades fall, confusion increases, and they will ask you for more help than before. Most of this confusion is because the concepts covered in 1302 are more abstract than previous ones. For example, this is the first time many students encounter the *field* concept. This material builds on the knowledge of physics that students should have learned earlier. Students' weaknesses in their systematic problem solving, or comprehension of vectors, integrals, forces, and energy will become a major stumbling block. Furthermore, much of this material was not taught to students in high school; everything is brand new. The 1302 labs have been written with these concerns in mind. The students will find problems designed to illustrate the necessity of connecting new ideas and techniques with ones learned previously. Examples from the book are actually done in lab so abstract concepts can become more concrete. Students will have opportunities to explore things that are unfamiliar.

THE GOALS OF LAB

The goal of the introductory physics labs at the University of Minnesota is to provide students with practice and coaching in using a logical, organized problem solving process to solve problems. The goal of the labs is the *same* as the goal of the discussion section – to help students slowly abandon their novice problem-solving strategies (e.g., plug-and-chug or pattern matching) and adopt a more logical, organized problem-solving procedure that includes qualitative analysis of the problem.

Since one reason that students cannot solve physics problems is that they have misconceptions about physics, a second goal is to confront some of those misconceptions in the laboratory. The labs include problems that try to illuminate known misconceptions and help students connect their lab experience to reality – all problems begin with a context statement. Now more than ever, the labs give the students a chance to learn physics in the real world. Because your students are so unfamiliar with this material, they may find the labs more frustrating than usual. This lack of familiarity coupled with misconceptions will often lead the students to conclude that the equipment "does not work," since it does not behave the way they think it should. If you are prepared, this is the ideal teaching opportunity. Your students will need you more than ever, and it is crucial that you are familiar with the equipment.

The U of M problem-solving labs do not contain step-by-step instructions; students are generally told *what* to measure, but they must decide in groups *how* to make the measurements (guided qualitative exploration). The students must also decide in their groups the details of the analysis. At the conclusion of the lab session, students must determine if their own ideas (predictions) match their measurements.

LAB SESSION STRUCTURE

OPENING MOVES:

Typically, the first 15-20 minutes of lab are spent preparing students for group work and focusing the lab session on what students should learn. Your "opening moves" as a TA begin when you ask the members of each group to arrive at a consensus about one or two of the warm-up and prediction questions. You should decide which warm-up questions to have students discuss and put on the board from your examination of the answers your students turned in before lab. Make sure to give an explicit time limit for this group discussion; for most lab problems it should take no more than 5-10 minutes (however the discussion for more difficult problems may take longer.)

At the end of the group discussion time, have one representative from ach group put their group's answers to the selected warm-up questions on the board. Ask each group to give their reasons for their answers, and then conduct a class discussion comparing and contrasting their answers and reasons. ***The discussion need not arrive at the correct answers to the questions.*** In fact, more learning occurs in a lab session when there are unresolved disagreements. Wait to resolve the disagreement in the closing discussion, after students have completed checking their solution.

After the opening discussion, *briefly* discuss the measurements students will make to check their solutions. It is often a good idea to ask students, "What are we trying to measure in this lab?" to get their mind focused on the target quantity or quantities. This is also a good time to point out the pieces of equipment they will be using, or give particular instructions about the equipment. This Instructor's Guide also includes suggestions for what to discuss. For the students to get the most out of their lab experience:

DO NOT LECTURE AT THE BEGINNING OF LAB!

Reasons:

1. There is already a lecture component of the course; lab is a time for students to *apply* the theories from their text and lecture. Even though they are unsure of themselves and might *think* they would benefit from explanations of the material, more lecturing will not help - experience and coaching will. Do not reduce the time the students need for hands-on learning activities. If students have not yet attended a lecture on the material, you might need to give them helpful hints to get them started, but keep it short. The lab experiences will serve as a good introduction to the material when it comes up in lecture.

2. If you give the students the answers before they start, you are telling your students that you do not care about their ideas and that they should not care either. Answer their questions only after they have made their best attempt to answer it themselves and within their groups. Let them investigate their own ideas to find which are correct and which are misconceptions. When they are cognitively engaged, they learn.

3. Lecturing often places the listeners in a passive mode, but effective learning takes place in an active mode. Students are in an active mode when they are doing or thinking about a specific problem. Active modes are what the laboratory and discussion sections are designed to evoke.

It is **your responsibility to inform the professor** for the course topics are not synchronized, as well as about any other issues involving the lab and lecture sequence. If you notice this is the case, bring it up at your team meetings and respectfully request a slower pace until the lectures catch up, or discuss alternative methods to approaching the lab topics. You should **resist** if the professor asks you to introduce a new topic in lab by giving students a lecture! Another option would be to hold a problem solving session during lab to allow the lecture to "catch up".

MIDDLE GAME:

During the lab session, your role is one of observer, listener, and coach. You should circulate around the room, observing what groups are doing, listening to what students are saying, and observing what the groups are writing in their lab journals. Intervene when a group needs to be coached on an aspect of physics or the Exploration, Measurement, or Analysis procedure.

It is your job as a TA to guide the lab groups and help them focus their questions. Here's where you really earn your money, because it's up to you to decide when and how to help the student groups. It is important that they attempt to work through the problem themselves. However, if they struggle too much they will gain nothing from the lab except frustration and despair.

With 10-20 minutes left of class, have a representative from each group put their group's *corrected* answers to the warm-up questions on the board (if possible, below their original answers.)

END GAME:

A good end game helps students consolidate their ideas and explicitly summarizes the learning focus for the lab session. Give students a few minutes to examine what other groups wrote on the board, and then lead a whole-class discussion of the results (how do their measurements and predictions compare?) and the objectives for the lab session. Depending on time constraints, you may decide to discuss some of the answers to the warm-up and prediction questions.

When you were an undergraduate, your laboratory instructor probably did not stop you to have a class discussion. Doing this is one of the hardest things you will have to do as a TA. You may be tempted to either let students keep working so that they can get as much done as possible, or let them go home early so they will like you better. However, students do not learn from their laboratory experiences unless they are actively engaged in figuring out what they have learned.

TEACHING TIPS

1. Carefully tell the students what you expect of them in the laboratory and why these rules are necessary. Be very strict in enforcing these rules during the first half of the semester. It is easer to establish good habits in your students early in the semester than to try to establish them later. If you are strict and fair, your students will respect you for it. If you do not consistently enforce your rules, some students will never believe anything you say. If you have any questions about this concept, please talk about it to your mentor TAs.

2. Always tell students explicitly that they should hand in answers to both the Predictions and Warm-up questions for the problem(s) that you assign before they come to lab. The deadline for handing them in will be decided in your teaching team – it is usually 1or 2 days before the lab session. *Make sure the students understand that the Warm-up questions are there to help guide them through the analysis*, as well as to help them solve the problem. Even thought the Prediction comes first in the lab manual, they should do the Warm-up questions before the Prediction.

3. It is well known that students do not like to read instructions. They will come to you and ask questions that are answered in the lab manual. If this happens, first ask the student a question to

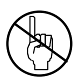
determine if they have read the manual. If not, refer them back to the manual. If they have, give them a straightforward answer.

4. Tell the students what resources are available to them and encourage going to the tutor room 230 if they have any questions. The student lab manual has plenty of information in the Appendices. For example, there are sample lab reports (do not assign these problems for reports!)

SAFETY

Your students' safety is your primary responsibility. For example, if a group blows a 10A fuse they have done something potentially dangerous. You must check what they are doing and inspect the circuits they have built before replacing the fuse.

A first aid kit is available in equipment closet #7 on the second floor. Make sure you are the only person to access the kit unless there is an emergency and an urgent need to do otherwise.



It is important to **verbally warn students about potential dangers.** The lab manual and this guide provide warnings, which are marked with a symbol of a hand with one finger raised in warning, as seen to the left**.**

EQUIPMENT

The batteries run down quickly. Make sure you check the batteries before your students enter the room. Students will grow despondent if they are stuck doing a lab with dead batteries. The fastest way to check a battery is to see if it will light a bulb brightly. Dispose of light bulbs that are burned out.

The DMMs are of high quality and durability. Count them at the beginning and end of each lab, as they may tend to "walk off." Don't "borrow" them from another room without leaving a note in the logbook for that room.

Discharge all capacitors before students enter the room, as they can create a mild shock and spark. To discharge a capacitor, use a wire with banana plugs to briefly connect both terminals of the capacitor (never grasp a wire by its metal end!)

Check all of the DMMs before your students enter the classroom and make sure you get enough spare fuses before class begins. In an emergency check to see if there is an extra fuse tucked inside the DMM itself. You'll have to take its back off to find out. There are both 200 mA and 10 A fuses. If a fuse is blown, replace it. There should be spare fuses in the room, and Sean has screwdrivers. **It is you responsibility to make sure that your students' equipment works.** Nothing is more frustrating for students than trying to start a lab with equipment that does not work.

If there is any bad, broken, or erratic equipment, **use the problem report form** located on any lab computer desktop to **immediately notify the lab coordinator**. Be sure to include a complete description of the problem, and the room number. **Make a note on the clipboard about it** or on the blackboard to inform the next TA of the problem, and that a problem report form has already been submitted.

Remove any broken equipment from the front lab table immediately: students are less respectful towards equipment that they don't see working well.

USING THIS INSTRUCTOR'S GUIDE

This instructor's guide is designed to help you help your students, make sure you:

1. Don't rely on it too much. It is only a guide, not a substitute, for preparation. Make sure you prepare to teach the lab as if you didn't have this manual.
2. **Don't let students have access to it**. It's basically like having a solution manual for textbook problems. It can short circuit the learning process.

We are continually working to improve the instructor's guide. **To add any suggestions, you should write down notes and suggestions on the TA Lab Evaluation found at the end of the Instructor's Guide section for each lab.** Return these forms to Sean Albiston or one of the mentor TAs. You can also e-mail the information to Sean directly at lab@physics.umn.edu

Information from previous laboratory instructors was used to construct this guide as well as modify this year's student lab manuals. Your input is greatly appreciated. Include anything that you feel will be useful. Your notes may include additional comments to be included in the Instructor's Guide, difficulties you or your students had with the problems or the apparatus, and suggestions for changes in the labs.

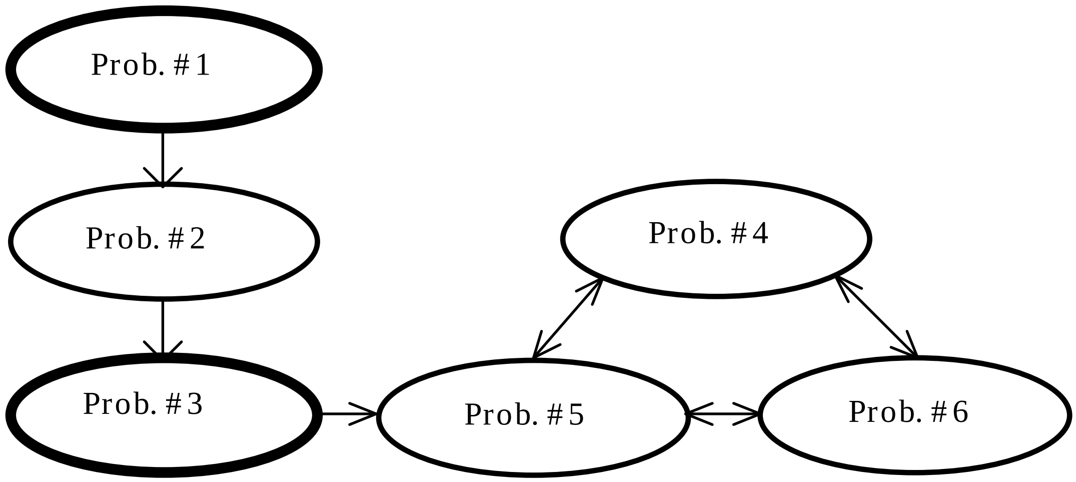
At the start of each chapter in this guide is a **flow chart** that shows the connections between the different problems in that lab. This chart is designed to help you plan your lessons. The elements of the flow charts have the following definitions:

- Bold ovals with stars are the problems that contain knowledge and techniques that are prerequisites to other problems. It is strongly suggested students be required to do these problems.
- The arrows on the connecting lines are directional symbols.
- Dashed lines are optional paths.
- The X across a connecting line implies that if a group has completed one of the problems, that group should skip the other problem.
- Any one group can do any number of problems on the same level.

You can expect your average groups to complete about 2 problems per week.

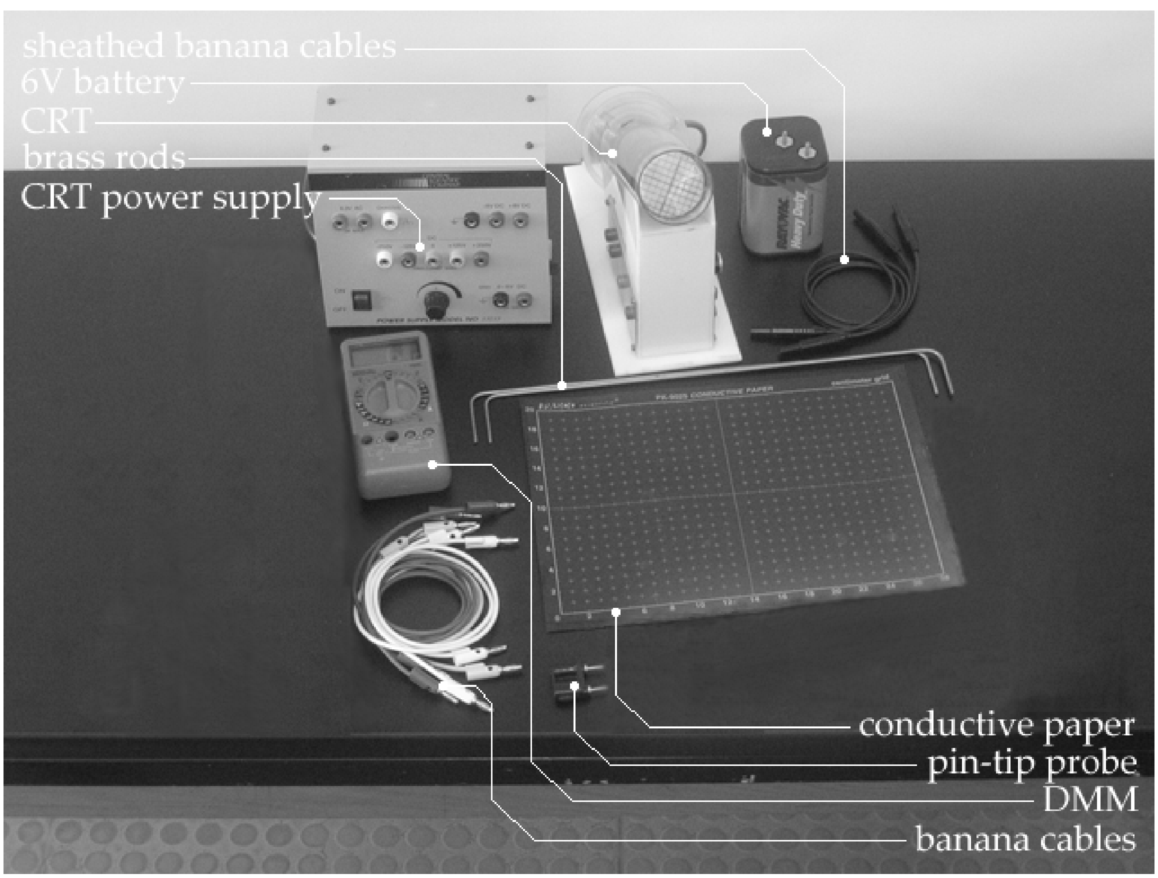
Laboratory I: Electric Fields and Forces

The flow chart for the sequence of problems is shown below.



You can do the first flow chart tree for the first week and the other tree for the next week depending on how your team wants to proceed. It is useful to do Problem #3 before Problems #5 or #6. You do not need to do Problem #3 to do Problem #4.

Many of the problems done is this lab will be repeated in Lab 5 with magnetic fields.



WARNING

Your students will be working with electrical equipment that generates **large voltages**. Improper use can cause **painful burns**. To avoid danger, make sure that they know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to a power supply; they must **never touch** the conducting **metal** of any **wire.**

Things your students should know by the end of this lab

- Determine qualitatively where the electric field will be "strong" and "weak" in a charge distribution.
- Be able to construct the electric field based on the geometry of charged objects.
- Determine the magnitude and direction of a force on a charged particle in a simple electric field.

Things to check out before teaching the lab

- Hook up the water tray set up to verify that it works.
- Make sure you know how to connect the CRT safely (see appendix for detailed instructions).
- Move the CRT around to see the effect of the earth's magnetic field.
- Try deflecting the beam in the CRT by changing the electric field between the parallel plates.
- Make sure all of the batteries are all right just before your lab. That means testing that you can draw current from the battery.

Things to Do the First Day

- Give the FCI
- Divide students into groups and explain group roles
- Show the students the introduction and different appendices in the lab manual.

Problem #1: Electric Field Vectors

Problem

Draw a vector electric field map for a positive point charge, a negative point charge, and an electric dipole.

Purpose

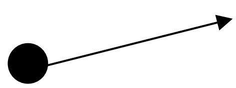
- To show the students an example of a field (in this case an electric field). To emphasize that a field has a magnitude and direction at every point in space.
- To develop skills with EMField needed for the rest of the course.

Equipment

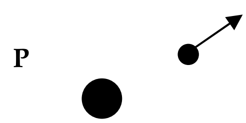
EMField computer program

Teaching tips

1. The lab instructions use the term map to describe either a measurement or a prediction of the electric field at selected points in space. For each point there can be only one electric field vector.
2. Be sure that the students use primarily (or exclusively) the electric field vector capabilities of EM Field. Some other possibilities from the pull down menu such as field lines are particularly confusing for students. The differences between electric field lines and field vectors should be discussed thoroughly. (What the students see in the textbook are field lines. What we are emphasizing in this problem are field vectors, though they need to know the differences.)



Field line



Field vector

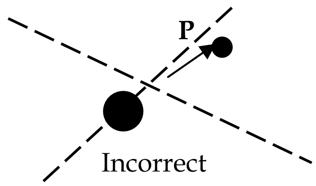
Difficulties and Alternative Conceptions

The field concept is a difficult abstraction for most students. It is difficult to envision that every point in space near a charge has a property called an electric field, which is affected by that charge. Many student misconceptions come from their interpretation of pictures of field lines. Many think that something is coming out of a charge, which exerts a force on another charge by "grabbing" it or "pushing" it away. Many students will draw pictures of electric field lines from the textbook, especially for the case of the electric dipole, without any knowledge of what these lines represent. If they do this, ask them what these lines correspond to, how do they show the strength and direction of the field at each point? Remind them that field vectors (which were requested in the question, and which do show the magnitude and direction of the field) must be represented by straight-line arrows.

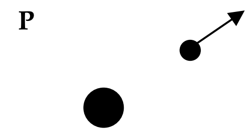
Another misconception is that the electric field is not necessarily unique at a point. For example, many students will represent the electric field caused by a point charge with several electric field vectors, at the location of the charge, pointing out in all directions.

The field idea that objects interact with space and not with each other is a difficult one to understand. This is not a strict Newtonian view of the world. For example, Newton's 3rd law, with which they had so much trouble at the beginning of the course, no longer applies in a straightforward manner.

Some have difficulty in drawing a vector at a certain point properly; instead of beginning the vector from P (test charge) they end the vector at the test charge.



Incorrect



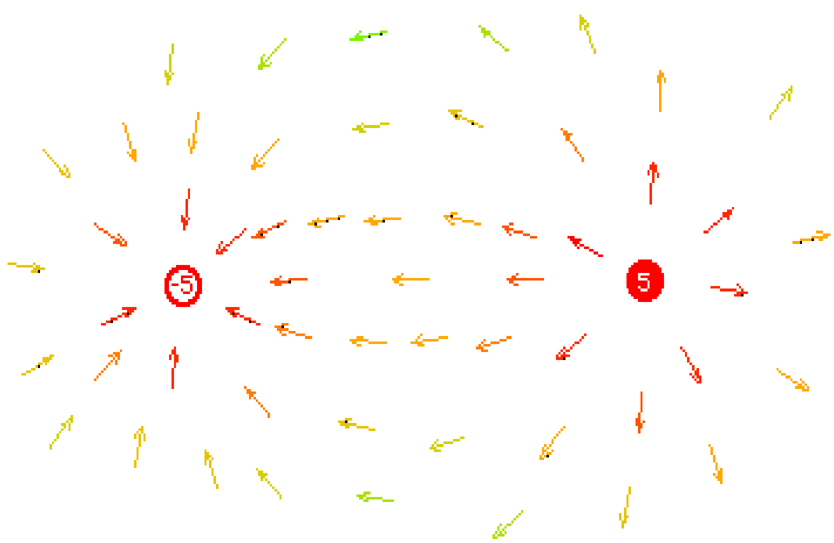
Correct

Prediction

Make sure that field vectors go from positive to negative. Make sure no field vectors originate from a point charge. Remember there can only be one field vector at each point in space. The electric field at a point charge is undefined.

Warm-up Questions

Below is a picture of a dipole field drawn by <u>EM Field</u> in the Directional Arrows mode. Unfortunately in your black and white copy you can't see the color, which represents the magnitude of the electric field. This type of representation can be misleading if students don't remember that when they use "Directional arrows", the magnitude of the vector is represented by color, not by length. Check it out on the computer screen.



Problem #2: The Electric Field from Two Point Charges

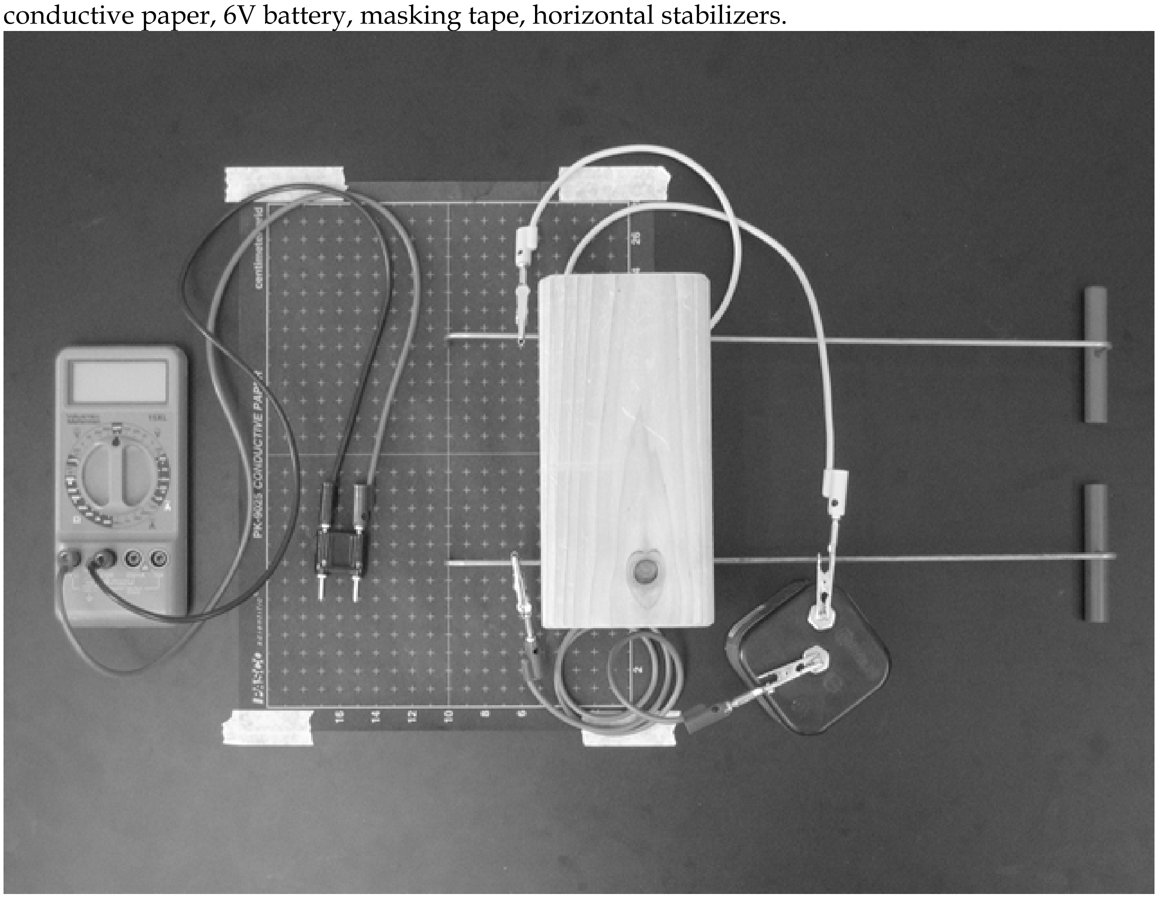
Problem

Find the vector field pattern produced by the tips of two metal rods with opposite charges in contact with conductive paper.

Purpose

- To show students the electric field is a plausible theory for describing the space around electric charges in the real world. Remember, exploration with the conductive paper (real world) is done to evaluate the correctness of the program EM Field (theoretical construct).
- To emphasize that the electric field at a point in space caused by a group of charged objects is the vector sum of the electric fields at that point from each charged object.

Equipment: DMM, pin-tip probe, banana cables, wood block, brass rods, alligator clips, conductive paper, 6V battery, masking tape, horizontal stabilizers.



*NOTE***:** The photo shows a block resting on top of the rods, although this is not mentioned in the lab manual. This is recommended for consistency of data. It was found that the numerical results are sensitive to the pressure with which the rods push down on the paper, and that if they are not weighed down the voltage values can vary by as much as 20% over time. It is also recommended to place a few sheets of paper *under* the conductive paper. Also make sure that your students push the probes down firmly.

Teaching tips

1. This problem has a dual purpose: to familiarize the students with the field probe, and to give experience using the "field" concept. This charge configuration was selected since it is in the textbook, so the student should know what results to expect.

2. If your students do not know how to measure potential difference or current, refer them to Appendix D.
3. In mapping the electric field between the tips of the two rods, the students are asked to use the field probe connected to the DMM set to volts. At this point, the students will **not** have been introduced to the ideas of voltage or potential. **DO NOT** attempt to explain these concepts to them, since this is likely to be confusing, and is not necessary in order to do the lab. Just tell your students that the DMM reading shows the maximum value when the probe is aligned parallel to the electric field, and that this reading is proportional to the electric field at each point. The numerical values do not give a $1/r^3$ result. This is not the field in free space. This is why we do not ask the student to quantitatively predict the results. The emphasis of this lab is the ***field concept*** and its ***qualitative*** behavior.
4. Batteries should be used for this exercise. **Make sure you check out all of the batteries before the beginning of class.** If too many batteries are dead, the Sorensen power supplies are OK. Any voltage higher than 16V is **NOT** OK. Remember that power supplies are potentially dangerous pieces of electrical equipment. If you use them be sure you instruct your students in their safe use. **Remember you are always responsible for your students' safety**. Put the bad batteries on the chalkboard tray or mark them in some way. If you can remove them from the lab and take them to the laboratory coordinator's office, even better. The laboratory coordinator will exchange them for new ones when he is on his rounds but that may not be for several hours.
5. As mentioned above, have your students put a few sheets of paper under the conductive paper and weigh down the rods with a block to ensure a good consistent contact. Make sure they push the probe down firmly.
6. Many of the probes give readings with large fluctuations. If a group of students has this problem, get them a new probe. If the fluctuations are small, have them decide on a consistent way to pick a value and choose uncertainty limits.

Difficulties and Alternative Conceptions of Students

- Many student misconceptions come from their interpretation of pictures of field lines. Many think that something is coming out of a charge, which exerts a force on another charge by "grabbing" it or "pushing" it away. Many students will draw pictures of electric field lines from the textbook, especially for the case of the electric dipole, without any knowledge of what these lines represent. If they do this, ask them what these lines correspond to, how do they show the strength and direction of the field at each point? Remind them that field vectors (which were requested in the question, and which do show the magnitude and direction of the field) must be represented by straight-line arrows.
- Another misconception is that the electric field is not necessarily unique at a point. For example, many students will represent the electric field caused by a point charge with several electric field vectors, at the location of the charge, pointing out in all directions.
- The idea that objects do not interact directly with each other but rather through an intermediate agent (the field) is a difficult one to understand. This is not a strict Newtonian view of the world. For example, the 3rd law, with which they had so much trouble at the beginning of the course, no longer applies in a straight forward manner.

Prediction

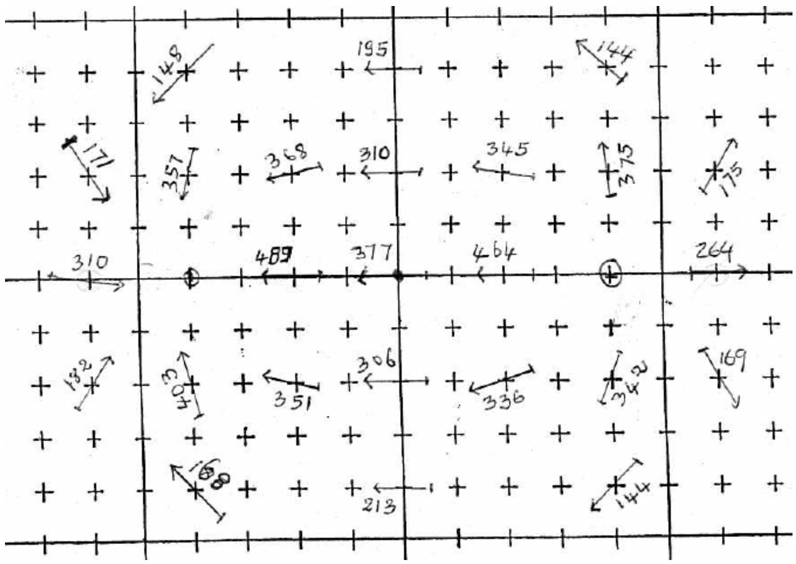
See comments for the previous problem.

Warm-up Questions

See comments for the previous problem

Data

Below is a copy of some raw data taken using the recommendations described above. The numbers are in mV. As can be seen, the data display the appropriate symmetries to within roughly 10%.



Problem #3: Gravitational Force on the Electron

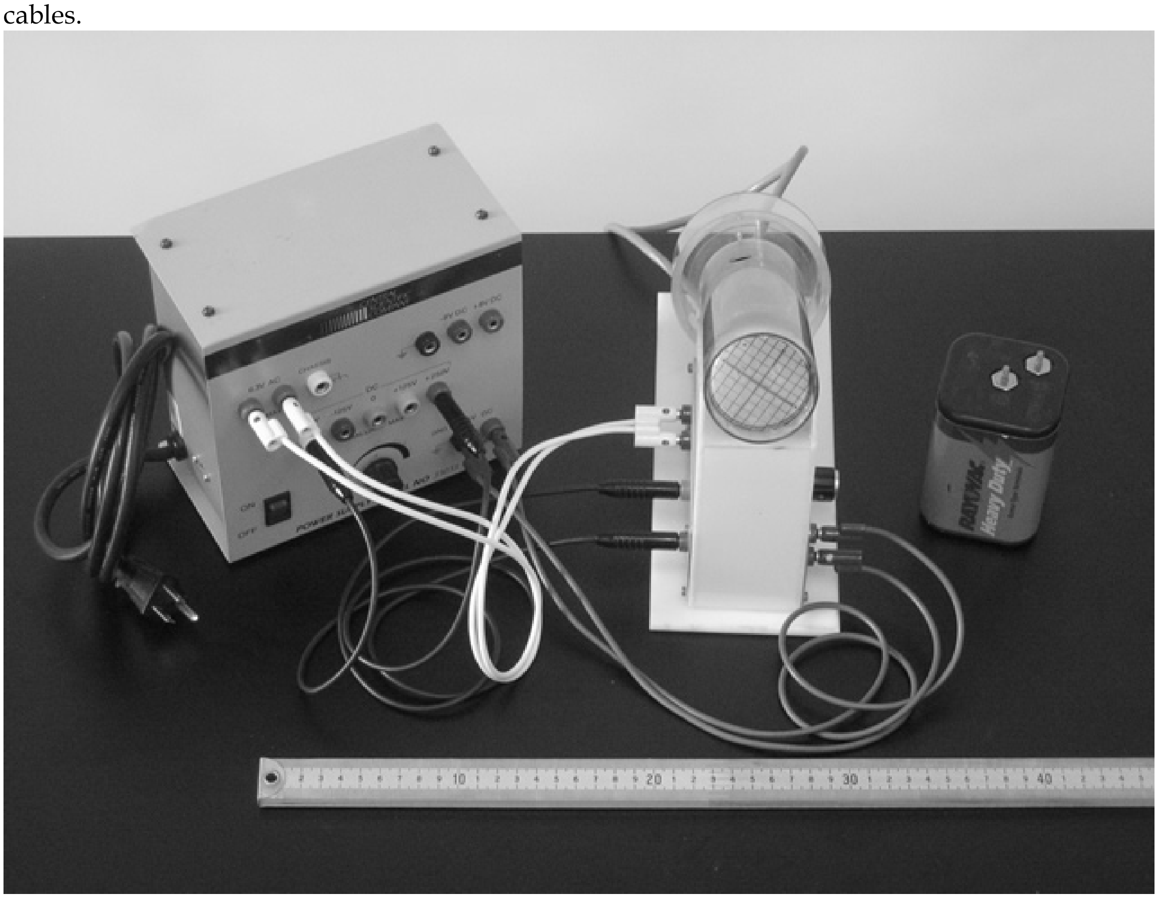
Problem

Calculate how far an electron falls during its flight within a CRT as a function of the angle of incline of the CRT from the horizontal.

Purpose

- To remind the students that they can determine an electron's motion using the familiar concepts of forces and kinematics.
- To show the students that the gravitational acceleration has a very small effect when the electron is moving very fast.
- To show students that a new force (the magnetic force) can be discovered using basic physics. This unknown force can add some interest and speculation while preparing students for the magnetic field, which will be introduced later. There is no need to mention that this new force is a magnetic force, just that this is something new that is outside of what they have learned so far.

Equipment: CRT, CRT power supply, meter stick, 6V battery, banana cables, sheathed banana cables.



WARNING

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Teaching tips

1. The deflection in the tube from the gravitational field of the Earth is on the order of 10^{-13} mm. This obviously is not observable, but have your students move the CRTs anyway. We want the students to recognize that the electric force (and magnetic force) is much greater than the gravitational force. This is hard for some students to really believe since the gravitational force is the main force they deal with in everyday life. When they see a deflection due to the magnetic field of the Earth, they may not believe their calculation or may decide that the apparatus "does not work." Such responses are "unscientific," and prevent intellectual growth. Students will need your help wrestling with both these issues.
2. Make sure you do not let students come away with the misconception that the gravitational deflection is small due to the small mass of the electron. Remind them that a large mass and a small mass when dropped hit the ground at the same time. Have them consider how fast the electron is moving and what distance it travels in this time.
3. The pertinent dimensions of the CRT are in the appendix.
4. The retractable banana leads are to be used **ONLY** for the connections between the Cathode, Anode and the power supply. **DO NOT** use them with the DMM's, the Heater, or the x-y deflections. The retractable banana leads are there for **SAFETY REASONS** to prevent someone from getting zapped by the +/- 250 V and +/- 125 V supplies!
5. If a student does not get the green dot on the CRT screen, check that the heater is working (you'll see a dull orange glow). If the heater is working the accelerating field may be backwards (actually stopping the electrons.) Try switching the anode and cathode potentials around. If the heater is out, get a replacement CRT from Room 233 (this is not a common problem).
6. When the tube is moved from a horizontal position (maximum deflection) to vertical (zero deflection) the beam spot will visibly move perpendicular to the expected deflection. This is due to the Earth's magnetic field. It is this discrepant event that we want the students to observe. **Do not lecture on the Earth's magnetic field before class or there will be no point in doing this lab**. Save any comments until the end of lab. Here we simply want to raise the question of an "unknown" force and its property. For now let your students have the fun of thinking about what it could be. They should be able to determine, with your help, that the "unknown" force does not have the properties of the gravitational force. At the end of the lab, lead a discussion to get their ideas but don't steal their opportunity to really apply physics and make a discovery on their own by telling them the answer. You should return to this observation later in the course when we are investigating magnetic fields.
7. Remember that Minneapolis is not at the equator, so the earth's magnetic field has a large vertical component. The net field is not restricted to the horizontal north - south direction.
8. The PASCO power supply high-voltage terminals can really give a nasty shock, and even burn you. We have had a few students injured. It could kill a student with an undetected heart condition. Tell your students to:
   NEVER CHANGE CONNECTIONS UNLESS THE POWER SUPPLY IS TURNED OFF
   NEVER USE MORE THAN ONE HAND WHEN CHANGING CONNECTIONS.
9. Make sure they obey the cautions in the lab manual. Go over this in your introduction. **You are responsible for your students' safety.**
10. Here are some fundamental constants pertinent to this lab.
    $m_e = 9.11 \times 10^{-31}$ kg , $q_e = -1.60 \times 10^{-19}$ C , 1eV = 1.6022×10^{-19} J .
11. A 500eV electron has a speed of 1.32×10^7 m/s (about 4.4% the speed of light).

Difficulties and Alternative Conceptions

Students have difficulty believing that the gravitational force is so much smaller than the electromagnetic force.

Faced with a discrepancy between prediction and experiment, students are most likely to think there is something wrong with the equipment, they made a mistake in the calculation, or the physics they are using doesn't really apply. Sometimes there are difficulties, which need to be checked, but your students also need to gain confidence that they know what they are doing, that they can determine when something new and unexpected is happening. This is such an opportunity.

Prediction

$$y = -\frac{m_e g D_{tot}^2}{4 q_e V_{acc}} \cos\vartheta \;= 2.6 \text{ x } 10^{-16} \text{ m} \;\; \text{(calculated with } V_{acc} = 500\text{V)},$$

where D_{tot} = 9.6 cm, the distance from the accelerating plates to the screen, m_e is the mass of the electron, q_e is the charge of the electron, V_{acc} = 500 V, the accelerating voltage, and θ is the angle the CRT makes with the horizontal.

Note: The case of a general angle of inclination, θ, as given above, is slightly complicated, as some approximations need to be made, namely, that the gravitational deflection in the accelerating plates is negligible compared to the deflection outside of it.

Warm-up Questions

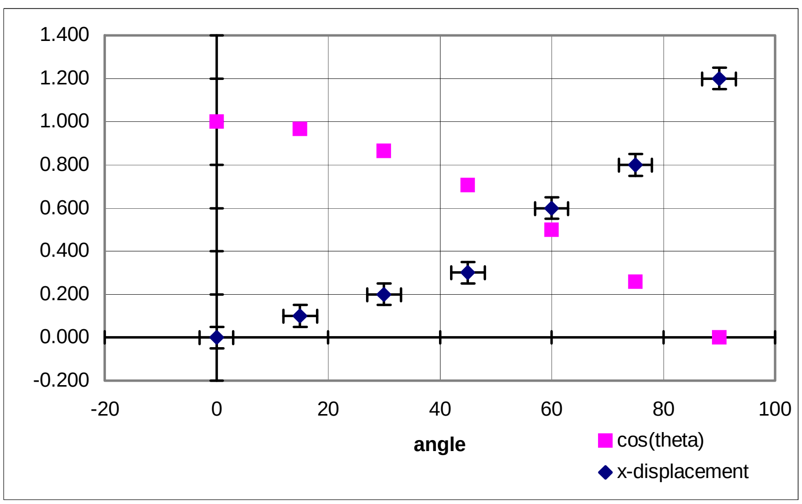
** Make sure your students put in the numbers and calculate a value for the deflection due to gravity. Few will predict how absurdly small this distance really is. **

Data

The data appended below shows the displacement of the electron beam as a function of the angle to the horizontal. The CRT was facing south at the time.

Angle	cos(theta)	x-displacement
0	1.000	0
15	0.966	0.1
30	0.866	0.2
45	0.707	0.3
60	0.500	0.6
75	0.259	0.8
90	0.000	1.2

As can be seen, the displacement clearly does not have the same form as that for gravity, which has cosine theta dependence.



Problem #4: Deflection of an Electron Beam by an Electric Field

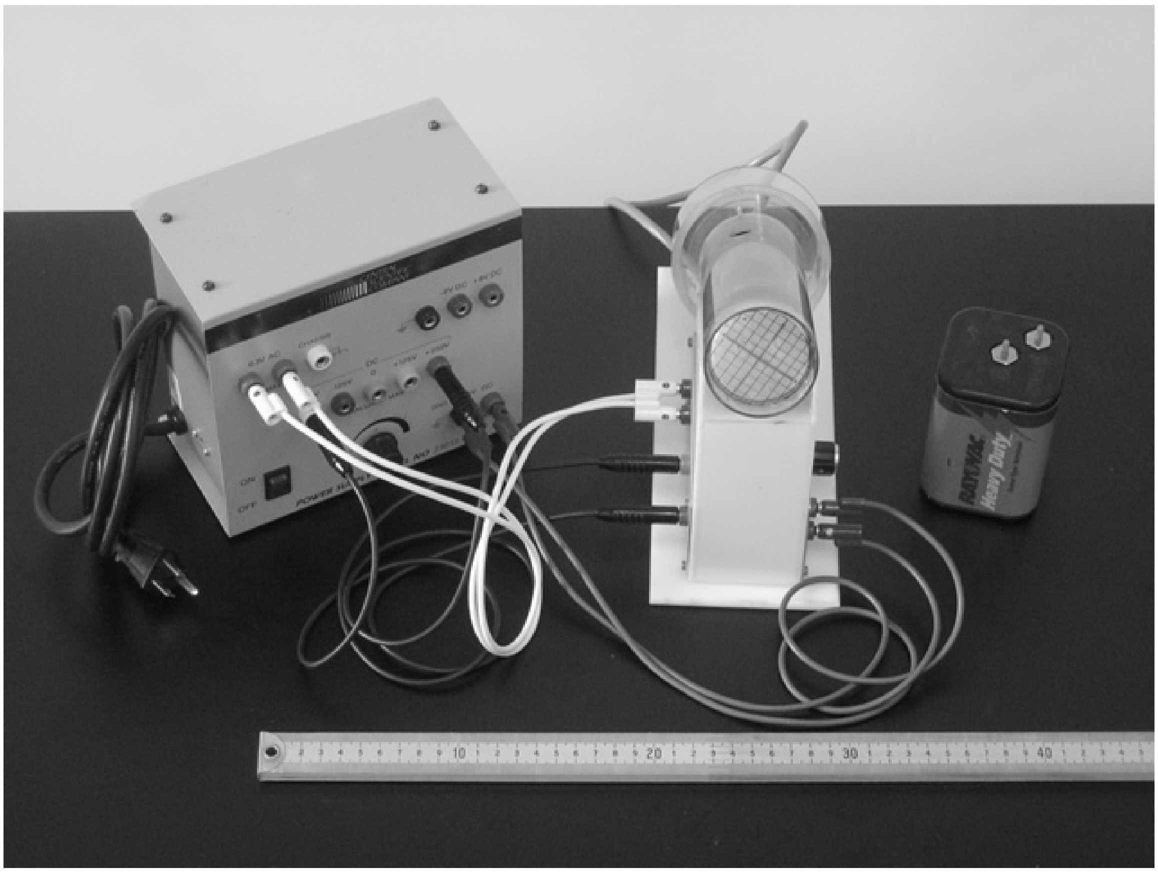
Problem

Find the deflection of an electron beam in a CRT as a function of an electric field oriented perpendicular to the initial velocity extending for a portion of the electrons' path.

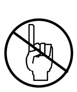
Purpose

To have students recognize that we are simply applying the same old physics to a new situation by giving them a projectile motion problem where the force involved is created by an electric field instead of the gravitational field.

Equipment: CRT, CRT power supply, meter stick, 6V battery, banana cables, sheathed banana cables.



WARNING



Your students will be working with electrical equipment that generates **large voltages**. Improper use can cause **painful burns**. To avoid danger, make sure that they know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to a power supply; they must **never touch** the conducting **metal** of any **wire.**

Teaching tips

1. If the students haven't been introduced to potentials yet, don't bring it up. **Do not lecture about potentials**.
2. The students must keep their CRT pointing in the same direction for all measurements (see Problem #4). The earth's magnetic field will displace the beam differently for different orientations.
3. If you look at a CRT that's been broken open, the deflection plates do not have a uniform separation distance, i.e. they are BENT. This was taken into account by finding the effective length of the plates based on the plate separation. Your students do not have to account for this bend. The necessary measurements are in the appendix.
4. **Be sure to warn your students of the danger when connecting the high voltage leads.**
5. Explain the relative displacements to your students if they find the electron beams are not located at the origin of the coordinates without applying any deflection potential.
6. Ask your students to look up the parameters of CRT in Appendix D.

Difficulties and Alternative Conceptions

Many of the misconceptions about projectile motion will reoccur. Some students still do not really believe in the independence of perpendicular components of motion or in the vector nature of forces. Many students do not believe that there is an electrostatic force on the electron only in the region of electric field. Some students will not have a parabolic trajectory in the region of constant force and straight line motion in the region where there is no force. This is an excellent problem to determine what parts of mechanics you must work on with each student.

Prediction

Deflection is expected to change linearly with the applied electric field.

Warm-up Questions

The total deflection is gained in two regions of the CRT. First, the deflection is caused by the electric field between the plates; the rest of the deflection occurs after the electrons leave the plates and continue along a straight line path until they hit the screen.
The final result for the deflection is shown next.

$$\text{Total Deflection} = EL\left(D + L/2\right)/2V_{acc} \;,$$

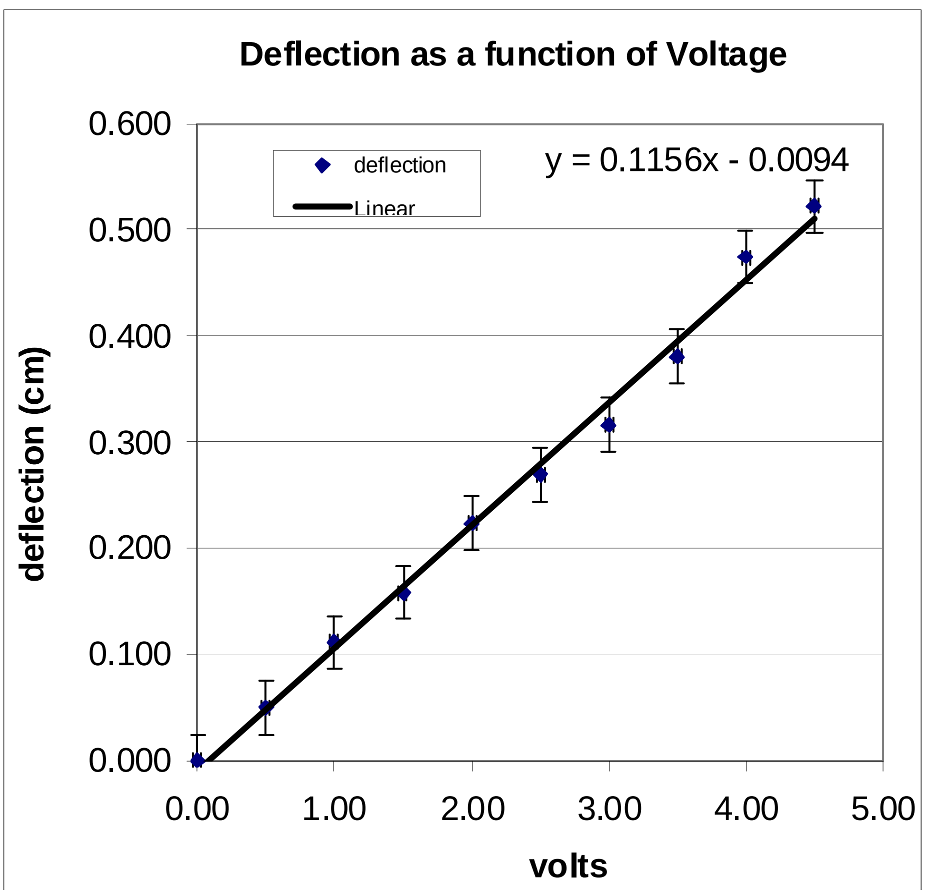
where E is the applied electric field, V_{acc} is the accelerating potential, L is the length of each plate, and D is the distance from the plates to the screen. Remember that the applied electric field is found from $E = V_x/S$, where V_x is the potential across the deflection plates, and S is the separation of the deflection plates. It's interesting to note that the result is independent of the mass and charge of the electron. In the lab summary you might conduct a discussion on why that might be reasonable.

Data

All distances are given in centimeters.

voltage	deflection
0.00	0.000
0.50	0.050
1.00	0.112
1.50	0.158
2.00	0.224
2.50	0.269
3.00	0.316
3.50	0.381
4.00	0.474
4.50	0.522
5.00	0.585

From App D:
D = 7.4 cm
L = 2 cm
S = 0.3 cm
V = 250 cm



Problem #5: Deflection of an Electron Beam and Velocity

Problem
Find the deflection of an electron beam in a CRT as a function of the initial velocity of the electrons, given an electric field oriented perpendicular to the initial velocity extending for a portion of the electrons' path.

Purpose
To show the students how the deflection of the beam is affected by the initial velocity of the electron.

Equipment:
Same as for problem 4.

WARNING

Your students will be working with electrical equipment that generates **large voltages**. Improper use can cause **painful burns**. To avoid danger, make sure that they know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to a power supply; they must **never touch** the conducting **metal** of any **wire.**

Teaching Tips
1. An analogy, which might be useful in your summary discussion, is to consider three people aiming projectiles at the same target. One fires a bullet, the other shoots an arrow, the third throws a baseball. If all aim straight for the target, which one will be furthest from the mark?
2. This is the problem where students have been hurt changing the high-voltage connections. **Make sure you warn your students of the danger.**
3. The following are for your reference values (make your students figure these out themselves!).

A 250eV electron has a speed of 9.37×10^6 m/s [$\beta = 0.0312$]
A 375eV electron has a speed of 1.15×10^7 m/s [$\beta = 0.0383$]
A 500eV electron has a speed of 1.33×10^7 m/s [$\beta = 0.0443$]

4. The 500eV electron has $\gamma = 1.001$, so relativity isn't a factor here.
5. You can refer your students back to Problem #4. Ask them why there isn't a deflection from the gravitational force. This problem should help them realize how the deflection over a fixed distance depends both on the magnitude of the applied force and the speed of the object.

Major Alternative Conceptions
Many of the misconceptions about projectile motion will reoccur. Some students still do not really believe in the independence of perpendicular components of motion or in the vector nature of forces. Many students do not believe that there is a force on the electron only in the region of electric field. Some students will not have a parabolic trajectory in the region of constant force and straight-line motion in the region where there is no force. This is an excellent problem to determine what parts of mechanics you must work on with each student.

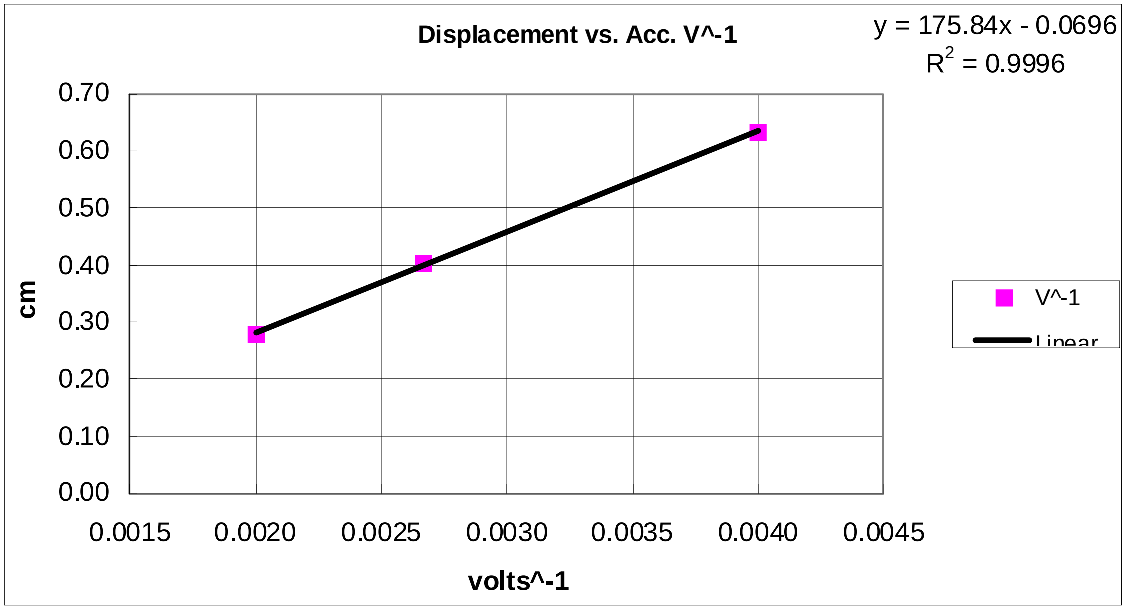
Prediction
Deflection is inversely proportional to accelerating voltage, and hence increases as the initial velocity decreases.

Warm-up Questions

See the warm-up questions for Problem #4.

Data

voltage	V^-1	displacement	
250	0.0040	0.63	D = 7.4 cm
375	0.0027	0.40	L = 2 cm
500	0.0020	0.28	S = 0.3 cm
			V = 5.58 cm



This is a linearized plot of the displacement as a function of accelereating potential

TA Lab Evaluations
Physics 1302 Lab 1

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

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____

____

Students:

Did the students find these exercises: (circle one) enlightening / boring / fun / other?

Do you have additional comments regarding student learning and these labs?

____

____

____

TA:

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results:

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room:

Was the room kept neat and clean by your class and other classes? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

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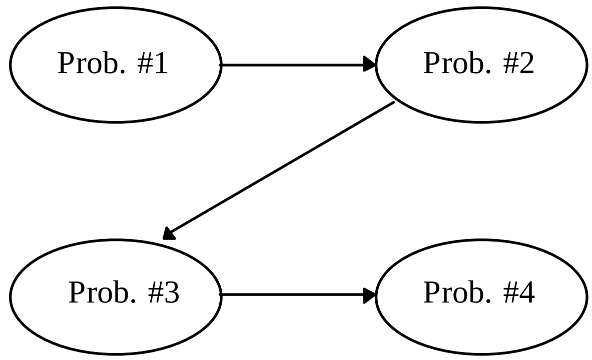
Laboratory II: Electric Fields and Electric Potentials

The flow chart for the sequence of problems in this lab is shown below.



Teaching Tips

- The students will have particular difficulty recognizing the usefulness of a conversion factor between simulated data and calculated values. They may also become confused about how to find the conversion factor and what to do with it. You should ask the students those questions that will keep them focused on their end goal, which is to convert simulation information to real results.

Things your students should be able to do by the end of this lab

- Calculate the electric field and electric potential at points near a single point charge.
- Use the principle of superposition to calculate the electric field and electric potential at points near multiple point charges.
- Add vectors to calculate the above.
- Use integration to calculate the electric field and electric potential near a uniform line of charge.
- Understand the relationship between electric field and electric potential.

Things to check out before teaching the lab

- Make sure that you understand how to use the <u>EMField</u> program to construct charge configurations and measure the electric potential and electric field at various points around the charge configuration.

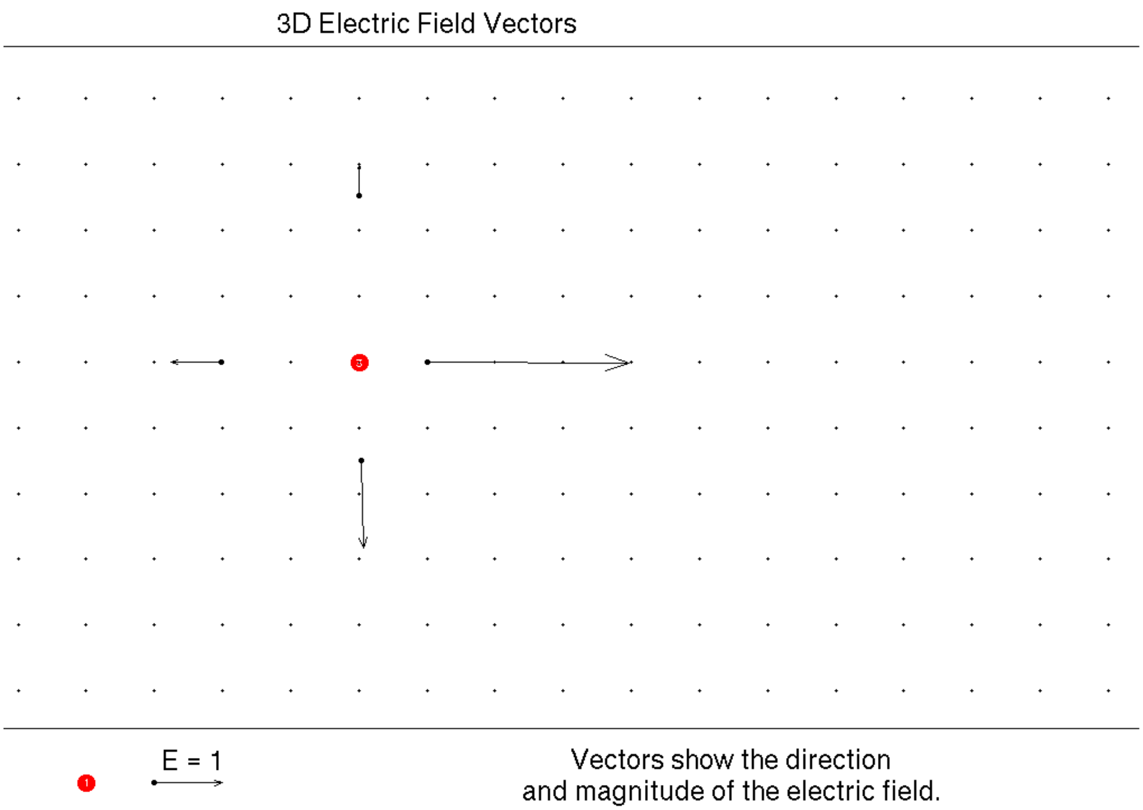
Problems #1 and #2
The Electric Field from Multiple Point Charges
The Electric Field from a Line of Charge

Problem

1-Find the electric field at the corner of the square made of the points charged objects.
2-Find the electric field due to a continuous charged distribution.

Purpose

- To give students practice quantitatively calculating the electric field due to increasingly complex charge configurations.
- To emphasize that the electric field at a point in space caused by a group of charged objects is the vector sum of the electric fields at that point due to each charged object.



A full screen image of EMField and the vectors representing the magnitude of the electric field.

Teaching Tips

1. Students should only use the electric field vector capabilities of <u>EM Field</u>.
2. Make sure that your students pick appropriate charge magnitudes and distances for these problems. If the resulting electric field vector is too short it is difficult to measure accurately. If it is too long it will go off the screen. For problem 2, if the magnitudes of the charges that are chosen are too large, or if too many charges are placed on the screen, the field vectors will quickly disappear off the screen. Using a line of around twenty unit charges works quite well.
3. To get accurate measurements students should use the snap to grid feature of <u>EMField</u> and should also **expand the <u>EMField</u> window to fill the whole screen**. This is important for consistency in size measurements

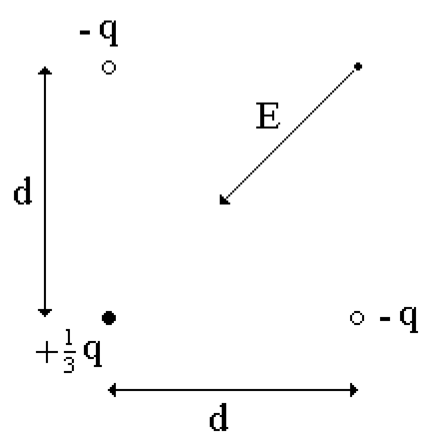
4. The reference vector given at the bottom of the computer screen shows the electric field strength a unit distance from a unit charge to be of unit length and to be unity. The system of units used are simply those whereby $k_e = 1$, i.e. Gaussian units. **Do not lecture on Gaussian units**, the students just need to know how to translate the number the computer gives them into a value in the appropriate units, as described in the laboratory manual.

Difficulties and Alternative Conceptions

- Many students will still not understand what electric field vectors are and why physicists are so interested in them.
- The idea of superposition is also a difficult one. Make sure that when your students solve these problems they have appropriately drawn vectors at the point where they are calculating the electric field. It can also be helpful to have the students place an electric field vector at a point on the screen and then build up the charge configuration one charge at a time and watch how the electric field changes.
- Many students do not understand the meaning of charge density. This will be an important concept for the rest of the semester so it is helpful if they learn it now. Problem #4 should help them with this by treating closely spaced discrete charges as a uniform line of charge. The difference between these might be a useful part of a closing discussion.

Prediction

Problem #1

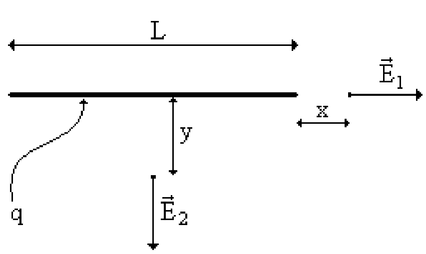


The direction of the electric field, E, at the fourth corner of the square is, as shown in the diagram, directed towards the corner of the square where the positive charge is located. The magnitude of the electric field at this point is:

$$E = \frac{k_e q}{d^2}\left(\sqrt{2} - \frac{1}{6}\right)$$

Problem #2

Make sure that your students do not think that the line of charge is infinitely long. A prediction of an infinitely long line of charge gives a slightly larger value for the electric field than the measured value for the finite line of charge.



The magnitudes of the electric fields at the two different points are given by:

$$E_1 = \frac{k_e q}{x(x+L)} \text{ and } E_2 = \frac{k_e q}{y\sqrt{y^2 + \frac{1}{4}L^2}}.$$

1-For any integration, students can use http://integrals.wolfram.com

2- In this problem, one has to evaluate the following integral.

$$I = \int \frac{dx}{r^3}\,.$$

In order to do that, we define $x = y\tan\vartheta$, so that $dx = y\frac{d\theta}{\cos^2\theta}$. Then

$$I = \int \frac{dx}{r^3} = \int \frac{dx}{(y^2+x^2)^{3/2}} = \frac{1}{y^2}\int \frac{d\theta}{\cos^2\theta(1+\tan^2\theta)^{3/2}} = \frac{1}{y^2}\int d\theta\cos\theta = \frac{1}{y^2}\sin\theta\,.$$

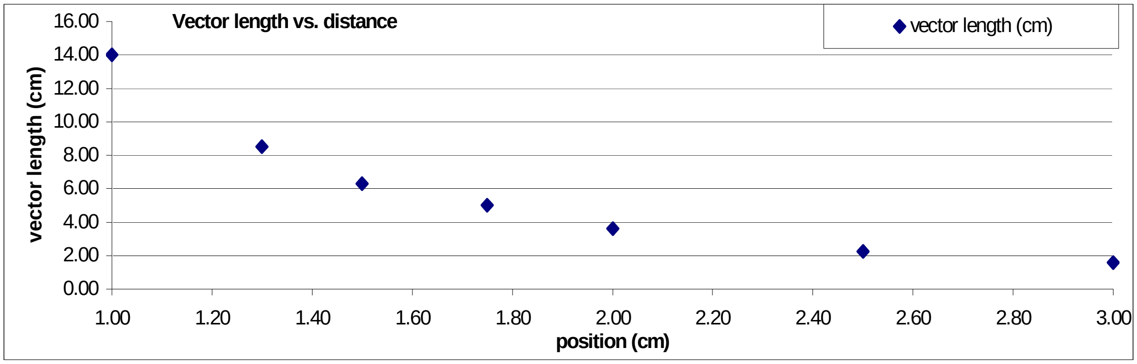
Sample Data

The data on the next page was taken using a 3C point charge. Using the calculated slope of field strength vs. vector length, the electric field at that point was converted from the vector length. The calculated electric field is within 6 percent.

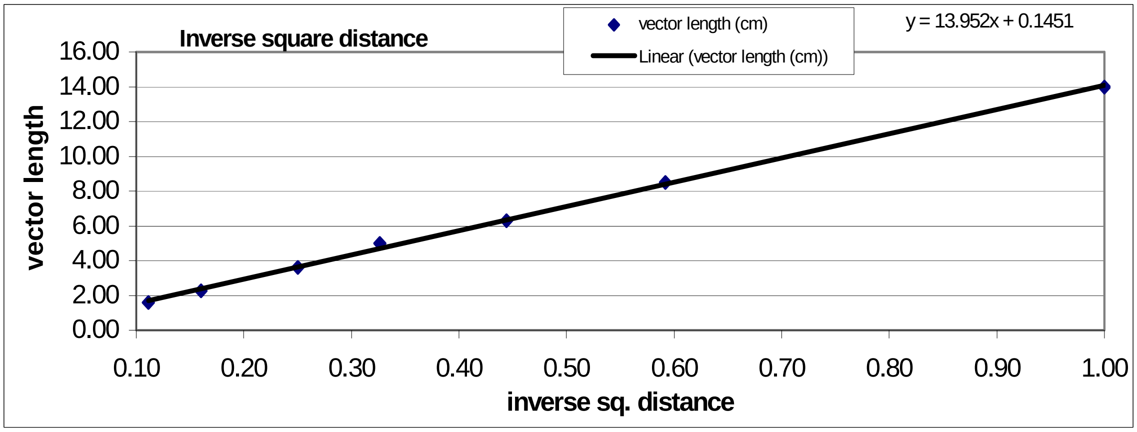
position (cm)	position^-2	vector length (cm)	field strength (nN/c)
1.00	1.00	14.00	269700
1.30	0.59	8.50	159586
1.50	0.44	6.30	119867
1.75	0.33	5.00	88065
2.00	0.25	3.60	67425
2.50	0.16	2.25	43152
3.00	0.11	1.60	29967

(Analysis) Compare simulation to calculation

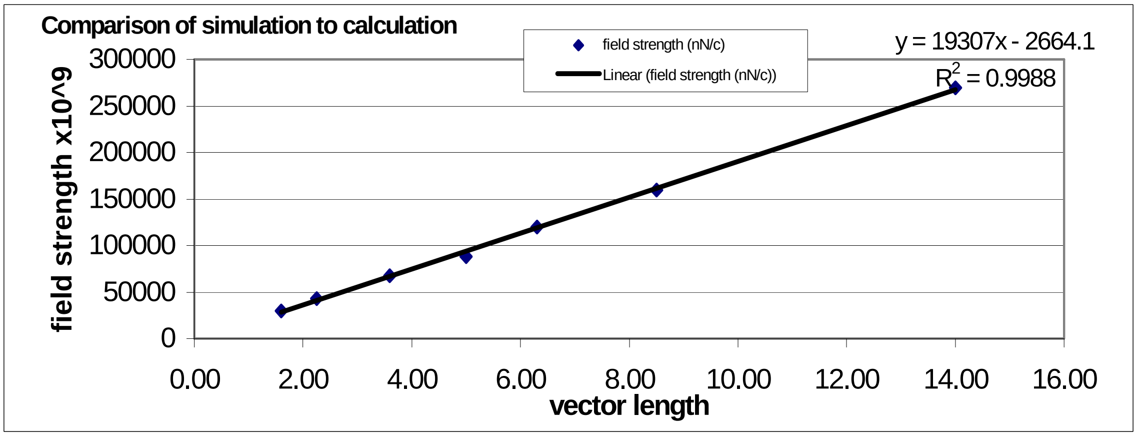
slope =	19307 x10^9 (N/c)/cm
vector length =	1.6 cm
E(simulation) =	30891 x10^9 N/c
E(calculated) =	29106 x10^9 N/c



(EXPLORATION) Raw data showing x^-2 behavior; difficult for student to fit in lab.



(EXPLORATION) Linearized data allows a good fit and confirmation of inverse square behavior



(EXPLORATION) Slope of this graph is conversion factor between simulation and calculation

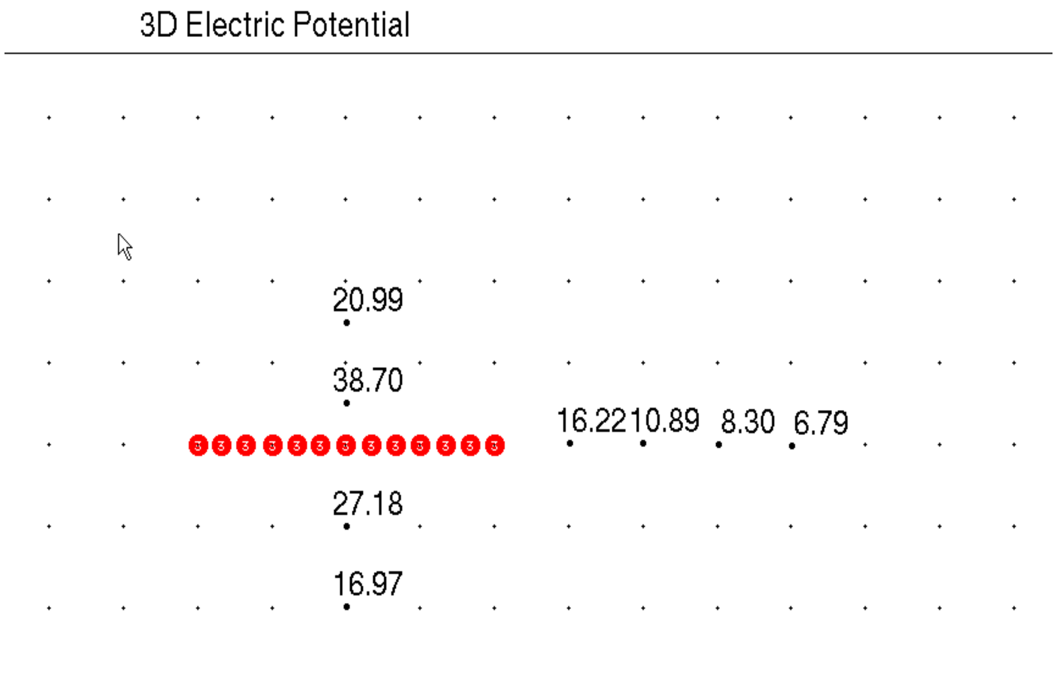
Problems #3 and # 4
The Electric Potential from Multiple Point Charges
The Electric Potential from a line of Charge

Problem

Find the electric potential for a point charge and also for a continuous charge distribution.

Purpose

- To give students practice quantitatively calculating the electric potential due to increasingly complex charge configurations.
- To emphasize that the electric potential at a point in space caused by a group of charged objects is the sum of the electric potentials at that point due to each charged object.



A full screen image of EMField and the points at which the simulated electric field is observed

Teaching Tips

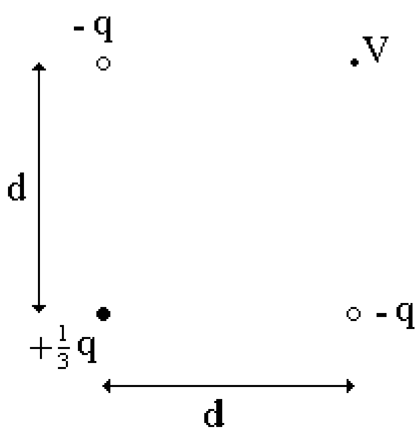
1. The options the students can use from the *Field and Potential* pull-down menu in <u>EMField</u> are: Potential, Equipotentials, or Equipotentials with Number. They may find, however, that using equipotentials can quickly make the screen very messy.
2. Make sure that your students pick appropriate charge magnitudes and distances for these problems.
3. To get accurate measurements students should use the snap to grid feature of <u>EMField</u> and should also **expand the <u>EMField</u> window to fill the whole screen**. This is important for consistency in size measurements
4. When talking about electric potential it is often useful to make an analogy between electric potential energy and gravitational potential energy.
5. <u>EMField</u> gives the potential a unit distance away from a unit positive charge to be unity. The system of units used are simply those whereby $k_e = 1$, i.e. Gaussian units. **Do not lecture on Gaussian units**, the students just need to know how to translate the number the computer gives them into a value in the appropriate units, as described in the laboratory manual.

Difficulties and Alternative Conceptions

- The idea of electric potential is similar to the idea of electric field in that every point in space has this quality called electric potential even when there is no physical object there.
- There are several differences between the electric field and electric potential that students often don't understand. One is that the electric field is a vector while the electric potential is a scalar. Many students will try to find components of the electric potential and add these together to find the total potential. The other is that the electric field can be measured at only one point in space whereas the electric potential is really an electric potential difference between two points in space. Be sure to reinforce this idea of potential difference by asking students to tell you where the second (reference) point is that corresponds to their measured (or calculated) potential difference.

Predictions

Problem #3

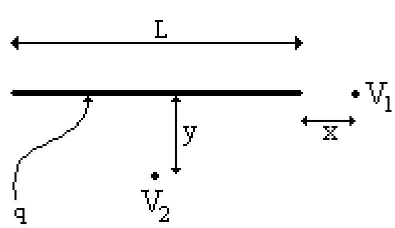


The electric potential at the fourth corner of the square is given by:

$$V = -\frac{k_e q}{6d}\left(12 - \sqrt{2}\right)$$

Problem #4

Make sure that your students do not think that the line of charge is infinitely long. A prediction of an infinitely long line of charge gives a slightly larger value for the electric potential than the measured value for the finite line of charge.



The electric potentials at the two different points are given by:

$$V_1 = \frac{k_e q}{L}\ln\left(1 + \frac{L}{x}\right),$$

$$V_2 = \frac{k_e q}{L}\ln\left(\frac{\sqrt{4y^2 + L^2} + L}{\sqrt{4y^2 + L^2} - L}\right).$$

1-For any integration, student can use http://integrals.wolfram.com

2-In this problem, one has to evaluate the following integral.

$$I = \int_{-\frac{L}{2}}^{+\frac{L}{2}} \frac{dx}{\sqrt{x^2 + a^2}} .$$

In order to do that, we define $x = a\tan\vartheta$, so that $dx = a\dfrac{d\theta}{\cos^2\theta}$. Then

$$\int\frac{dx}{\sqrt{x^2+a^2}} = \int\frac{\cos\theta}{\cos^2\theta}d\theta = \int\frac{d\sin\theta}{1-\sin^2\theta}.$$

We introduce a new variable by

$$z = \sin\theta$$

to get

$$\int\frac{d\sin\theta}{1-\sin^2\theta} = \int\frac{dz}{1-z^2} = \frac{1}{2}\int\frac{dz}{z+1} - \frac{1}{2}\int\frac{dz}{z-1} = \frac{1}{2}\ln\left|\frac{z+1}{z-1}\right|.$$

Thus,

$$I = \frac{1}{2}\ln\left(\frac{1+z}{1-z}\right)\Bigg|_{\sin\vartheta_1}^{\sin\vartheta_2} = \frac{1}{2}\ln\left[\frac{(1+\sin\vartheta_2)(1-\sin\vartheta_1)}{(1+\sin\vartheta_1)(1-\sin\vartheta_2)}\right].$$

Since $\vartheta_{1,2} = \mp\arctan(L/2a)$, we have

$$\sin\vartheta_{1,2} = \mp\frac{L}{\sqrt{L^2+4a^2}}.$$

Thus, our integral is

$$I = \frac{1}{2}\ln\left[\frac{(1+b)^2}{(1-b)^2}\right] = \ln\left(\frac{1+b}{1-b}\right),\ \text{where}\ b \equiv \frac{L}{\sqrt{L^2+4a^2}}.$$

Finally,

$$I = \int_{-\frac{L}{2}}^{+\frac{L}{2}}\frac{dx}{\sqrt{x^2+a^2}} = \ln\frac{\sqrt{L^2+4a^2}+L}{\sqrt{L^2+4a^2}-L}.$$

The result takes a compact form if we introduce a dimensionless parameter.

$$I = \int_{-\frac{L}{2}}^{+\frac{L}{2}}\frac{dx}{\sqrt{x^2+a^2}} = \ln\left(\frac{\sqrt{1+p^2}+1}{\sqrt{1+p^2}-1}\right),\ \text{where}\ p = {}^{2a}\!/_{L}.$$

3-Alternatively, one can look at the derivative of $f(x) = \ln\left(x+\sqrt{x^2+a^2}\right)$ to determine the integrand and evaluate the integral.

Sample Data

The appended data and graph show sample results. The data was taken for a 3Cb point charge. Using the slope of calculated potential vs. simulated potential, the potential at that point was converted from the simulated potential.

position (cm)	position^-1	simulated potential	calculated potential
0.50	2.00	8.22	5394
1.00	1.00	4.20	2697
1.30	0.77	3.31	2075
1.50	0.67	2.77	1798
1.70	0.59	2.49	1586
2.00	0.50	2.09	1349
2.50	0.40	1.66	1079
3.00	0.33	1.38	899

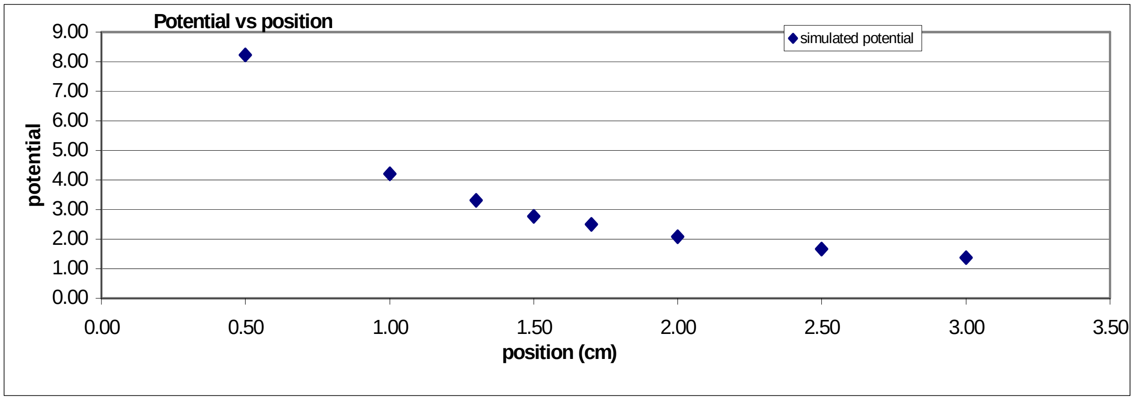
(Analysis) Compare simulation to calculation

slope = 657.5 x10^9 V/cm

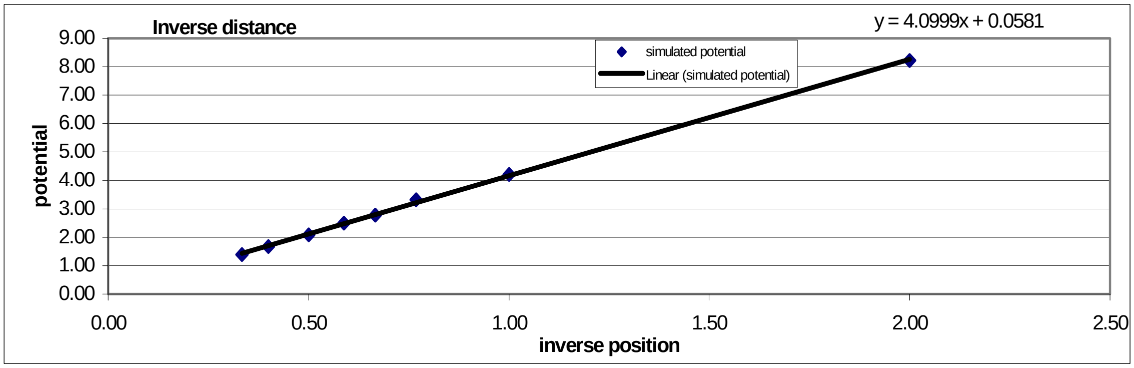
V at corner = -1.78

V (simulation) = -1170 x10^9 V

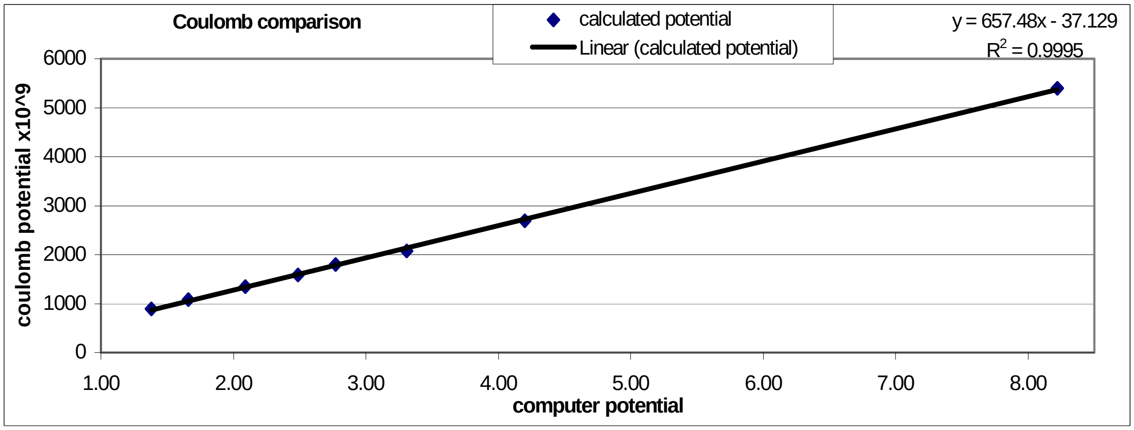
V(calculation) = -1057 x10^9 V



(EXPLORATION) Raw data showing x^-1 behavior; difficult for students to fit in lab



(EXPLORATION) Linearized data is a good fit and confirms the inverse dependence on position



(EXPLORATION) Slope of this graph is conversion factor between simulation and calculation

TA Lab Evaluations
Physics 1302 Lab 2

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

____

____

____

Students:

Did the students find these exercises: (circle one) enlightening / boring / fun / other?

Do you have additional comments regarding student learning and these labs?

____

____

____

TA:

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results:

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room:

Was the room kept neat and clean by your class and other classes? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

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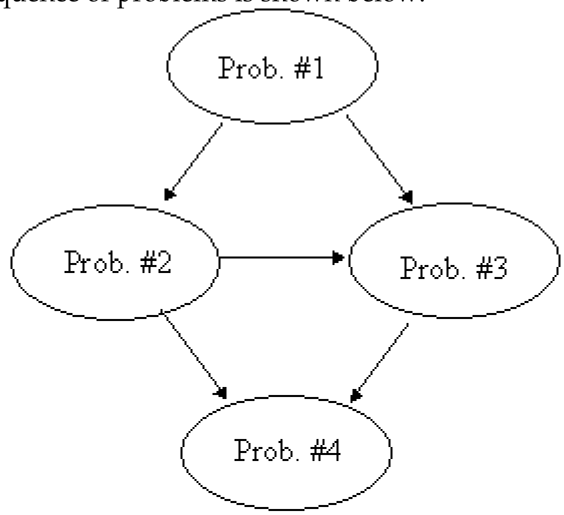
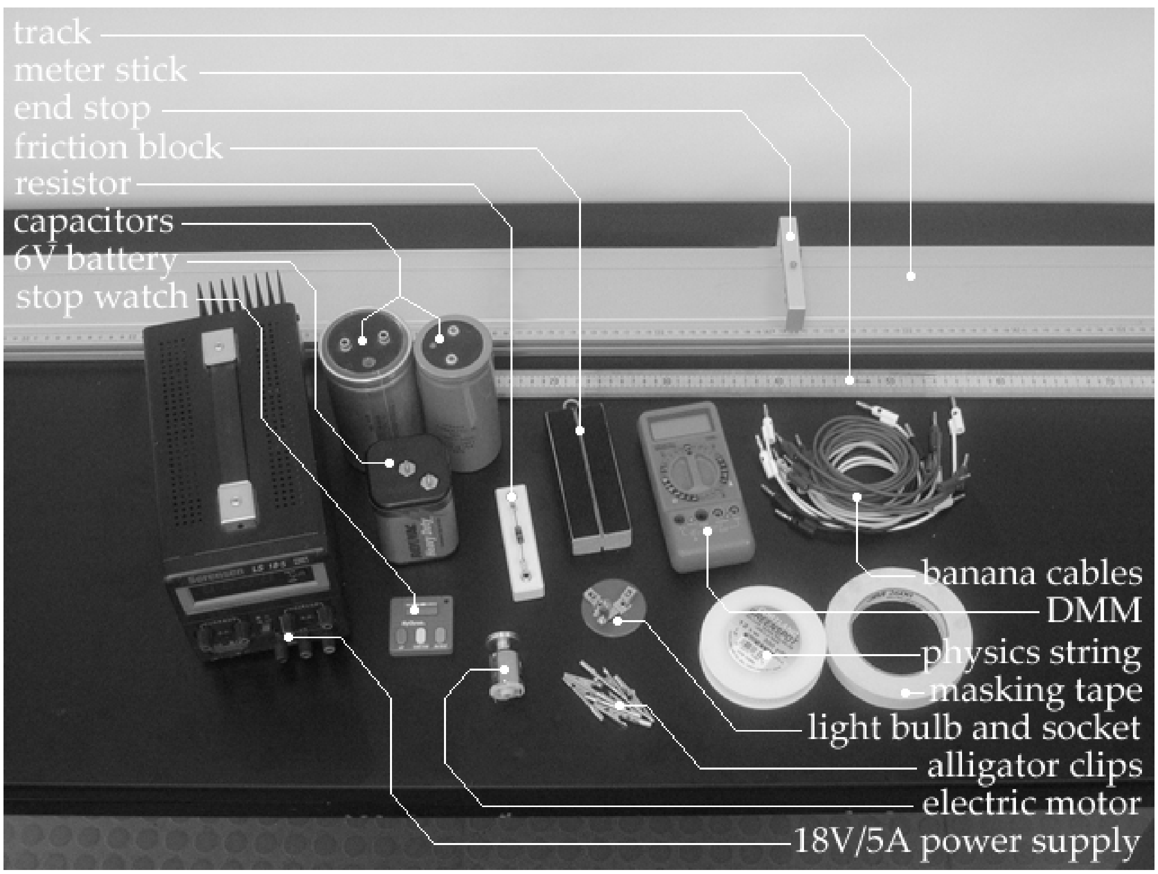
Laboratory III: Electric Energy and Capacitors

The flow chart for the sequence of problems is shown below.





WARNING

A charged capacitor can discharge quickly producing a **painful spark**. Make sure your students know the safe way to handle capacitors: they **must never handle the capacitors by electrical leads or by metal ends of connected wires**; they **must discharge a capacitor as soon as they are finished using it.**

Things your students should know by the end of this lab

- How to calculate the energy stored in a capacitor or group of capacitors.
- The time that is takes a capacitor to fully charge or discharge is directly proportional to its capacitance (this is the idea of the capacitive time constant, *RC*, which students learn from their text.)

Things to check out before teaching the lab

- Check that all capacitors are discharged prior to the beginning of lab.
- Check that all batteries still work, i.e. produce 6 V and a reasonable current.

Problem #1: Electrical and Mechanical Energy

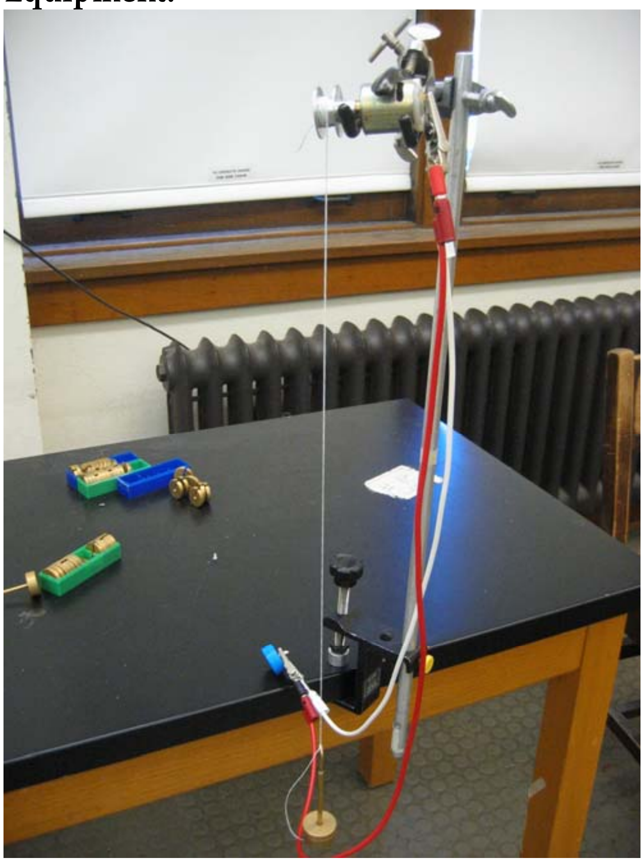
Problem

Find the distance a weight is pulled against gravity by a motor powered by a capacitor charged to a certain voltage, as a function of the capacitance. (THE Fall 2010 manual still has the problem done with a friction block. TA's can do it either way…)

Purpose

To show students that capacitors store energy and that this stored energy can be used to do mechanical work.

Equipment:



WARNING

A charged capacitor can discharge quickly producing a **painful spark**. Make sure your students know the safe way to handle capacitors: they **must never handle the capacitors by electrical leads or by metal ends of connected wires**; they **must discharge a capacitor as soon as they are finished using it.**

Teaching Tips

1. Make sure students **observe the correct polarity** when connecting a capacitor to a battery: + to + and − to −, **or the capacitors will be damaged** (the real capacitance will not be the nominal shown value anymore). The longer electrical lead with double stripes on its side is **NEGATIVE.**
2. The capacitance is written on the side of the capacitors. All values are in farads (F). You may need to point these numbers out to students, as they are difficult to find on some capacitors.
3. For safety reasons, be sure that all of the capacitors are at the front table and that each is discharged before your students enter the lab room.
4. The motors seem to operate most efficiently when the diameter of the spool attached to the motor is around 5/8".
5. The energy efficiency of this energy transfer is about 5% — about 5% of the energy stored in the capacitor is transferred into mechanical work to pull the weight. This is relatively constant over the range of capacitances used in the lab, but will change if the situation changes.
6. The weight must be chosen so that the distance it moves is neither too small nor too large for any of the capacitors used.
7. A good problem for the students to solve is the effective efficiency of the motor, as stated in the conclusion section.
8. The aim of this lab is to emphasize the conversion of electrical energy to mechanical energy, NOT "the efficiency", though we know since friction exists in the motor we also need to discuss the concept of efficiency. We should remind them this problem is another form of conservation of energy discussion.

Difficulties and Alternative Conceptions

- Capacitors are a mystery to most students. Many students also have difficulty with the concept of conservation of energy (remember that whether energy appears to be conserved or not depends on how you define your system).

Prediction

The amount of energy in a charged capacitor is $\frac{1}{2}CV^2$. So, if the energy efficiency is relatively constant (as in this situation), the amount of work a charged capacitor can do is proportional to the capacitance.

Defining the system as the capacitor, motor and weight, the only external force acting to do any work is the constant frictional force, so the work done is proportional to the distance the weight travels.

Thus, the distance the weight is pulled by the motor is directly proportional to the capacitance of the capacitor.

$$d = \frac{CV^2}{2\mu_k mg} \times \text{efficiency}$$

Data

The appended data was taken using the stated weights and capacitors. Having observed the distance traveled, the efficiency of the motor was calculated using the equation found in the prediction section. An average was calculated for each mass-capacitance pair.

mass (kg)	capacitance (Farads)	voltage (V)	distance traveled (m)	calc efficiency
0.2255	0.28	6.3	0.284	0.031
0.2255	0.28	6.3	0.251	0.027
0.2255	0.28	6.3	0.251	0.027
0.2255	0.28	6.3	0.263	0.029
0.2255	0.28	6.3	0.264	0.029
			Avg =	0.029

mass (kg)	capacitance (Farads)	voltage (V)	distance traveled (m)	calc efficiency
0.1755	0.10	6.3	0.113	0.027
0.1255	0.10	6.3	0.229	0.039
0.1255	0.10	6.3	0.265	0.045
0.1255	0.10	6.3	0.238	0.041
0.1255	0.10	6.3	0.252	0.043
			Avg =	0.039

coefficient of friction:	0.275
g:	9.8

Discussion Question

It may be useful to have a discussion about the types of energy that one needs to keep track of in this situation and how these types of energy change during the experiment.

Problem #2: Simple Circuits with Capacitors

Problem

Describe qualitatively the brightness as a function of time of a light bulb in series with a battery and an initially uncharged capacitor.

Purpose

- To show students that capacitors store energy and that this stored energy can be used to do electrical work.
- To show students that the rate at which energy is stored in a charging capacitor decreases with time.

Equipment: capacitors, banana cables, light bulb, battery, stopwatch, alligator clips

WARNING

A charged capacitor can discharge quickly producing a **painful spark**. Make sure your students know the safe way to handle capacitors: they **must never handle the capacitors by electrical leads or by metal ends of connected wires**; they **must discharge a capacitor as soon as they are finished using it.**

Teaching Tips

1. For safety reasons, be sure that all the capacitors are at the front table and that each is discharged before your students enter the lab room.
2. Remember the bulbs are not exactly ohmic, so do not expect an exact exponential decay.
3. This problem emphasizes qualitative understanding, not numerical wizardry. Lead a discussion on the concepts of conservation of energy before moving on to the next problems.

4. The capacitance is written on the side of the capacitors. They are large enough that the voltage decay is observable over time.
5. Some students may not have seen a circuit diagram like the one shown in the problem. They may need a little help translating the diagram into a real circuit.

Difficulties and Alternative Conceptions

- Capacitors are a mystery to most students. Most students expect the bulb to become increasingly brighter.

Prediction

One should see the bulb grow dimmer over time.

Discussion Question

Can you light the bulb with only a charged capacitor and no battery?

Problem #3: Capacitance

Problem

Determine how the time during which a light bulb remains lit depends on the capacitance of the capacitor in a series circuit consisting of a battery, a bulb, and an initially uncharged capacitor.

Purpose

To help the students see how capacitance affects the time it takes for a capacitor to fully charge or discharge.

Equipment

Same as for problem #2.

WARNING

A charged capacitor can discharge quickly producing a **painful spark**. Make sure your students know the safe way to handle capacitors: they **must never handle the capacitors by electrical leads or by metal ends of connected wires**; they **must discharge a capacitor as soon as they are finished using it.**

Teaching tips

This problem is somewhat similar to Problem #1 in that different capacitances are used to do work – the type of work, however, is different. It might be helpful to lead a discussion about the similarities and differences between these two situations.

Difficulties and Alternative Conceptions of Students

Many students will not immediately see that the rate at which work is being done by the capacitor is proportional to the brightness of the light bulb.

Prediction

The time for a bulb to completely turn off will increase with increasing capacitance. The time will actually be proportional to the capacitance, however students will not learn about the RC time constant until Chapter 26. Here, they should be encouraged to think about it in terms of conservation of energy.

Discussion Question

It might be helpful to make a graph of the energy stored in a capacitor as a function of time for different capacitances as well as the potential difference across each capacitor as a function of time. Have students find and explain the differences between the graphs, as well as the similarities.

Problem #4: Circuits with Two Capacitors

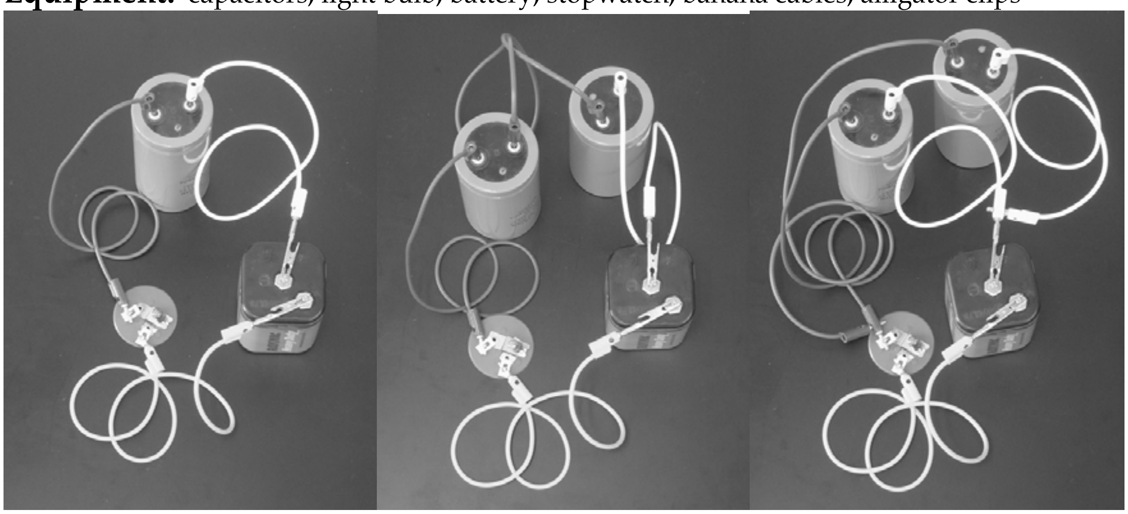
Problem

Determine which configuration of two capacitors stores the most energy when connected to a battery, series or parallel, by measuring the length of time for which a light bulb remains lit after completing the circuit, in a circuit with a battery, a light bulb, and two capacitors.

Purpose

- To help students calculate the energy stored in a collection of capacitors.
- To give students experience determining the relative charges on each capacitor plate in a collection of capacitors.
- To give students experience determining the relative potential differences across each capacitor in a collection of capacitors.

Equipment: capacitors, light bulb, battery, stopwatch, banana cables, alligator clips



WARNING

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Difficulties and Alternative Conceptions of Students

With this set of circuits, many students will answer incorrectly because they have over generalized from their experiences from the previous problems. This means the students are probably "pattern matching" instead of reasoning from an appropriate model. In circuit III, many students will reason that the bulb will not light because it is not really connected to the battery (open circuit).

When doing the warm-up questions many students will not know why the charge on each capacitor plate with capacitors in series has the same magnitude (refer to the discussion in the students' text.)

Prediction

Circuit I: $E_1 = \frac{1}{2}CV^2$.

Circuit II: $E_2 = \frac{1}{2}(C + C')V^2$.

Circuit III: $E_3 = \frac{1}{2}CV^2\left(\frac{C'}{C + C'}\right)$.

The capacitor in Circuit I has capacitance *C*, while the other capacitor, used in Circuits II and III, has capacitance C'. The battery has voltage *V*, and the total energy stored in each of the circuits is denoted E_1, E_2, and E_3.

It follows from the above formulas that $E_3 < E_1 < E_2$.

Discussion Question

How does bulb B have a current through it if it is not connected to the battery? Why does each capacitor in Circuit III have the same charge stored on it?

TA Lab Evaluations
Physics 1302 Lab 3

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

____

____

____

Students:

Did the students find these exercises: (circle one) enlightening / boring / fun / other?

Do you have additional comments regarding student learning and these labs?

____

____

____

TA:

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results:

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room:

Was the room kept neat and clean by your class and other classes? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

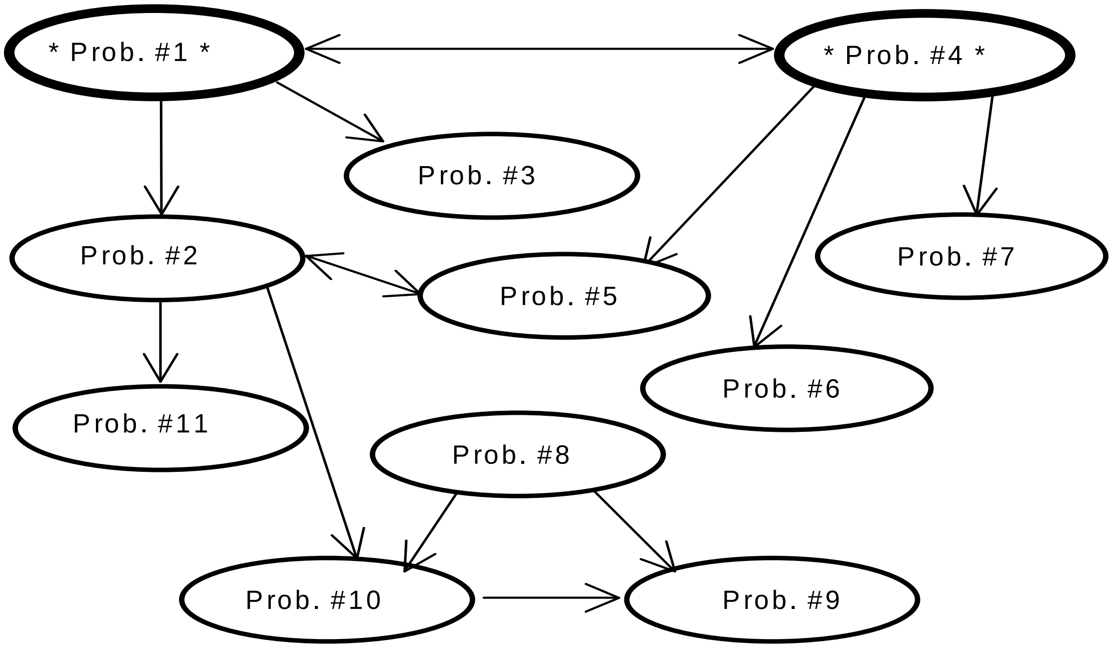
____

____

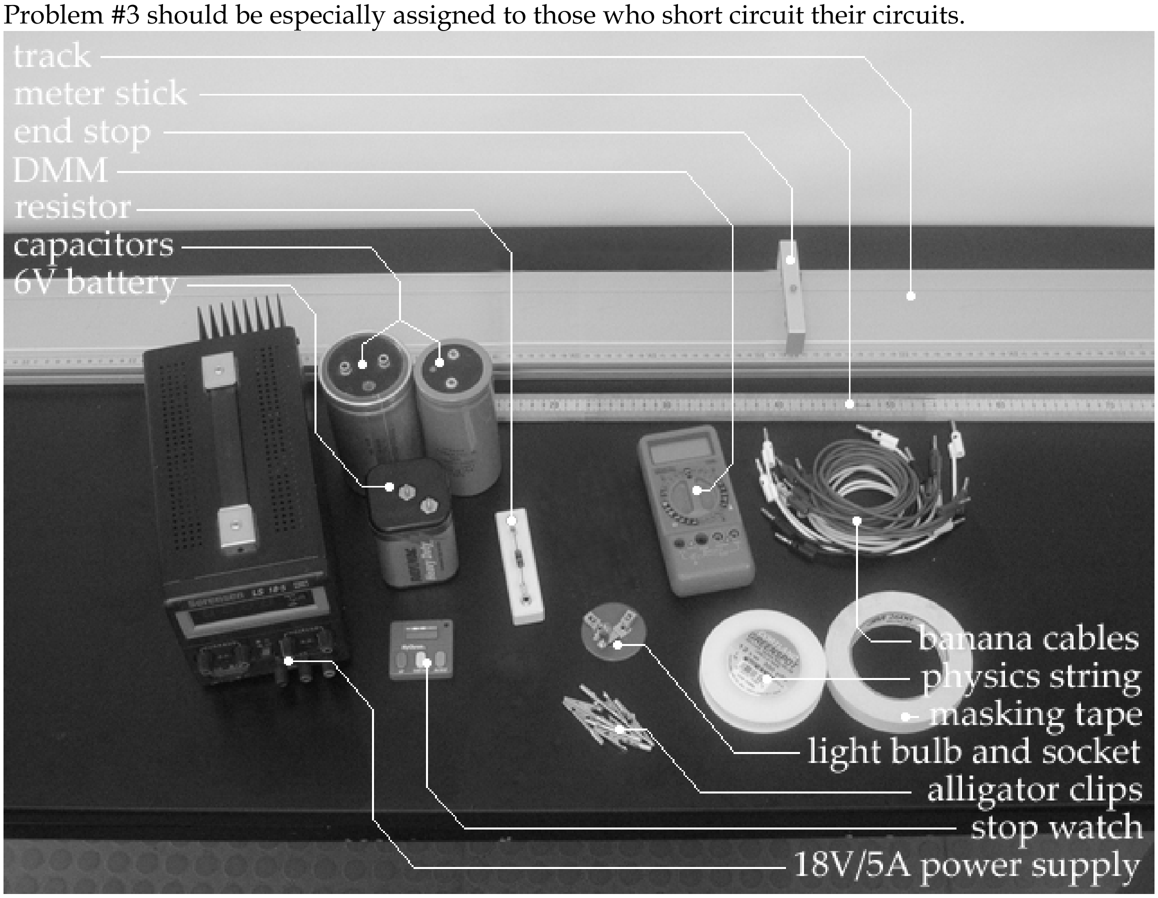
____

Laboratory IV: Electric Circuits

The flow chart for the sequence of problems is shown below.



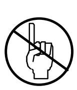
Problem #3 should be especially assigned to those who short circuit their circuits.



Teaching Tips

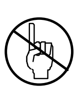
- Circuits provide the most immediate and practical application of electricity. However, it is difficult for students to connect circuit behavior to simple calculations based on electric forces or electric fields. The two fundamental concepts that are most useful in the understanding of circuits are conservation of charge and conservation of energy.
- Remember that light bulbs are just hot wires and are almost ohmic. Their resistance does depend somewhat on their temperature. Light bulbs give the students immediate visual feedback for their predictions. Since students have serious misconceptions about circuits, which an algorithmic approach tends to hide, many of the problems in this lab are qualitative. Coach your students to think about what is happening in terms of energy (voltage is just energy per unit charge) and current instead of applying formulae. There are two quantitative resistor problems to practice the mathematical representation of these concepts (Kirchoff's rules are just another version of conservation of energy and conservation of current).
- It is not unusual for students to finish these labs (and indeed all of E&M) and still not know how to use a DMM as an ammeter or a voltmeter in a circuit. This means they do not really understand the concept of current and potential difference. Make sure your students do not have this difficulty by always having them explain the behavior of the currents and potential differences in a circuit.
- Be sure to check the batteries before you let your students into the class. They get worn down quickly, especially when students accidentally short-circuit their circuits. Use a light bulb to check the batteries, if the bulb lights brightly, it's okay. Make sure your students unplug the batteries when they are not using them!
- The DMMs are of high quality and durability. Count them at the beginning and end of each lab, as they occasionally tend to walk off. Don't "borrow" them from another room without leaving a note in the logbook for that room.
- Make a note of any bad equipment on the clipboard in each lab. Mark the bad equipment as such with masking tape, and note the problem. This will help your fellow TA's.
- If a fuse in the DMM is blown please deliver the DMM to closet 8 on the second floor and place them in the box labeled *"Bad" DMMs*. Do not try to fix them yourself. Replacements are also located in closet 8, in the *"Good" DMMs* box 8.
- **DO NOT under any circumstances use the center strip (-250V, -125V, +125V, +250V) on the power supply!** Using these higher voltages on the light bulbs and resistors will damage them. The light bulbs will blow and the resistors will either break in half or the resistance will be permanently altered.

WARNING



Your students will be working with electrical equipment that generates **large voltages**. Improper use can **cause painful burns**. To avoid danger, make sure that the students know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to the power supply; they must **never touch** the conducting **metal** of any **wire**.

WARNING



A charged capacitor can discharge quickly producing a **painful spark**. Make sure your students know the safe way to handle capacitors: they must **never handle the capacitors by electrical leads or by metal ends of connected wires**; they must **discharge a capacitor as soon as they are finished using it.**

Things your students should know by the end of this lab

- The necessity of having a closed circuit for electric current to flow.
- The behavior of current in a circuit with a capacitor.
- The relationship between electric current, resistance and voltage in the circuit.
- The relationship between the electric charge in a capacitor, the potential difference across that capacitor, and its capacitance.
- Proper application of conservation of charge and conservation of energy (Kirchoff's rules) to determine the current in a simple circuit.
- How to measure the current through a circuit element with a Digital Multimeter (DMM).
- How to measure the voltage between two points in a circuit with a DMM.
- How to measure the resistance of a circuit element, both with a DMM and by using Ohm's law.
- The role of a battery as a constant voltage provider (not a constant current source) in a circuit.

Things to check out before teaching the lab

- See how the non-ohmic light bulbs affect the results of the circuits by trying out some of the circuits.
- Set up the circuits in Problem #11. Determine under what conditions some of the bulbs are barely lit, which might mislead your students.
- Check out the timing of the capacitor problems. Make sure the effects are neither too fast nor too slow for your students to appreciate.

Problems #1 and #2: Simple Circuits and More Complex Circuits

Problem

1-Connect two bulbs across a battery to have the brightness of each bulb the same as that of a single bulb connected to the battery.
2- Connect three bulbs so that the all have the same brightness.

Purpose

To help students understand the qualitative aspects of the circuit as examples of conservation of charge and conservation of energy. These are "classic" problems and have proven to be effective. With your active coaching students will overcome their many serious misconceptions about circuits.

Equipment:

Problem 1 (only the most complex set-up is shown) – 6V battery, banana cables, light bulbs, alligator clips

**Equipment Note: To find identical bulbs, check that the bead on the filament is the same color (clear or white).

Problem 2 (only the more complex set-up is shown) – 6V battery, banana cables, light bulbs, alligator clips

Teaching Tips

1. Students who have already had circuits may get through these problems very quickly and still have serious misconceptions. Make sure you demand they explain their results without resorting to equations. Some students might take two hours to do the two problems. They will need help just formulating their ideas in an organized way. Be prepared for both and everything in between.

2. Do not use the DMM's for these problems. The DMM's tend to confuse the students and allow the students to hide misconceptions by using numbers

3. These problems run down the batteries quickly. It should be possible to wean the students from the batteries and on to the power supplies after the first couple of problems – some regard the power supply as a "black box" and may not immediately understand that it's similar to a battery. Do not let a group use a power supply until you are convinced they understand that a battery is a constant potential difference and not a constant current source.

4. REMEMBER that light bulbs are NOT quite ohmic. Quantitative analysis is not the purpose of the first two labs. They can practice with the math later.

5. To the students who finish quickly, we suggest assigning Problem #9, or the Check Your Understanding Problems #1 and #2.

Difficulties and Alternative Conceptions

The point of most of these problems is to challenge the misconception that current is somehow "used up" by circuit elements like a light bulb. Get students to think about conservation principles to explain what they see: conservation of charge (current) and conservation of energy (potential difference).

Prediction

Rankings of bulbs by brightness

Problem #1	A = D=E > B = C.
Problem #2	A = D = L = M = N > B = C > H = J = K

Problem #3: Short Circuits

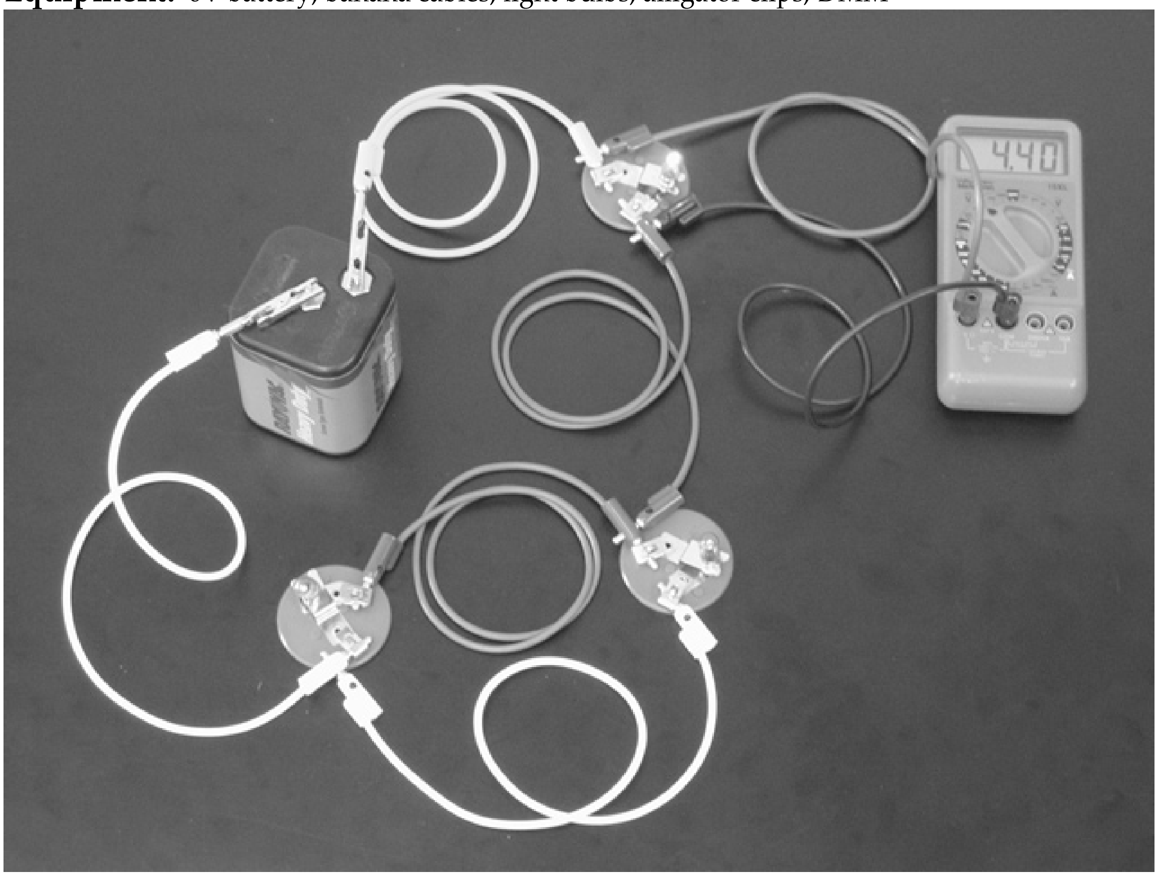
Problem

To demonstrate the consequences of shorting out certain elements of a circuit.

Purpose

To formally introduce the students to the idea of a short circuit as a reasonable and potentially damaging consequence of Ohm's law.

Equipment: 6V battery, banana cables, light bulbs, alligator clips, DMM



**Equipment Note: To find identical bulbs, check that the bead on the filament is the same color (clear or white).

WARNING

A short circuit is what happens any time a very low-resistance path (like a wire, or other piece of metal) is provided between points in a circuit that are at different potentials, like the terminals of a battery or power supply. **Short circuits can destroy equipment and injure people!** Any short circuits suggested in this manual have been tested, and determined not to significantly damage the equipment. Tell your students that they must **always avoid shorting out elements in other circuits!**

Teaching tips

1. This problem is primarily meant for those students who consistently set up a short circuit and don't understand the problem. Explain to them that a short circuit is what happens any time a very low-resistance path (like a wire, or other piece of metal) is provided between

points in a circuit that are at different potentials, like the terminals of a battery or power supply.
2. Explain to your students that **s**hort circuits damage equipment by causing currents that are larger than those the circuit is designed for. These currents can cause great heat, which can damage nearby circuit elements or measuring devices.
3. Finally, tell the students that any short circuits suggested in this manual have been tested and determined not to significantly damage the equipment.

Difficulties and Alternative Conceptions

Most students have heard the phrase "the current takes the path of least resistance", but really don't know what that means. Many believe that the amount of current through a part of the circuit is always the same and is not influenced by other connections in the circuit. Others believe that the current always splits in half when it encounters a branching point in a circuit. You will be surprised at the number of students who have incorrect predictions. The good news is that they tend to figure this problem out quite quickly and correctly once they actually see the results.

Prediction

Circuit I
Bulb A should turn off when a wire is attached across it.
Circuit II
Bulb B should turn off. Bulb C should brighten.
Circuit III
Bulbs D and E should turn off when a wire is connected across E.

Discussion Questions

What are the dangers of a short circuit? Why may the current in a household circuit increase dramatically if a short circuit is introduced?

Problems #4 through #7 Charging Capacitors (Parts A, B, and C)
Circuits with Two Capacitors

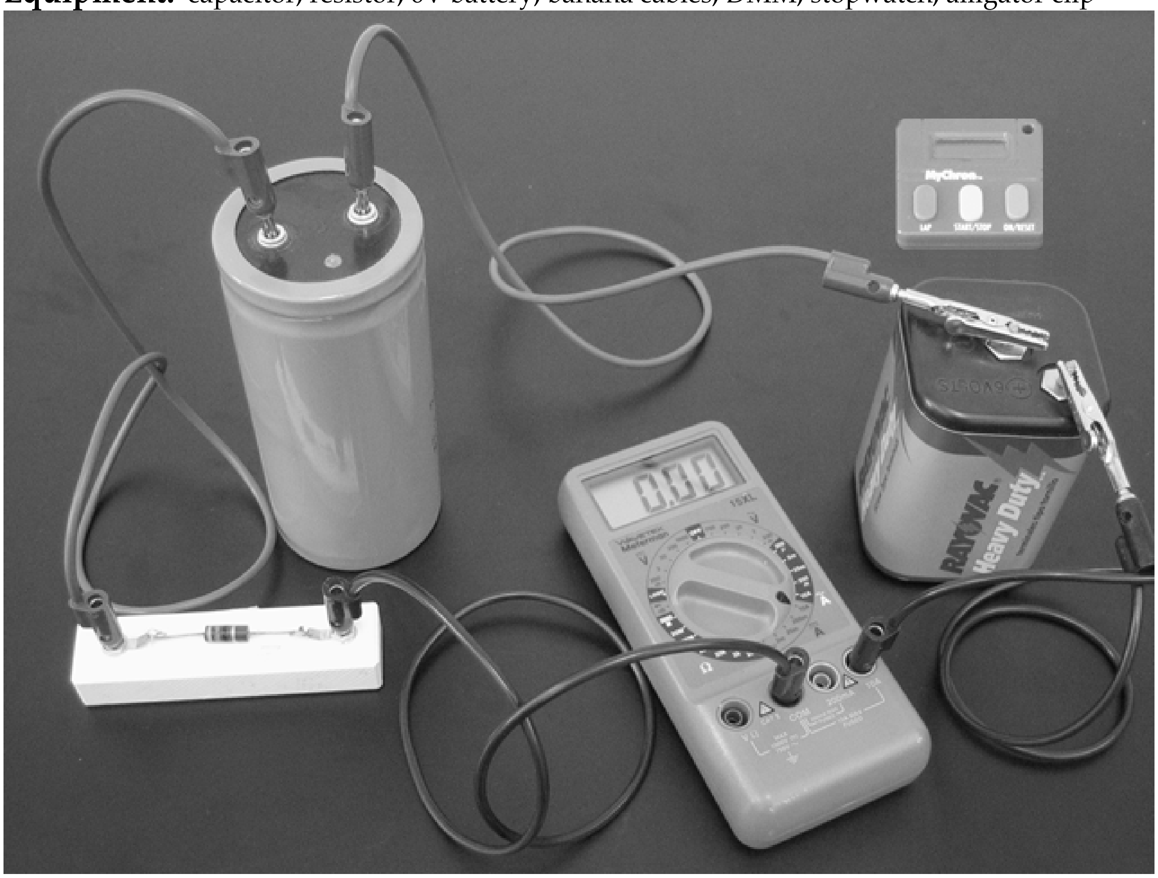
Problem

4- In an RC-circuit, study how the current changes with time.
5- Study how the rate of change of the current depends on the capacitance.
6- Study the time it takes for the current to fall to half of its initial value.
7- Observe quantitatively how the time it takes for the current to fall to half of its initial value depends on the resistance in an RC-circuit.

Purpose

- To demonstrate to students the <u>quantitative</u> behavior of RC-circuits
- To provide practice in applying Ohm's Law, as well as laws of conservation of charge and energy, to circuits that have capacitors in addition to resistors.
- To introduce students to an exponential decay since it occurs in RC-circuits (the rate of decrease of a quantity - charging current - is proportional to the quantity itself).

Equipment: capacitor, resistor, 6V battery, banana cables, DMM, stopwatch, alligator clip



WARNING

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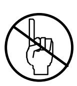
Teaching tips

1. These problems are all very similar, and it is not intended that the students should complete all four of them. Problem #4 and #5 are similar to Lab III, Problem #2 and #4, respectively, but solved in a rigorous, quantitative manner. Problem #6 and #7 follow on from Problem #4, and each show a particularly interesting property of exponential decays. In particular, Problem #7 shows why it is that the time taken for a bulb in the circuit to dim is directly proportional to both the capacitance of the capacitor and the resistance of the bulb. This gives a quantitative answer to Lab III, Problem #3, which the students could only make an educated guess at before. I would assign Problem #4 to all groups, and Problem #5 to those needing the extra practice. It may be a good idea to assign Problem #6 and #7 to different groups, and then have a discussion of the results at the end.
2. These problems each are intended to show the students how each quantity in the circuit changes with time. For example, the current in the circuit, the voltage across the resistor/bulb/capacitor, the charge stored on the capacitor. From their knowledge of Lab III, the students will know that the current in the circuit changes with time, and the charge on the capacitor increases, but how exactly do they change?
3. For safety reasons, be sure that all of the capacitors are at the front table and that each is discharged before your students enter the lab room.
4. Remember the bulbs are not exactly ohmic, so for Problem #5 make sure the students use resistors for data talking and light bulbs only for exploration.
5. The students should use reasonably high values of resistance and capacitance in their circuits so that the current changes sufficiently slowly for accurate data to be taken.
6. Many students use the phrase "exponential decay" for all non-linear decays they encounter. This problem illustrates one example of a true exponential decay. It may be useful to discuss the important characteristics of exponential decays, and how they arise. **What are the characteristics of an exponential decay graph that set it aside from other decays?**

WARNING



Your students will be working with power supplies that generate **large voltages**. Improper use can **cause painful burns**. To avoid danger, make sure that the students know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to the power supply; they must **never touch** the conducting **metal** of any **wire**. A charged capacitor can discharge quickly producing a **painful spark**. Make sure your students know the safe way to handle capacitors: they must **never handle the capacitors by electrical leads or by metal ends of connected wires**; they must **discharge a capacitor as soon as they are finished using it.**

Prediction

Problem #4

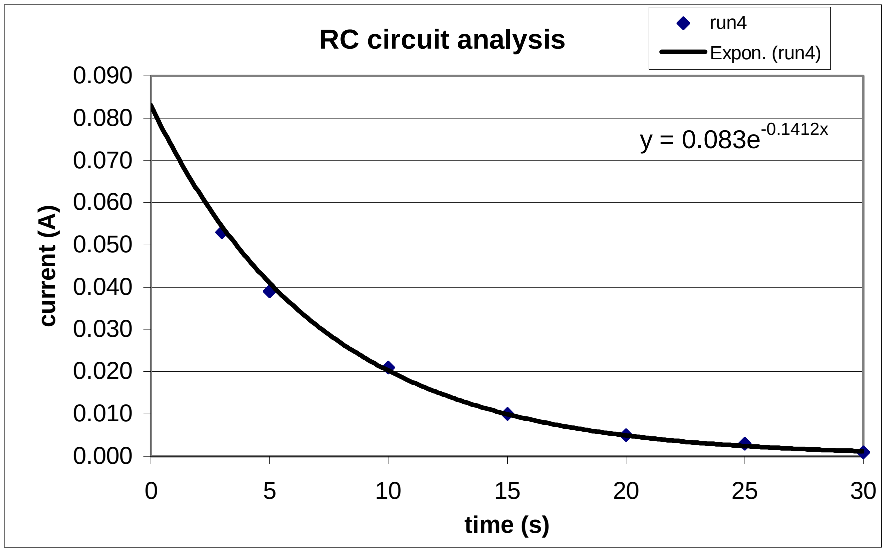
The current in the circuit depends on time as

$$I(t) = \frac{V}{R}\exp\left(-\frac{t}{RC}\right),$$

where V is the voltage of the battery, R is the resistance of the resistor, C is the capacitance of the capacitor, and t is the time since the switch was closed. Sample data is shown below.

time	run4
0	
3	0.053
5	0.039
10	0.021
15	0.010
20	0.005
25	0.003
30	0.001

Voltage	6
Initial Current	0.0830
R(effective)	64
Capacitance	0.1
1/RC	0.1383



The time constant 1/RC for the circuit was calculated using R(effective).
R(effective) was found using the initial current extrapolated from the graph.

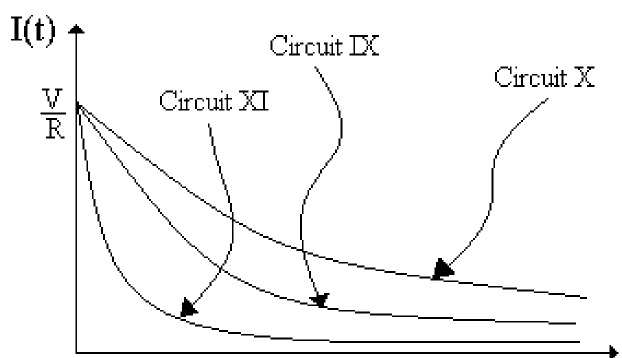
Problem #5

Circuit IX has one resistor, Circuit X has two parallel resistors, and Circuit XI has two resistors in series. A sketch comparing the three $I(t)$ graphs is shown below.

Circuit IX: $I(t) = \frac{V}{R}\exp\left(-\frac{t}{RC}\right)$

Circuit X: $I(t) = \frac{V}{R}\exp\left(-\frac{t}{2RC}\right)$

Circuit XI: $I(t) = \frac{V}{R}\exp\left(-\frac{2t}{RC}\right)$



Problem #6

The time it takes the current to fall to half of its initially measured value is independent of the instant the initial measurement is taken.

Problem #7
The time it takes the current to fall to half its initial value is

$$t = RC \ln 2.$$

Thus, it is directly proportional to both the resistance of the resistor and the capacitance of the capacitor. The data below shows the calculated "half-life" of the current for two different resistor–capacitor pairs at different current levels.

resistance =	64		**resistance =**	64
capacitance =	0.28		**capacitance =**	0.1
calculated t =	12.4		**calculated t =**	4.4
current	**1/2 time**		**current**	**1/2 time**
80 mA to 40 mA	14.4		70 mA to 35 mA	4.7
80 mA to 40 mA	14.3		70 mA to 35 mA	4.9
60 mA to 30 mA	14.8		50 mA to 25 mA	4.96
average:	14.5		**average:**	4.85

Problem #8: Resistors and Light Bulbs

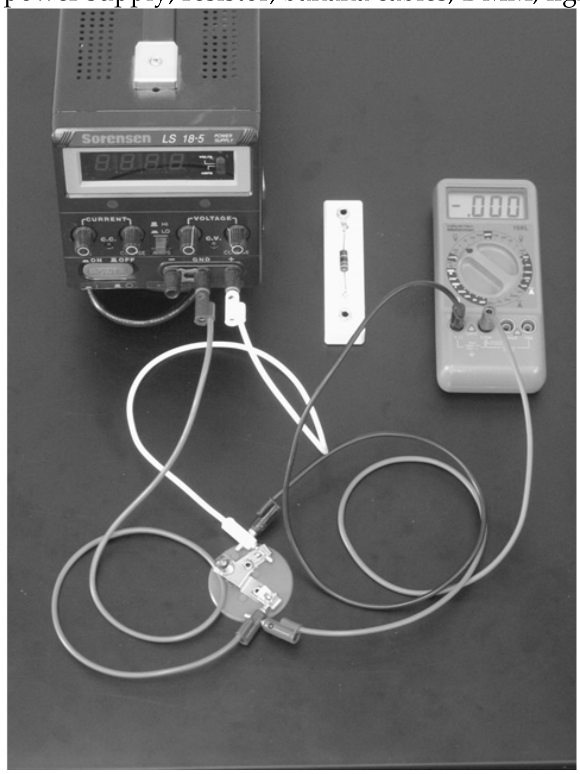
Problem

How well can a light bulb substitute for a resistor in a circuit?

Purpose

To show students explicitly that Ohm's law is a special case and it is a useful approximation even for a light bulb.

Equipment: 18V/5A power supply, resistor, banana cables, DMM, light bulb



WARNING

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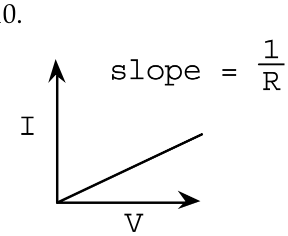
Teaching Tips

This is a nice transition from Problems #1 and #2 to Problems #9 and #10.

1. This problem provides a bit of practice with Ohm's law.
2. The students need to design their own circuit for this problem. They also must use some graphical analysis techniques – getting the resistance of the resistor from the slope of the current against voltage graph, for instance. These are both places your students might get hung up.



3. The light bulb doesn't respond linearly. The resistor should. As a bulb lights up, the filament gets hot and the resistance goes up about a factor of 10 (from 4Ω to 40Ω, at least for

the bulbs we tested). You might try using this change to measure the temperature of the filament, via a simple generalization of the Tipler equation 26-9 (page 791), according to which resistivity changes with temperature as

$$\rho - \rho_0 = \alpha(\rho_0)(T - T_0).$$

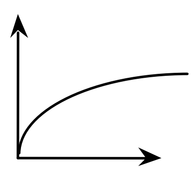
The table on the facing page gives the temperature coefficients for various materials.

4. It is good idea to discuss the fact that resistors are only ohmic within a reasonable range (the students should NOT try to confirm this).
5. It is possible to connect the batteries to get data from 0V to 12V in 1.5V increments; however, you should use the power supplies with adjustable voltages to get a smoother range of points.

Difficulties and Alternative Conceptions

Many students will have over generalized to believe that every conductor obeys Ohm's Law. This problem disproves that concept, yet shows that Ohm's law is a useful approximation within a region of behavior. (I know of one engineer who insists on calling Ohm's Law "Ohm's Suggestion.")

Prediction



Warm-up Questions

See the graphs on the previous page to see how slope is related to resistance.

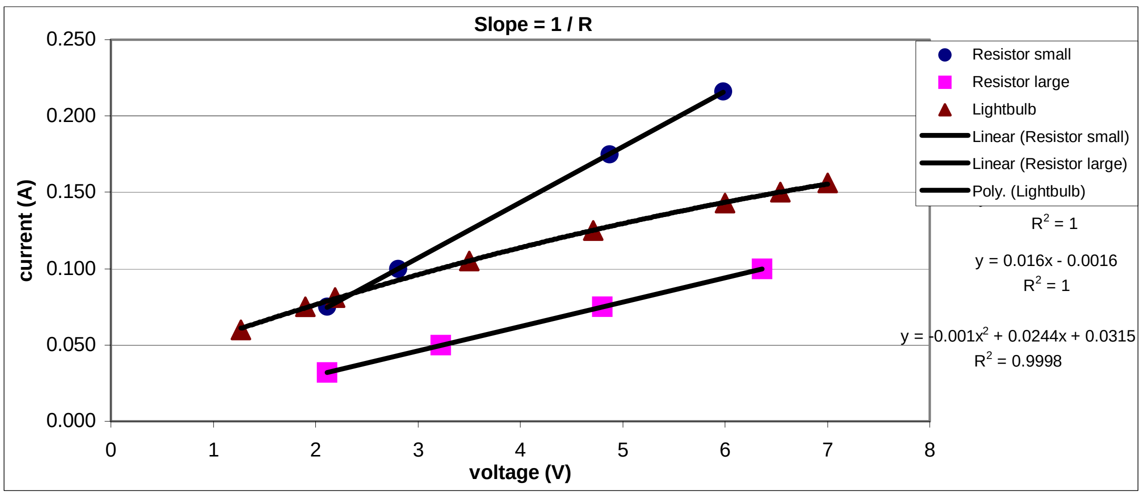
As the temperature increases, so will the resistance. Therefore, the current levels off at high voltages.

Data

Below is some sample data for a large resistor, small resistor, and a light bulb. The quadratic term is not insignificant at voltage levels typical of a battery. However, for most experiments the students will do it can be treated as linear.

Resistor small			Resistor large			Lightbulb		
Code:	R = 22 +/-5%		Code:	R = 68 +/-10%				
DMM:	R = 28.1		DMM:	R = 64.2		DMM:	R = 28.7	
Current	Voltage	R(calc)	Current	Voltage	R(calc)	Current	Voltage	R(calc)
0.216	5.98	27.7	0.032	2.11	65.9	0.156	7.00	44.9
0.175	4.87	27.8	0.050	3.22	64.4	0.15	6.54	43.6
0.100	2.81	28.1	0.100	6.36	63.6	0.143	6.00	42.0
0.075	2.11	28.1	0.075	4.8	64.0	0.125	4.71	37.7
						0.105	3.50	33.3
						0.081	2.19	27.0
						0.075	1.90	25.3
						0.06	1.27	21.2

Ave 1/R: **0.035795** **0.015508** **0.023794**



Problems #9 and #10: Quantitative Circuit Analysis (Parts A and B)

Problem

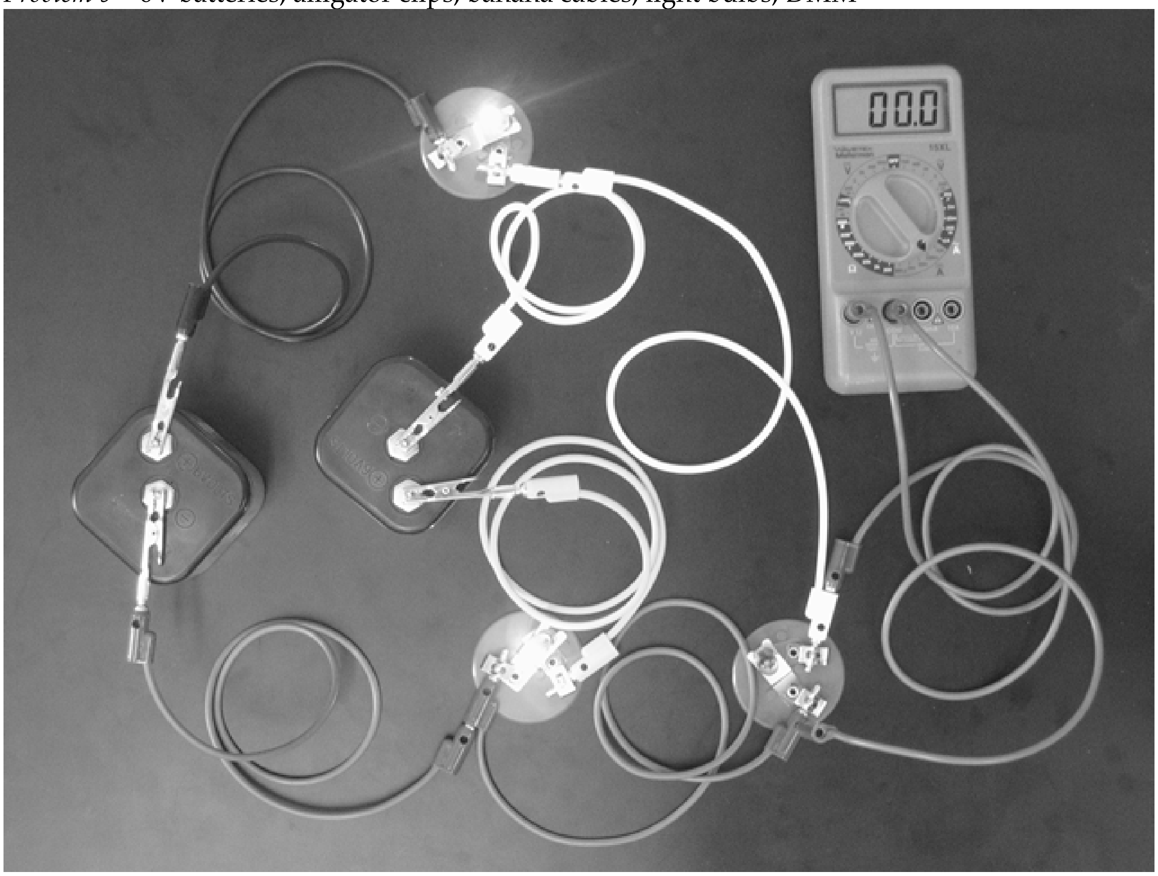
What is the current through each resistor in the circuit?

Purpose

To give students practice using Ohm's law together with conservation of charge and energy (Kirchhoff's rules). To give students practice using DMM's to measure currents, voltages and resistance correctly.

Equipment

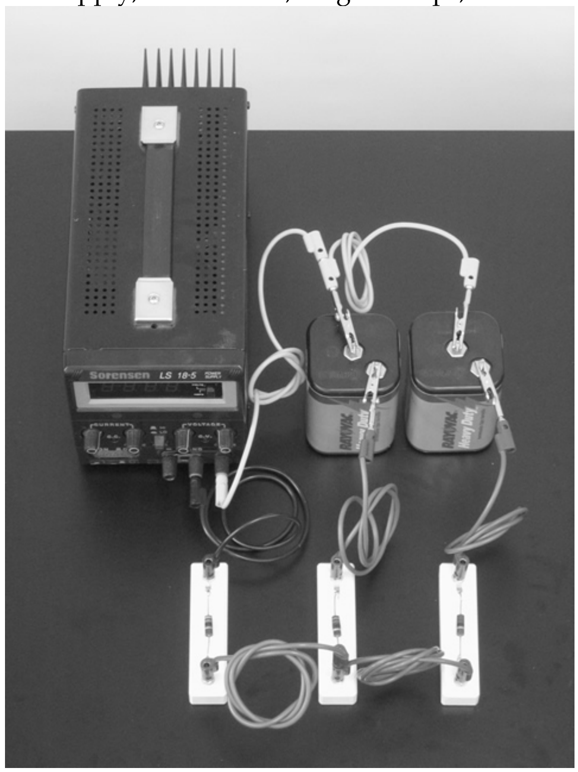
Problem 9 – 6V batteries, alligator clips, banana cables, light bulbs, DMM



WARNING

Your students will be working with power supplies that generate **large voltages**. Improper use can **cause painful burns**. To avoid danger, make sure the students know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to the power supply; they must **never touch** the conducting **metal** of any **wire**.

Problem 10 – 18V/5A power supply, 6V batteries, alligator clips, banana cables, resistors



WARNING

Your students will be working with power supplies that generate **large voltages**. Improper use can **cause painful burns**. To avoid danger, make sure the students know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to the power supply; they must **never touch** the conducting **metal** of any **wire**.

Teaching tips

1. This problem should reinforce the concept that "the voltage at point A" is meaningless. They should measure the potential difference *between* two points.
2. Repeated measurements of current and potential difference reinforce the relationship between these two quantities.
3. If, when reading current on the DMM's, you do not get a reading and the light bulb (in the circuit) does not light up, the fuse in the DMM has probably blown. If a fuse in the DMM is blown please deliver the DMM to closet 8 on the second floor and place them in the box labeled *"Bad" DMMs*. Do not try to fix them yourself. Replacements are also located in closet 8, in the *"Good" DMMs* box.
4. These problems seem especially likely to bring out the "take data and run" approach in students – probably because students don't understand Kirchoff's rules and the predictions are algebraically messy. Make sure, however, that your students understand the data they are taking and compare the data with their predictions. Also make sure that students can look at their data and see if it makes sense (i.e. the sum of the currents into and out of an intersection equals zero and the sum of the potential rises and drops around a closed loop equals zero) – many cannot.

5. Notice, in Problem #10, if the voltages of all three batteries are identical, all the currents vanish, no matter what resistors you use! If the voltages are different, but very close in value, the currents are extremely small, so that measuring them with any degree of accuracy is almost impossible. For this reason, it is a good idea to use a power supply in place of one or two of the batteries. Just ensure that the voltages on the central strip are **NOT** used.

WARNING

Your students will be working with power supplies that generate **large voltages**. Improper use can **cause painful burns**. To avoid danger, make sure that the students know the safe way to operate the equipment: they must **never use higher voltage settings** on the power supplies**.**

Difficulties and Alternative Conceptions

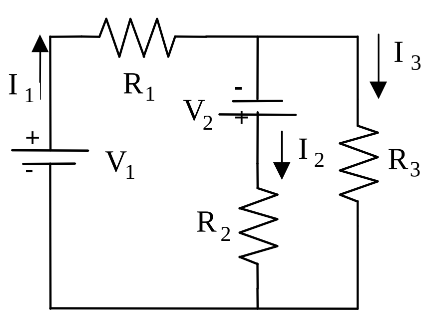
Many students confuse the concepts of current and potential difference and how to measure each. They don't understand that current is measured **through** a point in the circuit and potential difference is measured **across** two points of interest in the circuit. All possible circuit misconceptions will resurface in these problems.

Many students are also very confused about the signs of the current and potential difference. Be sure to ask each group to explain how they determined their signs.

Many students will also be confused about the difference between potential difference and energy. Many will add up the energy output from each resistor and, using conservation of energy, will set this equal to the sum of the voltages of the batteries (believing this to equal the total energy input).

Predictions

Problem #9



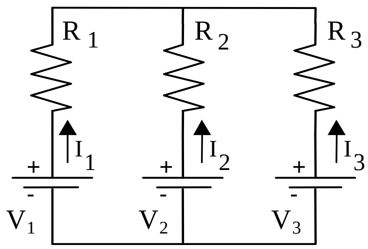
Circuit XII

$$I_1 = \frac{V_1(R_2 + R_3) + V_2 R_3}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

$$I_2 = \frac{V_1 R_3 + V_2(R_1 + R_3)}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

$$I_3 = \frac{V_1 R_2 - V_2 R_1}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

Problem #10



$$I_1 = \frac{V_1(R_2 + R_3) - V_2 R_3 - V_3 R_2}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

$$I_2 = \frac{V_2(R_3 + R_1) - V_3 R_1 - V_1 R_3}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

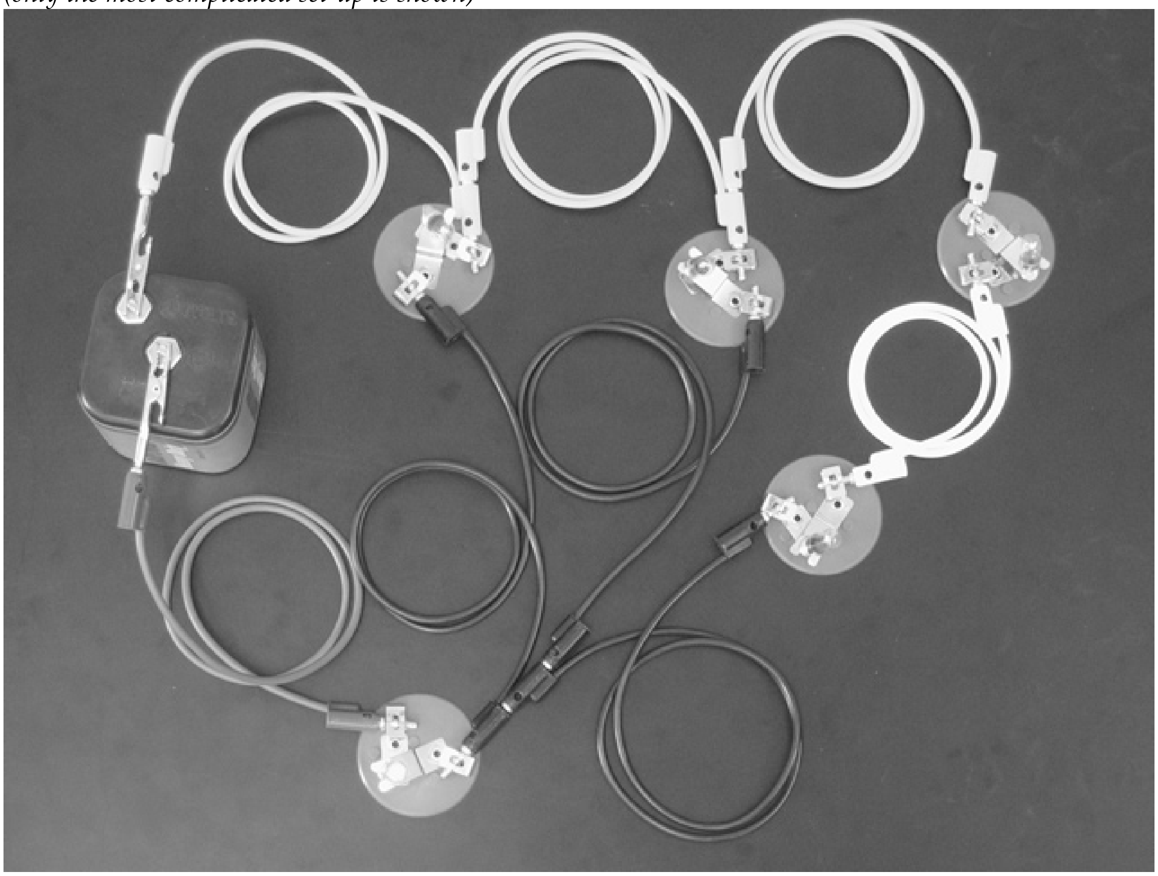
$$I_3 = \frac{V_3(R_1 + R_2) - V_1 R_2 - V_2 R_1}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

Problem #11: Qualitative Circuit Analysis

Problem
How will the brightness of the bulbs compare in the three circuits.

Purpose
To apply the ideas of conservation of current, conservation of energy, and Ohm's Law directly without hiding incorrect concepts behind mathematics.

Equipment: 6V battery, banana cables, light bulbs, alligator clips
(only the most complicated set-up is shown)



Teaching tips
1. This problem helps connect the mathematics of Kirchhoff's rules to the basic physics of the way that circuits behave. If the lecturer has not covered Kichhoff's rules, this problem is useful to surface many of the remaining circuit misconceptions. Reasoning this problem through qualitatively is much more difficult than using the mathematics of Kirchoff's rules.
2. Do not let your students do their predictions only by solving equations. This problem is meant to build their confidence and intuition by qualitatively using the rules of circuit analysis.
3. Remember that light bulbs are not ohmic, so any calculations are only an approximation to the real situations. This shows up when comparing bulb A between Circuit XIV and Circuit XV. Since BCDE in Circuit XV are less hot than C in Circuit XIV, the effective resistance of BCDE does not equal C.
4. Some of the situations lead to dimly lit bulbs. Remind students that the bulb brightness can only help you determine the relative currents between the two places (i.e. which one is

larger), not the magnitude of either. DMM's are available if accurate current measurements are needed.

Difficulties and Alternative Conceptions

Many students still believe that a battery is a constant current source instead of providing a constant potential difference. Some students still believe that current always divides in equal parts at a junction.

Prediction

The currents through each bulb of each circuit are listed below, along with the relative brightness of each bulb. *V* is the voltage of the battery, *R* is the resistance of each light bulb as we assume all the bulbs to be identical.

Circuit XIV

The currents through bulbs should be

$$I_A = I_C = \frac{V}{2R}, \qquad I_B = \frac{2V}{3R}, \qquad I_D = I_E = \frac{V}{3R} .$$

Ranking bulbs by their brightness, one should get B > A = C > D = E .

Circuit XV

The currents through bulbs should be

$$I_A = \frac{V}{2R}, \qquad I_B = I_C = I_D = I_E = \frac{V}{4R} .$$

Ranking bulbs by their brightness, one should get A > B = C = D = E .

Circuit XVI

The currents through bulbs should be

$$I_A = \frac{5V}{7R}, \qquad I_B = I_C = \frac{2V}{7R}, \qquad I_D = I_E = \frac{1V}{7R} .$$

Ranking bulbs by their brightness, one should get A > B = C > D = E

Ranking the circuits by the brightness of bulb A, one expects

XVI > XIV = XV .

Discussion Question

What does a battery keep constant, current or voltage? Students should see that with more light bulbs, the circuit would draw more current if they were in parallel and less current if they were in series. With a larger current, the rate at which energy transferred from the battery is larger, and the battery is drained faster.

Check Your Understanding Answers

1. If more bulbs were added as shown in the diagram, bulb A would grow brighter. The reason is that by adding bulbs in parallel, the net resistance is decreased and more current is drawn from the power source.

   A is the position of a circuit breaker to regulate the amount of current that flows through a circuit.

3. Circuit I, $R_{\text{equivalent}} = \dfrac{R}{2}$, Circuit II, $\mathrm{R}_{\text{equivalent}} = \dfrac{3\mathrm{R}}{7}$

   Circuit III, $R_{\text{equivalent}} = \dfrac{R}{2}$, Circuit IV, $\mathrm{R}_{\text{equivalent}} = \dfrac{6\mathrm{R}}{11}$

Thus, ranking the circuits by the current through point 1 is II > I = III > IV .

TA Lab Evaluations
Physics 1302 Lab 4

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

____

____

____

Students:

Did the students find these exercises: (circle one) enlightening / boring / fun / other?

Do you have additional comments regarding student learning and these labs?

____

____

____

TA:

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results:

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room:

Was the room kept neat and clean by your class and other classes? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

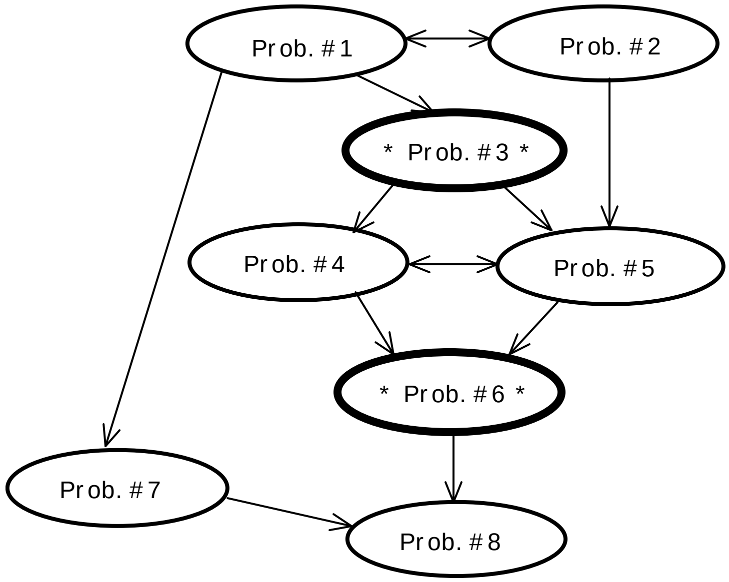
____

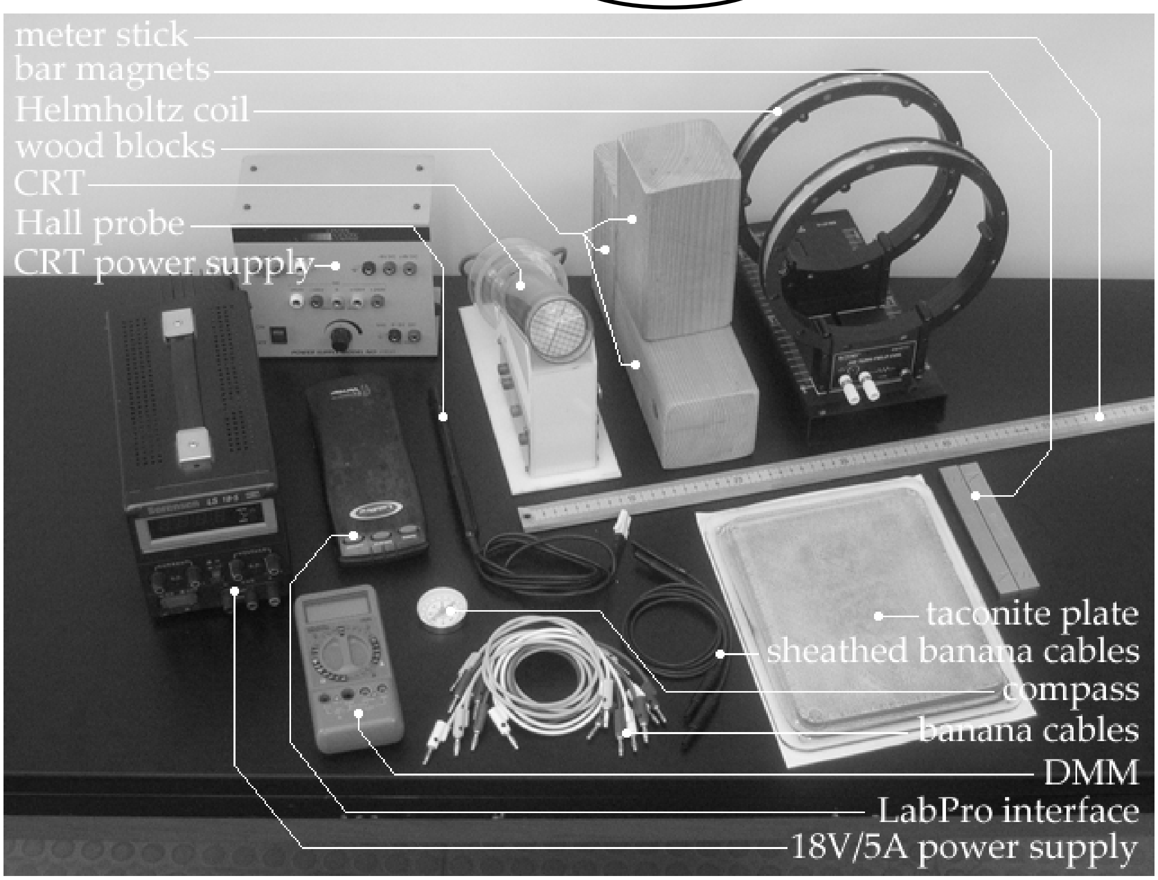
____

____

Laboratory V: Magnetic Fields and Forces

The flow chart for this lab is shown below.





**Note: the LabPro is replaced by the SensorDAQ interface for labs 5, 6 & 8.

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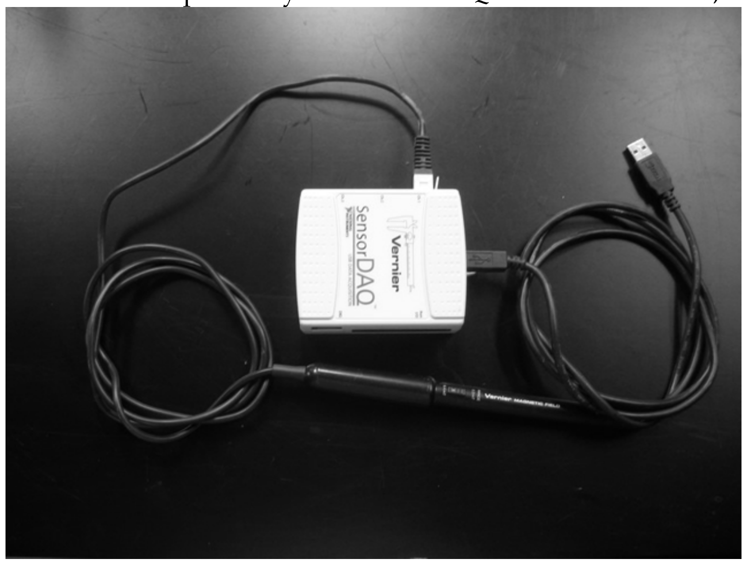
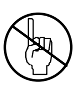


Teaching Tips

1. You should emphasize the differences and similarities between electric and magnetic fields at the end of these problems.
2. Lines of force are not useful for simple calculations and lead to student misconceptions; it is probably best to avoid them as much as possible. Just use the field vector at a point in space.
3. You will need to ask a lot of questions when working with the groups to make sure your students are really making appropriate connections between these new concepts and fundamental physics.
4. It is not necessary to do both Problems #4 and #5, although you may want some students to do so. Which one you choose will depend on how much you want to emphasize the Biot-Savart law.

WARNING



Your students will be working with electrical equipment that generates **large voltages**. Improper use can cause **painful burns**. To avoid danger, make sure that they know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to a power supply; they must **never touch** the conducting **metal** of any **wire.**

Things your students should know by the end of this lab

- The differences and similarities between magnetic fields and electric fields.
- The difference between an electric charge and a magnetic pole.
- The pattern of magnetic fields near various sources such as permanent "bar" magnets, straight current-carrying wires, and coils of wire.
- How to calculate the magnetic field at a point in space caused by a complex configuration of sources (at least two) given the field of each source by using vector addition.
- How to calculate the magnetic force on a charged particle moving in a uniform magnetic field and describe its motion.
- How to measure a magnetic field using a Hall probe.

Things to check out before teaching the lab

- Make sure you know which direction is North in your lab room. Do not rely on your compasses for this.

- The taconite plates are fun to play with. Play with them to determine what suggestions to give students who are having difficulty getting clear patterns. Make sure you know how to explain how this pattern tells you about the magnetic field at each point of space. Do this without any reference to "lines of force."
- Make sure you know how to hook up the Hall probe (see Appendix E) and make measurements using the computer program. Explore different possible mistakes that your students might make with calibration so that you can spot them during class.
- Make sure you know where to place the CRT in the magnetic field to get good results. Try various other configurations so that you can advise your students when they have difficulty.
- Just before your students enter class, test every Hall probe on the permanent magnet. They do become damaged. Replace any that do not work.
- **Just before your students enter class, remagnetize every permanent magnet**. Students can do amazing things, which change the pole structure. Your students will really be confused and frustrated if you do not make sure that all the magnets are really dipoles before they start class. After you remagnetize the magnets, check that they are now dipoles using the taconite plate. Just for fun, look at the magnets using the taconite plates before you remagnetize them.
- **Just before your students enter class, make sure all of your compasses point North**. You can reverse the poles of the compass needle by bringing it close to a magnet. That is how students reverse them in the first place.

Problem #1: Permanent Magnets

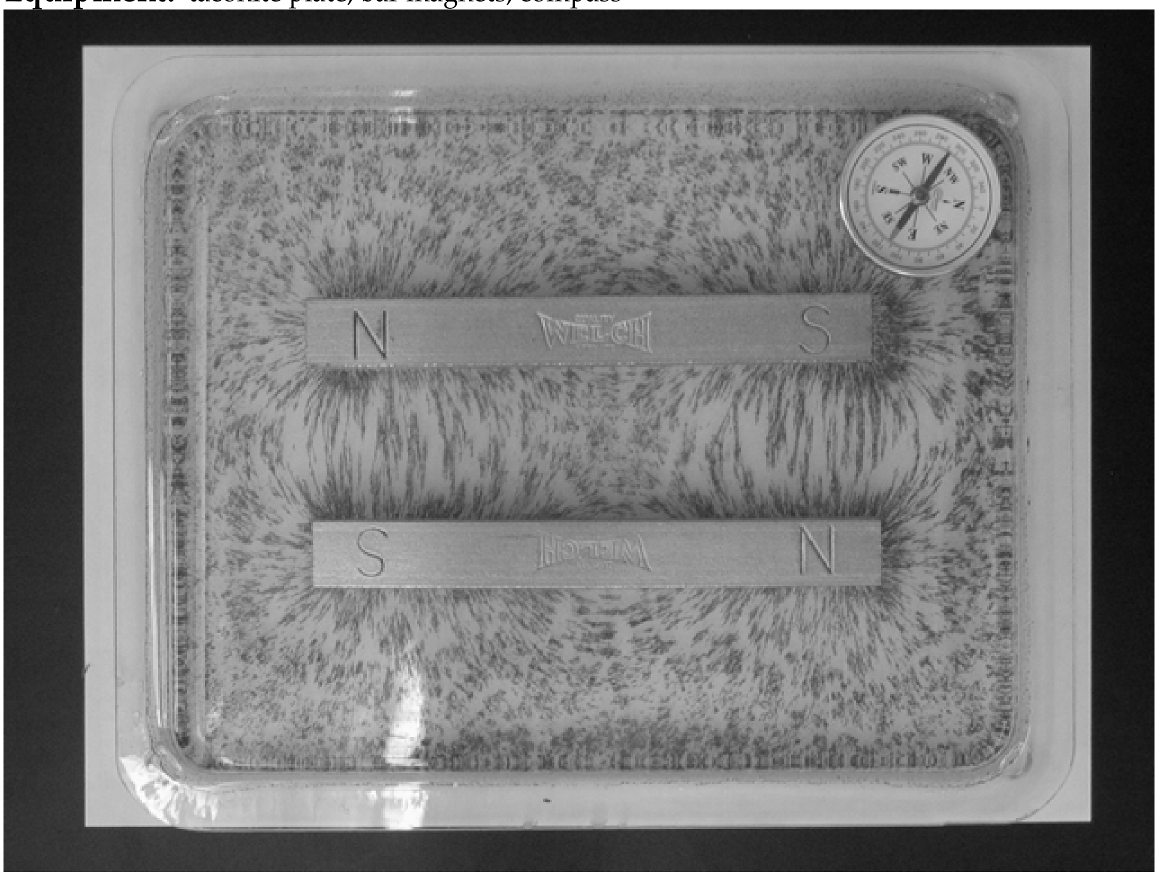
Problem

Sketch field-line diagrams for various arrangements of two bar magnets.

Purpose

To allow the students to become familiar with the magnetic fields of a bar magnet and how these fields combine by vector addition. Also to show that magnetic poles are different from electric charges.

Equipment: taconite plate, bar magnets, compass



Teaching tips

1. **Check the magnets!!** They can become different from simple dipoles when they are dropped or are in the field of another magnet. **Remagnetize all the magnets in the lab.** Use a taconite plate to check the field of every bar magnet. If it is still not a dipole, remagnetize it again or replace it. Poor magnets are a large source of frustration to the students and can reinforce many misconceptions. It is necessary to remagnetize the magnets **before each class period**.
2. This is a field-mapping problem and it is very similar to the electric field problems from the first lab. It might be helpful to explicitly say that the iron particles are like mini-compasses. We don't want this to be a magical apparatus.
3. Make sure your students explore the properties of a compass. Have a short discussion after they have done so to make sure that every student knows that a compass is just a small dipole magnet. Emphasize the concept of torque by making a free body diagram of the compass needle in a magnetic field.

4. Some of the configurations can be challenging. Encourage your students to follow the guidelines in the warm-up questions to help them through the analysis. Emphasize vector addition of the field from every magnetic pole.
5. You may wish to consult a map to determine which way is north (North is basically pointing towards Morrill Hall). Remember the north pole of a magnet is the north seeking pole. That means the Earth's magnetic north pole is at the south pole. Also, remember that the earth's magnetic field has a large vertical component in Minneapolis. This is not shown by flat compasses which only work when horizontal.
6. Since the compasses only give direction and not magnitude of the magnetic field, there is not enough information to make a complete translation between compass data and field maps. The students should be able to make educated guesses about the magnitude of the magnetic field and add this information to the maps.
7. Be sure to warn your students not to get any glycerin on their hands in the event of a leak of the taconite plates. If they do, make sure they wash their hands immediately. Glycerin is not dangerous, but it is a skin irritant. The iron powder suspended in the glycerin should not be ingested. If any plate leaks replace it immediately.
8. The taconite does take a little time to align with the field, be patient. If it takes more than 5 or so minutes let the lab coordinator know and he will adjust the viscosity of the glycerin. To distribute the taconite, just shake or tap the Plexiglas frame. Once distributed, keep the taconite plates flat on the table and don't leave the magnets on plates when the exercise is done.
9. DO NOT leave the magnets stuck together! This will demagnetize them and destroy them over time. There are boxes for the magnets to be kept in when not in use. Align the magnets with opposite poles together and put the keeper bars at the ends.

Difficulties and Alternative Conceptions of Students

Your students will have many misconceptions about magnetic fields. Many students believe that magnetic poles are just electric charges. They may even label their poles '+' and '-'. Make sure they explore the properties of their magnets enough to determine that they are not electrically charged. Your questioning is crucial here. Based on pictures of lines of force, many students believe that these lines come out of magnets and forces occur when these lines push on each other (repel) or grab each other (attract). They do not believe in the field concept that the object (magnet) modifies the space around it (field); that a group of magnets each independently modify the space around them so that the net effect (field) is the vector sum at each point in space of the field from each magnet; and that the force on yet another magnet is due to the interaction of its poles with the field (from the other magnets) at each of its poles. Most of your students probably do not separate the magnet causing the field from the magnet on which a force is exerted.

Prediction

We think the most interesting configuration is Figure III. There is a region where the field from each magnet is exactly opposite to the field from the other magnet. It is interesting to move the compass (shown as a circle) perpendicularly away from the center of the two magnets and watch what happens.

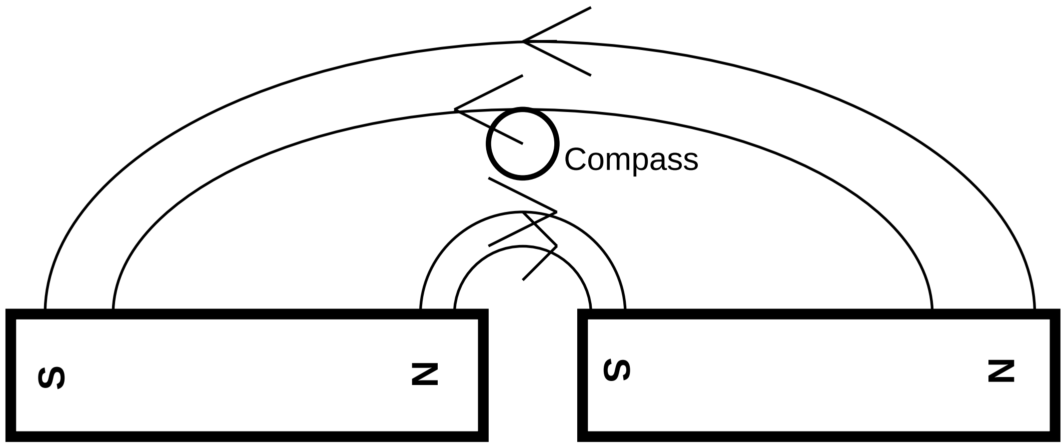


Figure III.

Exploratory Problem #2: Current-Carrying Wire

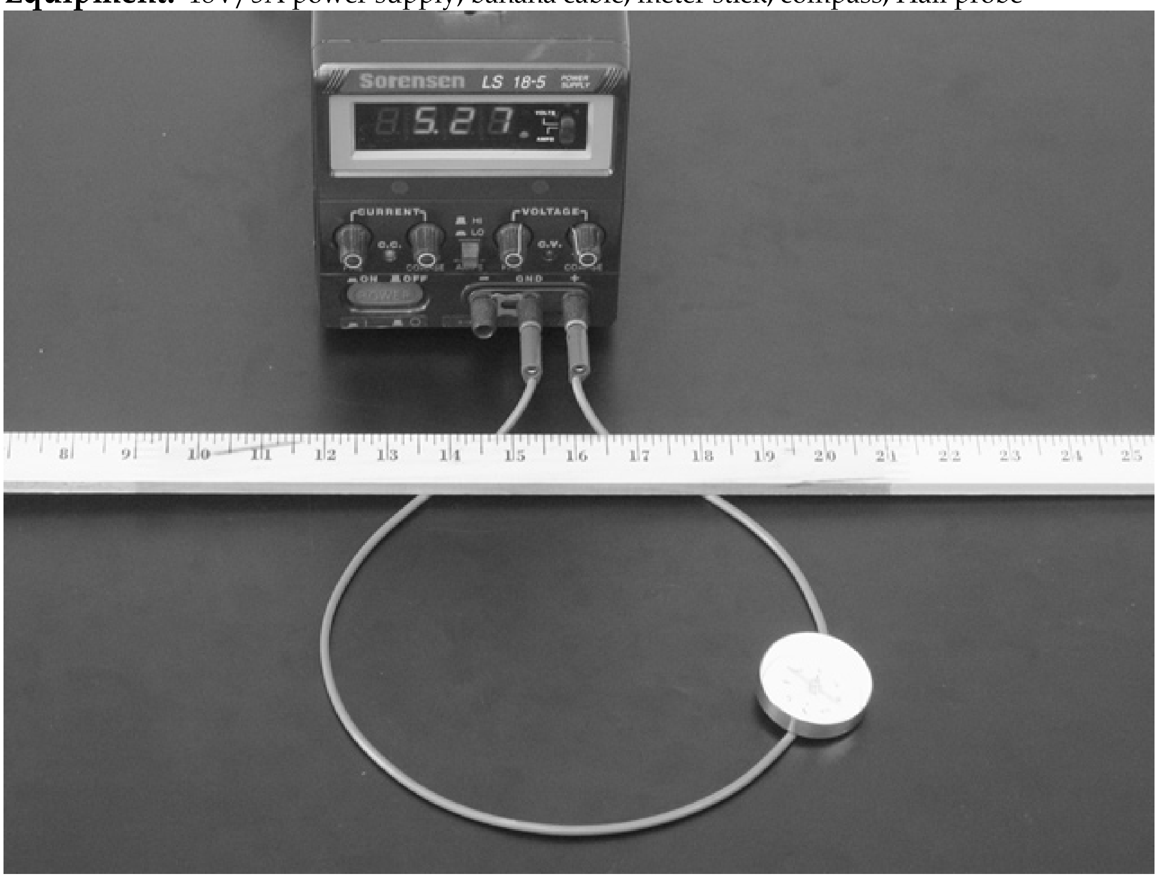
Problem

Sketch the map of the magnetic field near a current carrying wire when the wire is (a) stretched straight, and (b) formed into a loop.

Purpose

To show students that a magnetic field that deflects the compass in Problem #1 can be created by a current carrying wire. To allow the students to "see" that the field map curls around the wire and does not point back to any source. Make sure they understand that the magnetic field at any point is still pointing in a straight line. The field vectors do not curve. This is another instance where field lines can be confusing.

Equipment: 18V/5A power supply, banana cable, meter stick, compass, Hall probe



Teaching tips

1. This lab shows that the field from a current-carrying wire exists and it introduces the right-hand rule for magnetic fields. Figure 29-2 in the text shows the results for field around a current-carrying wire. The EMField simulation allows another way of visualizing the field due to the current carrying wire.
2. To witness the magnetic field near a current-carrying wire, the wire should be vertical and the compass needle must be horizontal. A second possible configuration is with the wire lying across the compass. Many students will want the compass to point toward the wire.
3. Power Supplies – Make sure that only the batteries or the Sorensen power supplies are used! The Pasco CRT power supplies should **not** be used because the current causes them to break down. Also be sure to warn your students about the power supplies. They maintain a significant potential difference for at least a minute after they are turned off.

4. For small currents, the earth's field is larger than the current's field when the compass is just a few cm from the wire. If a group does not observe a compass deflection have them discuss how they think the field varies with distance from the wire and where the biggest effect would be observed. Then have them try it where the effect is largest. If there is still no deflection, try using a battery, though only keep it connected for very short periods of time.
5. Make sure that your students use **Channel 1 of Sensor DAQ**. Connection to any other channels does not give any signal.
6. The Hall probes are really very reliable, so if anything isn't working, check the connections and wires before hassling the people in room 233. Be sure that the probe setting is set to the maximum value in agreement with the software prompt before calibration. **Having inconsistent settings is one of the most common sources of mistakes in this lab.**

WARNING

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Difficulties and Alternative Conceptions

Based on their confusion, probably caused by seeing field lines in books, many students believe that magnetic fields go from one source to another source. This is not a field theory with a field vector defined at a point in space. Even students beginning to develop a concept of field can overgeneralize from magnets and think that field vectors must point to physical objects. This is also fed by their belief that electric charges and magnetic poles are the same.

Prediction

Make sure your students' predictions are magnetic field maps and not lines of force.

Problem #3: Measuring the Magnetic Field of Permanent Magnets

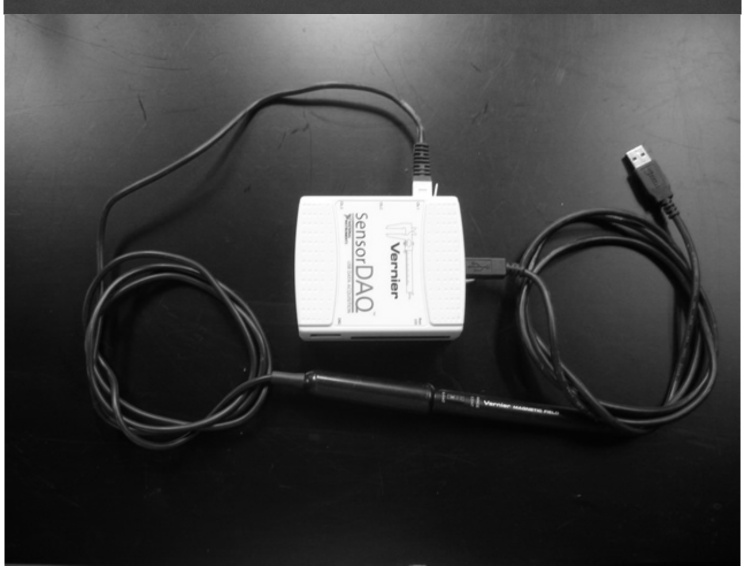
Problem

Determine how the magnetic field strength depends on distance from the center of a bar magnet along a line perpendicular to the magnet and along the axis of the magnet. Use a model in which the poles of the magnet are treated as monopoles obeying a Coulomb-type law.

Purpose

- To learn how to use the Hall probe to measure magnetic fields.
- To quantify the magnetic field of a bar magnet and to show the similarity of that field to an electric dipole's electric field.

Equipment: bar magnet, Hall probe, sensorDAQ interface, meter stick, compass. **Note: the LabPro is replaced by the SensorDAQ interface.



Teaching tips

1. This is mainly an introduction to the Hall probe. If you haven't used one before, take the time to see how the computer data acquisition program works with the Hall probe. Make

sure you try calibrating one yourself. The directions are in Appendix E. The program does all the converting from voltage into magnetic field strength.

2. Make sure that your students use **Channel 1 of Sensor DAQ**. Connection to any other channels does not give any signal.
3. Where you calibrate and use the Hall probe is very important. The computers put out enough of a magnetic field to affect the students results AS DO THE POWER SUPPLIES!! It is a good idea to put the power supply on the floor (or as far away from where the students are taking their data as possible). Also, watch to see where your students calibrate the probe. They should do it in the region in which they plan to take their data, but they seem to end up just holding it above their heads and spinning it around. That is not good enough, as the background fields are different in different parts of the room.
4. Make sure you understand the Hall effect. Students can be vicious if you cannot explain it simply and directly if they ask. It is easy to understand and a good application of the basic physics of the interaction of the magnetic field with electric charges. The Hall effect is not the purpose of this lab, so don't try to explain it to students unless they ask and are interested.
5. Chances are slim that the Hall effect will be covered in the students' lecture. Refer any of the boisterous ones (and yourself) to Tipler, section 28-4 (page 872).

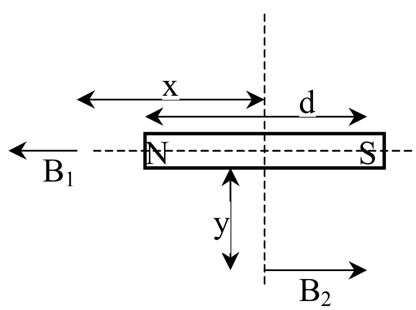
   Do not lecture on the Hall effect!

   For most students it is enough that the Hall probes can measure magnetic field.
6. You may wish to have your students test the $1/r^3$ behavior of their data (for 'large' distances from the poles).

Difficulties and Alternative Conception

By now many students have overgeneralized that everything falls off as $1/r^2$. This behavior is more complex but can be understood from limiting cases. Near a pole the field is like that from a monopole ($1/r^2$). The farther you are from one pole, the larger the fraction of the field is due to the other pole. After showing that magnetic poles are not electric charges, this problem shows that the dipole behavior of electric charges and magnetic poles is the same.

Prediction



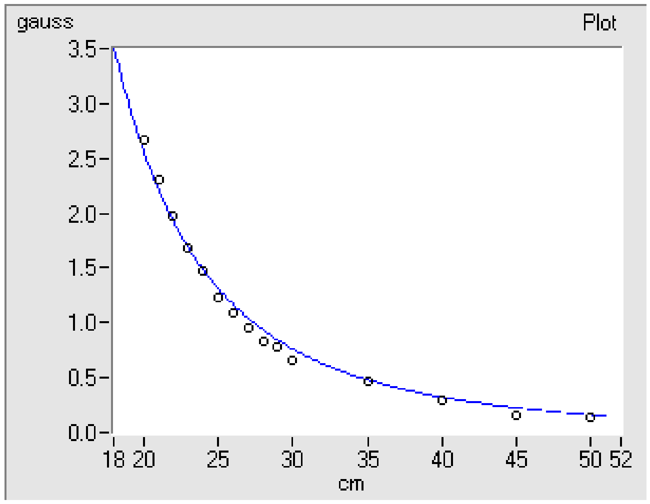
The magnetic field at points along the two axes of the magnet are given by:

$$B_1 = kg\left[\frac{1}{\left(x-\frac{1}{2}d\right)^2} - \frac{1}{\left(x+\frac{1}{2}d\right)^2}\right] = \frac{2kgd}{x^3} \quad \text{for } x >> \frac{d}{2}$$

$$B_2 = \frac{kgd}{\left(y^2+\frac{1}{4}d^2\right)^{3/2}} = \frac{kgd}{y^3} \quad \text{for } y >> \frac{d}{2},$$

where k is a constant analogous to Coulomb's constant for magnetism rather than electricity. The distance between the poles d is not necessarily the length of the magnet. The approximate position of the poles can be determined by examining the field pattern produced by iron filings.

The graph below shows the magnetic field parallel to the bar magnet. It was done under the High Sensitivity setting. The line shows the predicted $1/r^3$ behavior. The best prediction is based on a calculation of the electric field from an electric dipole.



Problems #4, #5, and #6
Magnetic Field of One Coil
Determining the Magnetic Field of a Coil
Measuring Magnetic Field of Two Parallel Coils

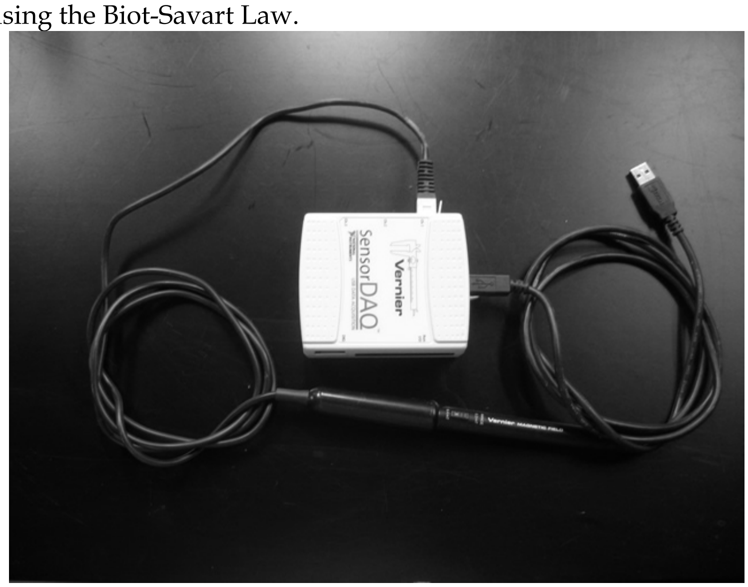
In Problem #5 the prediction should be based on a calculation using the Biot-Savart Law; if Biot-Savart calculations will not be emphasized on tests, then it is probably best to do Problem #4 instead of Problem #5.

Problem #4
Make a qualitative sketch of the magnetic field around a current-carrying coil of wire and compare to that of a bar magnet.

Problem #5
Determine how the magnitude of the magnetic field of a current-carrying coil of wire depends on the position along the central axis, the radius of the coil, the number of turns of the coil, and the current through the coil.

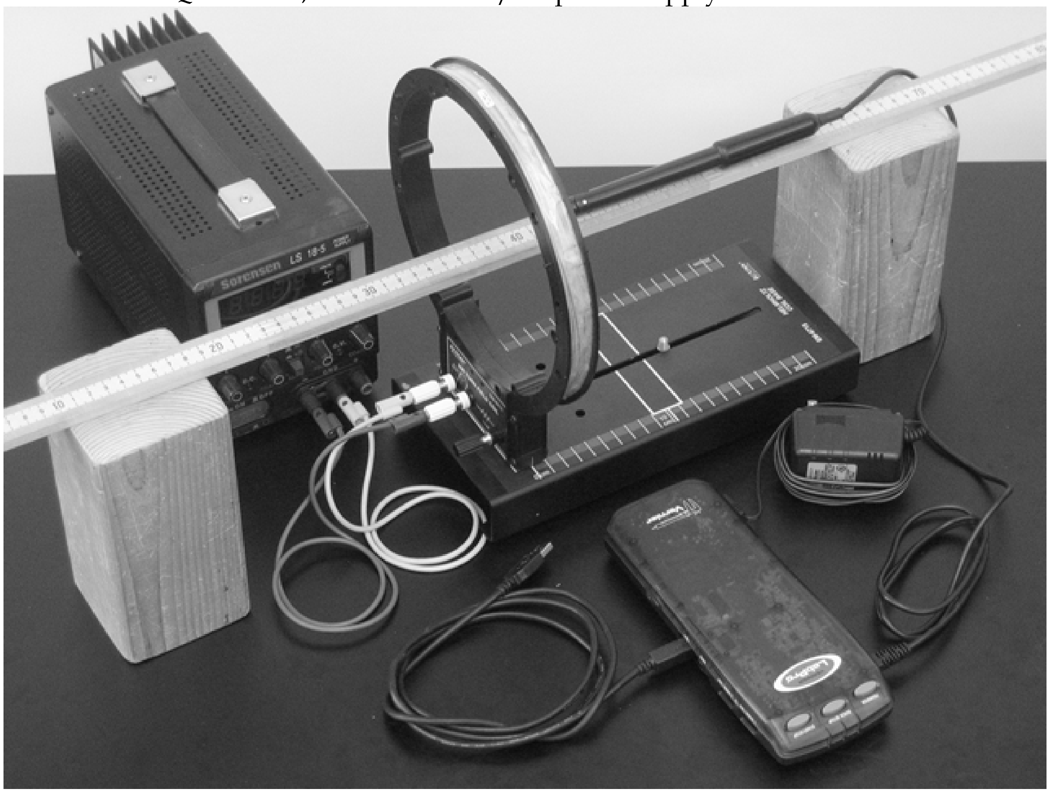
Problem #6
Determine how the magnitude of the magnetic field along the axis of two large identical parallel coils depends on distance from the middle of the two coils. The coils are oriented such that the distance between them equals their radii.

Purpose
- To show that electric currents can cause sizable magnetic fields.
- To explore the magnetic field of a current carrying coil(s) quantitatively.
- To show that a single coil has the magnetic field of a dipole.
- To show that the magnetic field from two sources is just the vector sum of the magnetic field from each source at each point in space.
- To practice using the Biot-Savart Law.

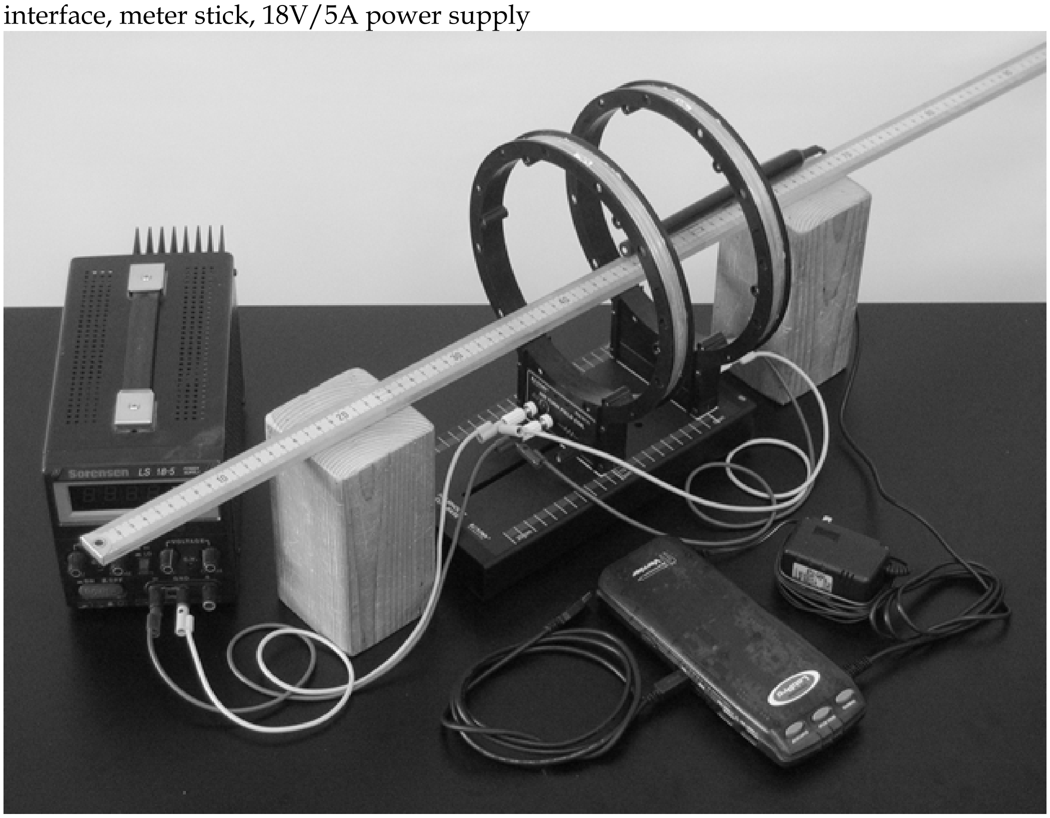


**Note: the LabPro is replaced by the SensorDAQ interface for labs 5, 6 & 8.

Equipment: *Problem 4,5* – Pasco large coil and base, wood blocks, banana cables, Hall Probe, SensorDAQ interface, meter stick 18V/5A power supply



Problem 6 – Pasco large coils and base, wood blocks, banana cables, Hall probe, SensorDAQ interface, meter stick, 18V/5A power supply



WARNING

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Teaching tips

1. The data for Problem #4 should show a field similar to that produced by a magnetic dipole.
2. Correct predictions for Problem #5 are made using the Biot-Savart law. If students use Ampere's law, they should see a difference between their results and predictions. After measurements are complete make sure they discuss why Ampere's law really does not apply.
3. In problem 5.59 (page #243 in the Second Edition) in D. J. Griffiths's upper-level undergraduate E&M text, the idea is given that the coils' separation is chosen so that both the first and second derivatives of the total field are zero at the midpoint along the axis of the coils (see Problem 30-72). The field changes very slowly between the coils and is approximately constant in this region. This arrangement is called a Helmholtz coil. **Do not go into this with your students**.
4. Make your students really measure distance along the axis of the Helmholtz coils.
5. The computer program measures magnetic fields in gauss (G). Point this out to students since they will undoubtedly have predictions in tesla (T). They can look up the conversion in their text. ($1\text{T} = 10^4$ G).
6. Make sure that the currents inside the double coils flow in the same direction, otherwise the students will get very small values of magnetic field around the center.

Difficulties and Alternative Conceptions of Students

Many students will still confuse the magnetic field with lines of force (or field lines) they see in books. This will probably lead some of them to try to use Ampere's Law to determine the magnetic field for a coil. Ampere's Law can be useful as a qualitative tool here but your students will need to be reminded that the magnetic field at any point in space near the coil is the vector sum of the magnetic field caused by every current element in that coil.

Predictions

Problem #5

$$B(x) = \frac{\mu_0 INR^2}{2\left(x^2 + R^2\right)^{3/2}},$$

where I is the current in the coil, R is the radius of the coil, x is the distance along the axis of the coil, and N is the number of turns of wire (the Helmholtz coils have 200 turns).

Problem #6

$$B(x) = \frac{\mu_0 INR^2}{2}\left[\frac{1}{\left(x^2 - xR + \frac{5}{4}R^2\right)^{3/2}} + \frac{1}{\left(x^2 + xR + \frac{5}{4}R^2\right)^{3/2}}\right],$$

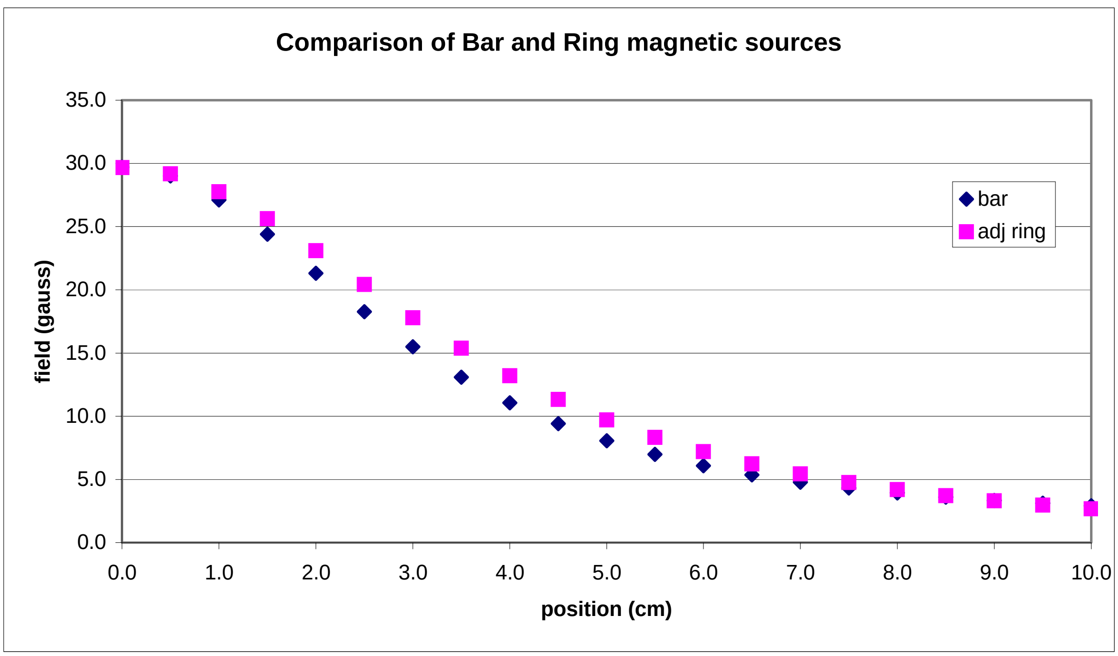
where I is the current in both coils, R is the radius of each coil, x is the distance along the axis of the Helmholtz coils from the point midway between the coils, and N is the number of turns.

Data

Problem 4

pos	bar	ring	adj ring
0.0	29.7	18.2	29.7
0.5	29.0	18.1	29.2
1.0	27.1	18.0	27.8
1.5	24.4	17.7	25.6
2.0	21.3	17.4	23.1
2.5	18.3	17.0	20.4
3.0	15.5	16.5	17.8
3.5	13.1	16.0	15.4
4.0	11.1	15.4	13.2
4.5	9.4	14.8	11.3
5.0	8.1	14.2	9.7
5.5	7.0	13.5	8.3
6.0	6.1	12.8	7.2
6.5	5.4	12.2	6.2
7.0	4.8	11.5	5.4
7.5	4.3	10.9	4.8
8.0	3.9	10.3	4.2
8.5	3.6	9.7	3.7
9.0	3.3	9.1	3.3
9.5	3.1	8.6	3.0
10.0	2.9	8.1	2.7

A comparison of the behavior of the magnetic fields of a bar magnet and current-carrying coil shows marked similarities; both act as a dipole.

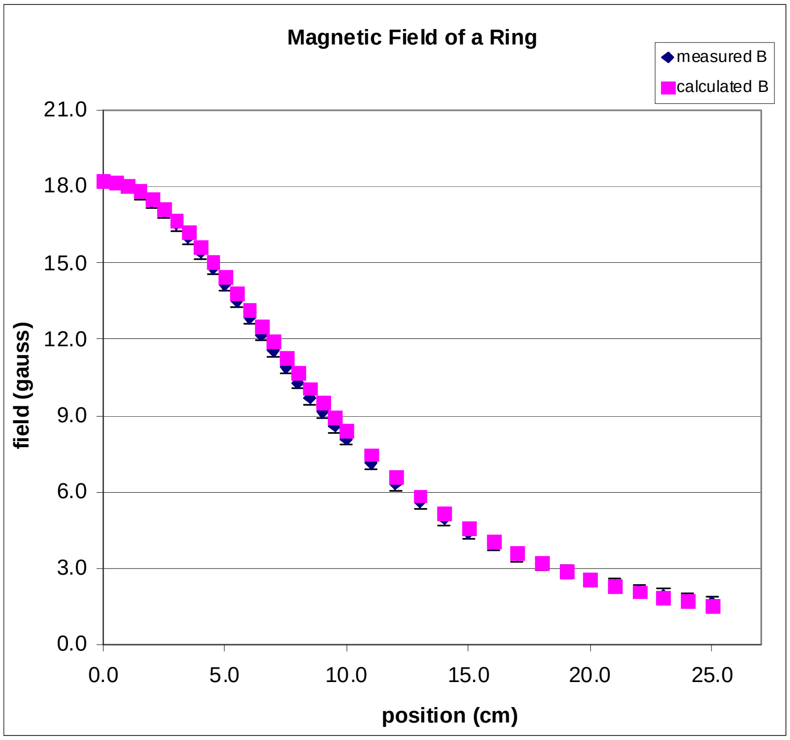


Problem 5

pos	measured B	calculated B
0.0		18.2
0.5		18.2
1.0		18.0
1.5	17.7	17.8
2.0	17.4	17.5
2.5	17.0	17.1
3.0	16.5	16.7
3.5	16.0	16.2
4.0	15.4	15.6
4.5	14.8	15.1
5.0	14.2	14.4
5.5	13.5	13.8
6.0	12.8	13.2
6.5	12.2	12.5
7.0	11.5	11.9
7.5	10.9	11.3
8.0	10.3	10.7
8.5	9.7	10.1
9.0	9.1	9.5
9.5	8.6	9.0
10.0	8.1	8.4
11.0	7.1	7.5
12.0	6.3	6.6
13.0	5.6	5.8
14.0	5.0	5.2
15.0	4.4	4.6
16.0	3.9	4.1
17.0	3.5	3.6
18.0	3.2	3.2
19.0	2.8	2.9
20.0	2.6	2.6
21.0	2.3	2.3
22.0	2.1	2.1
23.0	1.9	1.9
24.0	1.8	1.7
25.0	1.6	1.5

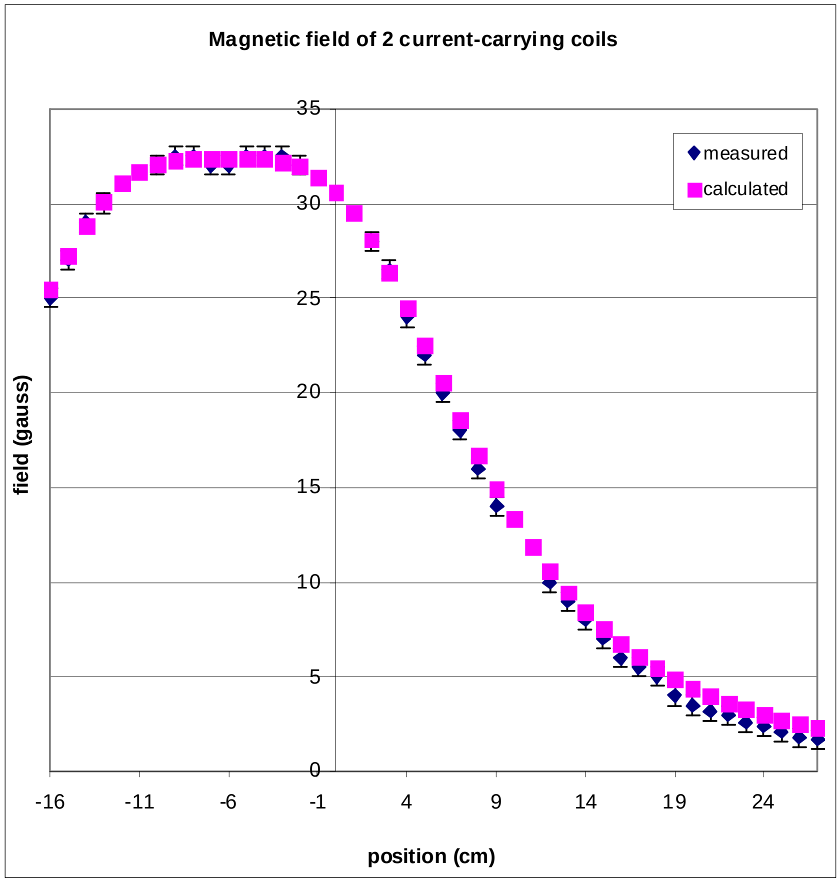
radius = 12.2 cm
N = 200 turns
I = 2.36 amps

As can be seen, the calculated B field is almost identical to the measured B field for a current-carrying coil



Problem 6

pos	measured	calculated
-16	25	25.5
-15	27	27.3
-14	29	28.8
-13	30	30.1
-12		31.1
-11		31.7
-10	32	32.1
-9	32.5	32.3
-8	32.5	32.4
-7	32	32.4
-6	32	32.4
-5	32.5	32.4
-4	32.5	32.3
-3	32.5	32.2
-2	32	31.9
-1		31.4
0		30.6
1		29.5
2	28	28.1
3	26.5	26.4
4	24	24.5
5	22	22.5
6	20	20.5
7	18	18.6
8	16	16.7
9	14	15.0
10		13.4
11		11.9
12	10	10.6
13	9	9.5
14	8	8.4
15	7	7.5
16	6	6.7
17	5.5	6.0
18	5	5.4
19	4	4.9
20	3.5	4.4
21	3.2	4.0
22	3	3.6
23	2.6	3.3
24	2.4	3.0
25	2.1	2.7
26	1.8	2.5
27	1.7	2.3



radius =	12.5 cm
separation =	12.5 cm
current =	3 amps
# coils =	200 turns

As can be seen, the calculated B field is almost identical to the measured B field in this Helmholtz coil arrangement. However, the central dip is less pronounced and the B field falls off slightly faster

Problem #7: Magnets and Moving Charge

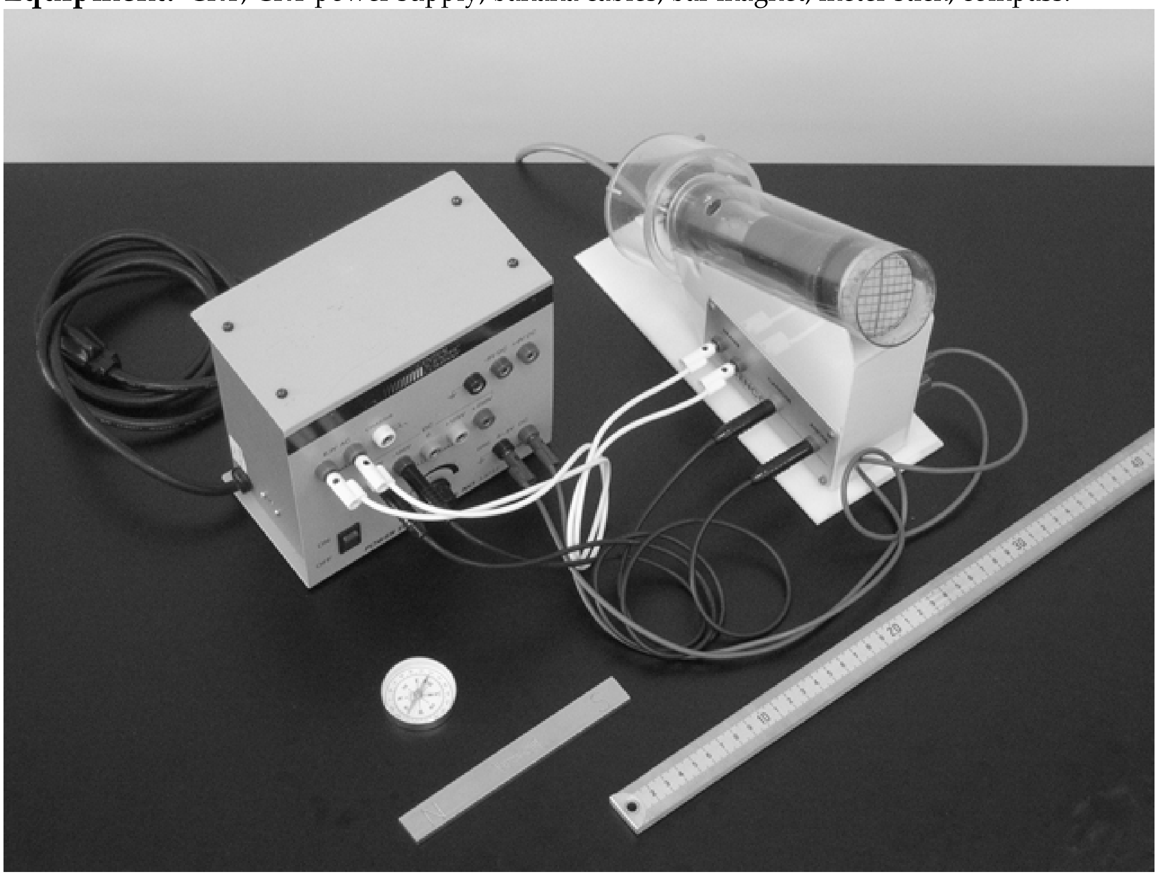
Problem

Determine qualitatively how the deflection of an electron beam by a magnetic field depends on the strength and direction of the field and on the speed of the electrons.

Purpose

To introduce the force caused by a magnetic field on a charged particle.

Equipment: CRT, CRT power supply, banana cables, bar magnet, meter stick, compass.



WARNING

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Teaching Tips

1. Many students find the concept that the force on a charged particle caused by a magnetic field is perpendicular to that field very difficult to grasp. This problem shows magnetic fields act differently to electric fields. Remember that electrons are negatively charged!
2. The last paragraph in the exploration asks the groups to think up their own question and check it with you before they start. They are asked to check with you for safety reasons, but ask them why they chose the question they did. Try to make sure that they are not just

copying what their neighbor did and that they have made a guess about the answer. Remember that a null result can be interesting, especially if they expect something to happen.

3. When these measurements are finished, it is good to refer back to Lab 1, Problem #4, when the electron was deflected by the earth's magnetic field instead of the gravitational field. Ask the students which direction the magnetic field of the earth should be pointing based on those results.
4. Students need to practice with the right-hand rule. Make sure that they are actually using it.

Difficulties and Alternative Conceptions of Students

Many of your students believe that if one object exerts a force on another object, that force must point toward (or away from) the object exerting the force. Many of your students will still believe that magnetic poles are the same as electric charges. There are also students who will confuse velocity and acceleration.

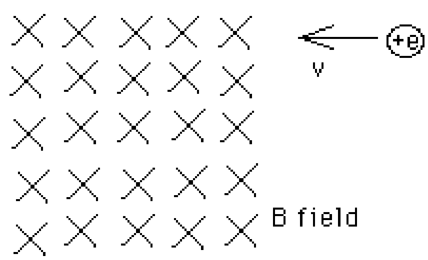
Prediction

Magnetic Force = $q\,\vec{v}\times\vec{B}$, where q is the amount of a moving charge, $\vec{v}$ is its velocity and $\vec{B}$ is the magnetic field.

Discussion Idea

This is a good opportunity to explain the path of a charged particle in a cyclotron. It's a great right-hand rule exercise. Some students are learning about vectors in calculus class, so here's your chance to integrate that knowledge into physics.

Describe the path of the positively charged particle in the situation shown below.



Problem #8: Magnetic Force on a Moving Charge

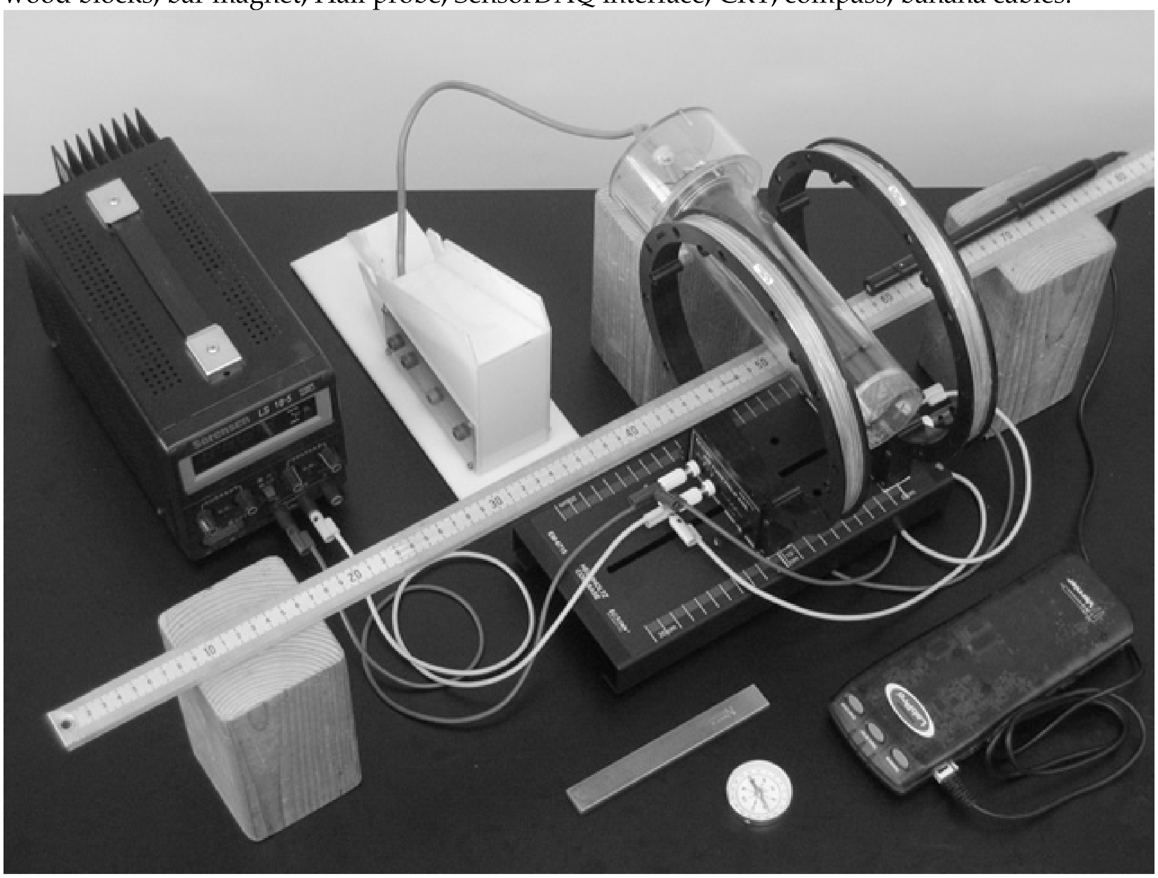
Problem

Determine how the deflection of electrons in a cathode ray tube depends on the magnitude of a magnetic field applied perpendicular to the path of the beam.

Purpose

To determine quantitatively the force and subsequent deflection of a charged particle as it travels through a magnetic field.

Equipment: 18V/5A power supply, Pasco large coils (Helmholz configuration) with base, wood blocks, bar magnet, Hall probe, SensorDAQ interface, CRT, compass, banana cables.



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Teaching tips

1. The field is along the axis of the coils; to get a good deflection you need to put the CRT in perpendicular to the axis. There is **some** deflection if you put the CRT along the axis but not much. You might want to have your students explore this to drive home the fact that the force is a vector and it depends on the component of **B** perpendicular to the velocity.

2. For a 250-Volt electron in a 100 μT (1 gauss) field (two times the earth's field), the radius of curvature is 0.53 meters.
3. Be sure to warn your students about the power supplies. Remind them that they are not safe immediately after turning the power supply off, either.
4. This problem is similar to Problems #5 and #6 in Lab 1; you can build off these problems or use them for review.

Difficulties and Alternative Conceptions of Students

Many of your students believe that if one object exerts a force on another object, that force must point toward (or away from) the object exerting the force. Many of your students will still believe that magnetic poles are the same as electric charges. There are also students who will confuse velocity and acceleration. All of the standard motion misconceptions from projectile motion may arise. Many students believe that the force on the electron is constant instead of changing direction as the electron changes its direction. This leads to an incorrect prediction, which unfortunately will agree with your students' measurements. Be alert to catch this.

Prediction

There are two ways to predict the deflection; only one is correct, but both will agree with the measurement. The correct method is to get the radius of the electron's path and deduce the deflection using geometry. Thus, the problem can be solved exactly and one should get

$$d_1 = \frac{mv}{eB}\left[1-\sqrt{1-\frac{L^2e^2B^2}{m^2v^2}}\right],$$

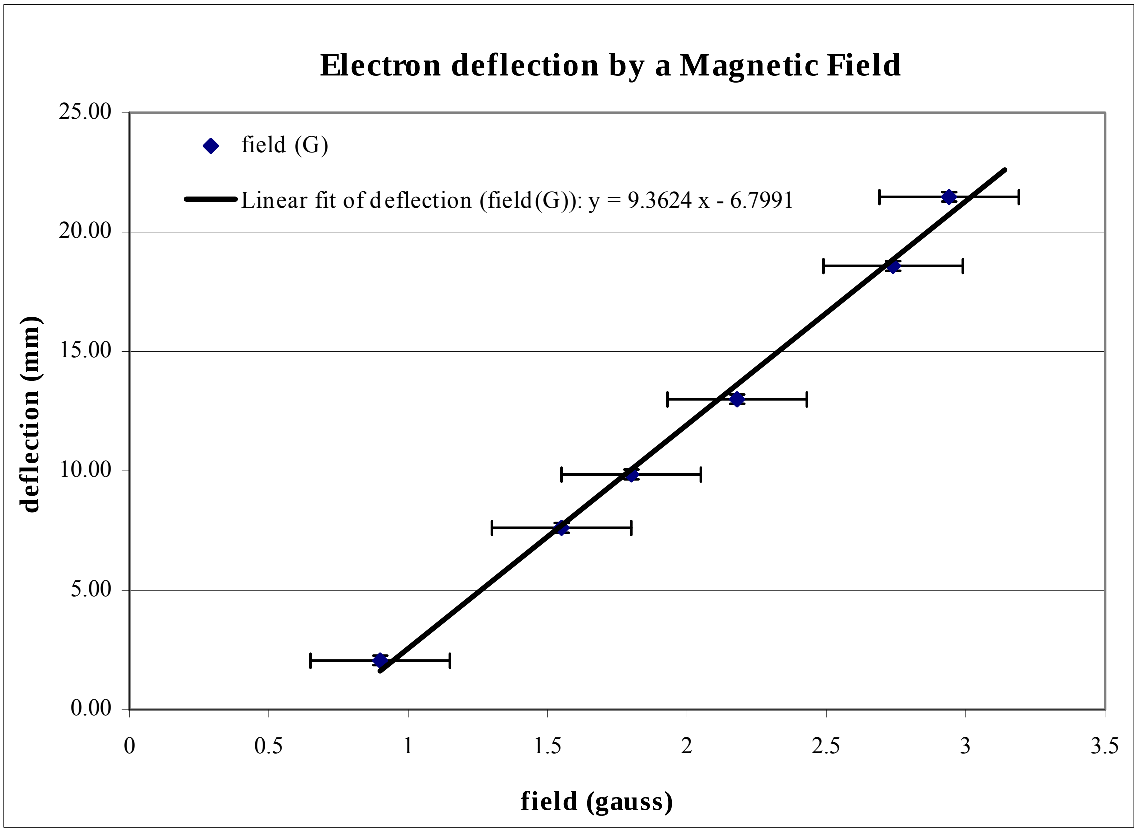
where e is the elementary charge, B is the magnetic field, L is the length of the CRT, m is the mass of electron, and V is the velocity of the electron.

The incorrect method assumes that the force on the electron is in the same direction while it is in flight. Then you can treat the force on the electron similarly to the projectile motion (gravitational or electric) case. Students need to understand this "works" because it is simply a fair first order approximation as it yields $d_2 = \frac{eBL^2}{2mv}$. This solution assumes a parabolic path for the electron. It is not such a bad approximation in this case but make sure your students know when they leave that it is an approximation. Make sure they understand how to do this problem correctly and how it differs from the approximation (if they use it).

Finally, let us mention that one can show that $d_1 = d_2 + O\left[\left(\frac{eLB}{mv}\right)^4\right]$.

Data

deflection (mm)	field (G)		
13.00	2.18	V =	250 V
18.58	2.74	L =	13.9 cm
21.48	2.94	Me =	9.11E-31 kg
9.85	1.80	Qe =	1.60E-19 C
7.62	1.55	v =	9377437 m/ s
2.06	0.90	y = [e*L^2/ (2*m*v)]*B =	18.12



Discussion Question

Compare the motion of a charged particle in uniform electric and uniform magnetic fields. Are the trajectories different? Can they be of the same shape? Discuss the role of the initial velocity direction. As a particular case, discuss the motion of a charged particle, which is initially at rest in either field.

TA Lab Evaluations
Physics 1302 Lab 5

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

____

____

____

Students:

Did the students find these exercises: (circle one) enlightening / boring / fun / other?

Do you have additional comments regarding student learning and these labs?

____

____

____

TA:

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results:

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room:

Was the room kept neat and clean by your class and other classes? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

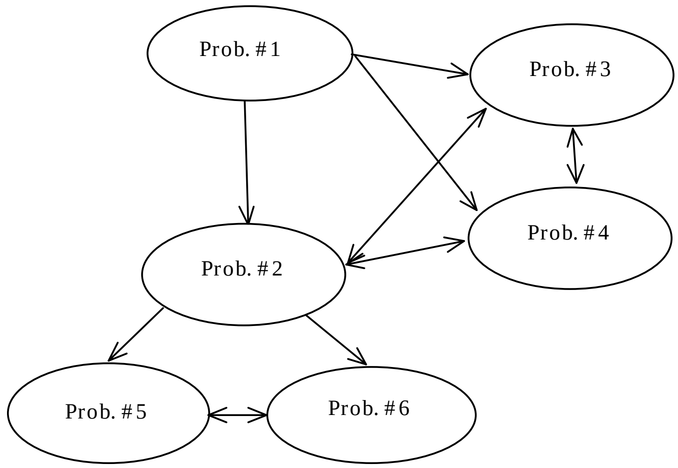
____

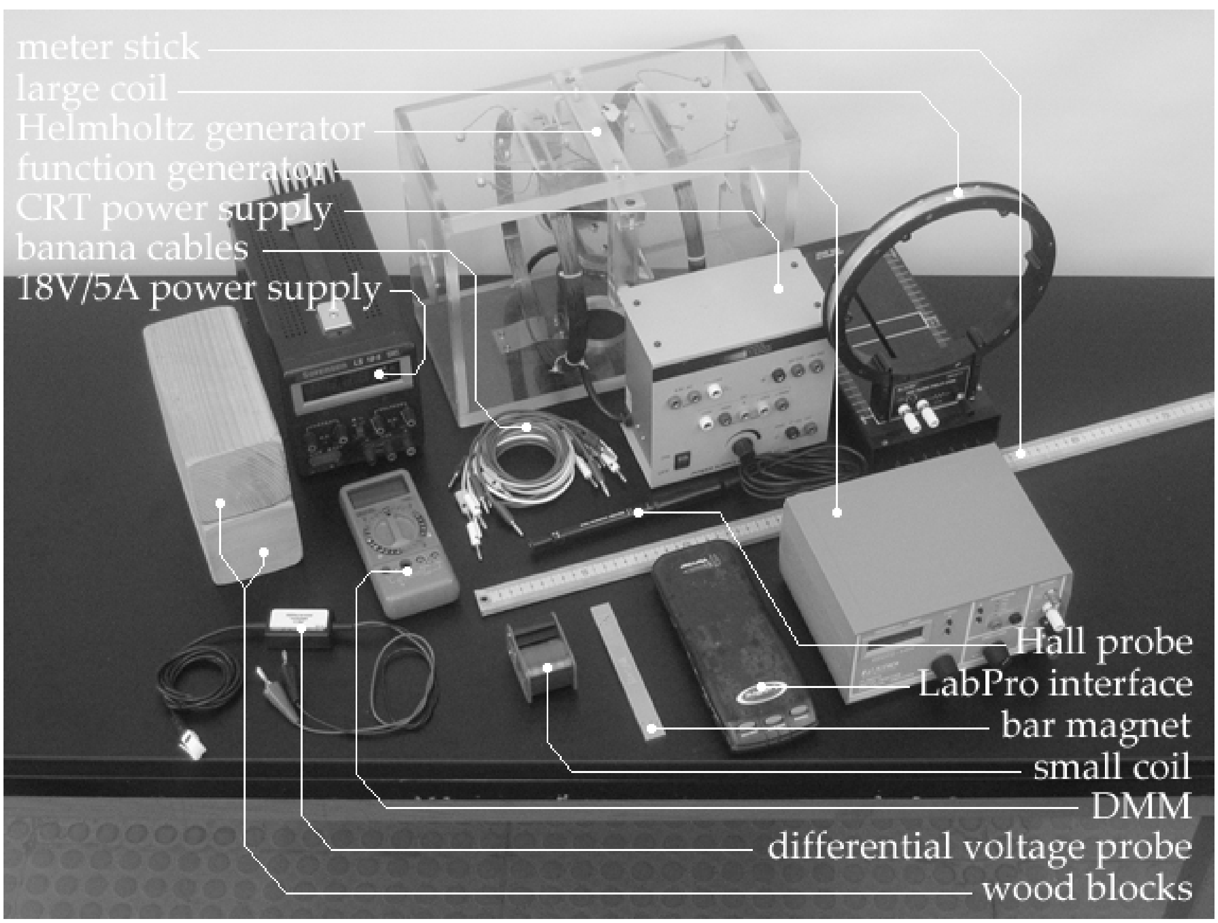
____

____

Laboratory VI
Electricity from Magnetism

The flow chart for these labs is shown below.





**Note: the LabPro is replaced by the SensorDAQ interface.

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Teaching Tips

- Most students have a great deal of difficulty with the very abstract concept of flux as the total amount of field through an area. The next big difficulty that students have is that the effect (change of electric potential) depends not on the size of the flux but on its change. Be ready to confront misconceptions arising from these problem areas.
- Calculus is still a foreign language to many of your students and they are not confident in its use. Encourage your students to get help if necessary, but make sure they do the math.
- The conceptual difficulties of the students are not helped by the strange language associated with this topic. We use words such as "induced" or "electromotive force" or "emf" which are meaningless to students. It is best to avoid such words whenever possible. This lab is designed to help students connect the abstract concept of a changing magnetic flux to reality.
- It is probably the end of the semester when you do this lab; don't let the students give up just because school is almost out. Staying enthusiastic and focused will help.

Things your students should know by the end of this lab

- How to determine a magnetic flux.
- The conditions necessary for a magnetic field to produce an electric current.
- The direction of a current induced by a changing magnetic field.
- How to use the concept of magnetic flux to determine the electric effects of a changing magnetic field.
- How to use Faraday's law to determine the magnitude of a potential difference across a wire from a changing magnetic flux.

Things to do before teaching this lab

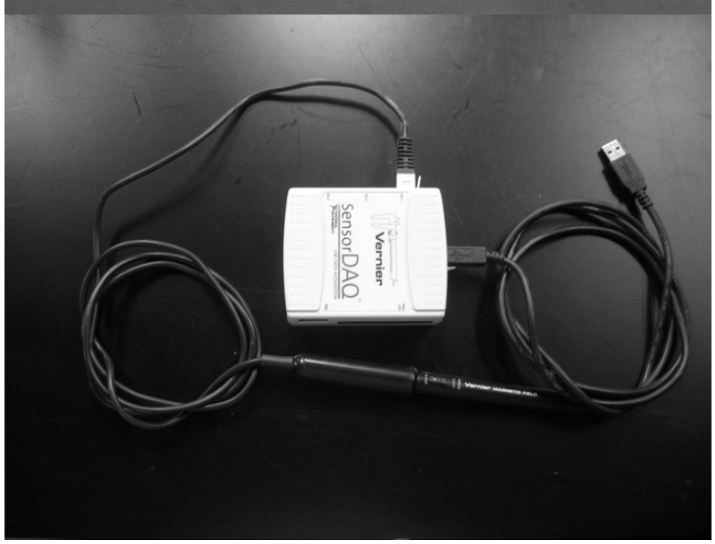
- In order to help your students if they don't notice an effect, determine how fast you must move the magnet through the coil to see a noticeable effect on the FaradayPROBE screen. How much deflection can you get if the magnet is moved so that it does not go through the coil? Try keeping the magnet steady and moving the coil.
- Make sure that you can correctly predict the sign of the induced potential difference as measured by the FaradayPROBE program. This requires careful thought and you won't be able to help your students with their reasoning problems if you do not fully understand it.
- Be sure you know how to connect the function generator and set its adjustments so that it outputs a sine with the appropriate frequency and amplitude. Check to see where the signal is clipped by the amplifier in the hall probe (where the amplifier saturates because the signal is too large).
- Determine how sensitive the flux is to the angle of the area of the coil to the magnetic field.
- Don't forget to remagnetize the magnets just before your lab begins.

Exploratory Problem #1: Magnetic Induction

Problem
Study different ways to use a bar magnet to generate a potential difference across two ends of a coil of wire.

Purpose
- To give students the experience of producing an electric potential difference by changing a magnetic flux and also seeing that a constant magnetic flux gives no potential difference.

Equipment: bar magnet, differential voltage probe, SensorDAQ interface, small coil. Please note that the sensorDAQ has replaced the LabPro interface for all lab problems.



Teaching Tips
1. This problem shows students that induction is a real effect. Make sure that students realize that to get a potential difference in a wire there must be a current in that wire. Also make sure that they are thinking in terms of what is happening to the magnetic flux.
2. Encourage open-ended exploration. The students need to develop their own ideas of ways of producing potential differences. Because of the many student misconceptions that are possible, allow the students plenty of time to qualitatively test their own ideas about causing

current with a magnetic field. Encourage your students to try as many different configurations and actions of the magnet and coil that they think might cause the ammeter to register.

3. This problem also asks the students to confirm Lenz's law. Practice this yourself before you teach the lab so that you can help the students with the various signs involved.
4. When you assign this problem, you should emphasize to your students that they should try to think of as many ways of producing a magnetic field in the coil as possible. Otherwise it is likely that they will simply think of one or two ways, spending only a minute or two thinking about the problem.

Difficulties and Alternative Conceptions

Students seem to have strong ideas about what should happen when producing currents using magnetic fields; many of these strong ideas are misconceptions. For example, many students believe that it is the closeness of the magnetic field to the coil that causes the current. They are surprised that slowly moving a magnet toward a coil (or even putting it in the coil) doesn't produce a current. If you let them push a magnet through the coil without having them stop the magnet when the pole is in the center of the coil, they might reinforce this misconception. Some students believe that moving the coil is different from moving the magnet. This may be because of misconceptions caused by an "active" interpretation of lines of force "pulling" things toward a magnet. Some believe that the magnet must go through the coil to produce an effect. Even if they believe that the moving magnet or moving coil will produce an electric current, many students predict the exact opposite of what will happen. Because of their many misconceptions, students find the textbook's explanation of Lenz's law difficult to understand, so you may have to spend time with each group making sure they have both read and understood their textbook and connect it to what they observe in lab.

Prediction

Remember that to induce a current, there must be a changing magnetic flux. The sum of the magnetic field through the area bounded by the coil has to change. It is probably more difficult to think or ways of moving the magnet without producing a current – the only way I can think of is by rotating the magnet (or coil) about its axis.

Problem #2: Magnetic Flux

Problem

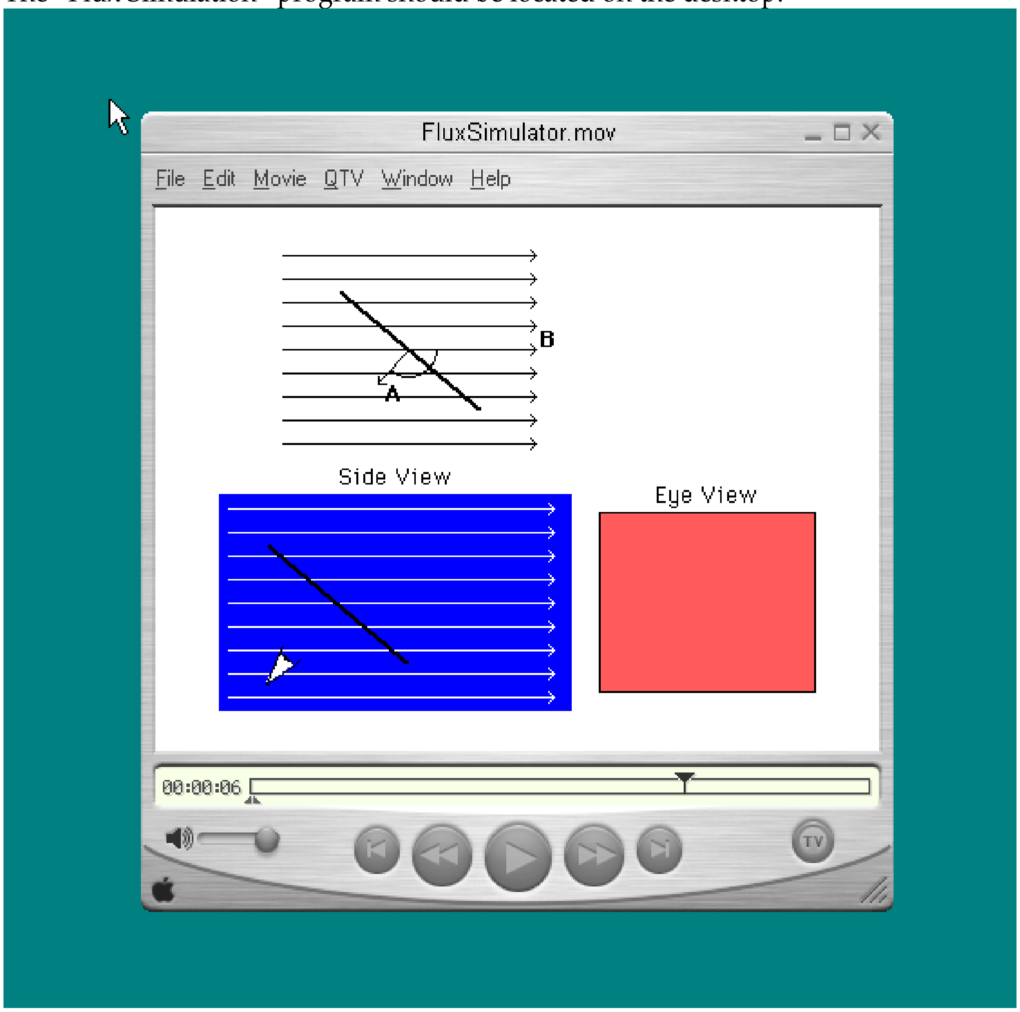
Study how the magnetic flux passing through a coil depends on the angle between the coil and the direction of the magnetic field. Calculate the magnetic flux as function of the angle.

Purpose

To use simple computer simulation software to help students learn how magnetic flux through a coil in a magnetic field depends on the coil's orientation with respect to the field. The students are to watch how the flux changes as the angle between the normal to the coil and the magnetic field varies.

Equipment

The "Flux Simulation" program should be located on the desktop.



WARNING

Your students will be working with electrical equipment that generates **large voltages**. Improper use can cause **painful burns**. To avoid danger, make sure that the students know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to a power supply; they must **never touch** the conducting **metal** of any **wire.**

Teaching Tips

1. Previously we told the students that the Hall probe measured magnetic field. Now we will tell them it really measures magnetic flux. In a discussion you need to make it clear why the probe really does measure the sum of the magnetic field over its area which is perpendicular to the probe surface (flux) and why this can be used to determine the magnetic field as long as the field does not change too much over the area of the probe.
2. Students should realize that the magnetic field is not changing, even though the Hall Probe's reading changes because it is difficult to hold the probe steady. Check that the students keep the probe in the same location as it is rotated.
3. In order to get the expected cosine dependence, students must take their first data point ($\theta = 0$) where the Hall Probe gives its maximum reading. In other words, the students must decide what the angle means with respect to the direction of the magnetic field.
4. In the calibration step of the Hall Probe, make sure that your students choose an angle quantity (degrees or radians) for their x-axis. It is difficult to make precise rotations. Increments of 30 degrees yield a good enough graph to determine the shape.

Difficulties and Alternative Conceptions

Many students believe that the flux is the magnitude of the magnetic field. Again, it is best to avoid the “field line” or “line of force” idea in any explanations.

Prediction

$\text{Magnetic Flux} = AB\cos\theta$, where A is the area, B is the magnitude of the magnetic field, and θ is the angle between the area vector and the magnetic field.

Students will have to measure the area of the Hall Probe themselves. It is the area of the white circle. Area = $(0.35\text{ cm})^2 (3.14) = 0.38\text{ cm}^2$.

Warm-up Questions

By asking appropriate questions of each group, make sure that the students are making the connection between the objects in the simulation and the objects in the lab.

Exploratory Problem #3: The Sign of the Induced Potential Difference

Problem
Study the sign of the induced potential difference across the ends of the coils when the North or the South Pole is pushed through the coil.

Purpose
- To give students an opportunity to get some experience in predicting the sign of an electric potential difference caused by a change in magnetic flux.

Equipment:


Teaching Tips
1. This problem shows students that induction is a real effect. Make sure that students realize that to get a potential difference in a wire there must be a current in that wire. Also make sure that they are thinking in terms of what is happening to the magnetic flux.
2. This problem also asks the students to confirm Lenz's law. Practice this yourself before you teach the lab so that you can help the students with the various signs involved.
3. Students may push one end of a magnet through the coil and then pull it out quickly making it difficult to tell from the computer screen what part of the graph was caused by what action. If this is a problem ask them to just do one action at a time so they can be sure that the measured potential difference is due to a particular movement.

Difficulties and Alternative Conceptions
Many students will still have many of the misconceptions mentioned in Problem #1. For example, many students believe that it is the closeness of the magnetic field to the coil that

produces the current. They are surprised that slowly moving a magnet toward a coil (or even putting it in the center of the coil) does not produce a current. If you just let them push a magnet through the coil without having them stop the magnet when the pole is in the center of the coil, they might reinforce this misconception. Some students believe that moving the coil is different from moving the magnet. This may be because of misconceptions caused by an "active" interpretation of lines of force "pulling" things toward a magnet. Some believe that the magnet must go through the coil to produce an effect. Even if they believe that the moving magnet or moving coil will produce an electric current, many students predict the exact opposite of what will happen. Because of their many misconceptions, student's find the textbook's explanation of Lenz's law difficult to understand, so you may have to spend some time with each group making sure they have both read and understood their textbook and connect it to what they observe in lab.

Prediction

Make sure that students draw good pictures with their predictions. The answer to the prediction is meaningless unless you have a picture showing the arrangement.

Exploratory Problem #4: The Magnitude of the Induced Potential Difference

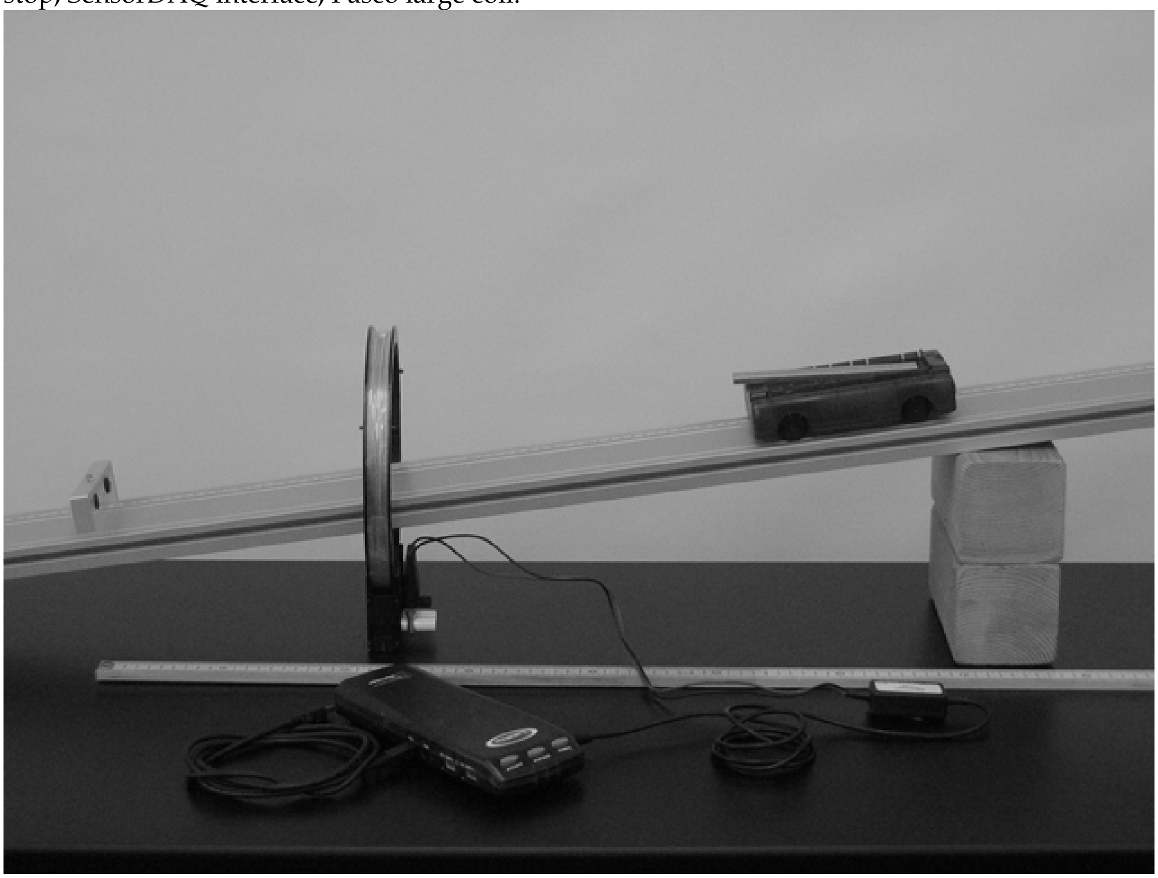
Problem

How does the magnitude of the induced potential difference across a coil depend on the speed of the magnet moving through the coil?

Purpose

To have students establish a quantitative relationship between the magnitude of the produced potential difference and the rate of change of magnetic flux.

Equipment: track, cart, bar magnet, wood blocks, differential voltage probe, meter stick, end stop, SensorDAQ interface, Pasco large coil.



Teaching Tips

1. More than one magnet can be put on the cart for a stronger magnetic field.
2. Make sure students understand each region of their graph of potential difference versus time (a sample graph is shown below). The change of magnetic flux is large when one end of the magnet enters the loop, is small while the magnet is inside the loop, and is large again (in the opposite direction) when the 2nd end of the magnet leaves the loop.
3. The SensorDAQ only sends a fraction of the data it receives to the screen. Your students will have to time their release of the cart with data updates on the screen to see results.
4. It is important for the students to be consistent about which peak they measure on the potential difference vs. time graph. They should also be careful to make sure they get the desired structure fully on the screen in order to accurately measure the peak height.

5. Once the students have taken the data, you might want to suggest they input it into an Excel spreadsheet to see how close their data comes to the correct one. (They should use the power law trend-line feature).
6. It is important to note that there is no easy way to predict the constant of proportionality between the induced emf and the cart's starting distance. It would be a very messy integration. Rather than do this, tell your students that the important thing is not the exact nature the constant of proportionality but the square root dependence on distance.

Difficulties and Alternative Conceptions

See the alternative conceptions from Problem #3.

Prediction

The induced potential difference across the coil should be proportional to the square root of the starting position of the cart.

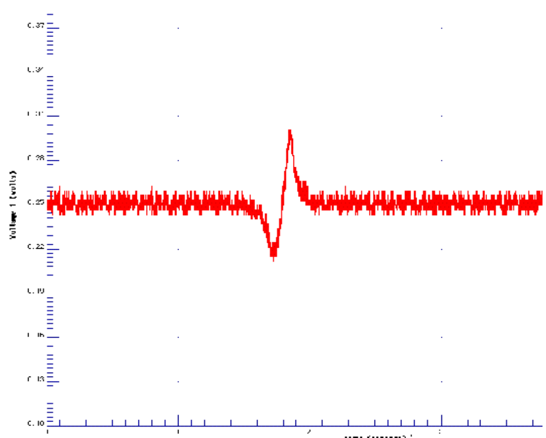
$$\varepsilon = \left[-N\sqrt{2g\sin\theta}\int_A \frac{d\vec{B}}{dx} \cdot d\vec{A} \right] d^{1/2},$$

where ε is the induced potential difference across the coil, N is the number of turns in the coil, θ is the angle of inclination of the track, B is the magnetic field of the bar magnet, A is the cross-sectional area of the coil, x is the cart's position as measured from the coil, and d is the cart's starting position as measured from the coil. To arrive at this expression, one needs to apply the chain rule to Faraday's Law, and use conservation of energy to find the cart's velocity through the coil.

Important Note:

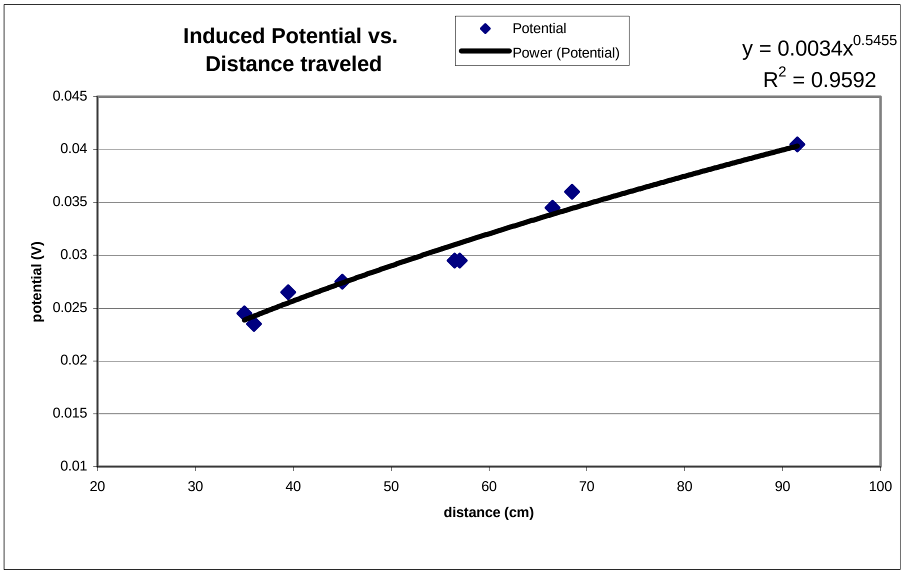
In the exploration section, have the students check if they can read the signal from the SensorDAQ interface. Most of the time, they may notice that the data readout begins with the signal, with half cut off. You might suggest starting the cart down slope from the coil and giving the cart a push up the ramp so that it rolls through the coil. If they then record the position that it stops upslope, this is the "release point" in the manual. The first pass through the coil is the first "trough-peak"; the second pass through, which is the actual data, is the second "trough-peak". The first pass is often necessary for triggering to display the data (the second pass). Make sure the students at least consider the situation before you give them suggestions.

Data



1. Faraday Probe results.

Distance	Potential
35	0.0245
39.5	0.0265
45	0.0275
57	0.0295
36	0.0235
66.5	0.0345
68.5	0.036
91.5	0.0405
56.5	0.0295



2. Graphed results.

Problem #5
The Generator

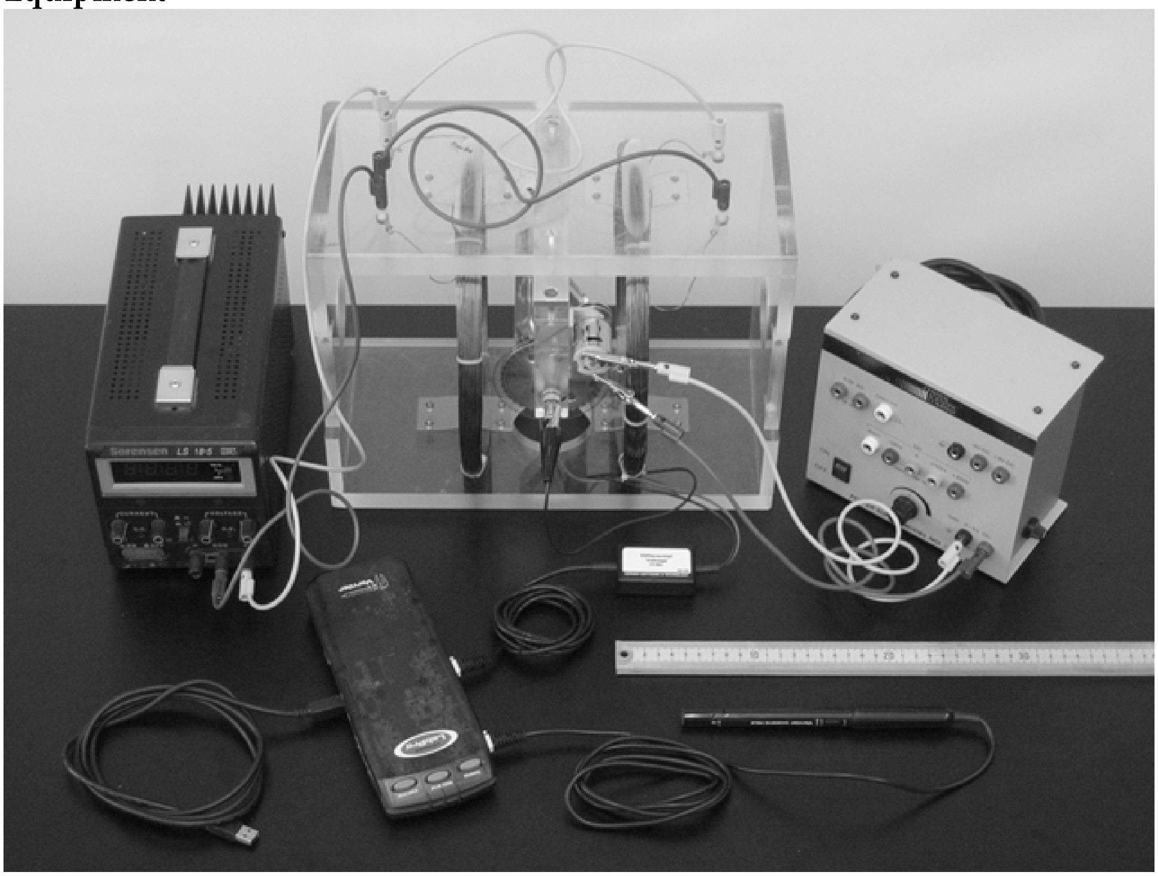
Problem

What is the potential difference induced in a coil of wire spinning in a uniform magnetic field?

Purpose

To show the students that a potential difference can be produced in a copper coil inside a constant magnetic field by changing the orientation of that coil with respect to the magnetic field.

Equipment



Teaching Tips

WARNING

Your students will be working with electrical equipment that generates **large voltages**. Improper use can **cause painful burns**. To avoid danger, make sure that the students know the safe way to operate the equipment: the **power** must be turned **OFF** and they must **wait** at least **one minute** before any wires are disconnected from or connected to a power supply; they must **never touch** the conducting **metal** of any **wire** and they must **never use higher voltage settings** on the power supplies to avoid destroying motors**.**

1. The motor should only be connected to the 0-5V variable output on the power supply. Increasing the voltage increases the motor speed but too high a voltage will burn out the motor. A rubber belt connects the motor to the spinning coil.

2. The Helmholtz coils should be connected to one or two 6V batteries or the power supply. Make sure your students make the connections so that the same amount of current goes through both coils in the same direction. Ask them to check by qualitatively predicting the direction of the field from each coil at the midpoint between the two coils.
3. You can use this problem to drive home the idea that even if the **field** is constant, the flux through the loop may be changing.
4. There are two vertical pins at the edges of the spinning coil. Attach the alligator clips to these in order to measure potential difference across the coil. Your students can check that these pins are connected together through a conductor by using their ohmmeter.
5. Your students must decide on the area of the pick-up coil. This is not obvious since the wire has a non-negligible width. The flux through the inner coils of wire is significantly different from the flux through the outer coils. Just using the inner lengths of the coils or the outer lengths gives a significantly incorrect result. The average between inner and outer lengths works well enough. Do not undermine your students' opportunity to learn by telling them what to do here. Making a correct decision goes to the very heart of understanding flux. After giving them time to begin their measurements, make sure each group has recognized the problem on their own and has made a rational decision about how to handle it. They might also recognize a necessary correction for the loop not really being a rectangle (rounded corners). Lots of active coaching in the groups is necessary here.
6. With the LabVIEW program one can directly read the frequency of the coil from the graph of the magnetic field as a function of time.

Difficulties and Alternative Conceptions

Most of your students still have all of their misconceptions about fields, fluxes, and directions. The students can clarify these concepts only if you make them explain what is happening and why it is happening in this problem. Trying to use an idea of "cutting field lines" can lead to further misconceptions especially in the case of a coil moving through a region of constant magnetic field at a constant angle to that field.

Prediction

Definition of Flux: $\Phi = \oint \vec{B} \cdot d\vec{A}.$

Angular Speed of coil: $\omega = \dfrac{\Delta\theta}{\Delta t}.$

Faraday's Law: $\varepsilon = -n\dfrac{d\Phi}{dt}.$

Potential Difference in the spinning coil: $\varepsilon = \omega BAn\sin(\omega t),$

where ε is the induced potential difference, ω is the angular speed of the small coil, B is the magnitude of the magnetic field, n is the number of turns of wire (4000), and A is the area of the small coil.

Warm-up Questions

Make sure your students understand the relationship between the angle the coil makes with the magnetic field (θ) and the angular speed of the coil. This small point of geometry and circular motion kinematics can be a big hang-up for some students.

Data (this data is collected with 3000 turn coils)

period	w	potential	amplitude
0.571	11.0	0.349	0.1745
0.306	20.5	0.64	0.32
0.214	29.4	0.892	0.446
0.172	36.5	1.148	0.574
0.127	49.5	1.554	0.777
0.339	18.5	0.583	0.2915
0.436	14.4	0.459	0.2295
0.267	23.5	0.706	0.353
1.244	5.05	0.166	0.083
0.921	6.82	0.219	0.1095
0.467	13.45	0.417	0.2085
0.436	14.41	0.459	0.2295
0.302	20.81	0.657	0.3285
0.243	25.86	0.805	0.4025
0.2	31.42	0.964	0.482
0.154	40.80	1.263	0.6315

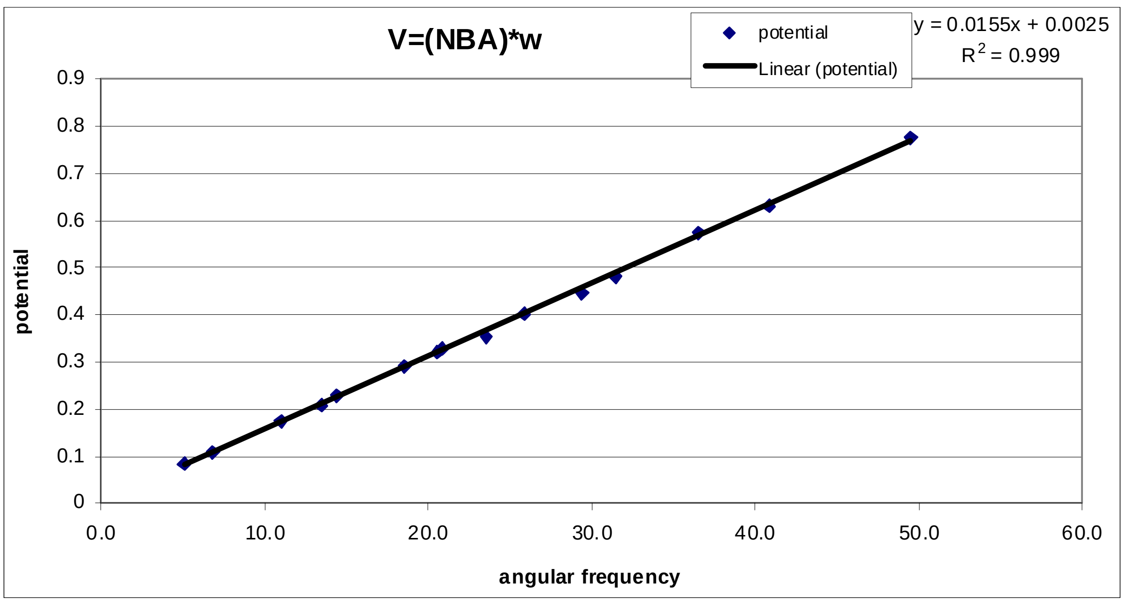
from data pts

NBA=.0155

from measurements

N=	3000
B=	0.00113 "+/- .00001"
A=	0.00452 "+/- .000004"
NBA=	0.01534

With N=3000, the experimental data and calculations match well



Discussion Question

This generator models the way we get our electricity. You might discuss why spinning the coil with an electric motor would not be a useful way of generating electricity. Ask the students what else might be used to spin the coil: hydropower, thermal energy (burning coal or oil), nuclear energy, etc. Stress that (i) the fundamental idea of a generator is the use of magnetic field to transform mechanical energy into electrical energy and (ii) energy conservation still holds: energy cannot be gained by this process!

Problem #6: Time-Varying Magnetic Fields

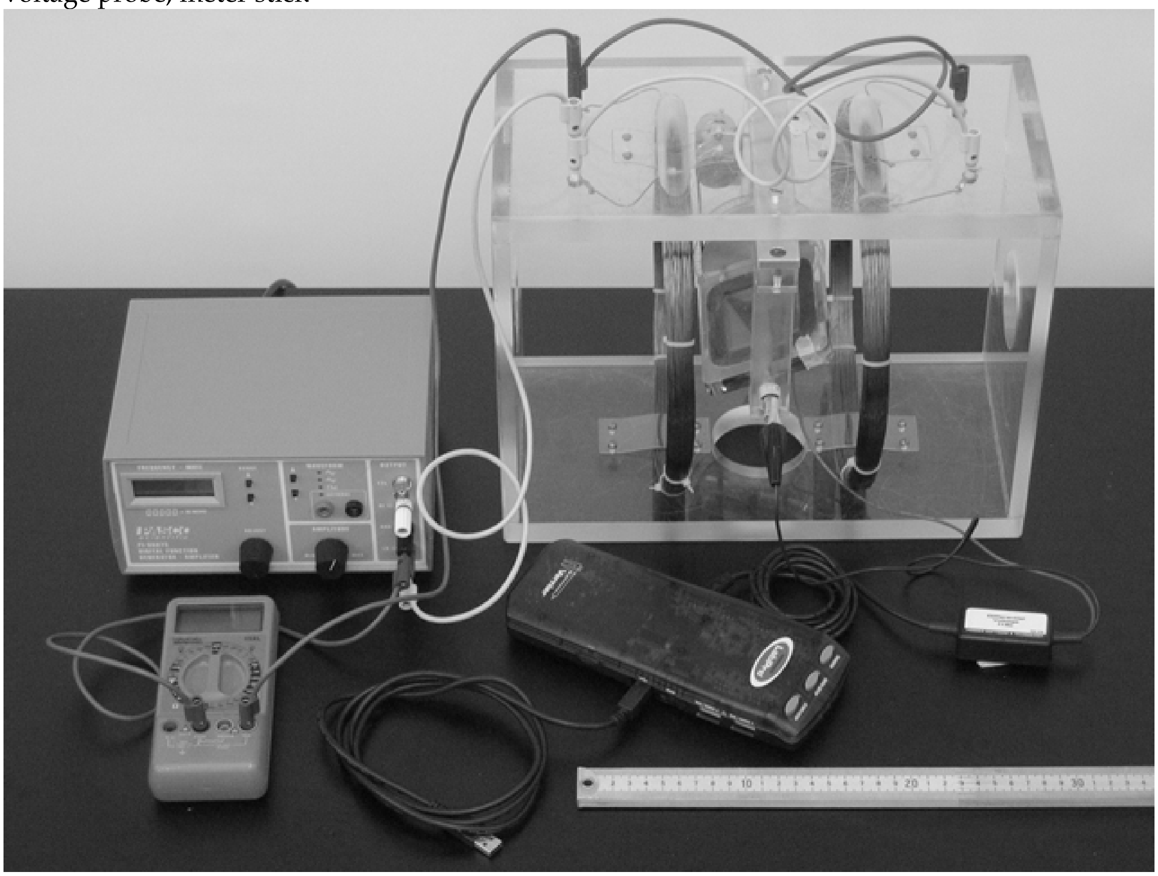
Problem

Study how the induced potential difference across the ends of the coils depends on the angle between the time-varying magnetic fields and the coil.

Purpose

To show the students that a potential difference can be induced in a stationary copper coil by changing the magnitude of the magnetic field.

Equipment: function generator, DMM, Helmholtz generator, banana cables, differential voltage probe, meter stick



WARNING

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Teaching Tips

1. Many groups may not get this far, but if your students understand the generator from Problem #5, this problem takes little time to make the measurements.
2. The Helmholtz coils should be connected to a Function Generator and a power source. Make sure your students make the connections so that the same amount of current goes through both coils in the same direction. Ask them to check by qualitatively predicting the direction of the field from each coil at the midpoint between the two coils.
3. There are two vertical pins at the edges of the pick-up coil. Attach the alligator clips to these in order to measure potential difference across the coil. Your students can check that these pins are connected together through a conductor by using their ohmmeter.
4. Your students must decide on the area of the pick-up coil. This is not obvious since the wire has a non-negligible width. The flux through the inner coils of wire is significantly different from the flux through the outer coils. Just using the inner lengths of the coils or the outer lengths gives a significantly incorrect result. The average between inner and outer lengths works well enough. Don't undermine your students' opportunity to learn by telling them what to do here. Making a correct decision goes to the very heart of understanding flux. After giving them time to begin their measurements, make sure each group has recognized the problem on their own and has made a rational decision about how to handle it. They might also recognize a necessary correction for the loop not really being a rectangle (rounded corners). Lots of active coaching in the groups is necessary here.
5. By changing the coil to several different orientations and observing the change of the magnitude of the oscillations on the computer screen, students can directly see how the magnitude of the potential difference across the coil changes with the coil orientation. The students will have to use their lab journals to make a potential difference versus orientation angle graph.
6. It is the oscillating magnetic field that produces the sinusoidal pattern you see on the oscilloscope. The cosine dependence in the dot product causes the sinusoidal (cosine) pattern in the graph of potential difference versus orientation angle that the students will draw. Make sure that your students understand that although they look similar, they have completely different causes and are unrelated.

Difficulties and Alternative Conceptions

Most of your students still have all of their misconceptions about fields, fluxes, and directions. They will only address them in this problem if you make sure they explain what is happening and why it is happening. This problem addresses misconceptions based on "cutting field lines" since the pick-up coil is stationary and only the magnitude (not the shape) of the magnetic field changes with time.

Predictions and Warm-up Questions

Faraday's Law $$\varepsilon = -n\frac{d\Phi}{dt}$$

Assume that magnetic field changes with time as $B(t) = B_0 \sin(\omega t + \varphi)$

The magnetic flux through a coil at an angle θ $\Phi(t) = B_0 A \sin(\omega t + \varphi)\cos\theta$

The induced emf

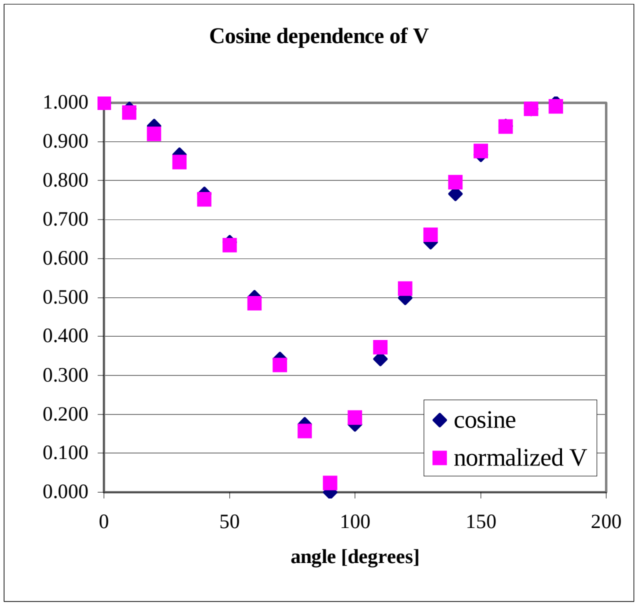
$$\varepsilon = -B_0 A n \omega \cos(\omega t + \varphi)\cos\theta$$

The maximum absolute value of emf

$$\varepsilon_{max} = B_0 A n \omega \cos\theta$$

Data

angle	cosine	voltage	normalized V
0	1.000	11.37	1.000
10	0.985	11.091	0.975
20	0.940	10.455	0.920
30	0.866	9.642	0.848
40	0.766	8.547	0.752
50	0.643	7.205	0.634
60	0.500	5.51	0.485
70	0.342	3.709	0.326
80	0.174	1.784	0.157
90	0.000	0.26	0.023
100	0.174	2.172	0.191
110	0.342	4.238	0.373
120	0.500	5.951	0.523
130	0.643	7.523	0.662
140	0.766	9.042	0.795
150	0.866	9.96	0.876
160	0.940	10.667	0.938
170	0.985	11.196	0.985
180	1.000	11.267	0.991



The potential is clearly seen to be proportional to the cosine of the angle its normal makes with the magnetic field.

TA Lab Evaluations
Physics 1302 Lab 6

We strongly encourage you to fill out this evaluation as soon as you are done teaching the labs. If you had issues or problems with any of the lab, please submit available information through the LabHelp system or email lab@physics.umn.edu.

Instructors Pages:

Did you find the instructors pages useful? (circle one) yes / no

What additional information would you include in these pages?

____

____

____

Students:

Did the students find these exercises: (circle one) enlightening / boring / fun / other?

Do you have additional comments regarding student learning and these labs?

____

____

____

TA:

Given the choice, would you teach these exercises again? (circle one) yes / no

Why or why not?

____

____

____

Results:

Did the students obtain sensible results from these exercises? (circle one) yes / no

What were the best / worst sets of results? Why?

____

____

____

Lab Room:

Was the room kept neat and clean by your class and other classes? yes / no

Was the equipment functioning properly? Could you fix it? yes / no

Any other comments regarding the room and equipment?

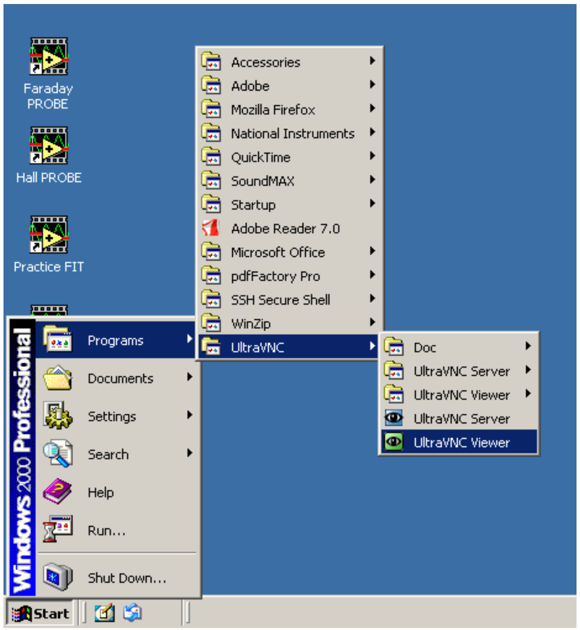
____

____

____

Reference Guide for Ultr@ VNC version 1.0.0

Ultr@ VNC is a computer program in the physics lab rooms that gives you the power to observe student computer screens and control a student's computer remotely via your keyboard and mouse. It is particularly useful for giving instructions about a program or displaying students' lab data.



To access Ultr@ VNC, log in to a lab computer with a TA username and password (most likely your physics department ID). If you would potentially like to broadcast a screen using the digital projector, log in to the instructor computer located near the printer. (Refer to the Digital Projector Reference for more information.) Access the program from the Start menu, Programs folder, UltraVNC, and UltraVNC Viewer. Refer to Figure 1.

You can also access the program from My Computer:
C:\Program Files\UltraVNC\UltraVNC Viewer

Fig. 1

The following pop-up window should appear, requesting the name of the display host:

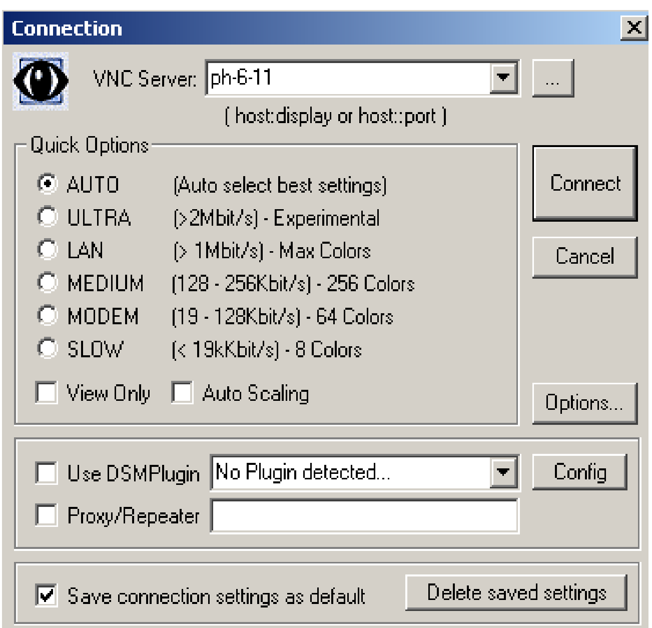


Fig. 2

In the *VNC Server* drop-down field, type the number of the student's computer that you want to observe. The numbers are printed on each computer and should be in the format ph-#-##.

If you want to change connection options, click the ***Options*** button. Another pop-up window will appear (Figure 3). *Auto select best settings* is the default. From this window you can change *Mouse Cursor* options and select *Display* options.

Click ***Connect*** to begin viewing the selected Desktop. An Authentication pop-up window will appear, requesting you to enter a username and password. Type in "vnc" and "labvnc". Click ***Log On***.

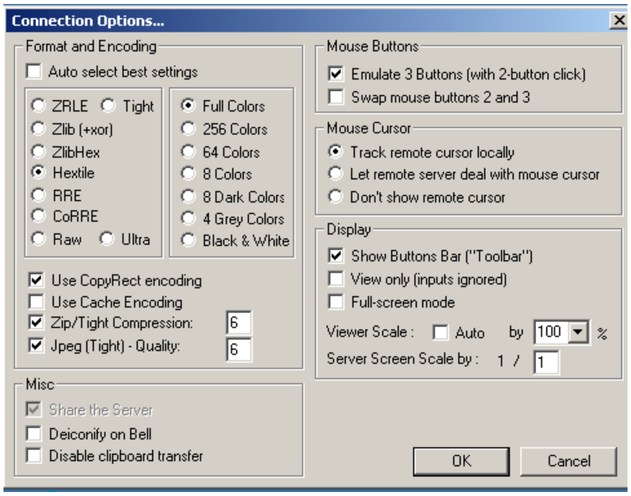


Fig. 3: Connection Options

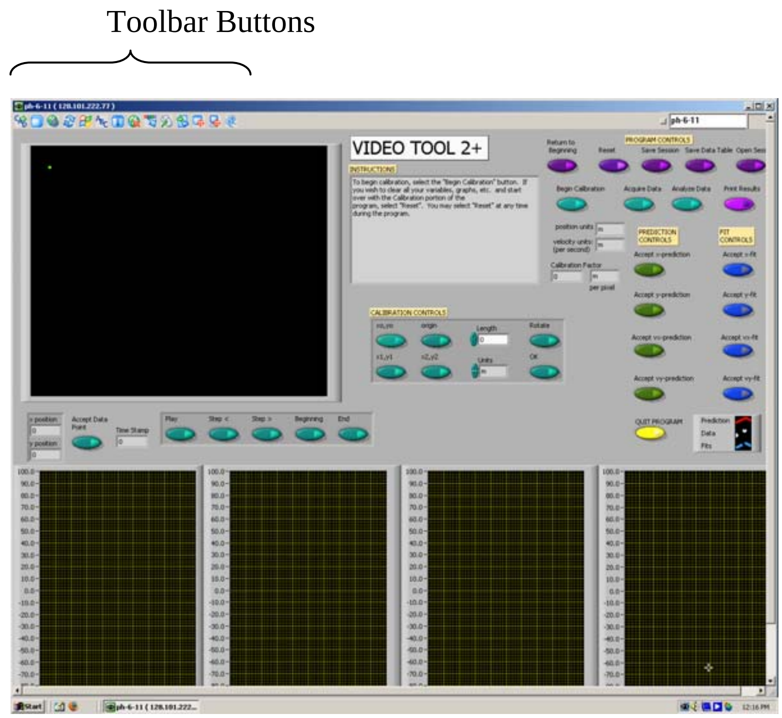


Fig. 4: Sample view of a student screen

Refer to Figure 4 for a sample view of a student screen. You can resize the window of the student screen using the arrows in the bottom right corner.

Use the toolbar buttons to navigate Ultr@VNC, as seen in Figure 5. Most buttons are self-explanatory, but selected descriptions are given on the next page.

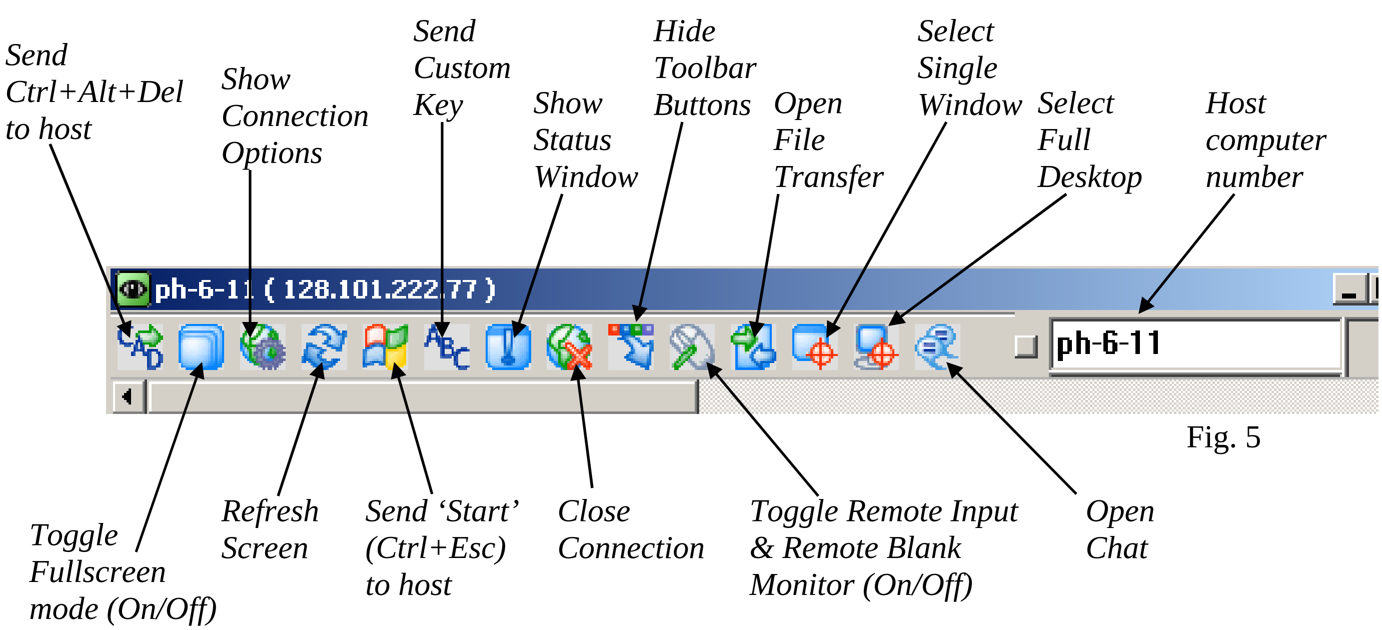
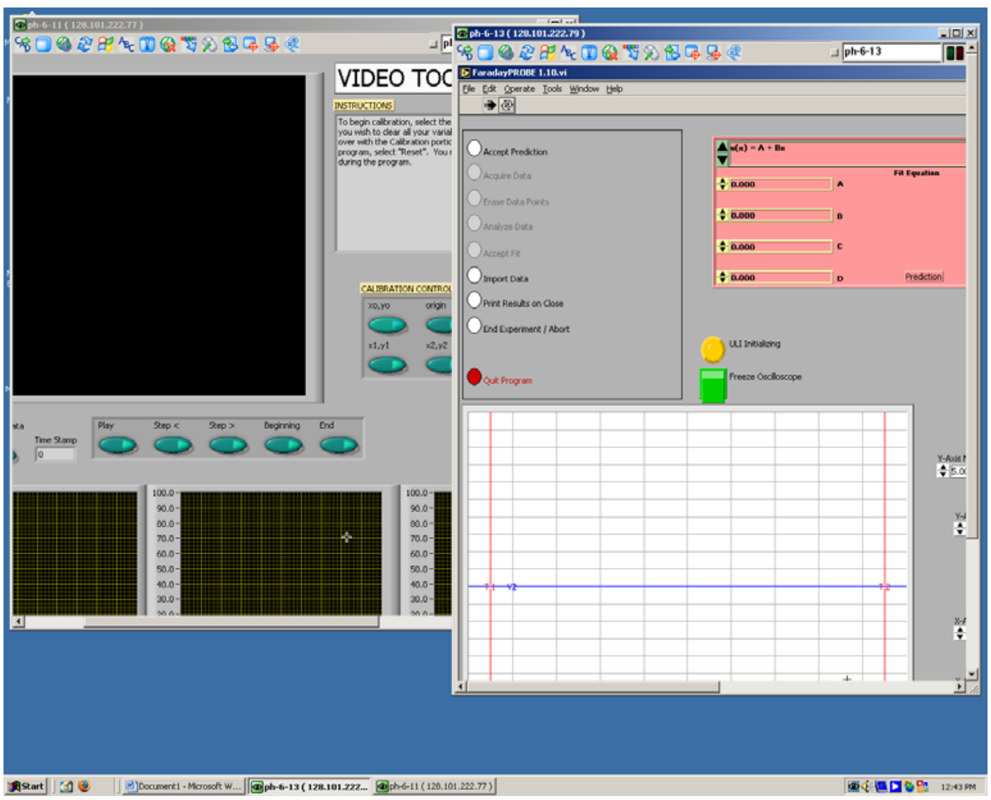


Fig. 5

<u>Selected Descriptions for Toolbar Buttons</u>:

- ***Send Ctrl+Alt+Del to host*** will bring up the physics logout window on the student's computer.
- ***Send 'Start' (Ctrl+Esc) to host*** will depress the start button on the student's computer, giving you the power to access programs, etc. from the host computer.
- ***Show Connection Options*** will display the same pop-up window that is available from the ***Options*** button of the initial ***Connection*** window (Figure 3).
  - o There are three options for the *Mouse Cursor*: Track remote cursor locally, Let remote server deal with mouse cursor, and Don't show remote cursor.
  - o The first two options appear to be a shared-control option between the student and instructor computers, with slight differences between what is seen on each screen.
- ***Toggle Remote Input & Remote Blank Monitor (On/Off)*** gives total control to the instructor by disabling the student's computer mouse.
- ***Select Single Window*** gives you the option to select and view one window that is open on a student's screen, providing multiple windows are opened at the same time. When this toolbar button is depressed, a crosshair appears and you can use this to click on the window to be viewed. Any remaining windows are "blacked out". To return to the fullscreen view, click the ***Select Full Desktop*** toolbar button.



It is possible to display multiple student screens on an instructor desktop, but you must reopen the Ultr@ VNC program each time and resize the windows (or only view one screen at a time).

Fig. 6

To exit Ultr@ VNC, click ***Close Connection***.

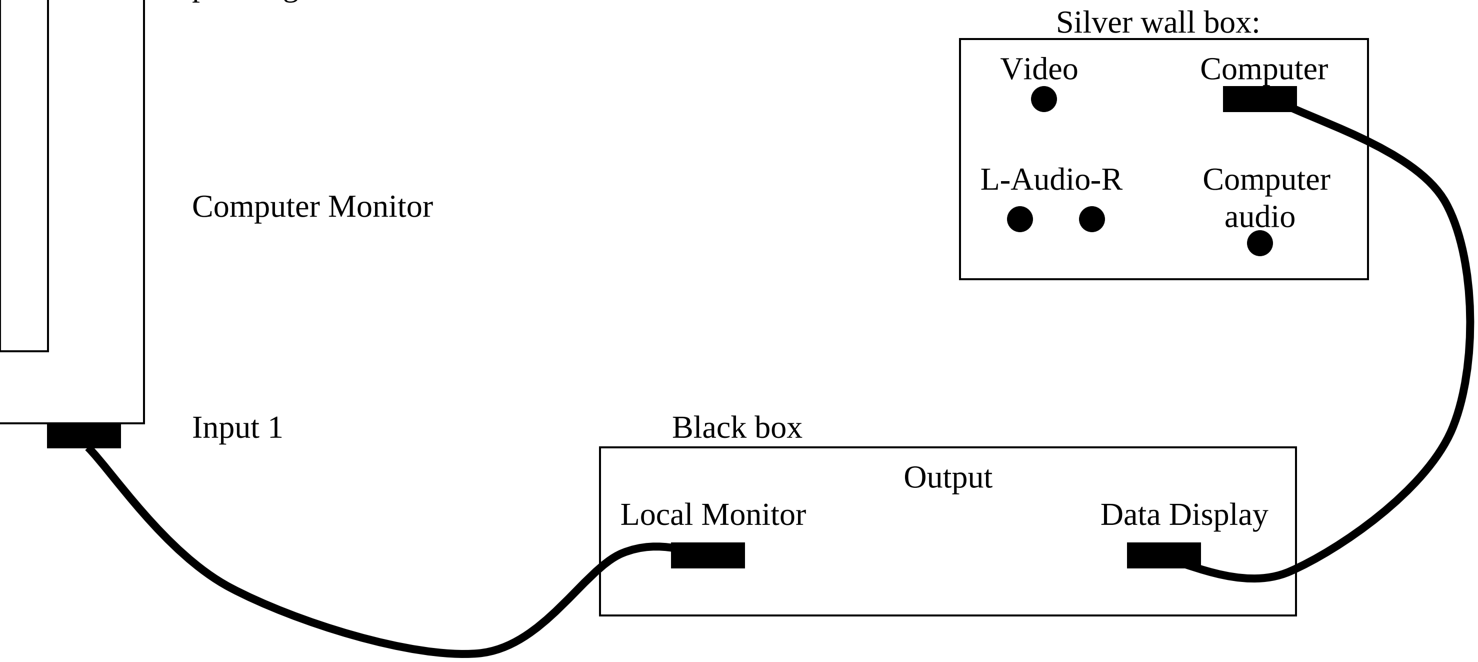
For more information, the software developers' website is:
<u>http://www.ultravnc.com/</u>

Digital Projector Reference:

Every lab room has a Panasonic® projector fixed to the ceiling with connections to a wall unit. This is useful to project documents or programs onto a pull-down screen for easy viewing by the entire class.

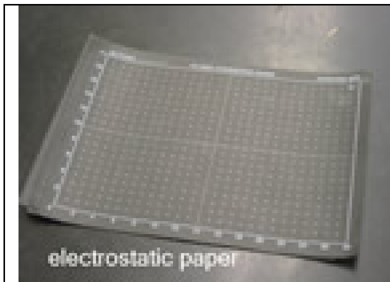
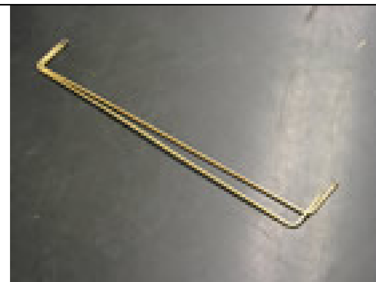
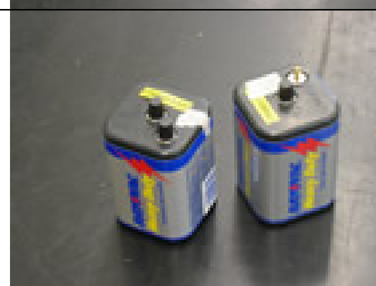
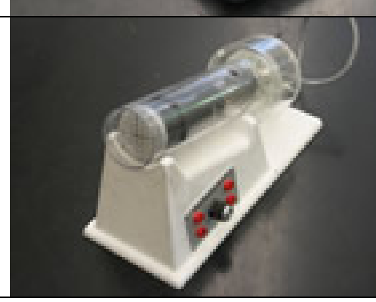
To project the instructor computer, log in using either a student ID and password or a TA username and password. This computer should have a serial cable connected from *Input 1* of the monitor to *Local Monitor* of the black Output box, and another cable from *Data Display* of the black Output box to *Computer* of the silver wall unit.

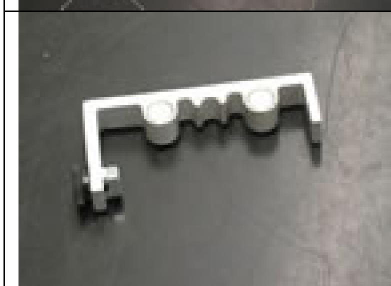
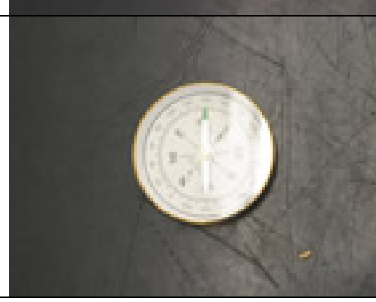
Turn on the Panasonic® projector by depressing the large *Power* button. You might need to use a meter stick to reach it. If the computer screen does not immediately display, cycle through the input by pressing the *RGB* button. Most will display on *RGB 1*. Turn off the projector by pressing *Power* twice.

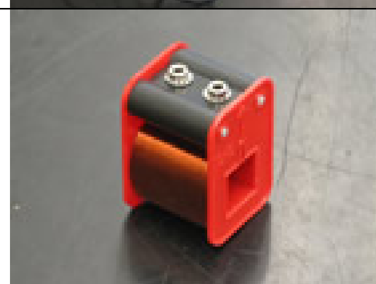
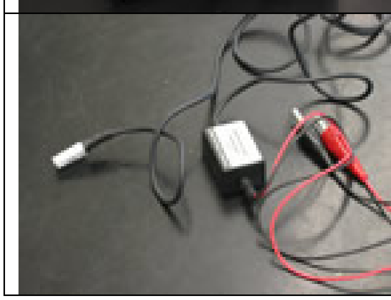
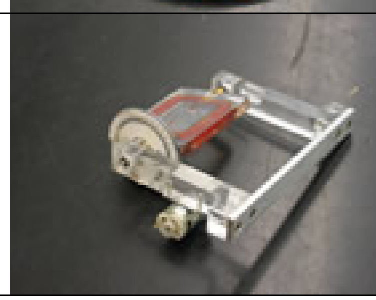


1302 Equipment Guide

Remember to submit a lab problem report using the link on the desktop of the lab workstations for any problems with the lab equipment. Some equipment is noted as being commonly available in supply closets on the second floor. If you take equipment, you still need to submit a problem report. **Please encourage your students to keep all parts of equipment together. Mass sets should remain as sets and nuts and bolts should be securely tightened after use.** Common problems are noted for some equipment that might provide potentially quick fixes. Thanks for you help!

	**Electrostatic Paper** Replacements in second floor closet #8		**Long Brass Rods – contacts for Electrostatic Paper** the labrooms.
	**Plastic Holders for Brass Rods**		**Batteries** Replacements in second floor closet #7
	**Pin Tip Probe**		**Alligator Clips** Replacements in second floor closet #8
	**Wood Block**		**DMM – Digital Multi Meter** Replacements in second floor closet #8 Box marked Bad for broken units
	**Cenco Power Supply (for CRT use only!!)** Check fuse		**CRT – Cathode Ray Tube** Check to see that bulb is seated in socket all the way.

	**Bar Magnets** Replacements in second floor closet #8		**Capacitors** Replacements in second floor closet #8
	**DC electric Motor** Clean motor of string after use. Replacements in second floor closet #8		**Friction Block**
	**Tape and String** Replacements in second floor closet #8		**Track**
	**End Stop** Replacements in second floor closet #8		**Light Bulbs** Replacements in second floor closet #8
	**Banana Cables** Replacements in second floor closet #8		**Resistors** Replacements in second floor closet #8
	**Magnetic Field Projectual** If it is leaking, please submit a report ASAP.		**Compass** Replacements in second floor closet #8

	**18Volt 5Amp power supply** Make sure it is set to MASTER on the rear of the unit.		**Meter Stick**
	**SensorDAQ**		**Magnetic Field Sensor** Replacements in second floor closet #8
	**Helmholtz Coil**		**Small Coils**
	**Function Generator**		**Large Coil**
	**Differential Amplifier** Replacements in second floor closet #8		**Induction Coil – Generator** Drive belts are fragile

Software

MAGNETLAB - MEASURING CONSTANT MAGNETIC FIELD

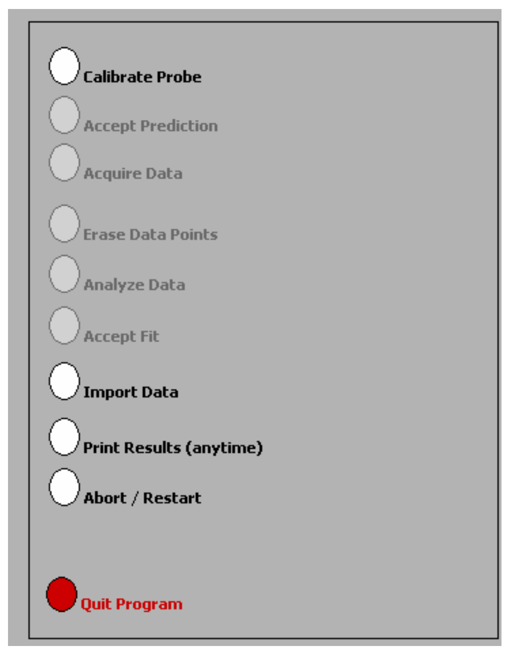
Application Basics

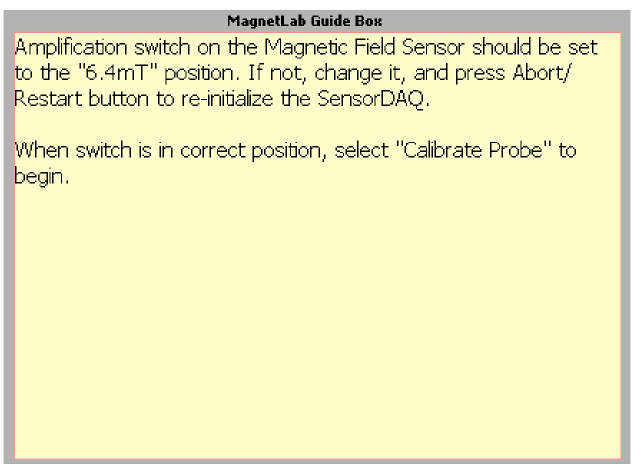
Before you begin, you should ensure that you have read the relevant sections of Appendix A to familiarize yourself with the equipment.

The software package that works in tandem with your magnetic field sensor is written in LabVIEW™. It allows you to measure and record magnetic field strength as a function of a number of different variables.

After logging into the computer, execute the application by double clicking the "MAGNETLAB" icon located in the PhysLab folder on the desktop.

Before you start using the program, you should take a moment to identify several key elements. The two most important of these are the Command Panel, shown to the right, and the Guide Box, shown below.





The Guide Box will give you directions and tasks to perform. It will also tell you when to select a command in the Command Panel. After selecting a command, it will "gray out" and the next command will become available.

You can also print and/or quit from the Command Panel or abort your analysis and try again.

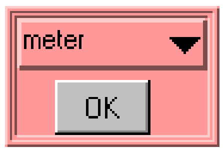
The primary data output you get is by generating pdf files of your results, so be careful not to quit without printing pdf files or exporting your data to be emailed amongst your lab

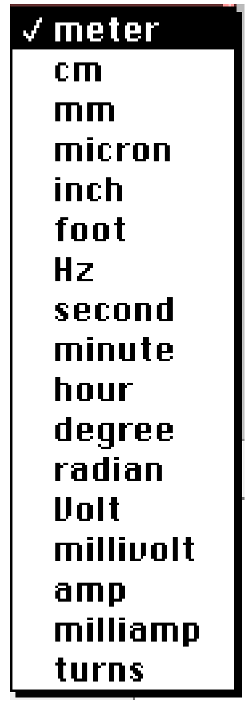
group.

Calibration

The first command is to calibrate the Magnetic Field Sensor. Before selecting this command, you need to set the probe to the 6.4mT setting.

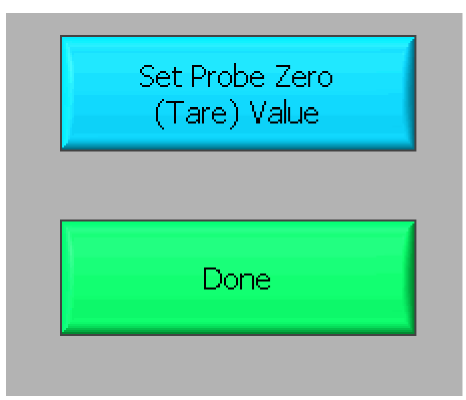
After selecting the "Calibrate Probe" command, you will be asked to do *two* tasks. Firstly, you will need to choose the quantity on the x-axis of your data graph. This is accomplished by moving the mouse cursor over to the word "meter" in the red-colored area (shown below) and then pressing the mouse button.





You should get a list of choices as shown to the right. By selecting any of these units, you will be making a choice about what you wish to measure. For example, if you choose to use "cm", you will make a graph of magnetic field strength as a function of distance (B vs. x). It is likely you will want to choose a small unit (cm's or mm's) to measure the distance in, since many magnetic fields are not very strong over long distances Selecting "degree" will make a plot of magnetic field strength as a function of angle (B vs. θ). Click "OK" when you are ready to proceed.

Secondly, you will need to eliminate the effect of the background magnetic fields. This process is called "zeroing the Hall probe" in the Guide Box. **Place the magnetic field sensor wand in the position you would like to take your measurement, but be sure that there are no magnets nearby.** Note that power supplies and computers generate magnetic fields, so it is a good idea to keep away from them! When you are ready, select the "Set Probe Zero" as shown below.



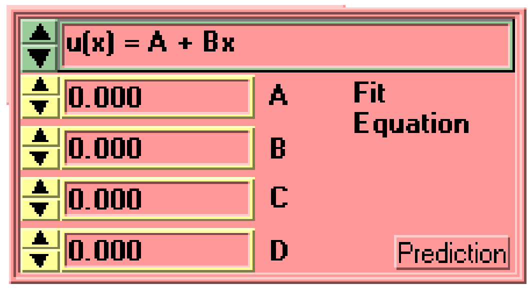
Then select the "Done" button. The calibration process is now complete.

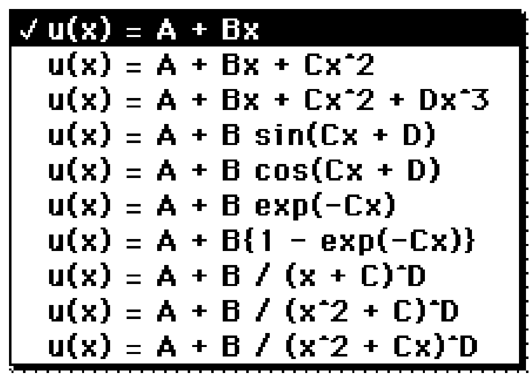
Predictions

This type of analysis relies on your graphical skills to interpret the data. You should be familiar with both Appendix D: *Graphing*, and Appendix C: *Uncertainties*.

The first task is to enter your prediction of the mathematical function you expect to represent your data. Making a prediction before taking data is the best way to determine if anything is going wrong (remember Murphy's Law). It's also a good way to make sure you have learned something, but only if you stop to think about the discrepancies or similarities between your prediction and the results.

In order to enter your graphical prediction, you first need to decide on your coordinate axes and scale (units) for your measurements. *Record these in your lab journal*.





Next, you will need to select the generic equation, u(x), which describes the graph you expect for the data. Clicking the equation currently showing in the box will bring up a list of equations to choose from; see the diagrams to the right.

After selecting your generic equation, you next need to enter your best approximation for the parameters A, B, C, and/or D. These values should come directly from your prediction equation you did for class. As you enter these values, you should see the red line in the "Plot" box changing.

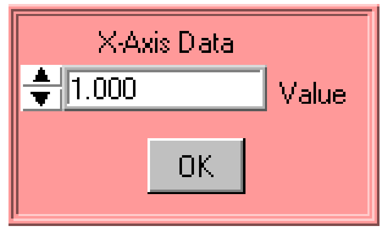
Once you have selected an equation and the values of the constants are entered, your prediction equation is shown on the graph on the computer screen. If you do not see the curve representing your prediction, change the scale of the graph axes or use the *AutoScale* feature (see Finding Data below). When you are satisfied, select the *Accept Prediction* option from the Command Panel. Once you have done this you cannot change your prediction except by starting over.

Exploration

After you have entered your prediction, you can explore the limitations of your magnetic field sensor before you take data. The value of the magnetic field strength is displayed directly under the Guide Box. When you are ready to take data, select *Acquire Data* from the Command Panel.

Data Acquisition

Collecting data requires that you enter the x-axis data each time the computer reads in a value for the magnetic field strength. You enter this data using the panel shown. For every x-axis data value you enter, the analysis program will record the magnetic field strength in gauss on the y-axis of the "Plot". Press "OK" to collect the next data point. Each data point should appear on the graph on the computer screen as you take it. If it doesn't, adjust the scales of your graph axes or use the *AutoScale* feature (see Finding Data below). If you are satisfied with your data, choose *Analyze Data* from the Command Panel.



Finding Data on the Graph

You can find your data on the graph by adjusting the scales of your X-axis and Y-axis plots manually. This scaling is accomplished by entering values into the legend of the graph. Click on the upper or lower legend value and enter a new value, then hit enter. If you cannot locate your data, you can select both "AutoScale Y-axis" and "AutoScale X-Axis" to let the program find the data for you. You can then adjust your axis scales to give you a convenient graph for analysis. Be careful, the AutoScale option will often set the scales in such a way that small fluctuations in the data are magnified into huge fluctuations.

Data Fits

Deciding which equation best fits your data is the most important part of using this analysis program. While the actual mechanics of choosing the equation and parameters is similar to what you did for your predictions, fitting data is somewhat more complicated.

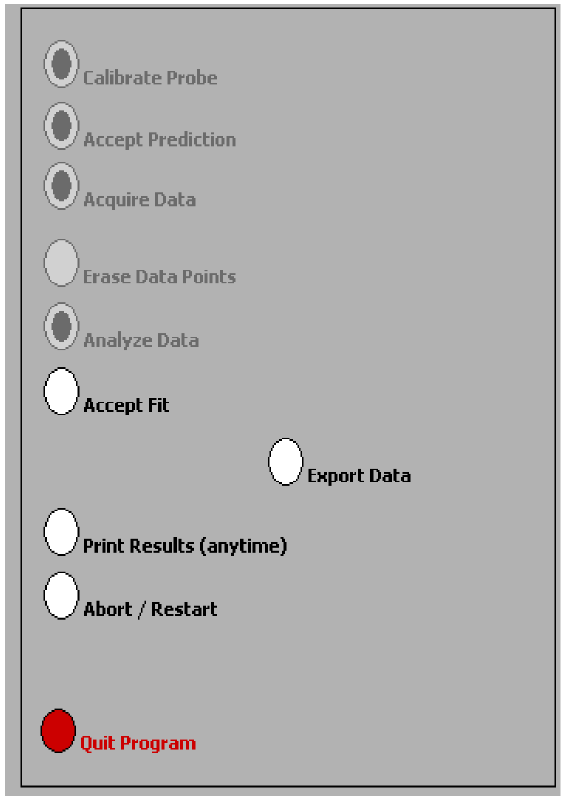
By looking at the behavior of the data on the graph, determine the best possible function to describe this data. After you have decided on the appropriate equation, you need to determine the constants of this equation so that it best fits the data. Although this can be done by trial and error, it is much more efficient to think of how the behavior of the equation you have chosen depends on each parameter. Calculus can be a great help here. *This can be a time-consuming task, so be patient.*

Now you need to estimate the uncertainty in your fit by deciding the range of other lines that *could* also fit your data. This method of estimating your uncertainty is described in Appendix D. Slightly changing the values for each constant in turn will allow you to do this quickly.

After you have computed your uncertainties, return to your best-fit line and use it as your fit by selecting *Accept Fit* in the Command Panel.

Importing / Exporting Data

After you have selected *Analyze Data*, it is possible to save your data to the computer's hard drive. This feature can come in handy if you need to analyze your data at a later date or if you want to re-analyze your data after you have printed it out.



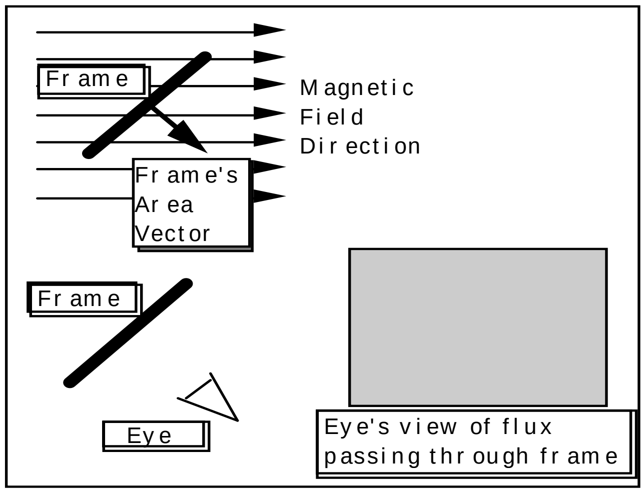
To save your data, simply select *Export Data* (as shown to the right) and follow the instructions in the windows. Your file should be saved in the **LabData** folder. To retrieve this file, restart *MagnetLab* from the desktop and select *Import Data.*

Last Words

These directions are not meant to be exhaustive. You will discover more features as you analyze more data. Be sure to record these features in your lab journal.

FLUX SIMULATOR

A computer movie called FluxSimulator shows the magnetic flux through a rectangular coil of wire (called a frame in the program). The frame is rotated in a uniform magnetic field changing the magnetic flux passing through it. The screen of this simulation is shown below. The magnetic flux is visualized by a “magic eye” that is always perpendicular to the cross-sectional area of the frame (as shown below). The amount of flux "seen" is indicated by the use of color intensity as the frame rotates. Blue indicates positive flux while red indicates negative flux.



Picture of FluxSimulator Screen

Use the control bar with the slider, as shown below, to control the rotation of the frame.

Slider

As you rotate the frame, observe both the angle the frame's area vector makes with the magnetic field and the color seen by the eye.

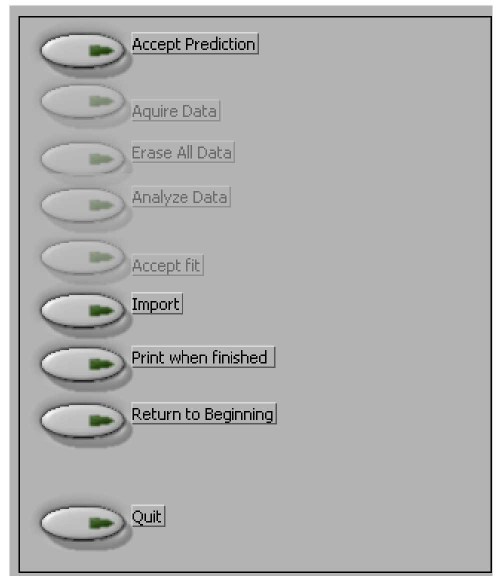
VoltageTimeLAB - MEASURING TIME-VARYING VOLTAGES

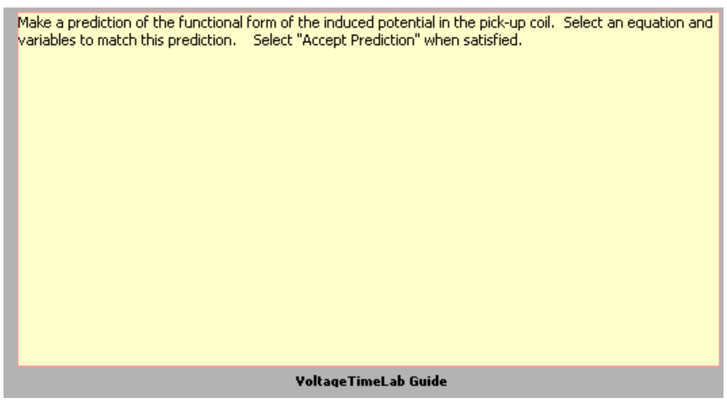
The Basics:

This software package, written in LabVIEW™, allows you to measure and record potential differences as a function of time. The software and voltage interface act much like an oscilloscope.

After logging into the computer, execute the application by double clicking the "VoltageTimeLab" icon located in the PhysLab folder on the desktop.

Before you start using the program, you should take a moment to identify several key elements. The two most important of these are the Command Panel, shown to the right, and the Guide Box, shown below.



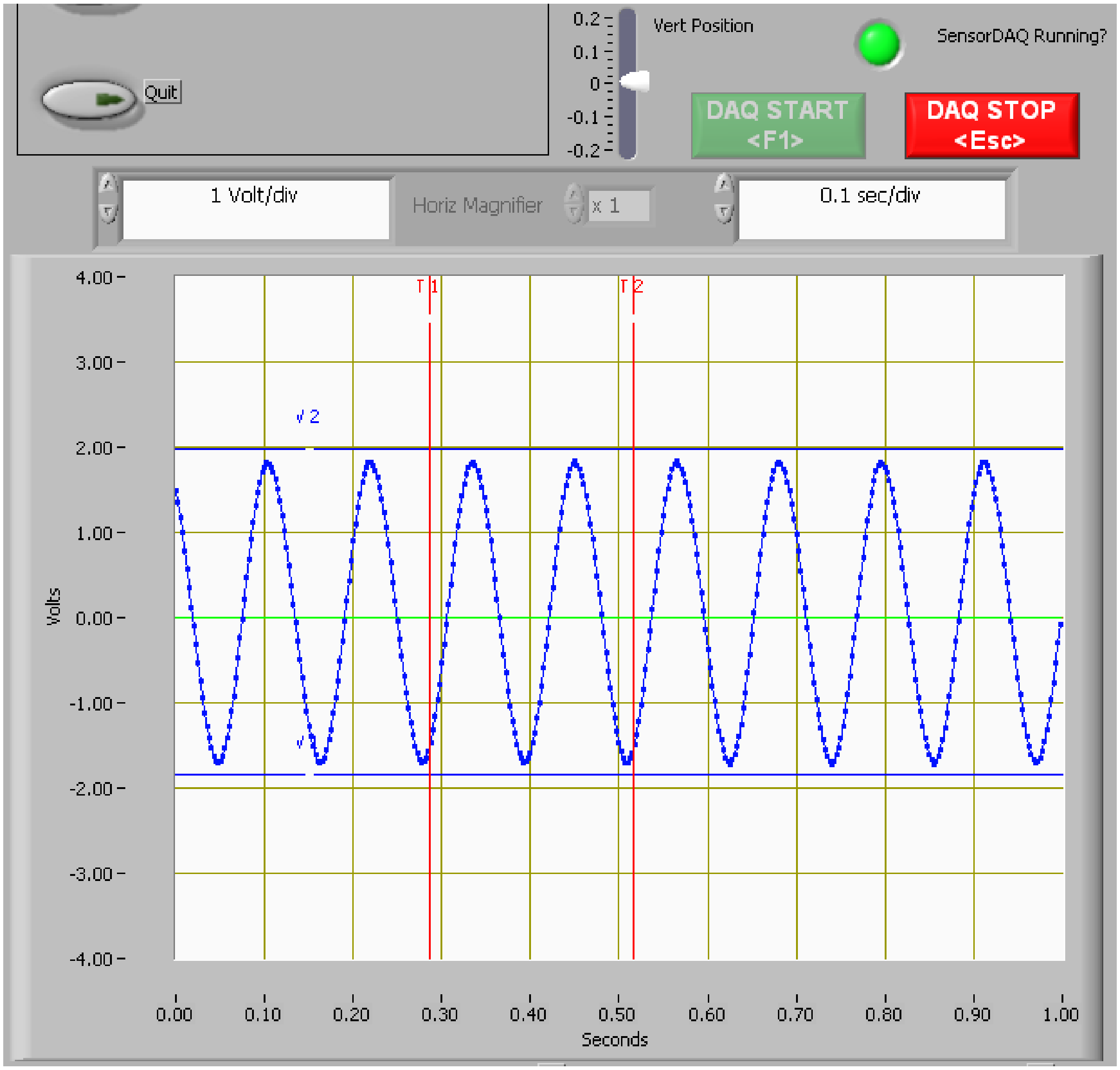


The Guide Box will give you directions and tasks to perform. It will also tell you when to select a command in the Command Panel.

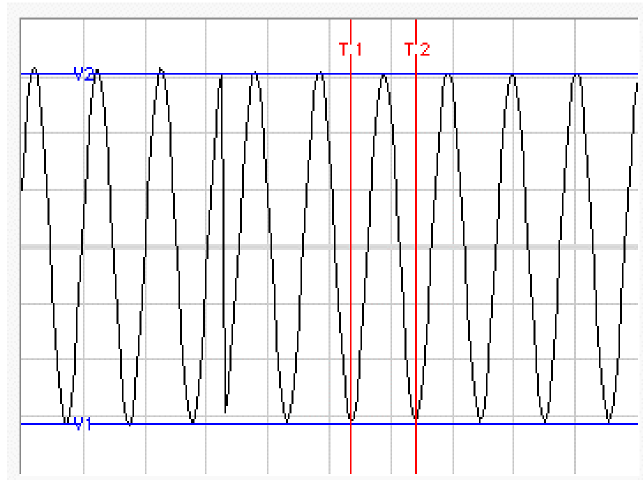
You can also print and/or quit from the Command Panel or abort your analysis and try again.

The primary data output you get is by generating pdf files of your results, so be careful not to quit without printing pdf files or exporting your data to be emailed amongst your lab group.

Since the application to measure time-varying voltage is a slight modification of the application to measure magnetic field, you are already familiar with how to use much of it. The basic difference between the TimeVoltageLab and the MagnetLab applications is an additional display that is much like an oscilloscope. The potential difference versus time display is shown on the next page. The DAQ (Data Acquisition) control buttons are located directly above this display. The "DAQ START" and "DAQ STOP" buttons do as they suggest, stop and start data streaming from the probe to the voltage versus time display. When you first start the application you will need to click the "DAQ START" button to start streaming the probe readings. You will use the "DAQ STOP" to freeze the data screen for taking measurements. A green indicator is used to indicate whether the interface is running or not.



The vertical axis is a measure of the potential difference (voltage) between the two leads of the voltage probe. The horizontal axis measures time. You should also notice that the display has a grid on it. The scale of each axis is shown at the bottom of the display. As you might suspect, it is possible to change the grid size of each axis. To change the scale of the axis, simply click on the highest or lowest number on that axis and type in a new value. The axis will automatically adjust to create even increments over the newly defined range.



The red and blue lines that are on the display are movable simply by putting your mouse pointer over one of the lines. When the mouse pointer changes shape, hold the mouse button down and drag the lines to mark a voltage or time as shown. The lines mark the voltage and time boundaries of the data that will be considered for analysis.

If you are unable to see the lines, it is possible that you changed the axes scale and "zoomed in" too far. Try changing the axes to "zoom out" again, and determine if you can locate the blue and red lines. Move the lines to within the values of the new scale, and they should remain visible on the screen when you zoom in.

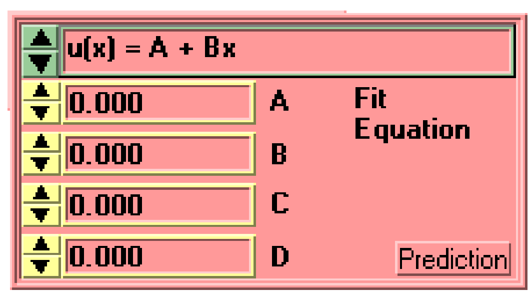
Predictions

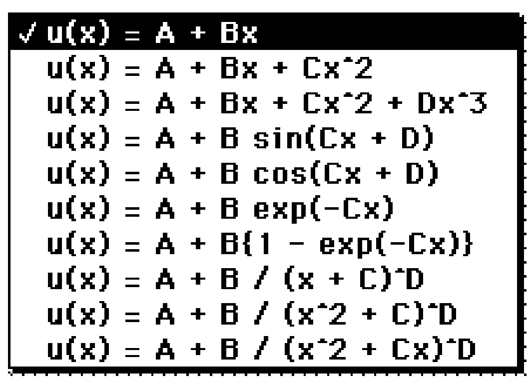
This type of analysis relies on your graphical skills to interpret the data. You should be familiar with both Appendix D: *Graphing*, and Appendix C: *Uncertainties*.

The first task is to enter your prediction of the mathematical function you expect to represent your data. Making a prediction before taking data is the best way to determine if anything is going wrong (remember Murphy's Law). It's also a good way to make sure you have learned something, but only if you stop to think about the discrepancies or similarities between your prediction and the results.

You will need to select the generic equation, u(x), which describes the graph you expect for the data. Clicking the equation currently showing in the box will bring up a list of equations to choose from; see the diagrams to the right.

After selecting your generic equation, you next need to enter your best approximation for the parameters A, B, C, and/or D. These values should come directly from your prediction equation you did for class. As you enter these values, you should see the red line in the "Plot" box changing.





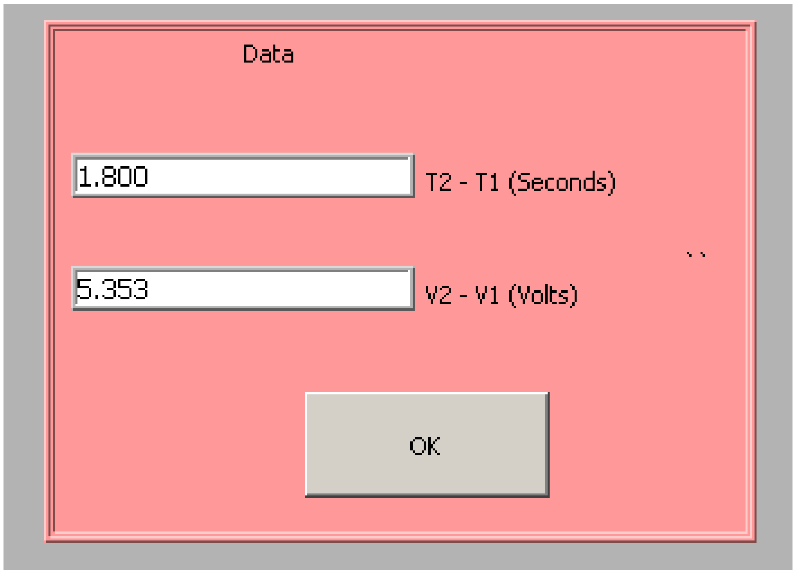
Once you have selected an equation and the values of the constants are entered, your prediction equation is shown on the graph on the computer screen. If you do not see the curve representing your prediction, change the scale of the graph axes (see Finding Data below). When you are satisfied, select the *Accept Prediction* option from the Command Panel. Once you have done this you cannot change your prediction except by starting over.

Exploration

After you have entered your prediction, you can explore the limitations of your voltage probe sensor before you take data. The value of the voltage is displayed directly on the voltage vs. time display. When you are ready to take data, select *Acquire Data* from the Command Panel.

Data Acquisition

Collecting data requires that you position the moveable red and blue lines on the voltage vs. time display. The blue lines will generate potential difference data and the red lines will generate time/period data. The data values are shown in the data box. The data box appears once you have selected *"Acquire Data"* from the Command Panel. Press "*OK*" to collect each data point. Each data point should appear on the graph on the computer screen as you take it. If it doesn't, adjust the scales of your graph axes. If you are satisfied with your data, choose *Analyze Data* from the Command Panel.



Finding Data on the Graph

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Data Fits

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By looking at the behavior of the data on the graph, determine the best possible function to describe this data. After you have decided on the appropriate equation, you need to determine the constants of this equation so that it best fits the data. Although this can be done by trial and error, it is much more efficient to think of how the behavior of the equation you have chosen depends on each parameter. Calculus can be a great help here. *This can be a time-consuming task, so be patient.*

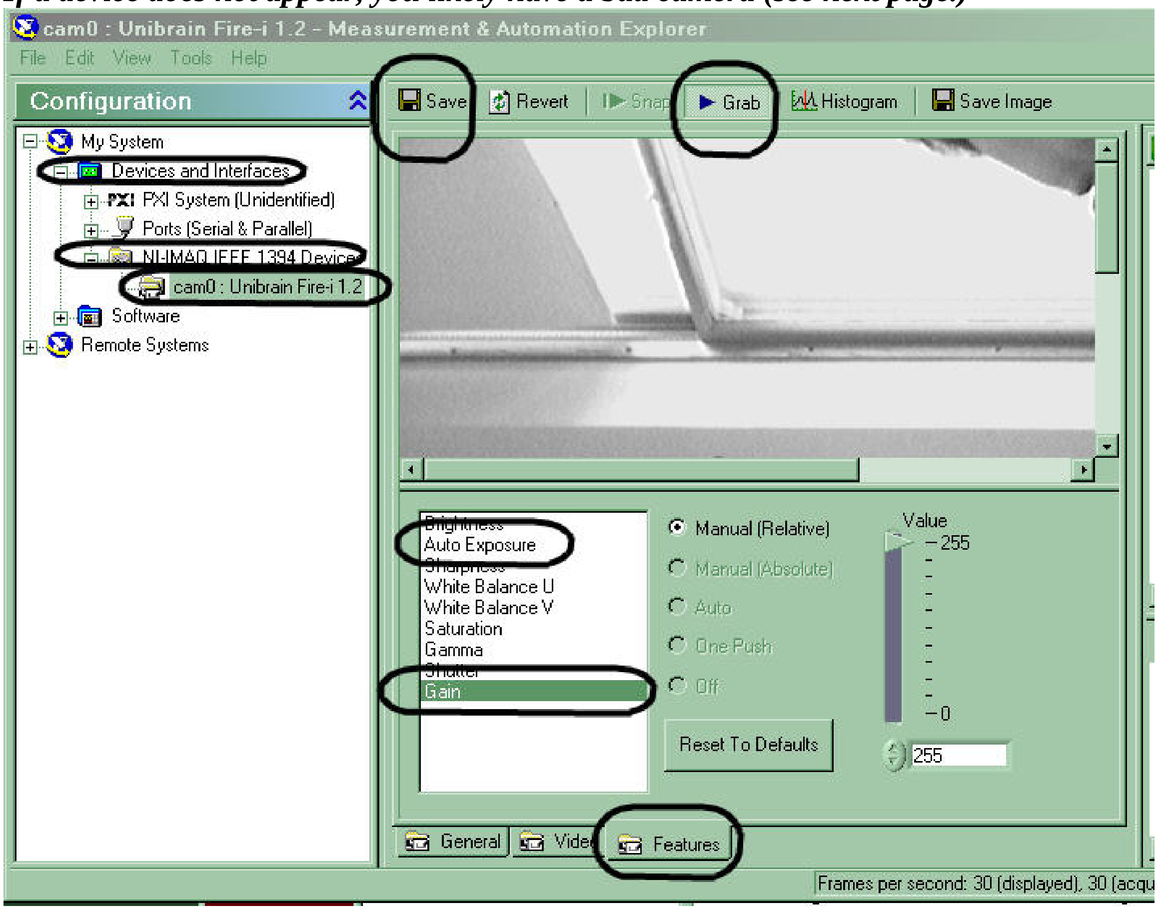
Now you need to estimate the uncertainty in your fit by deciding the range of other lines that *could* also fit your data. This method of estimating your uncertainty is described in Appendix D. Slightly changing the values for each constant in turn will allow you to do this quickly.

After you have computed your uncertainties, return to your best-fit line and use it as your fit by selecting *Accept Fit* in the Command Panel.

To install a camera:

1. Hook up new camera to firewire cable.
2. Launch the <u>"Measurement & Automation</u>" application (icon on desktop)
3. On the left-hand panel *(shown below)*, expand <u>"Devices and Interfaces"</u>
4. On the same panel, expand <u>"NI-IMAQ IEEE 1394 Devices"</u>

MAX has a generic camera setup initially; this needs to be switched to the Unibrain camera by right clicking on the device and selecting the NI-IMAQ driver using the menu. ***If a device does not appear, you likely have a bad camera (see next page.)***



5. On the same panel, click the icon for the camera <u>("Unibrain cam0:…")</u>
6. Click <u>GRAB</u> *(along the top, shown above)* to see what the camera sees
7. Click the <u>Video</u> tab (*along the bottom, next to the circled features tab*)
8. Change Video Mode by selecting the last option in the pull down menu (640x480 Y (Mono8)(30fps))

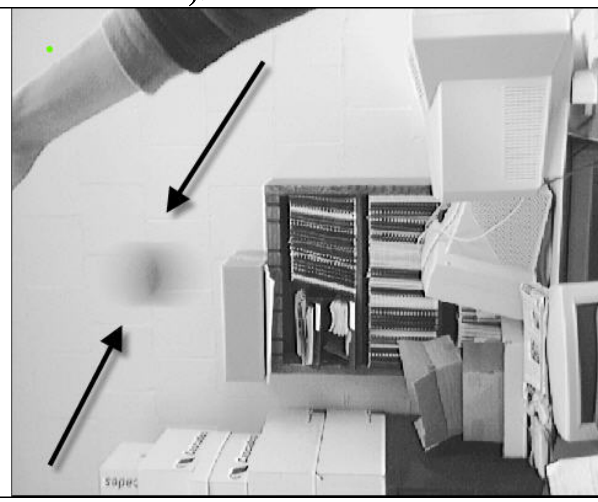
To help your students get useful data from the video camera, it may be necessary for you to adjust additional camera settings. (These settings should be stable, but may change when a camera is unplugged from its computer.)

9. Click the <u>FEATURES</u> tab (*along the bottom, shown above*)

In the picture below, "gain" is selected, and is set to its maximum value of 255.

10. **Set <u>GAIN</u> to its MAXimum value (this may cause a "washed-out" image).**
11. **Set <u>AUTO EXPOSURE</u> to the MINimum value that shows a useful image (depending on camera and lighting, 180 or below may be possible).**
12. Click <u>SAVE</u> (*top left*) to save the settings.
13. <u>Exit</u> the "Measurement & Automation" application.

To install a camera:

“Good” camera settings	**“Bad” camera settings (factory default)**
• short Exposure time • high amplification (Gain) Motionless objects may look grainy; objects in motion have well-defined edges (The ball below has fallen through the entire frame).	• long Exposure time • low amplification (Gain) Motionless objects look nice; motion causes blur (The blurred ball below has fallen only a short distance).
	

To check to see if a camera is bad:

1. Hook up camera to firewire cable.
2. Launch the “Measurement & Automation” application (icon on desktop)
3. On the left-hand panel, expand “Devices and Interfaces”
4. On the same panel, expand “NI-IMAQ IEEE 1394 Devices”

If a device (camera) does not appear, you have a bad camera, cable or firewire card. Check the cable, making sure the connectors are intact and not plugged by debris. Look at the firewire card in the back of the computer - try to use the port that looks best. If the camera still does not work, get a new camera and start over. If the new camera doesn’t work, reboot the computer and try again, possibly with a third camera. You can also use the TA computer and see if the camera will work on that machine. Remember to submit an electronic lab problem report form about any unresolved problems and bad cameras.