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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 1202 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 1202 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** if the course topics are not synchronized, as well as 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.

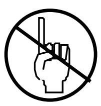
3. It is well known that students do not like to read instructions. They will come to you and ask questions that are answered in the lab manual. If this happens, first ask the student a question to determine if they have read the manual. If not, refer them back to the manual. If they have, give them 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 room 135.



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.

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 know where to find spares before class begins. **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, e-mail labhelp@physics.umn.edu. Be sure to include a complete description of the problem, and the room number. **Make a note** 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 student lab stations 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, possibly using the TA Lab Evaluation found at the end of the Instructor's Guide and give them to the lab coordinator. You can also e-mail the information to labhelp@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.

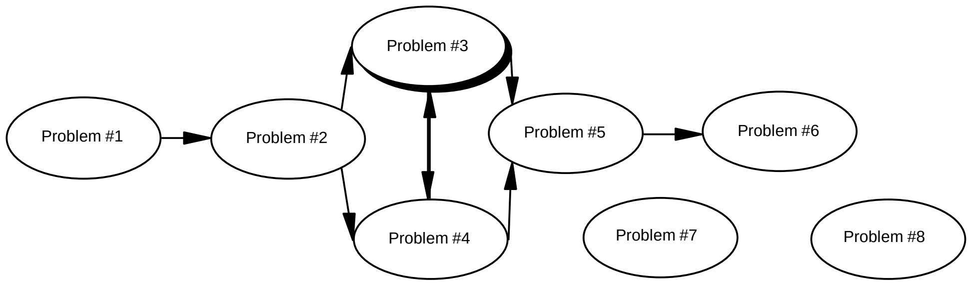
At the start of each chapter in this guide is a **flow chart** that shows the connections between the different problems in that lab. This chart is designed to help you plan your lessons. The elements of the flow charts have the following definitions:

- 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 1: Geometric Optics

The flow chart for the sequence of problems is:



Problems 1-4 of this lab are probably less challenging than problem 5, which is less challenging than problem 6. Students may be able to finish the first two problems in the first week, and the second pair of problems in the second week. The order of problems 3 and 4 is not of particular importance.

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

- Describe features of real optical systems in terms of ray diagrams (all problems).
- Connect mathematical descriptions of optical systems to ray diagrams.
- Use the concepts of real and virtual images, as well as real and virtual objects, to explain features of optical systems (problems 5 and 6).
- Explain the eye's function in human perception of images (problem 5).

Things to check out before teaching the lab:

- Make sure each group has the prescribed set of lenses.
- Before you teach the second problem, try to locate a real image without a screen (see the suggestion under "difficulties and alternative conceptions" for problem 2)
- Before you teach the sixth problem, be sure to try setting up a microscope … it can be tricky to see when it is properly focused, and your experience will be important for your students.

Lab 1 Problem #1: Images without Lenses or Mirrors

Purpose:

- To familiarize the students with geometric optics. To show that light rays travel in straight lines.
- To give an example of formation of an image without special optics devices.

Equipment: optics bench, screen, masks (black craft paper), Maglite, long-filament bulb, ruler.

Teaching Tips:

1. Make sure that your students are holding the mask vertically, so that they can read accurate distance.

2. To see the effect of magnification they should try different ratios of distance to the image to distance to the object. When the mask is about halfway between the lamp and the screen, the image will be approximately as big as the filament. Closer/ farther away positioning of the lamp will magnify/ shrink the image.

3. It's tricky to measure the length of the filament, you'll need to pick features (connection points, curves and bends) and use those for reference points.

4. It may be hard to see in this setup, but in principle a pinhole camera cannot resolve an object that is smaller than the size of the hole. An image of the long-filament bulb can be projected onto the screen, but not of the Maglite bulb.

Difficulties and Alternative Conception of Students:

- Students may have difficulty thinking in terms of light traveling in straight lines from a luminous object.
- In particular, students may not be able to break a luminous object into points.
- For example, they may think holistically of light traveling from the object to the screen, but not be able to think in detail about the path. (These students may predict that an image should appear on the screen even without a pinhole -- or without a lens, in later labs.)
- Students may not realize that the image formed in this lab is a smeared summation of bright spots in the shape of the mask's hole, caused by the summation of points in the luminous object.
- After this problem is done students may not understand why we need lenses to produce images. It worth stressing that to get a sharp image with a pinhole one has to make it smaller, and this would reduce the brightness. This would make a connection to the next problem, where they explicitly show that each part of a lens is producing an image.

Prediction and Warm-up Questions:

$$\frac{h'}{h} = -\frac{q}{p}$$

The convention used in the textbook is to assign magnification negative values if the image produced is inverted (so that its size is negative).

The bigger hole will produce a brighter but more smeared out image.

Sample Data:

The length of the filament is 75mm.

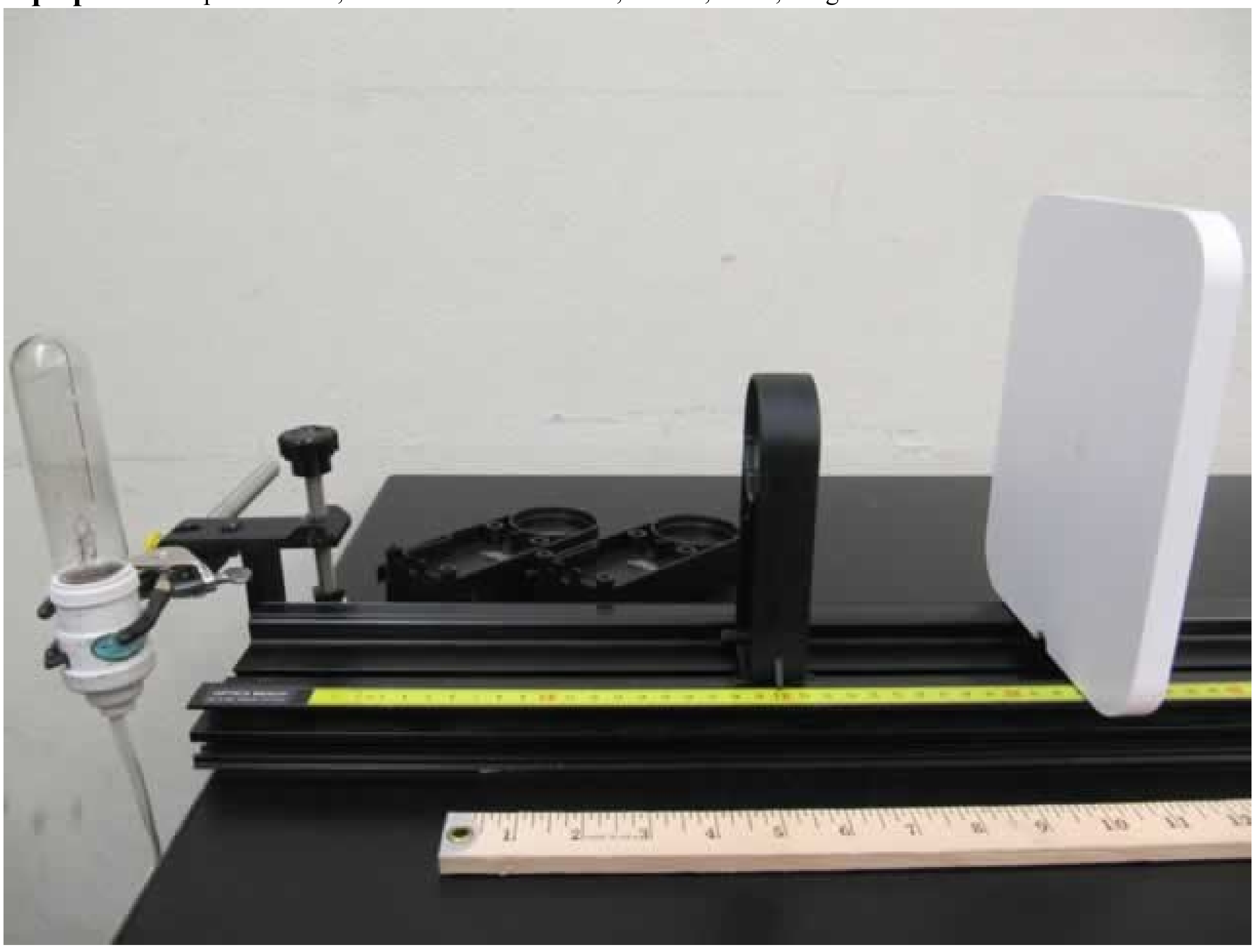
p (cm)	q (cm)	image size (mm)	predicted mag.	measured mag.
50	20	-33	-0.4	-0.44
40	20	-42	-0.5	-0.56
30	20	-54	-0.666667	-0.72
20	20	-78	-1	-1.04
15	20	-103	-1.333333	-1.373333
10	20	-147	-2	-1.96

Lab 1 Problem #2: Image Formation with a Partially Covered Lens

Purpose:

- To show students that an image is produced by every part of the lens independently.
- To emphasize that within geometrical optics light travels in straight lines.

Equipment: optics bench, set of lenses in holders, screen, ruler, long-filament bulb.



Teaching tips:

1. To estimate the focal length of a lens one can use some distant source and try to get an image of it. Fluorescence lamps in the room can give you a good idea of a focal length, when focused on a floor or a table. Longer-focal length lenses would suffer more corrections. Another possibility is to get a picture of the window on a screen.

2. It may be useful to move the mask back and forth between the lens and the object, observing the changes made in an image. When the mask is adjacent to the object, obviously part of the image will be blocked. On the other hand, when the mask is near the lens, the shape of the image is not changed. Make the students think of when does the transition happen, and what does it correspond physically (drawing a ray diagram may help).

Difficulties and Alternative Conceptions of Students:

- Many students think that parts of the image are formed by corresponding parts of the lens. It is important for them to realize that even a tiny piece of the lens will focus rays in the same point as a whole lens does, and will bend all the incoming rays to produce an image.
- Many students will predict that when part of the lens is blocked, part of the image will be blocked. In pre-experiment discussion, get these students to talk about their understanding of how images are formed. They should be surprised when the image changes differently from their prediction, and should have to change their understanding of image formation, as noted above.
- Students may believe that the whole image somehow travels through the air, and that the purpose of the lens is merely to flip the image. These students might predict that an image would appear on the screen even if no lens is present.
- Students may believe that no image exists unless the screen is present, or that the image exists in the lens. This is addressed briefly in the exploration. They can check it by looking through the lens (with their eyes behind the image point). They might need help locating the position of the image without a screen. By holding an object like a pencil at the image position, and moving their head back and forth, they can see that the object and the image only stay together when the object is at the image position.
- When drawing ray diagrams, students may believe that the "helpful" (i.e. the two or three rays used by the textbook in locating images) light rays cannot be used unless they actually pass through the picture of the lens. This may be related to a belief that ONLY the "helpful" rays form the image after this lab, we hope they realize that the light reaching each little piece of the lens makes a complete (but dim) image.

Prediction and Warm-up Questions:

When the lens is partially covered, the image will become dimmer but the shape won't change.

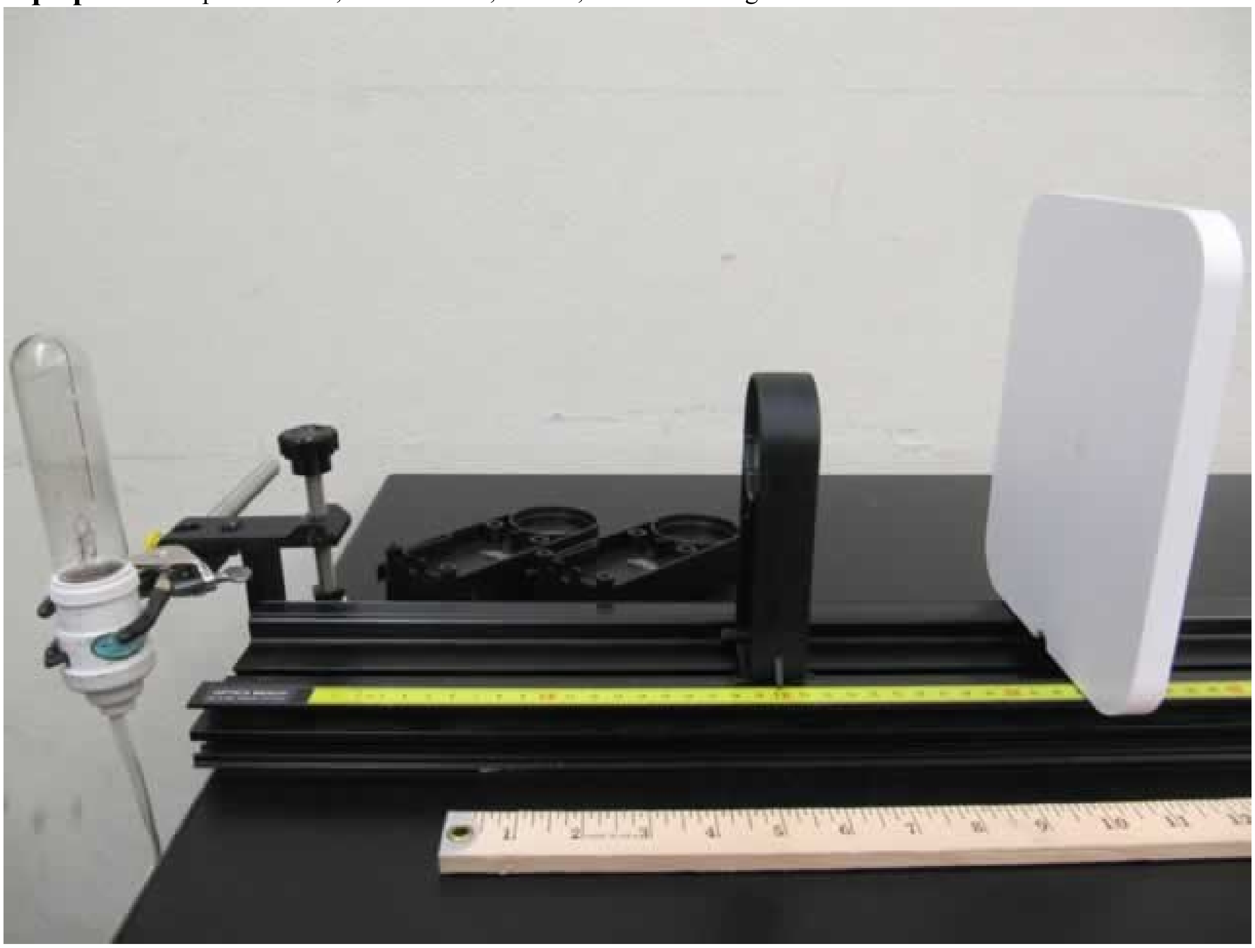
Part of the image will start to disappear when all of the rays coming from part of the object towards the lens will be blocked. For the object which is approximately the size of the lens and the screen blocking the upper half of the lens touching the optical axis the upper part of the object (lower part of the image) will start to fade when the screen is about halfway between the object and the lens.

Lab 1 Problem #3: Image Position I

Purpose:

- To give students qualitative and quantitative understanding of the ***p vs. q*** relation
- To give them practice calculating the focal lengths of lenses that will be used later during the course

Equipment: optics bench, set of lenses, screen, ruler and long filament bulb.



Teaching Tips:

1. The p vs. q graph is easier to visualize in terms of predicting q for a known p and other way around. On the other hand, the 1/ p vs. 1/ q graph makes fitting a lot easier and gives a possibility to estimate the focal length reliably, averaging out the experimental errors.

2. Make sure that your students pick appropriate range of distances. There should be one measurement around p~q~2f (which gives 1:1 image without magnification), and a couple of data points on each side from that.

3. It may be hard for students to realize that a constant step size in q (or p) does not result in a constant step size for 1/ q (of 1/ p).

4. To get the understanding of the correspondence between two graphs it's good to plot them simultaneously, labeling each data points.

Difficulties and Alternative Conceptions of Students:

- Expect the same difficulties and conceptions as in previous problems.

- Expect difficulties translating between p vs. q graphs and 1/ p vs. 1/ q graphs, and with understanding the importance of the intercepts in the 1/ p vs. 1/ q graphs.
- Students may have difficulty conceiving a way to estimate the focal length of a lens … this would be a good opportunity to reinforce the idea that parallel incoming light is focused to the focal plane of the lens, and that light from very distant objects is nearly parallel.

Prediction and Warm-Up Questions:

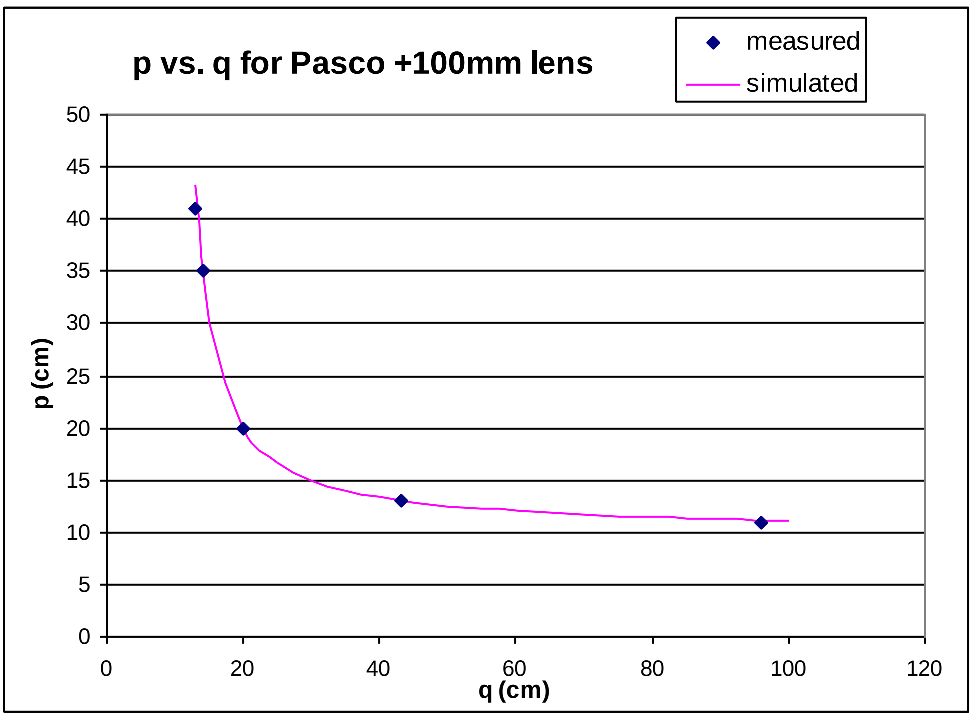
$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}, \qquad q=\frac{1}{\frac{1}{f}-\frac{1}{p}}=\frac{fp}{p-f}$$

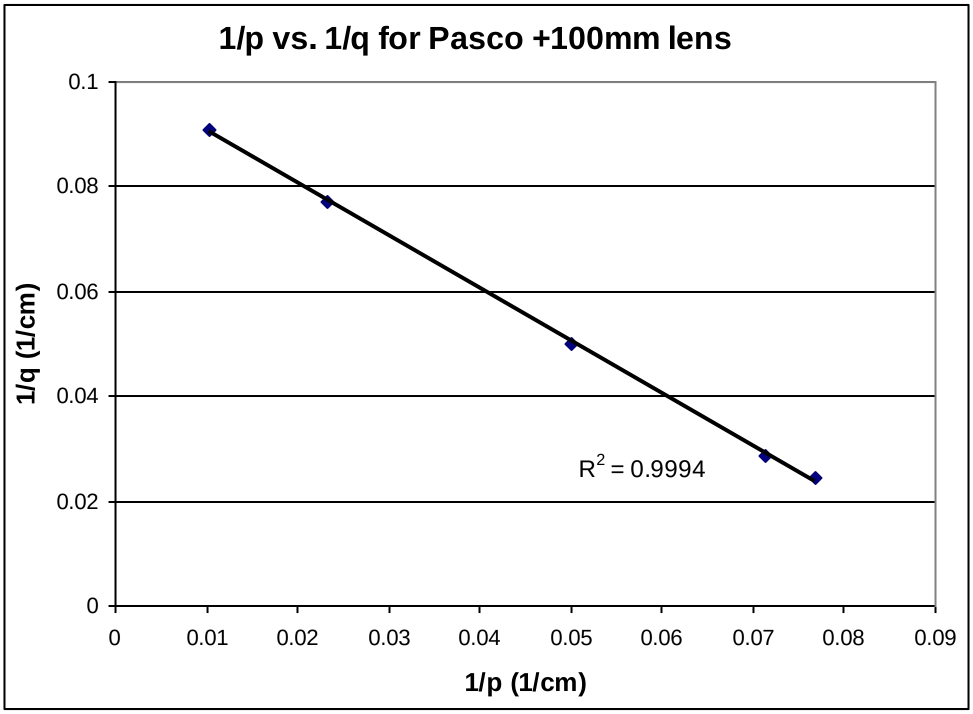
The first graph is a line at 45° intersecting axes at the 1/ f points, and the second one is a hyperbola, with a vertical asymptote at ***p=f*** and a horizontal one at ***q=f***.

Sample Data:

Pasco +100mm lens

p (cm)	q (cm)	1/p (cm^{-1})	1/q (cm^{-1})
11	96	0.090909	0.010417
13	43	0.076923	0.023256
20	20	0.05	0.05
35	14	0.028571	0.071429
41	13	0.02439	0.076923





Pasco +200mm lens

p(cm)	q(cm)	1/p (cm^{-1})	1/q (cm^{-1})
26	76	0.038462	0.013158
28	65	0.035714	0.015385
31	54	0.032258	0.018519
35	45	0.028571	0.022222
40	39	0.025	0.025641

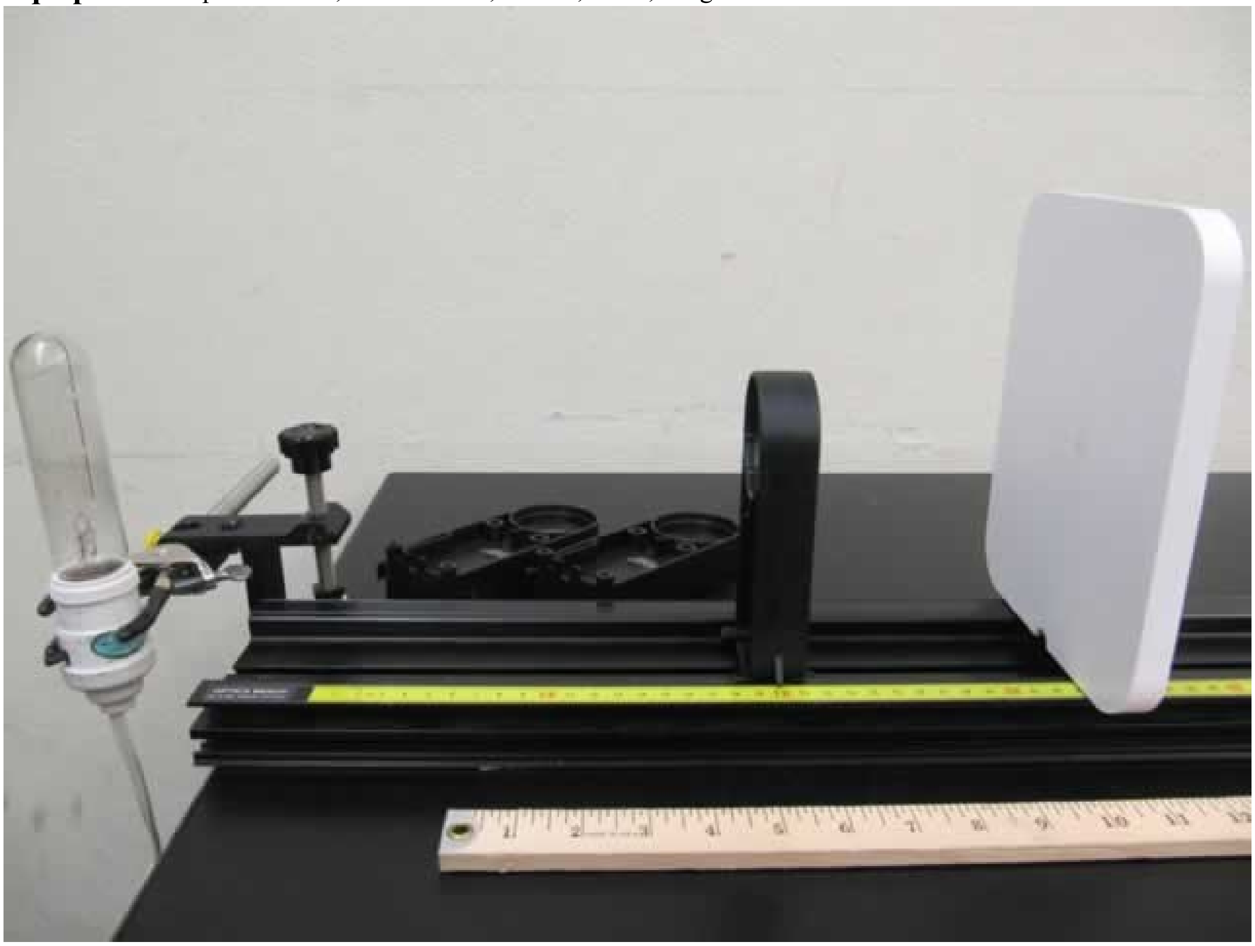
Pasco 250mm lens

p(cm)	q(cm)	1/p (cm^{-1})	1/q (cm^{-1})
45	59	0.022222	0.016949
50	53	0.02	0.018868
55	49	0.018182	0.020408
60	45	0.016667	0.022222
65	43	0.015385	0.023256

Lab 1 Problem #4: Image Position II (magnification)

Purpose:
- To teach the students to relate the position of points on the image with those on the object
- To explain the concept of magnification

Equipment: optics bench, set of lenses, screen, ruler, long filament bulb.



Teaching Tips:
1. When using the long filament lamps as a image source, students will need to pick distinct features of the filament that can be used to make measurements.
2. Lenses introduce some distortions on the edges, so it may lead to systematic errors on measuring the large separations.
3. Some parts of big objects can be obscured on the edges of the light source.
4. Again, for big objects the difference in distance to the optical center of the lens can be significant, so while the central part is in focus the edges may be not.
5. It's convenient to have one measurement at p~q~2f, when the image formed should be approximately the size of the object itself. The other data points should be closer/ farther away, so that the students get both magnification and de-magnification.

Difficulties and Alternative Conceptions of Students:
- Same as previous problems

- Students may believe that magnification is a property of the lens, and not a property of the optical system as a whole.
- Negative magnification might be confusing to some students.
- We expect this problem to be more straightforward than the other ones in this lab.

Prediction and Warm-up Questions:

$$\frac{h}{-h'} = \frac{p}{q}; \qquad M = \frac{h'}{h} = \frac{-q}{p}$$

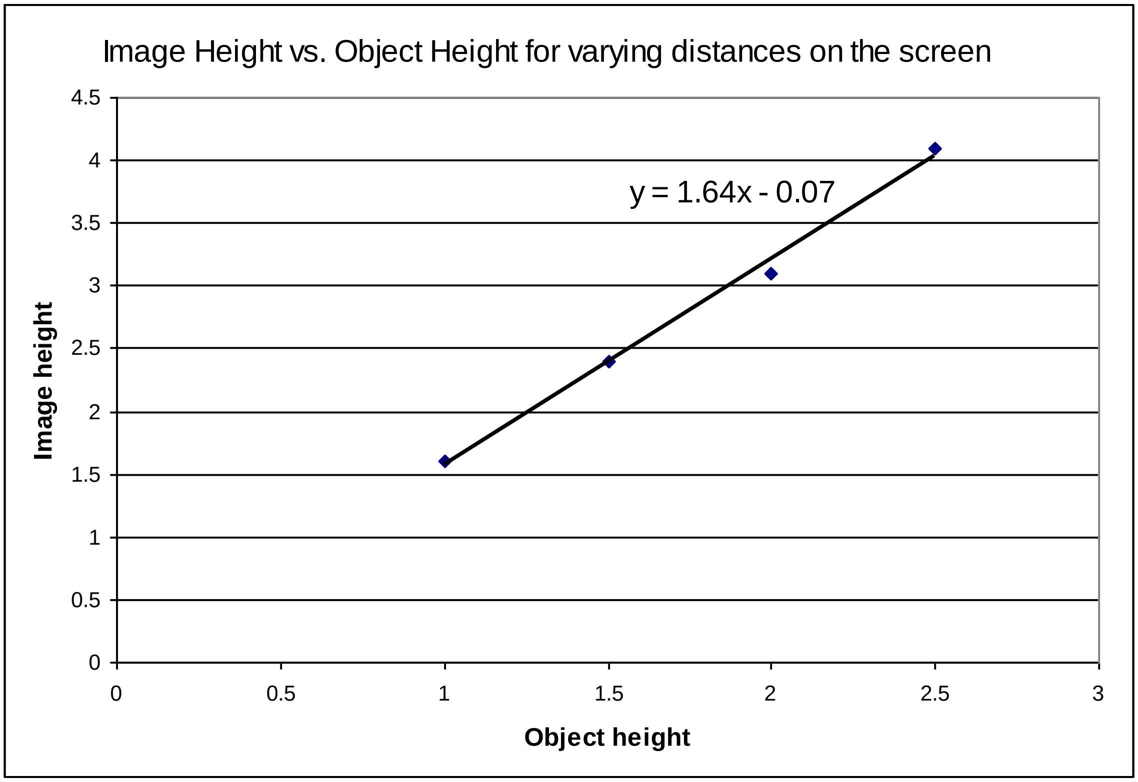
The graph of ***h' vs. h*** should be a straight line coming through the origin, with the slope equal to magnification. All the points of the object should be equally stretched or squeezed in all directions.

Sample Data:

This data was collected using the Pasco light source. M_m was calculated using measurements taken of the width of the smaller circle on the light source's grid. M_c is the magnification calculated using p and q.

p(cm)	q(cm)	M_c	M_m
13	43	3.3	3.2
16	26	1.6	1.6
35	14	0.4	0.4

To determine magnification graphically as the average of a few different data point, you may graph a set of distances on the object against their corresponding distances in the image: the slope of this graph is the average magnification.

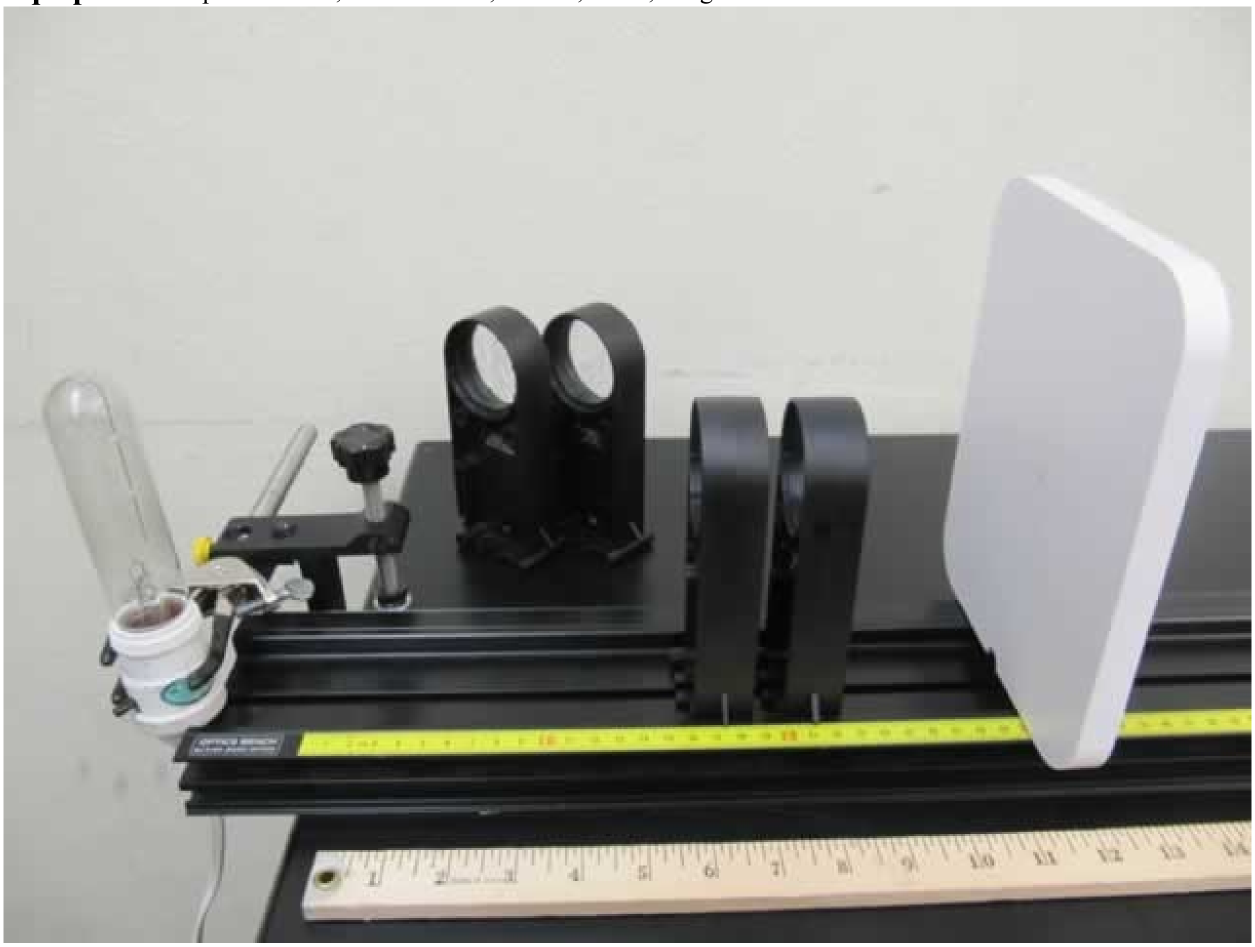


Lab 1 Problem #5: The Eye – Compensating for an Artificial Lens

Purpose:

- To show the students how to calculate the focal length of a combined optical system.

Equipment: optics bench, set of lenses, screen, ruler, long-filament bulb.



Teaching tips:

1. Make sure your students are putting the corrective lenses between the source and the "eye lens". The stronger the lens is – the more significant the correction due to the displacement between optical centers of lenses would be.

2. It's good to tape the lenses together and put them into one holder. If the lenses are put next to each other in different lens holders the discrepancy between the predicted and measured focal length may exceed 10%.

3. To make a working model of the eye, first set up the system with concave corrective lens in front and focus it at some distant object (like a picture of the window). This way the eye would be focused at infinity. This fixes the size of the "eye" (i.e. the distance between lenses and the screen is kept fixed). After that the concave lens can be removed and the "sharp picture" distance can be found (it will be somewhere closer). Then a convex corrective lens can be added and the procedure repeated.

4. For the sample trial we used the "middle" lens as an eye lens. Other setups are also possible, but you should keep in mind that the shorter focal length of a combined system is (the higher optical power) – the greater error would be introduced by the uncertainty of measurements of p and q.

Difficulties and Alternative Conceptions of Students:

- Same as previous problems
- Students may not understand how the eye works. For this problem, it is important that they understand that a real image is formed on the retina.
- Students may have a very hard time with the idea of using the image from the first lens as the object for the second lens in their ray diagrams … particularly when the image from the first image (second object) is on the same side of the "eye" lens as the final image. (This is an example of a "virtual object," with $p < 0$ in the thin lens equation.)
- You may wish to lead students to discover that taping two lenses together gets them much closer together than placing the "corrective" lens in a different holder than the "eye" lens … and that this is important if their measurements are to nearly satisfy the assumption that the two lenses are at the same position.

Prediction and Warm-up Questions:

In a combined lens system the optical powers of each lens should add.
f_{tot} = focal length of combined system
f_{eye} = focal length of eye lens
f_{corr} = focal length of corrective lens
p = object distance
q = image distance

$$\frac{1}{f_{tot}} = \frac{1}{f_{eye}} + \frac{1}{f_{corr}} \quad \Rightarrow \quad f_{corr} = \left(\frac{1}{p} + \frac{1}{q} - \frac{1}{f_{eye}} \right)^{-1}$$

Sample Data:

Tables of object and image distances for different corrective lenses

Eye Lens: 100mm Pasco lens
Corrective lenses:
-150mm Pasco lens
+200mm Pasco lens
+270mm lens

With separate lens-holders:

	f_e (cm)	f_c (cm)	p (cm)	q (cm)	$f_{c\ calc.}$, (cm)
Long range	10.2	-150mm	400	16.2	
Mid-range	10.2	none	27	16.2	
Short range	10.2	+200mm	13.6	16.2	
Short range	10.2	+270mm	17	16.2	

Placing both lenses inside the same lens-holder:

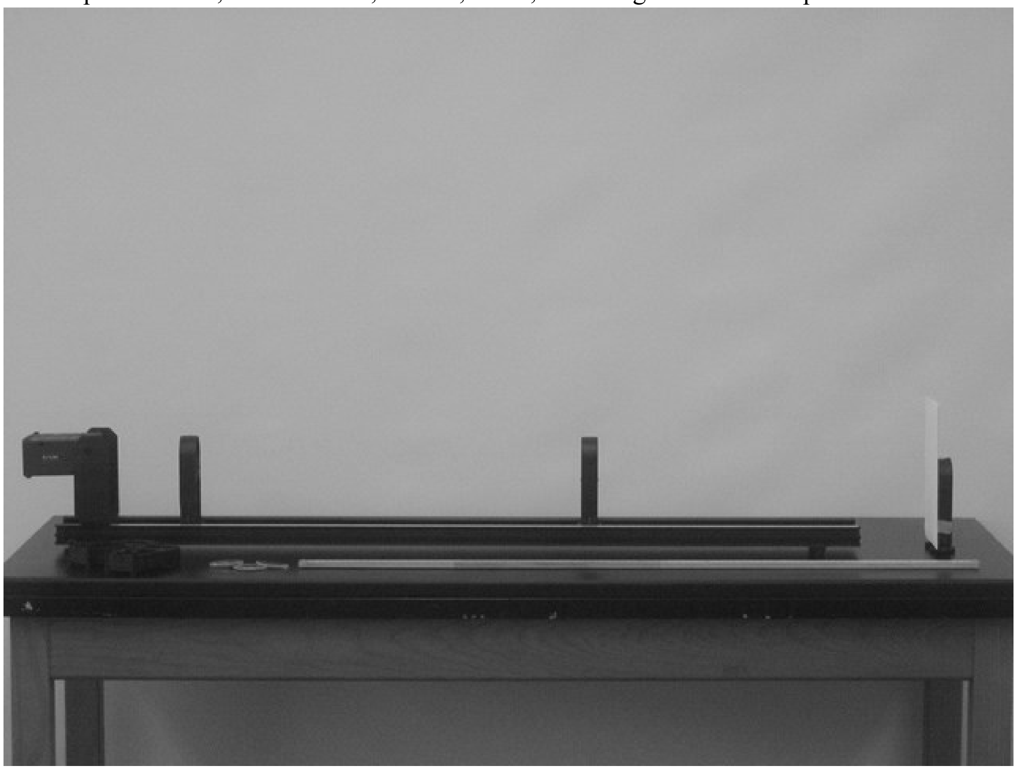
	f_e (cm)	f_c (cm)	p (cm)	q (cm)	$f_{c\ calc.}$, (cm)
Long range	10.2	-150mm	400	17.6	
Mid-range	10.2	None	27	17.6	
Short range	10.2	+208mm	11.1	17.6	
Short range	10.2	+270mm		17.6	

Lab 1 Problem #6: Microscope

Purpose:

- To familiarize students with a setup of a compound optical system such as microscope.

Equipment: optics bench, set of lenses, screen, ruler, and long filament lamp.



Teaching tips:

1. There is really only two choices for an objective lens: the Pasco 100mm lens and the stand-alone 50mm lens. Any of the weaker lenses are not strong enough to form images close enough so that optics rail is practical and the image is bright enough to see.

2. The lab manual tells students to place the eyepiece lens such that its focal point is at the place where the image from the objective lens forms. However, no image will form at all if this is followed strictly, since light rays originating at a convex lens's focal point emerge parallel and will never converge. A virtual image will form if the virtual object is *inside* the focal length of the second lens, but a real image forms if the virtual object is *outside* the focal length.

3. The useful range of distances between the object and the objective lens is from one to two focal distances. Larger distance would produce de-magnified image, but putting the object too close to the focal point will produce a huge image too far away, so that you would run out of optical bench.

4. When adjusting the eyepiece, it's useful to keep in mind that when the object is between the lens and its focus, the virtual image is not flipped (once again – it is already flipped by the objective lens). If the object is farther away than the focal point, one gets a real image which is flipped (twice – so, it is the same as the primary object in front of a microscope). You can see a flipped image when finding the position of the one produced by the objective, and a direct one when projected on a screen (say, moving a pen in the plane of the object).

5. The students will need to be careful selecting elements of the filament and/ or bulb to calculate magnification.

6. To avoid interference with the image produced by an eyepiece solely (bending the side rays) one can make a mask from a piece of paper and put it on the lens holder for the objective.

7. When focusing the system as a whole, remember that a convex lens will always produce a magnified virtual image if an object is placed in between the lens and its focal point. So, you will be able to see something through the eyepiece in a wide range of distances. The point is to try to put the object as close to its focal point as possible (and the virtual image at infinity) – to get the maximal magnification without losing the details and still forming the image at a reasonable distance from the optics bench.

8. Another thing to keep in mind is that the lamp is a three-dimensional object, so different parts of it will be in focus for different distances.

Difficulties and Alternative Conceptions of Students:

- Same as previous problems.
- When the eyepiece lens has a larger diameter than the objective, a mask around the objective lens may reduce the distracting second image formed by the eyepiece from light that did not pass through the objective.
- Students may have a difficult time deciding when their microscope is focused properly … this is an experimentally difficult problem, due to the relatively long focal lengths of the lenses available and the relatively short length of the optics benches.

Prediction and Warm-up Questions:

The light rays travel parallel after passing through the eyepiece lens. They do not converge, so no image is formed. There is no way to project an image onto a screen in the configuration for a compound microscope. Instead you must move the eyepiece away from the objective, so that the image from the objective forms just outside the eyepiece's focal length.

Formula for the total magnification (for reference only – we don't ask students to calculate it):

p_o = object distance for objective lens

q_o = image distance for objective lens

p_e = object distance for eyepiece lens

q_e = image distance for eyepiece lens

$$Magnification = \frac{q_o}{p_o} \cdot \frac{q_e}{p_e}$$

Positioning the screen farther away one may get any magnification, but the image gets dimmer very fast.

Sample Data:

Tables of magnification and position of image formation for microscope with varying eyepiece position

Objective Lens: 100mm Pasco

Eyepiece Lens: 200mm Pasco

	Eyepiece position 1	Eyepiece position 2	Eyepiece position 3
Object and image positions	p_o=15cm q_o=30.cm p_e=25.cm q_e=112.cm	p_o=15cm q_o=30cm p_e=30cm q_e=61cm	p_o=15cm q_o=30cm p_e=35cm q_e=46cm
Magnification	(calculated) 9.0 (measured) 9	(calculated) 4.0 (measured) 4	(calculated) 2.6 (measured) 2

Objective Lens: 100mm Pasco
Eyepiece Lens: 200mm Pasco

	Eyepiece position 1	Eyepiece position2	Eyepiece position 3
Object and image positions	p_o=13cm q_o=37cm p_e=25cm q_e=106cm	p_o=13cm q_o=37cm p_e=30.cm q_e=65cm	p_o=13cm q_o=37cm p_e=35cm q_e=50.cm
Magnification	(calculated) 12 (measured) 11	(calculated) 6.2 (measured) 6	(calculated) 4.1 (measured) 4

Objective Lens: 100mm Pasco
Eyepiece Lens: 250mm Pasco

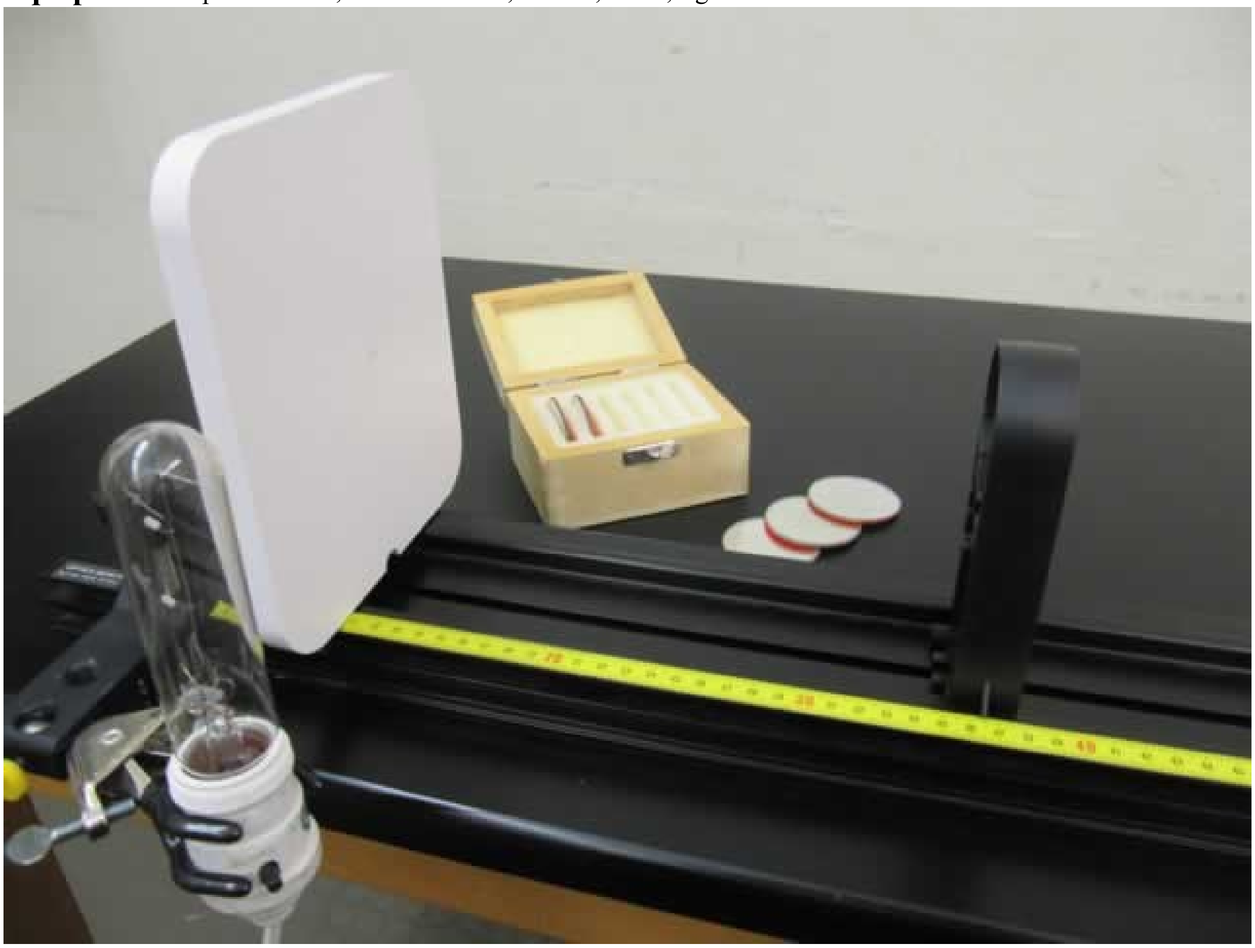
	Eyepiece position 1	Eyepiece position 2	Eyepiece position 3
Object and image positions	p_o=15cm q_o=30cm p_e=35cm q_e=94cm	p_o=15cm q_o=30.cm p_e=40.cm q_e=70.cm	p_o=15cm q_o=30.cm p_e=45cm q_e=58cm
Magnification	(calculated) 5.4 (measured) 5	(calculated) 3.5 (measured) 3	(calculated) 2.6 (measured) 2

Lab 1 Problem #7: Imaging with mirrors

Purpose:

- To give students qualitative and quantitative understanding of the ***p vs. q*** relation
- To give them practice calculating the focal lengths of mirrors that will be used later during the course

Equipment: optics bench, set of mirrors, screen, ruler, light source.



Teaching Tips:

1. The p vs. q graph is easier to visualize in terms of predicting q for a known p and other way around. On the other hand, the 1/ p vs. 1/ q graph makes fitting a lot easier and gives a possibility to estimate the focal length reliably, averaging out the experimental errors.

2. Make sure that your students pick appropriate range of distances. There should be one measurement around p~q~2f (which gives 1:1 image without magnification), and a couple of data points on each side from that.

3. It may be hard for students to realize that a constant step size in q (or p) does not result in a constant step size for 1/ q (of 1/ p).

4. To get the understanding of the correspondence between two graphs it's good to plot them simultaneously, labeling each data points.

Difficulties and Alternative Conceptions of Students:

- Expect the same difficulties and conceptions as in previous problems.

- Expect difficulties translating between p vs. q graphs and 1/ p vs. 1/ q graphs, and with understanding the importance of the intercepts in the 1/ p vs. 1/ q graphs.
- Help the students understand the concept of limits.
- Students may have difficulty conceiving a way to estimate the focal length of a lens … this would be a good opportunity to reinforce the idea that parallel incoming light is focused to the focal plane of the lens, and that light from very distant objects is nearly parallel.

Prediction and Warm-Up Questions:

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}, \qquad q=\frac{1}{\frac{1}{f}-\frac{1}{p}}=\frac{fp}{p-f}$$

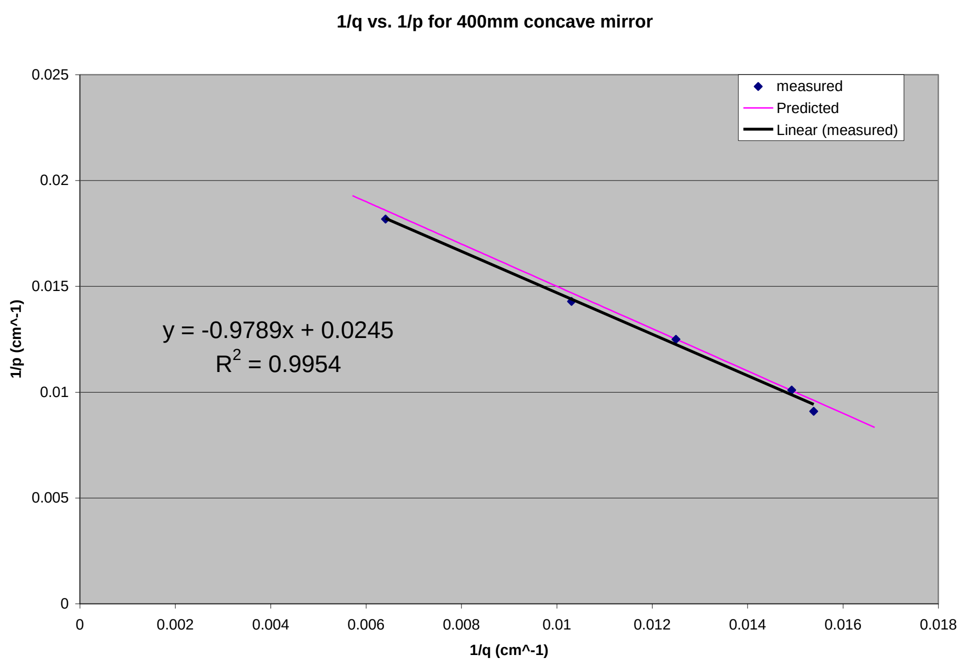
The first graph is a line at 45° intersecting axes at the 1/ f points, and the second one is a hyperbola, with a vertical asymptote at ***p=f*** and a horizontal one at ***q=f***.

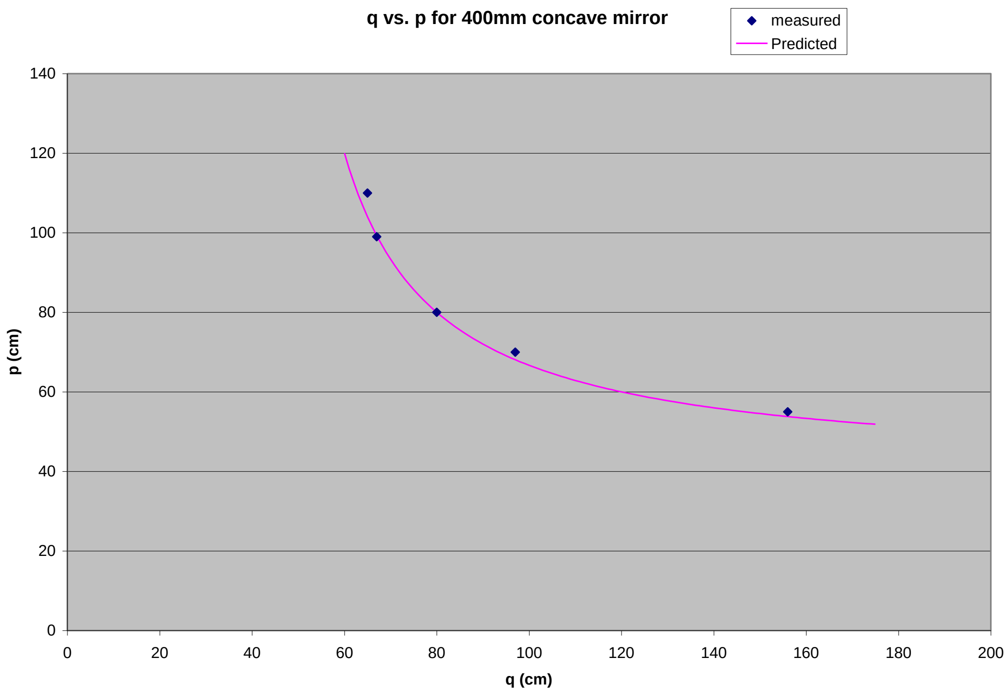
Sample Data: (± 1cm)

Measured focal length by focusing clouds from the sky on a piece of paper.
Due to in-exact focusing, uncertainties could be larger than the smallest unit on a ruler.

+400mm concave mirror

p (cm)	q (cm)	1/p (cm^{-1})	1/q (cm^{-1})
55	156	0.0181	0.00641
70	97	0.0143	0.0103
80	80	0.0125	0.0125
99	67	0.0101	0.0149
110	65	0.00909	0.0154





150mm concave mirror

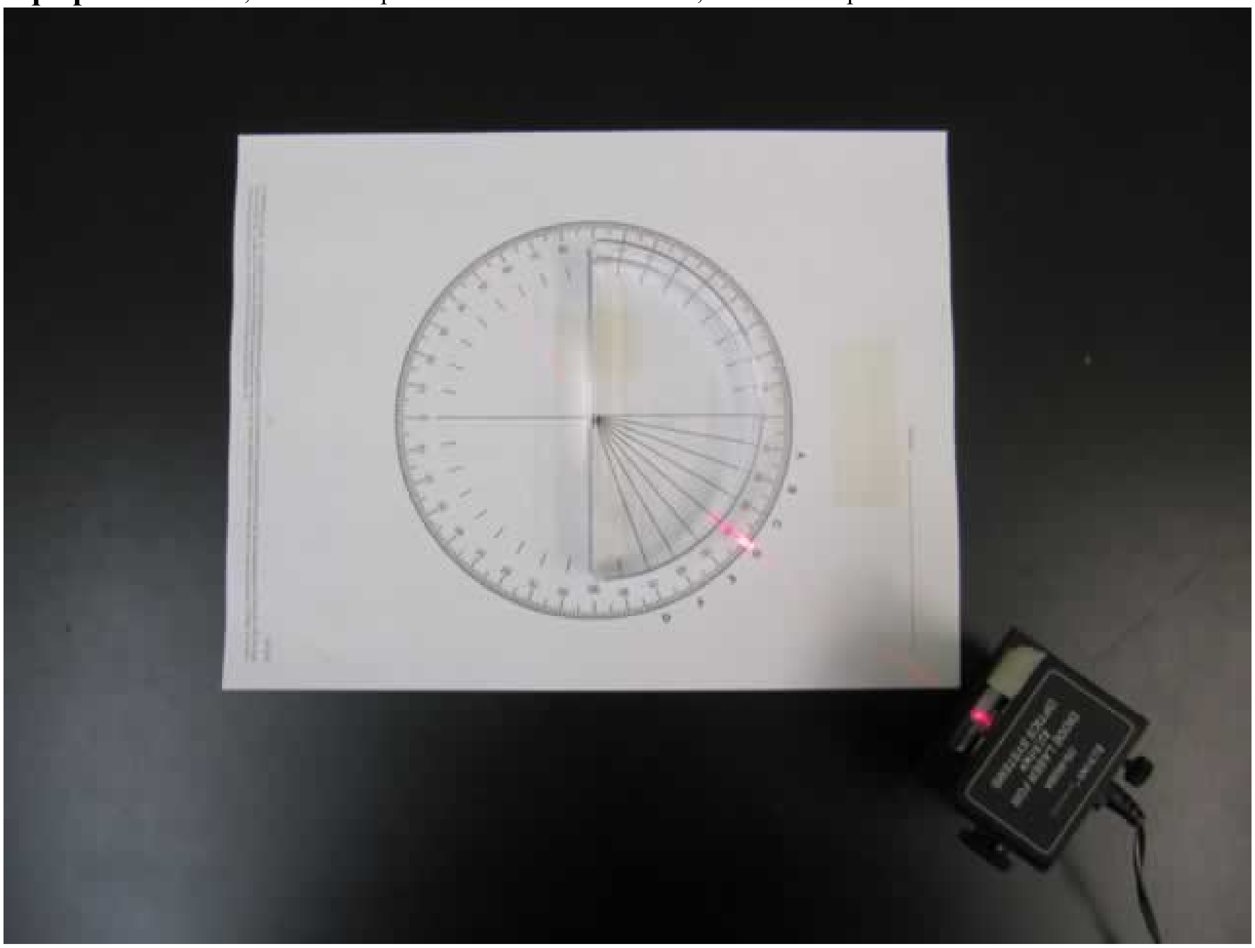
p(cm)	q(cm)	1/p (cm^{-1})	1/q (cm^{-1})
20	58.4	0.05	0.0171
25	37.5	0.04	0.0267
30	30	0.033	0.0333
35	25.5	0.0285	0.0392
40	24	0.025	0.0417

Lab 1 Problem #8: Total Internal Reflection

Purpose:

- To give students qualitative and quantitative understanding of refraction and how it applies to total internal reflection.
- To give them practice calculating/ measuring angles, basic geometry/ trigonometry, and estimating uncertainty of indirect angle measurements.

Equipment: laser, half-circle petri dish filled with water, ruler and a protractor.



Teaching Tips:

1. Students will probably need to be reminded that angles are measured from the normal.
2. Before taking measurements have students adjust the trajectory and locate/ explain why the beam reflects/ refracts where it does.
3. Instead of trying to hold the laser, have students set it on the table. This will make taking measurements simpler.
4. BE CAREFUL. PROTECT YOUR EYES. There are multiple reflections!

Difficulties and Alternative Conceptions of Students:

- There are two locations where the light is refracted that are relevant to the problem. Help students work through how to proceed from one location to another.
- The context of this problem is related to visual perception. Light going in `straight lines' in the eye. Students might need clarification in how this concept is related to the context of the problem.

Prediction and Warm-Up Questions:
Index of refraction of water: n=1.33

$$\theta_c = \sin^{-1}\left(\frac{1}{1.33}\right)$$

$$\theta_t = \sin^{-1}\left(1.33\cos(\theta_c)\right)$$

The critical angle is .851 radians or 48.8°.
The angle for the trajectory of the beam is 1.07 radians or 61.3°.

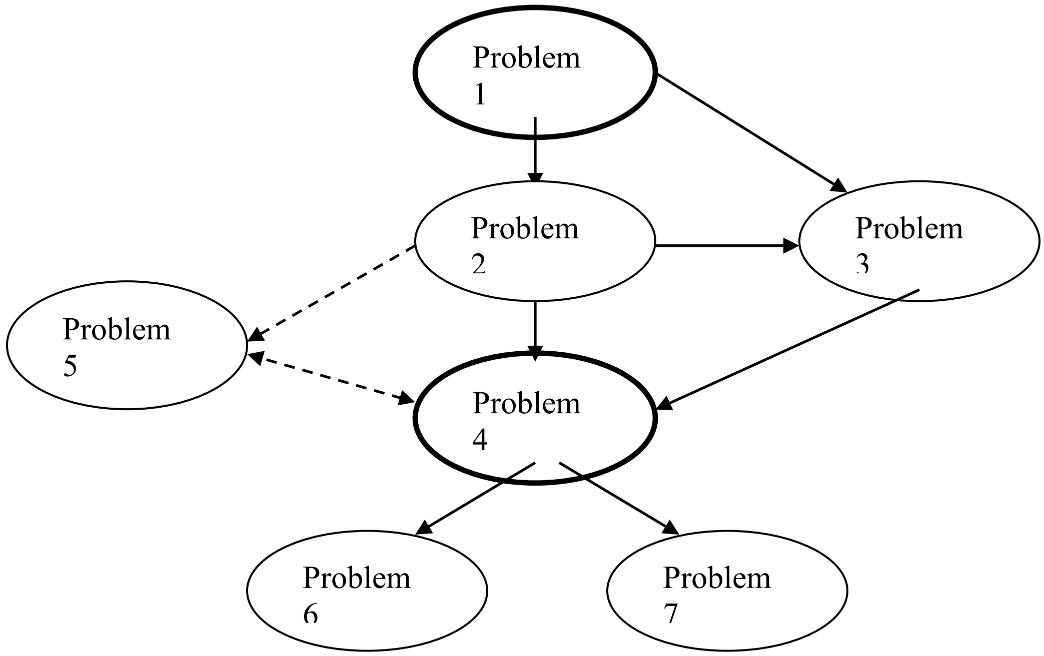
Sample Data:

(from old setup)
Referring to the picture on the left, the laser is **12.5cm** below the point of incidence (the red dot on the right side) and **6.4cm** to the right. The uncertainty estimate due to beam thickness and a quick measurement was **∓3 mm**. The angle of trajectory was measured to be **1.10 radians** with **∓3 radians**. (this estimate was calculated following the approach of the appendices).

The measurements could have better error estimates, but the results are still rather close.

Laboratory 2: Energy and Electric Circuits

The flow chart for the sequence of problems is:



Problem #2 and Problem #3 address the same common alternative conceptions and use the same physics reasoning; however the circuits in Problem #3 are more complex than in Problem #2. It is possible to skip #2 if students have a strong understanding of the physics concepts; if not, Problem #2 is good preparation for Problem #3.

Problem #5 is optional and should be especially assigned to those who short circuit their circuits.

Problem #4 can be done earlier in the sequence than the flow chart indicates if the students already have a good grasp of Ohm's Law.

Problem #6 and Problem #7 are both quantitative problems involving Kirchhoff's rules. Although the measurements are quick, the predictions are very involved and it is recommended that you select only one of these problems for a lab period.

Teaching Tips:

- Make sure to check that all the bulbs in the lab are the same kind. Check the markings on the bulbs and check if the color of the bead separating the light bulb filaments is the same.

- Circuits provide the most immediate and practical application of energy transfer. The fundamental concepts that are most useful in the understanding of energy transfer in circuits are conservation of charge and conservation of energy.

- Remember that light bulbs are just hot wires and are almost Ohmic. Their resistance depends somewhat on their temperature. Light bulbs give the students immediate visual feedback for their predictions. Since students have serious misconceptions about circuits and energy flow, 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 (Kirchhoff'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 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 students explain the behavior of the currents and potential differences in a circuit.

- Be sure to check the batteries before you let your students into 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!

- DMM's can be problematic, if you have problems, try new ones. DMM's are located in the equipment cabinet across from room 233 (#7).

- Make a note of any bad equipment in the lab, and submit a report to labhelp@physics.umn.edu. This will help your fellow TA's.

- The KELVIN branded DMMs do not have replaceable fuses. If a fuse in the DMM is blown, a replacement is required. If a student blows a 10 A setting, check what they are doing before replacing the DMM. Things that cause this fuse to blow are dangerous.

REMINDER: Your students will be working with equipment that can generate large electric voltages. Improper use can cause painful burns. To avoid danger, make sure your students turn OFF any power supply and WAIT at least one minute before any wires are disconnected from or connected to 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 relationship between electric current, resistance and voltage in the circuit.
- 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.

Lab 2 Problem #1: Electrical Connections

Purpose:

- To help students understand energy transfer and flow of charge in an electric circuit. The problem most students face in this lab is that they do not realize that a battery has two ends; that energy transfer to the device (bulb) and current (flow of charge) are possible if the circuit is closed or completed. If students are unfamiliar with the path of wires inside a light bulb, they will have difficulty predicting that both the side and tip of the metal base must be connected in the circuit for the light bulb to light.

Equipment:

Teaching Tips:

1. It is tempting to help the students in this lab. They will have had no lectures on this material, and it is doubtful that they will have read the chapter. Do not help them. Some groups may take as long as 30 minutes.
2. The reason the light bulbs are not in sockets is that we want to make them figure out that the two terminals of a light bulb are identical.
3. There is only one wire in this problem. We want them to see that the wire is a path for current to flow, but it is not the only possible one.
4. We have counted eight different methods of solving this problem. The battery has two terminals, the bulb has two terminals, and the wire has two ends, leading to eight combinations. The students may correctly conclude that the two ends of the wire are identical, as are the two

terminals of the light bulb. They may also decide that the two terminals of the battery are identical. They will learn later that this is not the case.

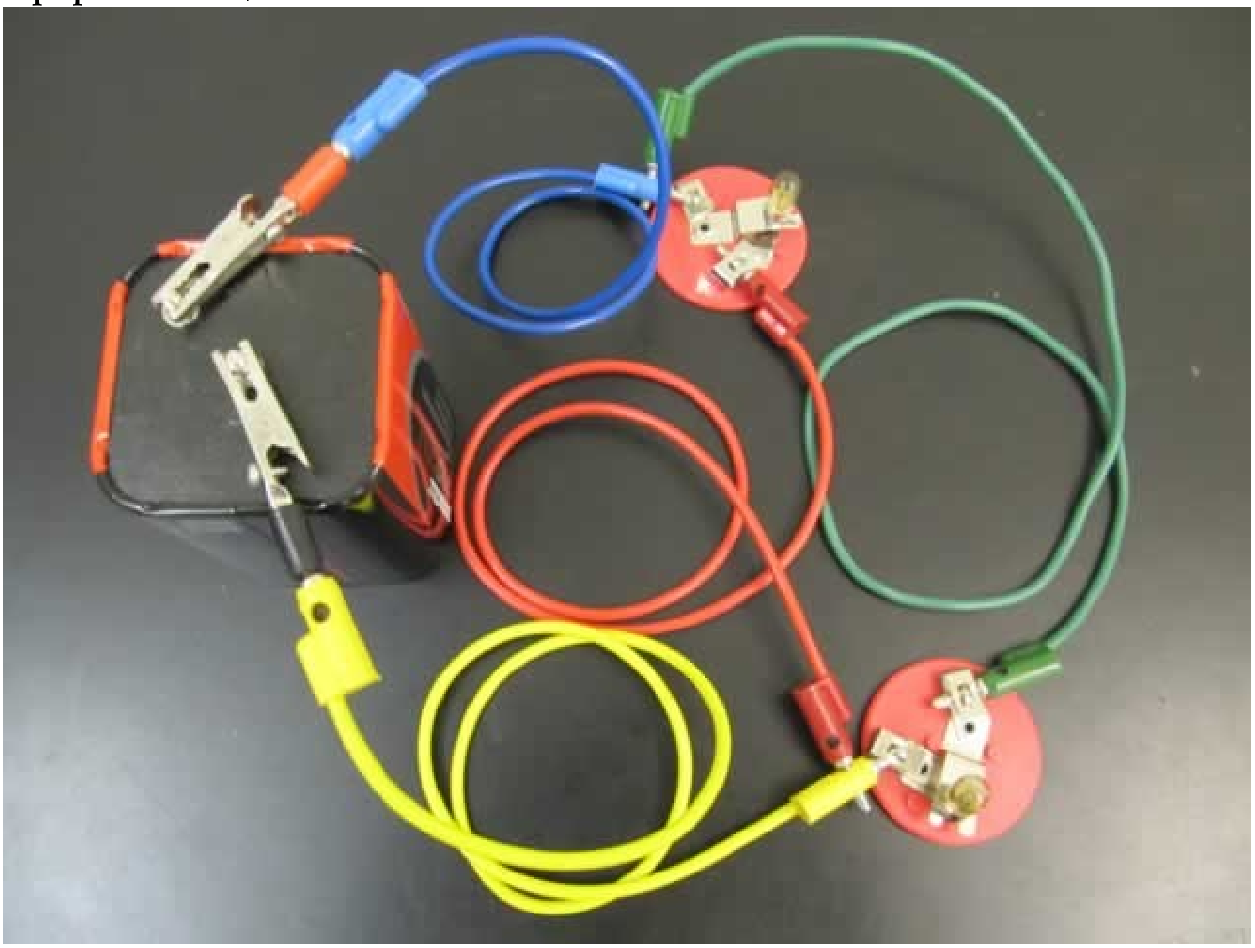
5. A good task for an opening discussion is to have student groups draw a large picture of the inside of a light bulb. Ask them to show where the two wires on either side of the filament connect inside the metal base. Students will often predict that both wires lead to the bottom tip, or that both connect to the sides of the base. This is an opportunity to ask them how a “complete” circuit is possible in each case, and how they plan to test their picture in the lab using only a single wire, battery, and bulb.

Lab 2 Problem #2: Qualitative Circuit Analysis

Purpose:

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

Equipment: bulbs, batteries and banana cables



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. 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 of Students:

Many students still believe that a battery is a constant current source instead of providing a constant potential difference. To address this in an opening discussion, ask students how the current in the battery compares for circuits I, II, III, and IV, and why. Some students also believe that current always divides in equal parts at a junction (Circuit IV tests this conception).

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 a light bulb (assumed constant here).

Circuit I: $I_A = \frac{V}{R}$

Circuit II:

The equivalent resistance of Circuit II is twice the resistance of Circuit I, so the current in the battery is halved. For two resistors in series, the same amount of charge passes through both resistors in a given time interval and thus the currents are the same in both resistors.

$$I_B = I_C = \frac{V}{2R}$$

Circuit III:

The equivalent resistance of Circuit II is half the resistance of Circuit I, so the current in the battery is doubled (2V/R). The current splits equally at the junction because each branch has the same resistance, so the current in each resistor is half the current in the battery..

$$I_D = I_E = \frac{V}{R}$$

Neglecting resistance in the wires, this means that the brightness of a single bulb connected to a battery (A) should be the same as two bulbs connected in parallel with a battery (D and E).

Circuit IV:

The equivalent resistance in Circuit IV is 2R/3, and the current in the battery is 3V/2R. Since the equivalent resistance of the F-G branch is 2R and the resistance of the H-branch is R, and the potential difference across each branch is the same, the current in the F-G branch will be half the current in the H branch.

$$I_F = I_G = \frac{V}{2R}$$

$$I_H = \frac{V}{R}$$

Currents:

$$I_A = I_D = I_E = I_H = \frac{V}{R}$$

$$I_B = I_C = I_F = I_G = \frac{V}{2R}$$

Brightness:

A=D=E=H > B=C=F=G

Discussion Question:

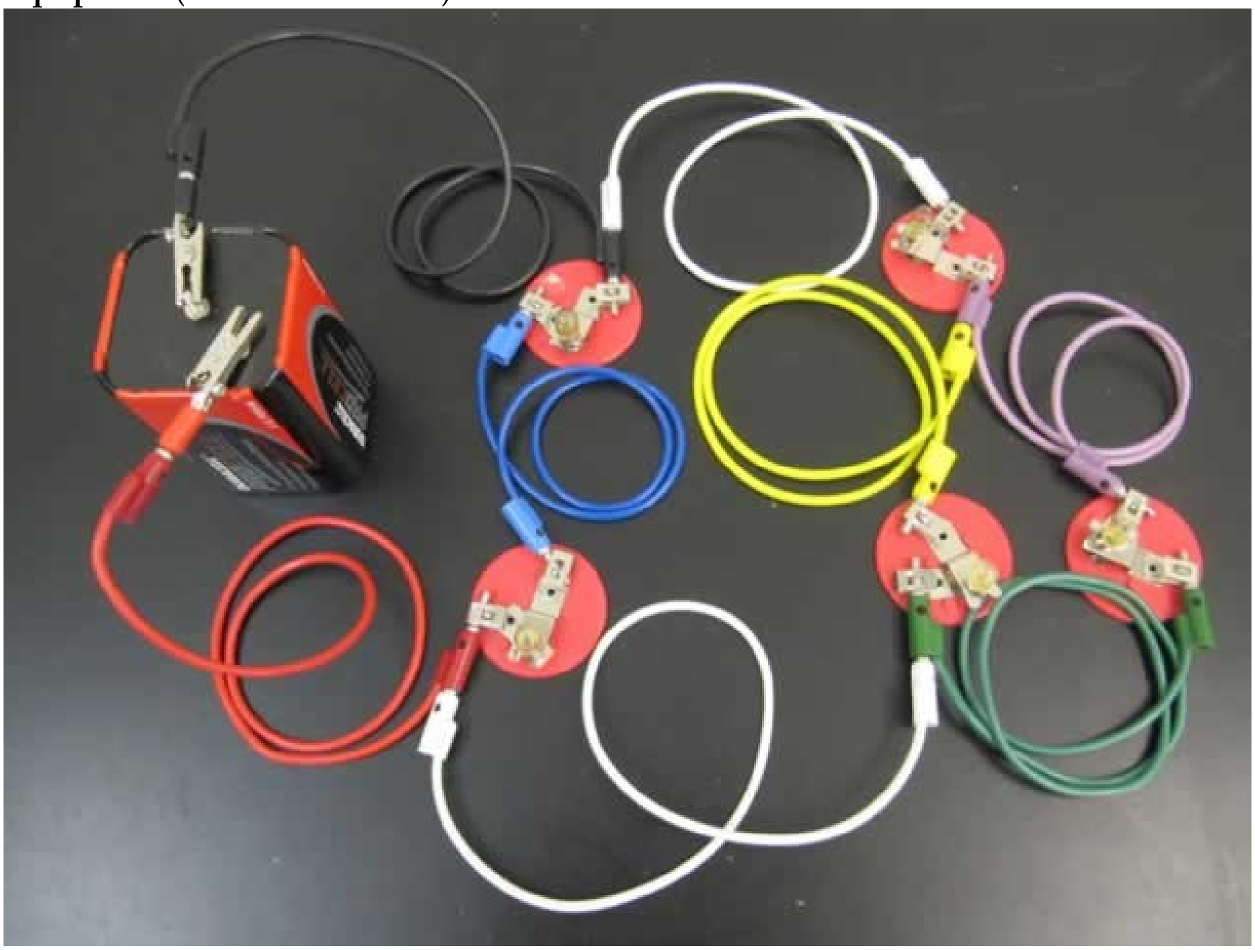
What does a battery keep constant, current or voltage? Students should see that with more light bulbs, the circuit would draw more current if they were in parallel and less current if they were in series. With a larger current, the rate at which energy transferred from the battery is larger, and the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

Lab 2 Problem #3 Qualitative Circuit Analysis B

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 (circuit XIV shown)



****EQUIPMENT NOTES:** To find identical bulbs look for markings and check to see that the color of the bead separating the filaments is the same.

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 of Students:

Many students still believe that a battery is a constant current source instead of providing a constant potential difference. To address this in an opening discussion, ask students how the current in the battery compares for circuits XIV, XV, and XVI, and why. Some students also 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 identical light bulb.

Circuit XIV:

The equivalent resistance of the circuit is 7/6R, so the current in the battery is 7V/6R. The currents in the bulbs should be

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

(As a check, $I_A + I_B = \frac{V}{2R} + \frac{2V}{3R} = \frac{7V}{6R}$)

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

Circuit XV:

The equivalent resistance of the circuit is 2R, so the current in the battery is V/2R. The currents in the 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 equivalent resistance of the circuit is 7R/5, so the current in the battery is 5V/7R. 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:

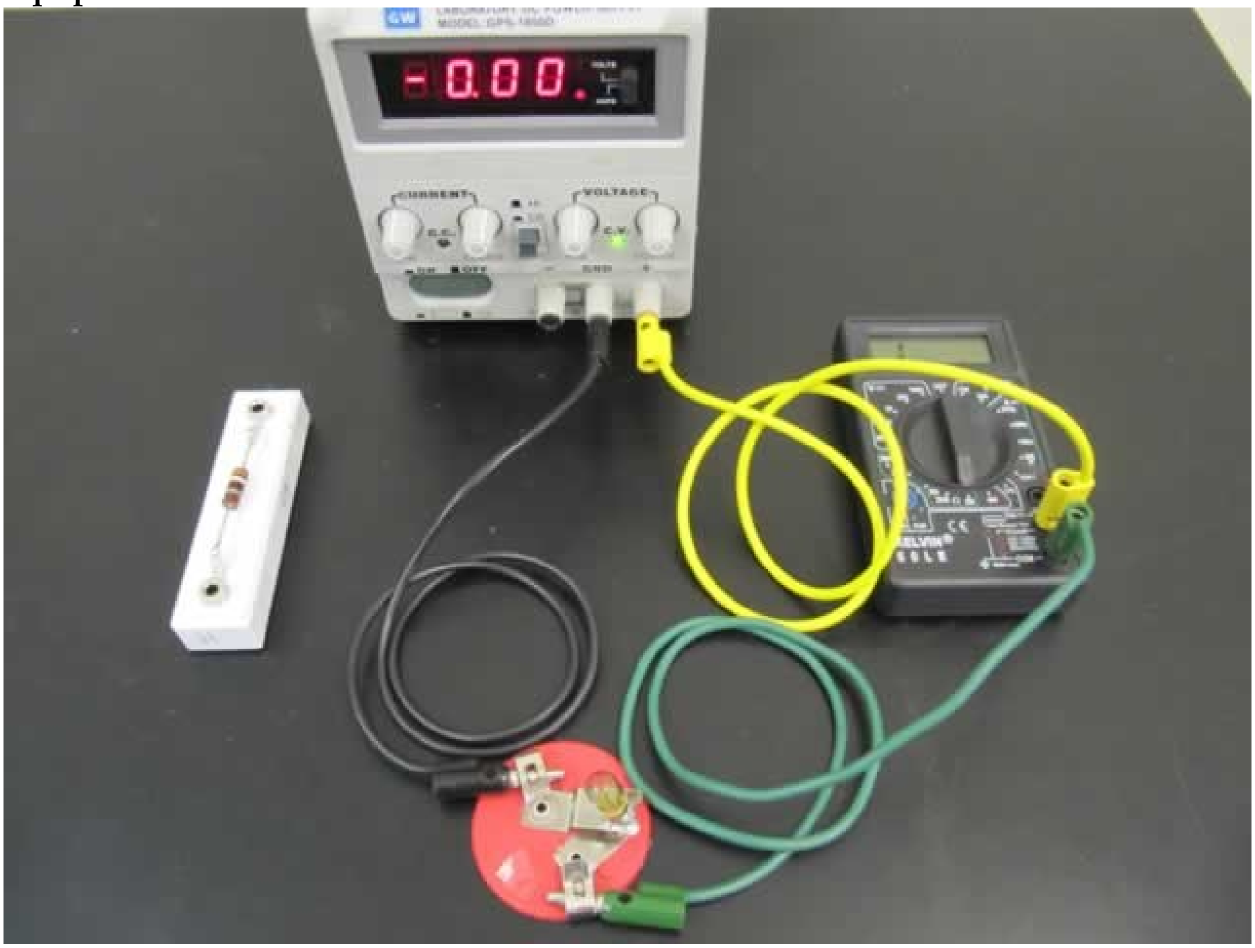
What does a battery keep constant, current or voltage? Students should see that with more light bulbs, the circuit would draw more current if they were in parallel and less current if they were in series. With a larger current, the rate at which energy transferred from the battery is larger, and the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

Lab 2 Problem #4: Resistors and Light Bulbs

Purpose:

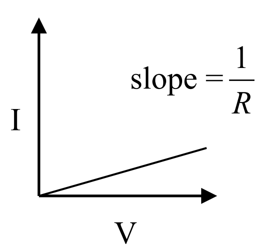
- To show students explicitly that Ohm's law is a special case and it is a useful approximation even for a light bulb.

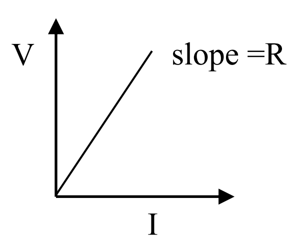
Equipment:



Teaching Tips:

1. This problem provides a bit of practice with Ohm's law. The students need to design their own circuit for this problem and must use some graphical analysis techniques – getting the resistance of the resistor from the slope of the current against voltage graph (or voltage versus current graph), for instance.





2. The light bulb doesn't respond linearly. The resistor should. As the bulbs light 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 the following relationship between resistivity and temperature

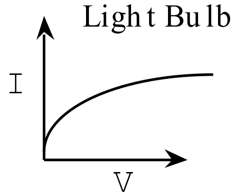
$\rho - \rho_0 = \alpha(\rho_0)(T - T_0)$. (note: this is not in the Kane text)

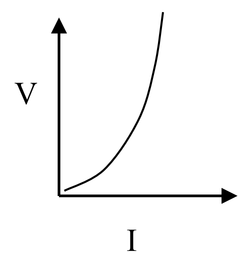
3. It is good idea to discuss the fact that resistors are only ohmic within a reasonable range (the students should NOT try to confirm this).
4. You should use the power supplies with adjustable voltages to get a smoother range of points.
5. You might also like to point out that other materials respond to an increase in temperature by decreasing, instead of increasing, their resistance, e.g. semiconductors.

Difficulties and Alternative Conception of Students:

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:



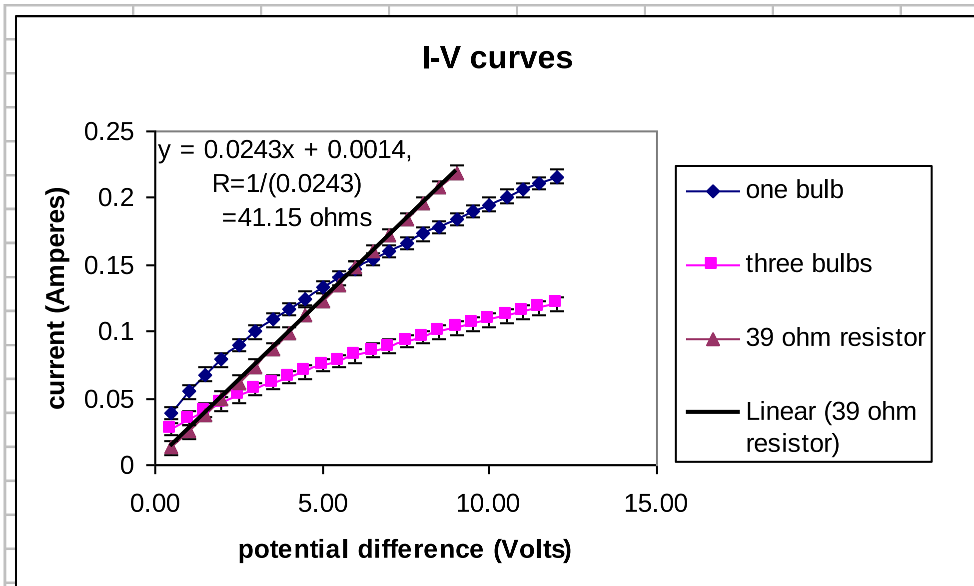


Warm-up Questions:

As the temperature increases, so will the resistance. Therefore, the slope 1/R decreases and current levels off at high voltages. Similarly, in the V vs. I graph the resistance increases, so the slope increases with increasing current.

Data:

The currents through a bulb (product marked "CM40 6.3V 150mA") were measured after setting voltages in increments of 0.5 volts using a Sorensen power supply. The initial 'cold' resistance of the bulb is 4.3 ohms. Readouts from the Sorensen display were verified with a DMM. Measurements were also made for three bulbs in series (if the rating of the bulb worries you). The resistor used has color code (ORANGE)(WHITE)(BLACK)(SILVER) giving a nominal resistance of 39+/-10% ohms. A DMM gave 41.3 ohms.



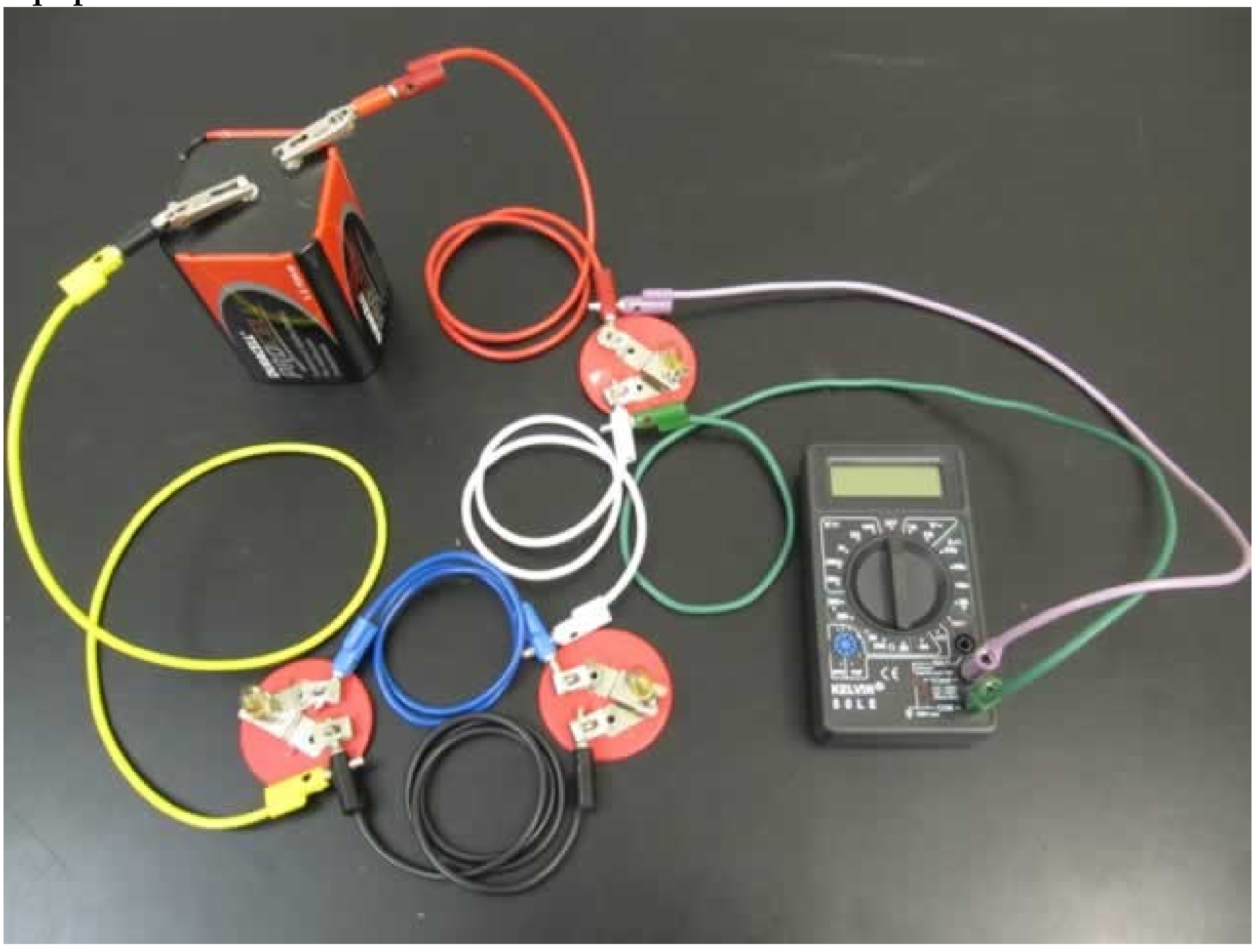
	one bulb	resistor (39 ohms)	
Voltage(V)	Current(A)	Current(A)	
0.50	0.039	0.013	Notes:
1.00	0.055	0.025	1. Initial 'cold' resistance of one bulb:
1.50	0.068	0.038	4.3 ohms
2.00	0.079	0.05	2. Initial 'cold' resistance of three bulbs
2.50	0.09	0.062	in series: 12.2 ohms
3.00	0.1	0.074	3. DMM yielded 41.3 ohms for resistor
3.50	0.109	0.087	4. Y-error bars are 0.005 amperes wide
4.00	0.117	0.099	on one side
4.50	0.125	0.113	
5.00	0.133	0.123	
5.50	0.14	0.135	
6.00	0.147	0.148	
6.50	0.154	0.16	
7.00	0.16	0.172	
7.50	0.166	0.184	
8.00	0.173	0.196	
8.50	0.178	0.208	
9.00	0.184	0.219	
9.50	0.19	Had to stop here. Resistor got very hot and smelled a bit.	
10.00	0.195		
10.50	0.201		
11.00	0.206		
11.50	0.211		RCL 06/02/04
12.00	0.216		

Lab 2 Problem #5: Short Circuits

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:



Teaching tips:

1. This problem is primarily meant for those students who consistently set up a short circuit and don't understand the problem.
2. Not all of the light bulbs in the lab are of the same kind. To find identical light bulbs with similar resistances look for marking on the bulbs and check to see if the color of the bead separating the light bulb filaments is the same.

Major Alternative Conception of Students: 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.

For your reference, a current I, entering a node in a path which splits into branches with resistances R_1 and R_2 , divides as follows: $I_1=I\ R_2/(R_1+R_2)$, $I_2=I\ R_1/(R_1+R_2)$.

Discussion Questions:

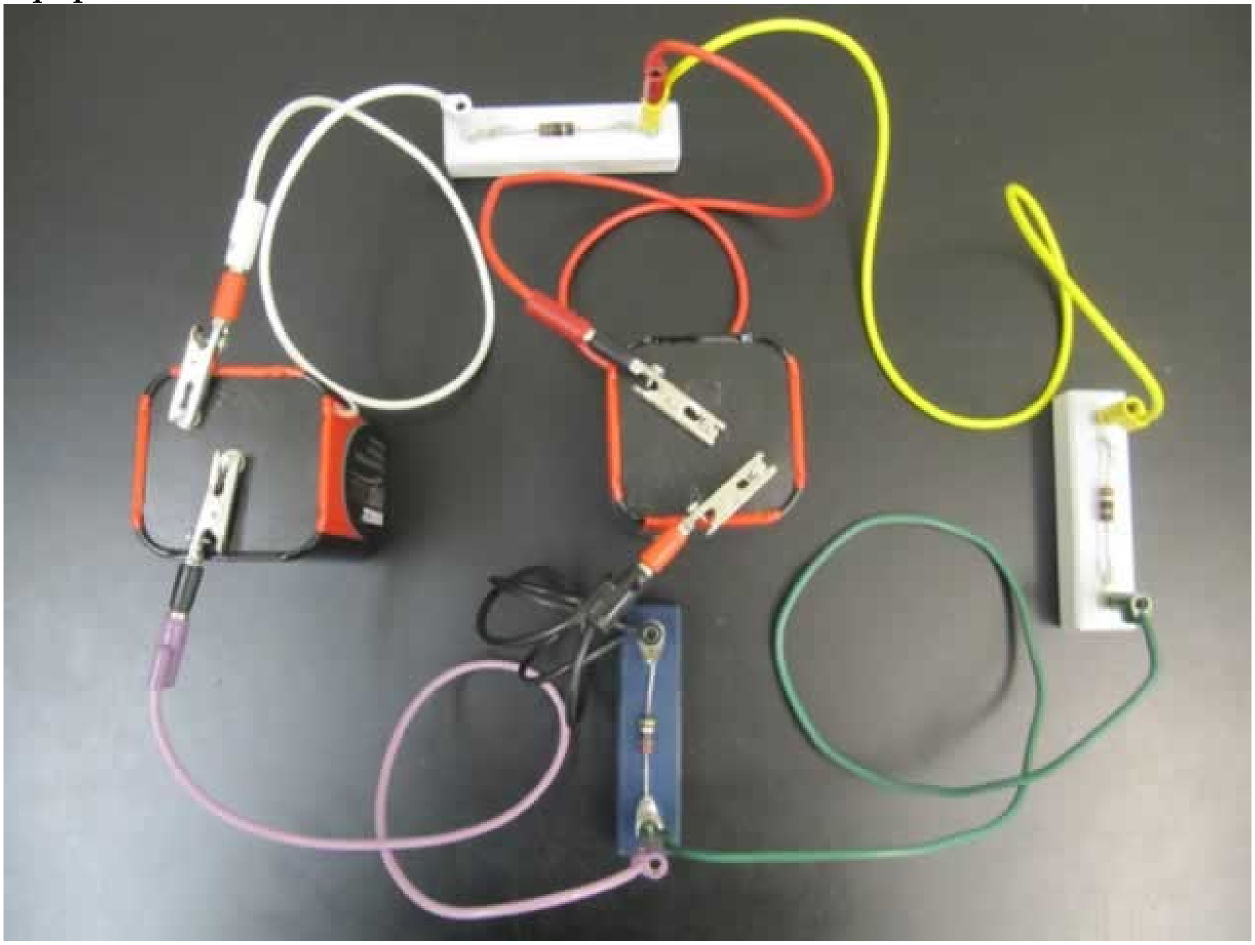
What are the dangers of a short circuit? Do you see why the current in a household circuit may increase dramatically if a short circuit is introduced? Do you see the significance of the rating of a fuse or wire?

Lab 2 Problem #6: Quantitative Circuit Analysis

Purpose:

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

Equipment:



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. If your students do not know how to measure potential difference or current, refer them to the equipment appendix.
3. Repeated measurements of current and potential difference reinforce the relationship between these two quantities.
4. It is easy to misread a circuit diagram. Help your students construct their circuits correctly.
5. 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. New DMM's are available in closet #7 across from room 233. If a 10A fuse is blown, your students are probably doing something dangerously wrong. Carefully check what your students are doing. Remember you are responsible for their safety.

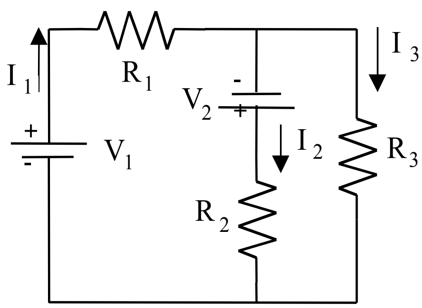
6. This problem seems especially likely to bring out the "take data and run" approach in students – probably because students don't understand Kirchoff's rules and the predictions are algebraically messy. To combat this tendency, make sure that your students understand the data they are taking and compare 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.

Difficulties and Alternative Conceptions of Students:

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:



Circuit XII

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

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

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

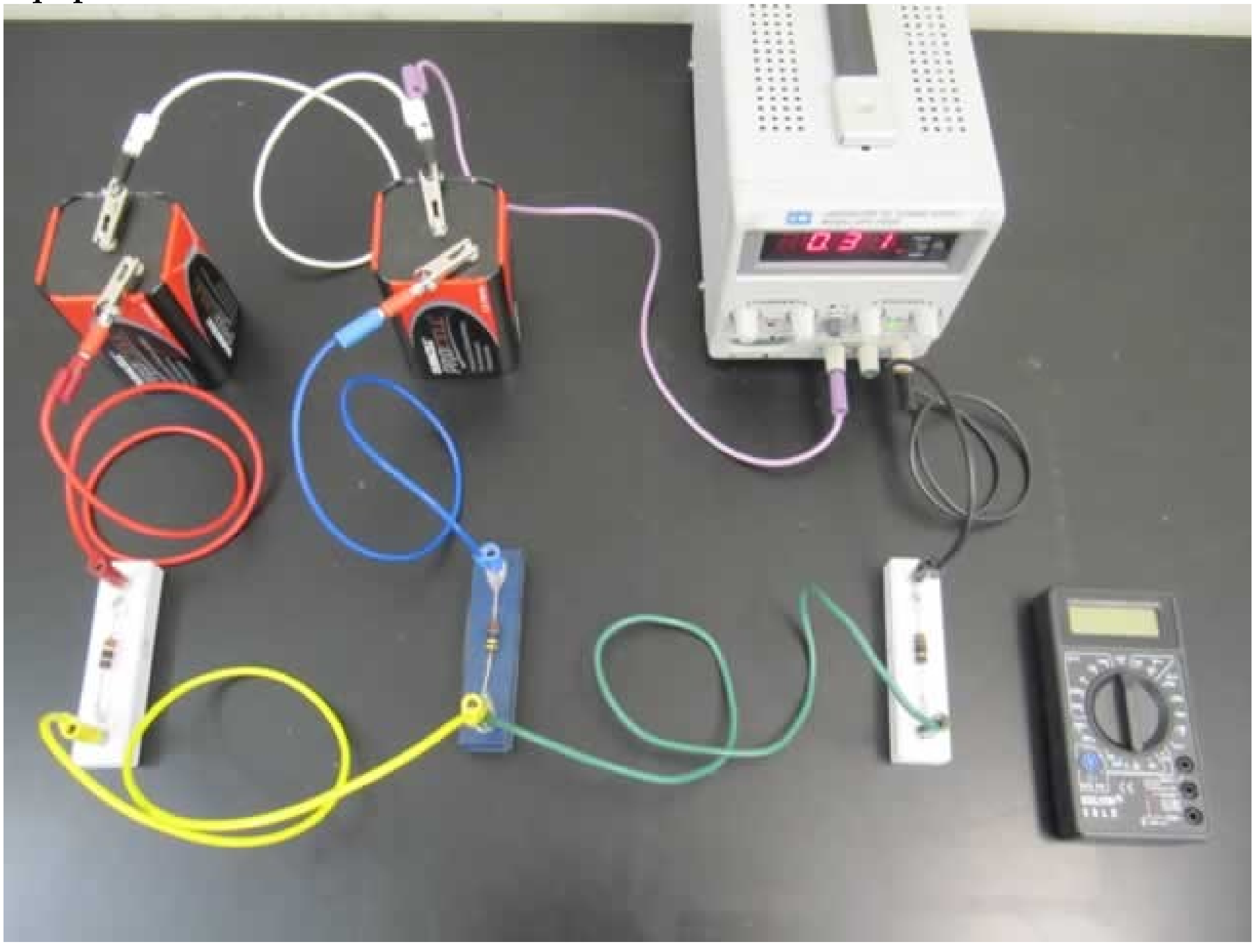
Lab 2 Problems #7: Quantitative Circuit Analysis B

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



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. If your students do not know how to measure potential difference or current, refer them to Equipment appendix.
3. Repeated measurements of current and potential difference reinforce the relationship between these two quantities.
4. It is easy to misread a circuit diagram. Help your students construct them correctly.
5. 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. New DMM's are available in closet #7 across from room 233. If a 10A fuse is blown, your students are probably doing something dangerously wrong. Carefully check what your students are doing. Remember you are responsible for their safety.

6. 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.
7. Notice 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.

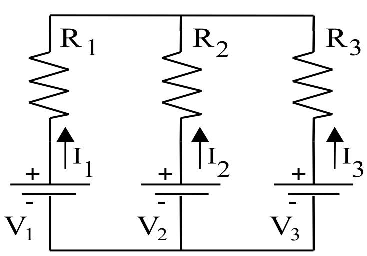
Difficulties and Alternative Conceptions of Students

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



Circuit XIII

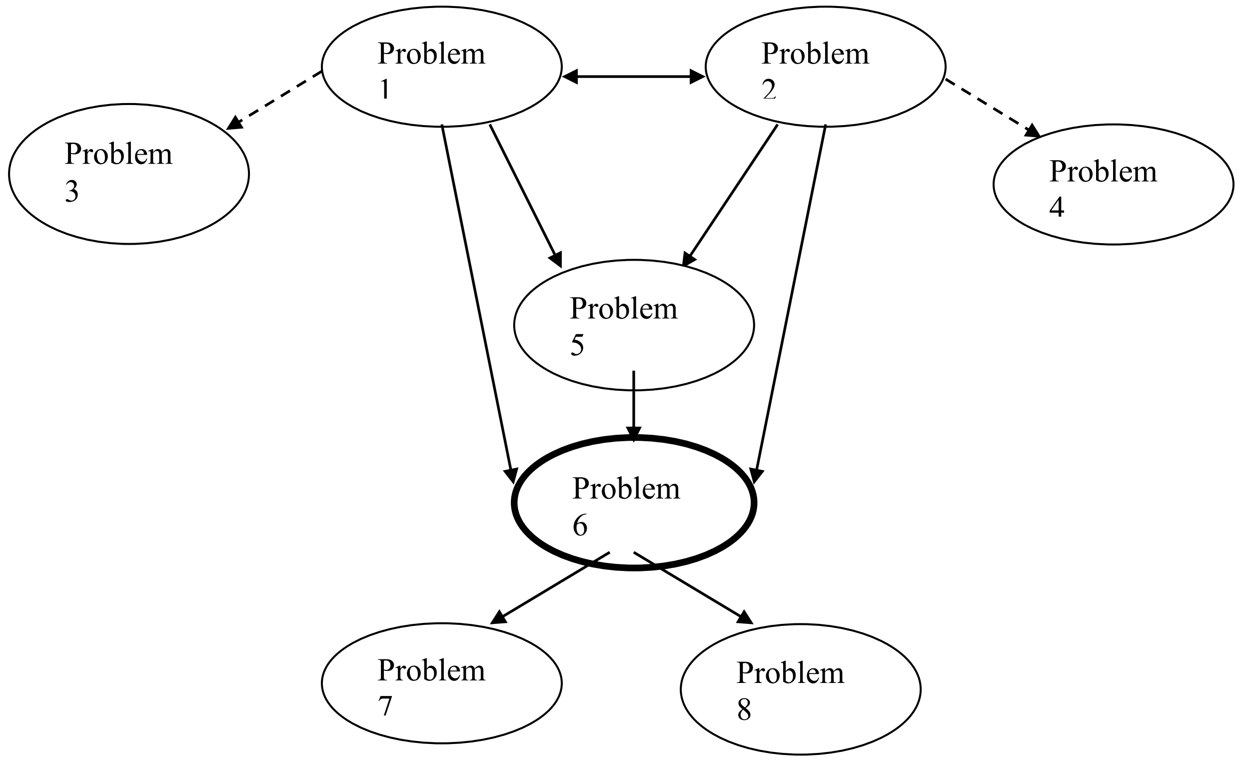
$$I_1 = \frac{V_1(R_2+R_3) - V_2R_3 - V_3R_2}{R_1R_2 + R_2R_3 + R_1R_3}$$

$$I_2 = \frac{V_2(R_3+R_1) - V_3R_1 - V_1R_3}{R_1R_2 + R_2R_3 + R_1R_3}$$

$$I_3 = \frac{V_3(R_1+R_2) - V_1R_2 - V_2R_1}{R_1R_2 + R_2R_3 + R_1R_3}$$

Laboratory 3: Energy and Capacitors

A flow chart for the sequence of problems is:



Problems #1 and #2 are a continuation of Kirchhoff's rules for electric circuits, applied to capacitors. The quantitative prediction steps are similar, so it is reasonable to choose only one of these problems for a lab period.

Problems #3 is redundant if it comes after problem #2 (the circuit in #3 is the same as Circuit I of #2) and problem #4 is redundant after problem #1.

Problems #7 and #8 both address the topics of energy transfer and efficiency; selecting one of these problems is sufficient.

WARNING: A charged capacitor can discharge quickly producing a painful spark. Make sure your students **do not** handle the capacitors by their electrical leads or connected wires by their metal ends. Make sure they **always discharge a capacitor when they are finished using it.** To discharge a capacitor, use a banana cable to briefly connect the two terminals.

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*, that students will see in the rate equation).

Things to check out before teaching the lab:

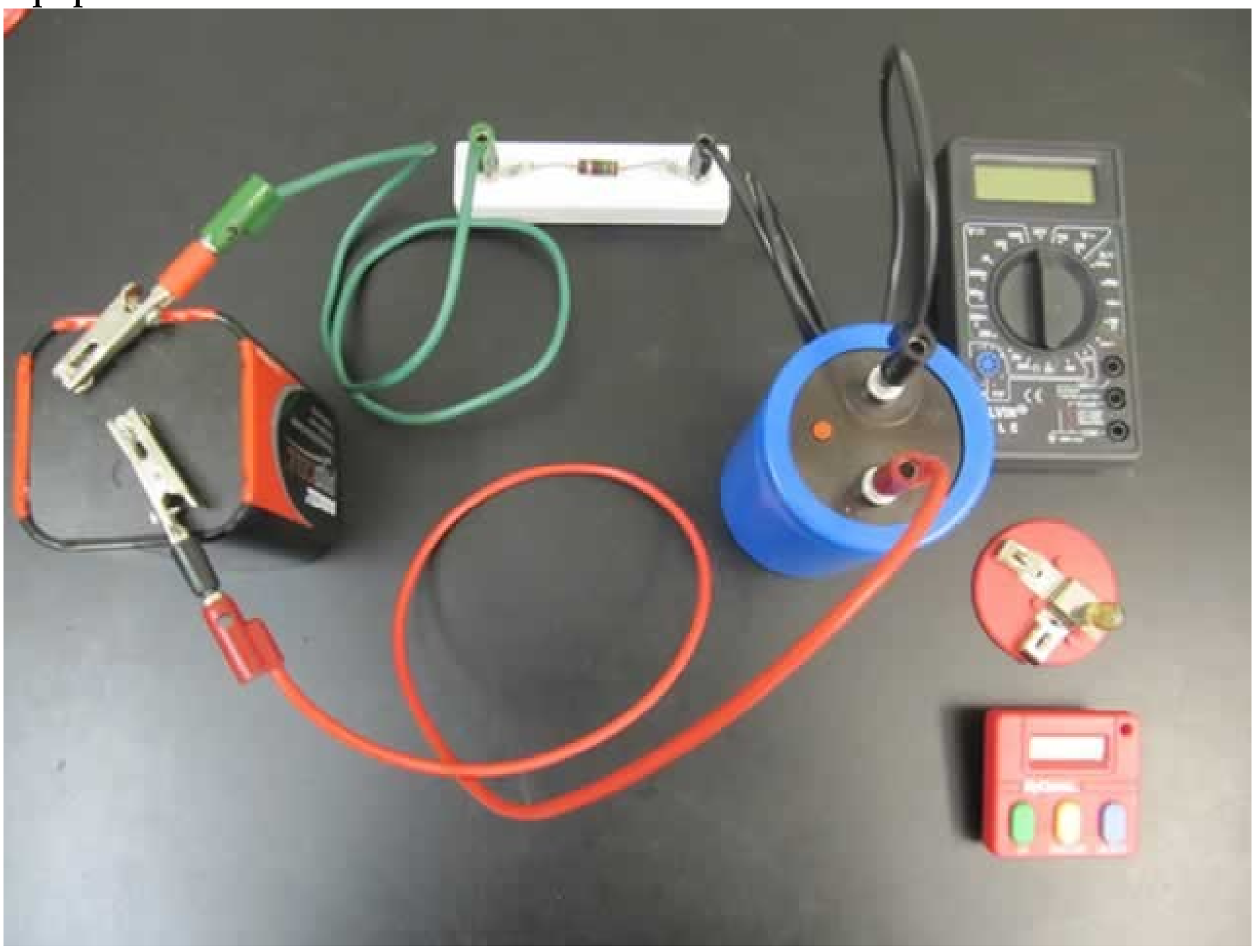
- Be sure that all capacitors are discharged prior to the beginning of lab.
- Be sure that all batteries still work, i.e., produce 6 V and a reasonable current to light a bulb brightly.

Lab 3 Problems #1: Charging a Capacitor

Purpose:

- To demonstrate to students the quantitative behavior of RC-circuits
- To provide practice in applying Ohm's Law, conservation of charge, and conservation of energy to a problem that doesn't just consist of resistors.
- As an illustration of exponential decay, and how this situation arises – when the rate of decrease of a quantity is proportional to the quantity itself.

Equipment:



****EQUIPMENT NOTES:** All values of capacitance printed on the capacitors have units of microfarads (μF) even though some might be labeled "MF". To find identical bulbs look for markings and check to see that the color of the bead separating the filaments is the same (clear or white).

Teaching tips:

1. Problem shows why 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.
2. This problems is intended to show the students how each quantity in the circuit changes with time (current in the circuit, the voltage across the resistor/bulb/capacitor, the charge stored on the capacitor.) From labs in 1201, the students may 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. Make sure students connect the capacitors to the battery correctly: + to +, - to - otherwise the capacitors will be destroyed (written value will be off from the real capacitance).
5. Remember the bulbs are not exactly ohmic, so make sure the students use resistors for data taking and light bulbs only for exploration.
6. 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.
7. 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? They will return to exponential decay later, in Lab VII on nuclear radiation.

Prediction:

The time dependence of the current in the circuit is as follows:

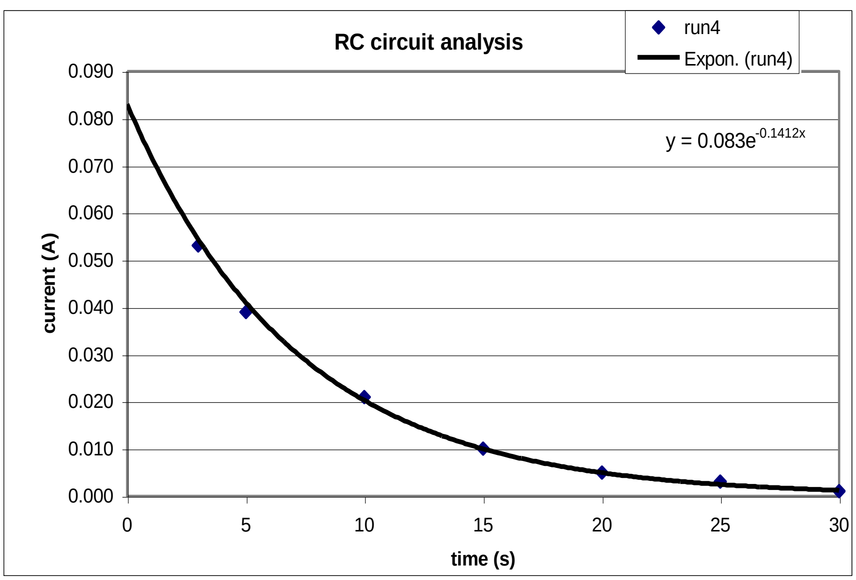
$$I(t) = \frac{V}{R}\exp\left(-\frac{t}{RC}\right),$$

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. When students are completing this prediction for current as a function of time in both Problems #1 and #2, make sure they read the warm-up carefully. Students are tempted to solve the equation in terms of *charge* (which is how textbooks typically derive this equation) but the questions prompt them to leave it in terms of *current*.

Sample data:

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

resistance	64
capacitance	0.1
voltage	6
Current0	0.0830
1/RC	0.1383



The time constant for the circuit was found by extrapolating the initial current from the graph, using that to find R(effective), and calculating 1/RC

The time taken for the current to fall to half its initial value is:

$$t = RC \ln 2 ,$$

and so depends linearly upon 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.

The time for the current to fall to 1/8 of its original value should be three half-lives.

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

Lab 3 Problem #2: Connection of Two Capacitors

Purpose:

- To demonstrate to students the quantitative behavior of RC-circuits
- To provide practice in applying Ohm's Law, conservation of charge, and conservation of energy to a problem that doesn't just consist of resistors.
- As an illustration of exponential decay, and how this situation arises – when the rate of decrease of a quantity is proportional to the quantity itself.

Equipment:

****EQUIPMENT NOTES:** All values of capacitance printed on the capacitors have units of microfarads (μF) even though some might be labeled "MF". To find identical bulbs look for markings and check to see that the color of the bead separating the filaments is the same (clear or white).

Teaching tips:

1. This problem is intended to show the students how each quantity in the circuit changes with time (current in the circuit, the voltage across the resistor/bulb/capacitor, the charge stored on the capacitor.) From labs in 1201, the students may know that the current in the circuit changes with time, and the charge on the capacitor increases, but how exactly do they change?
2. 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.

3. Make sure students connect the capacitors to the battery correctly: + to +, - to - otherwise the capacitors will be destroyed (written value will be off from the real capacitance).
4. Remember the bulbs are not exactly ohmic, so for Problem #2 make sure the students use resistors for data taking 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? They will return to exponential decay later, in Lab 7 on nuclear radiation.

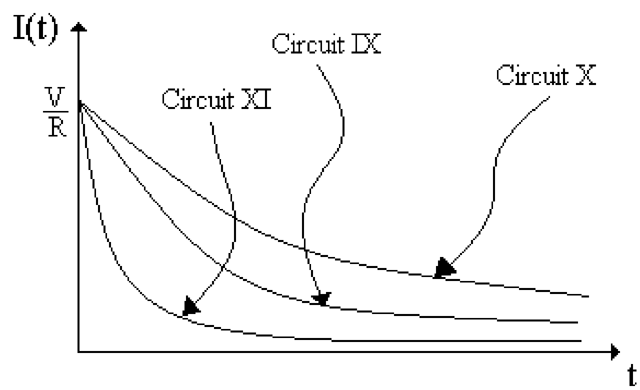
Prediction:

Circuit I (IX in graph) is one capacitor, Circuit II (X in graph) is two parallel capacitors, and Circuit III (XI in graph) is two capacitors in series. A sketch comparing the three graphs is shown below.

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

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

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

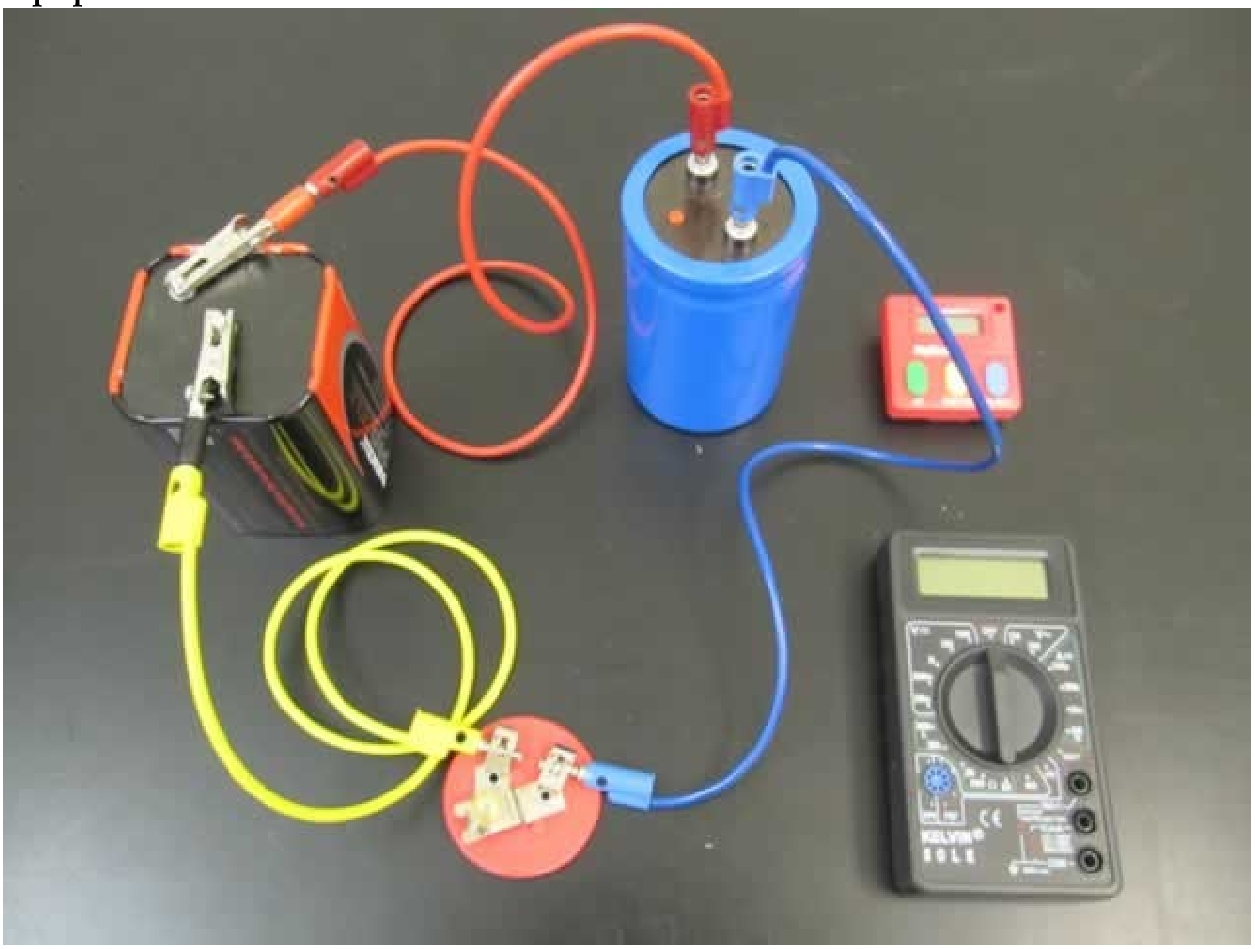


Lab 3 Problem #3: Capacitors I

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 delivered by a discharging capacitor decreases with time.

Equipment:



****EQUIPMENT NOTES:** All values of capacitance printed on the capacitors have units of microfarads (μF) even though some might be labeled "MF". To find identical bulbs look for markings and check to see that the color of the bead separating the filaments is the same (clear or white).

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. Make sure students connect the capacitors to the battery correctly: + to +, - to - otherwise the capacitors will be damaged (written value will be off from the real capacitance).
3. Remember the bulbs are not exactly ohmic, so do not expect an exact exponential decay.
4. 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.

5. The capacitance is written on the side of the capacitors. They are large enough that the voltage decay is observable over time.
6. 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 of Students: Capacitors are a mystery to most students. Most students expect the bulb to become increasingly brighter.

Prediction:

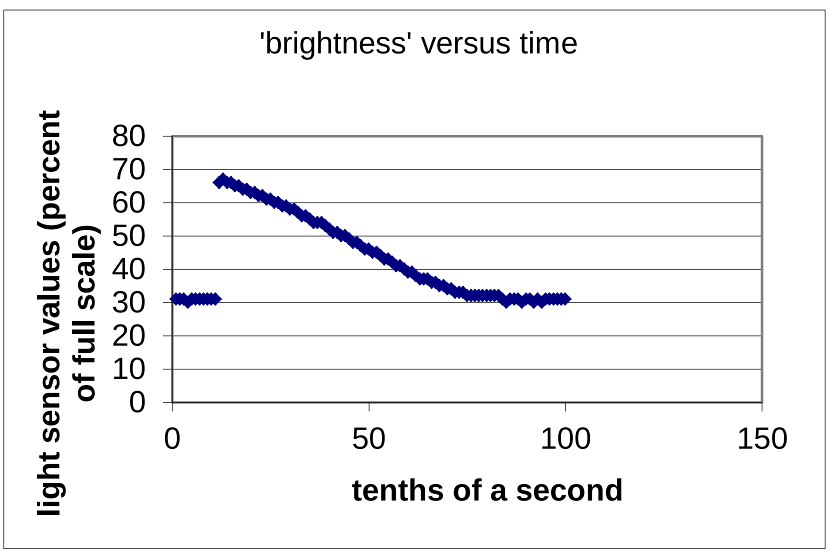
One should see the bulb grow dimmer over time.

Discussion Question:

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

Data using equipment not present in the lab:

Using a LEGO light sensor (part number W779758; contains a phototransistor, perhaps most sensitive at 800nm wavelength) and RCX (part number HD6433292; contains a microcontroller), the following graph was obtained for the 'brightness' of a bulb (in series with a 110,000 μF capacitor and 6Volt battery) versus time.

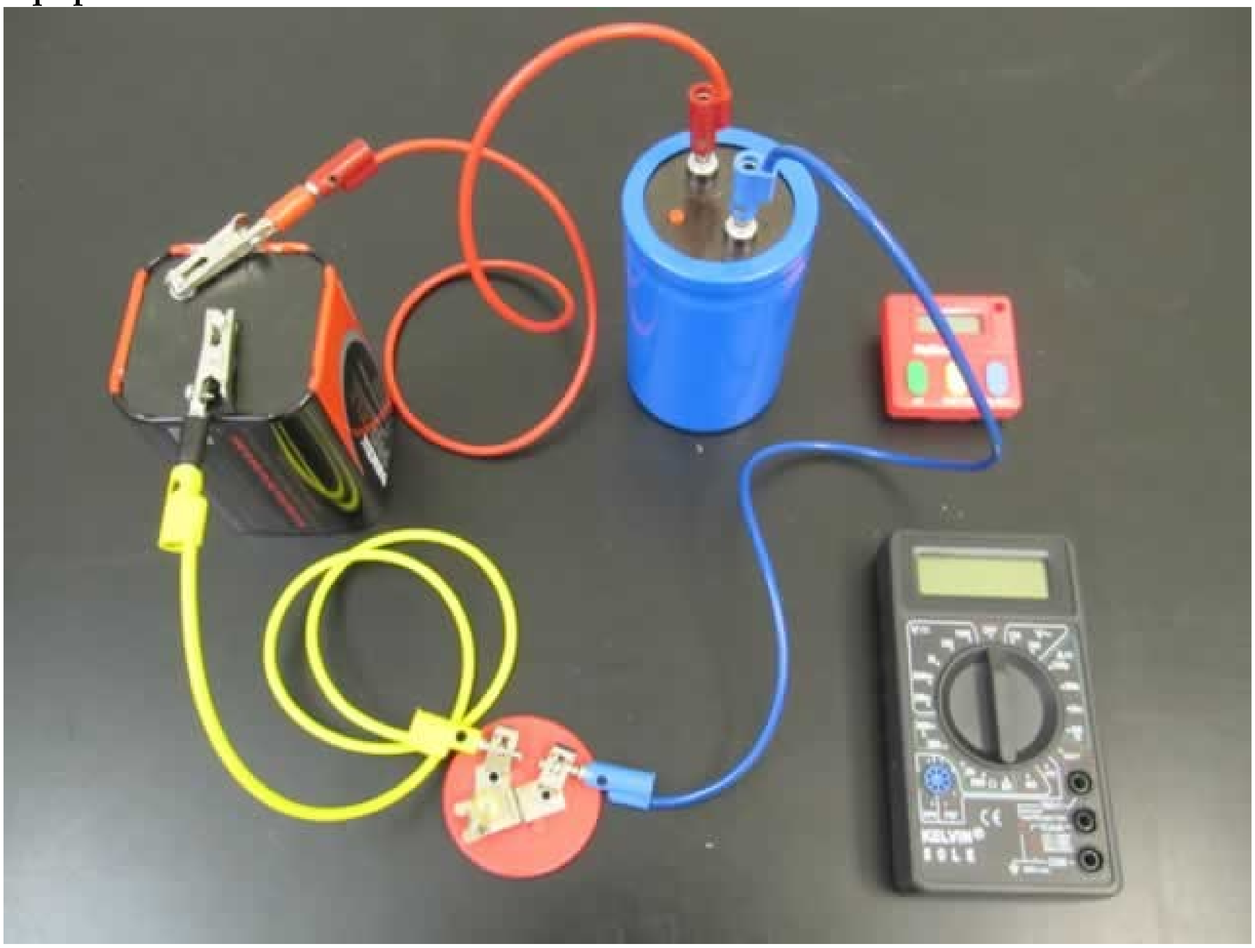


Lab 3 Problem #4 Capacitors II

Purpose:

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

Equipment:



Teaching tips:

This problem is somewhat similar to Problem #7 (electric motor) 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, perhaps when you get to problem #7.

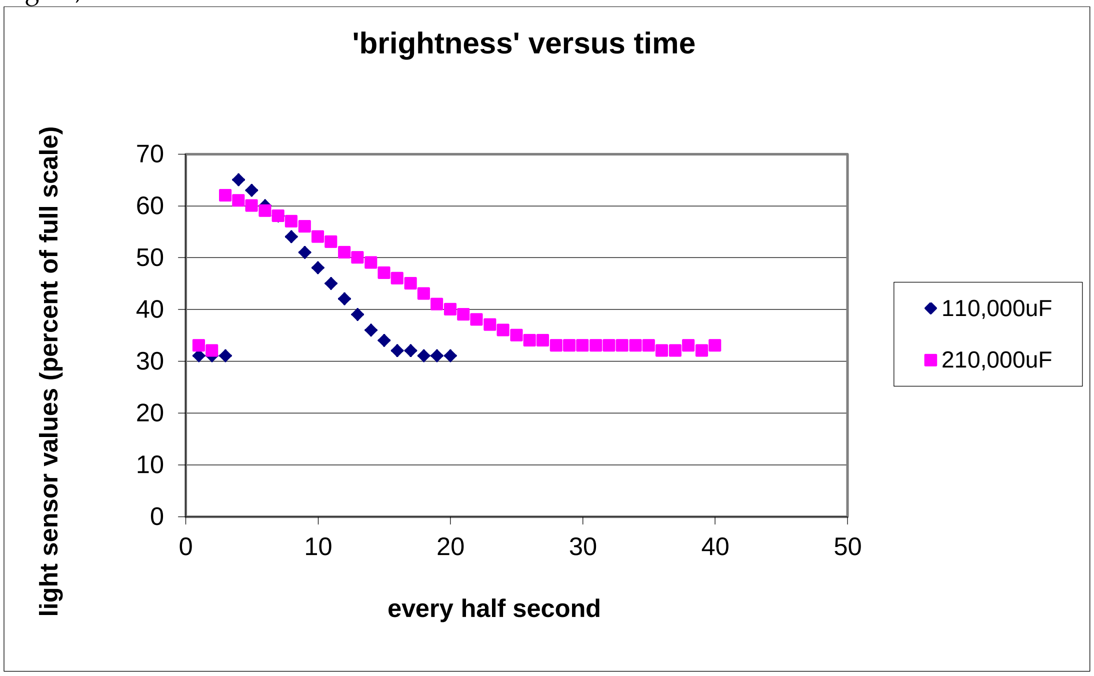
Difficulties and Alternative Conceptions of Students: Many students will not immediately see that the rate at which work is being done by the battery is proportional to the brightness of the light bulb.

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 might not be aware of the RC time constant yet. Here, they should be encouraged to think about it in terms of conservation of energy or some version of Kirchoff's voltage rule.

Data using non-standard equipment:

Again, here are measurements made with LEGOs.

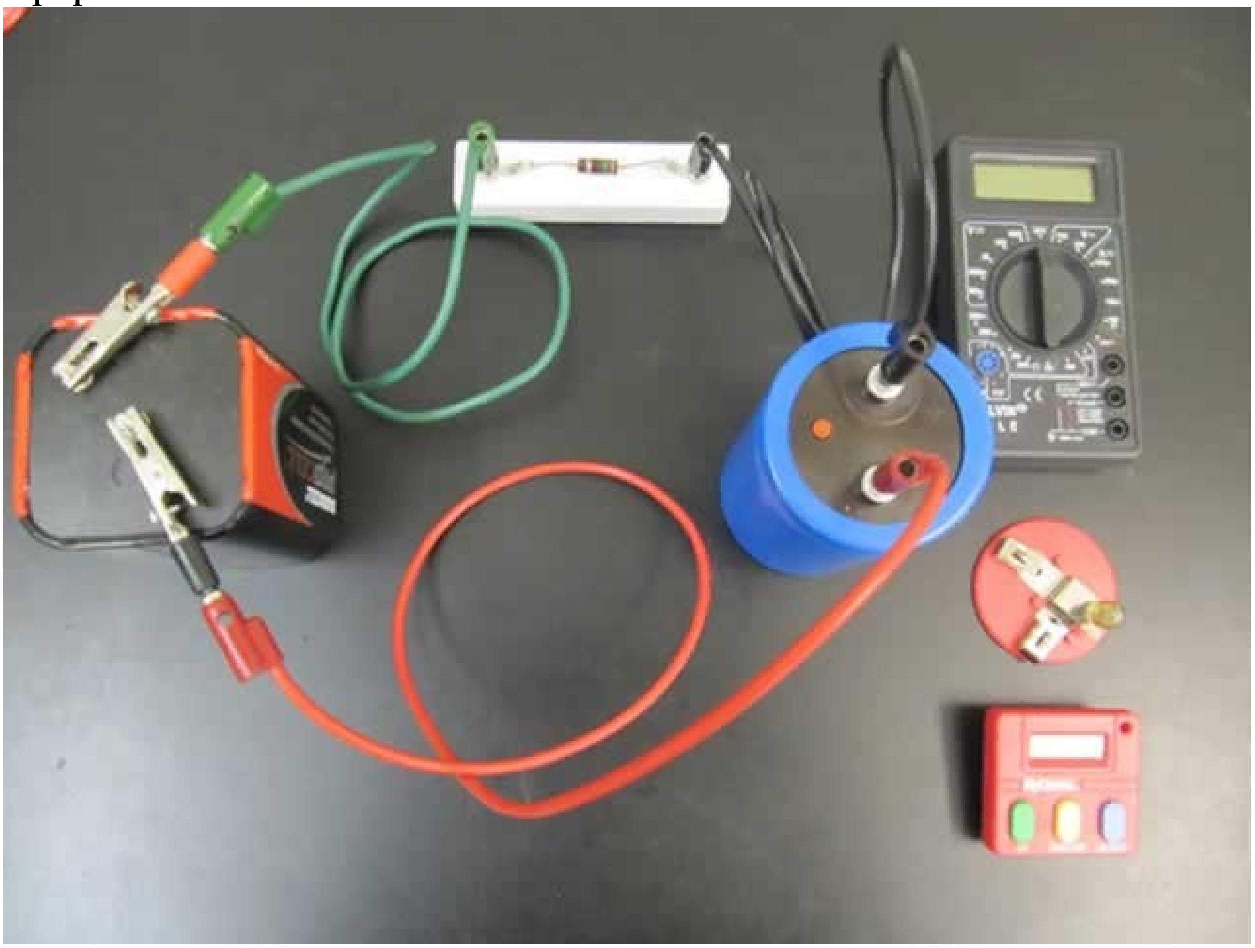


Lab 3 Problem #5: Rates of Energy Transfer in RC Circuits

Purpose:

- To help students calculate the rate at which energy is stored in capacitor.
- To give students experience with the rate equation.

Equipment:



**EQUIPMENT NOTES: All values of capacitance printed on the capacitors have units of microfarads (μF) even though some might be labeled "MF". To find identical bulbs look for markings and check to see that the color of the bead separating the filaments is the same (clear or white).

Teaching Tips:

1. The capacitances listed on the capacitors may not be accurate. This is because the capacitors are electrolytic capacitors with a well-defined polarity. When such capacitors are connected incorrectly, the properties change. These capacitors may have been connected incorrectly many times. Make the capacitance a fit parameter in the students' labs.
2. The students need to work from the rate equation in this lab. There are many possible equations that resemble the differential equation for radio-active decay:

   $$\frac{dI(t)}{dt} = -\frac{1}{RC}I(t) \qquad \text{for the current}$$

$$\frac{dV(t)}{dt} = \frac{1}{RC}(V_B - V(t))$$ for the voltage across the capacitor

$$\frac{dV(t)}{dt} = \frac{-1}{RC}V(t)$$ for the voltage across the resistor

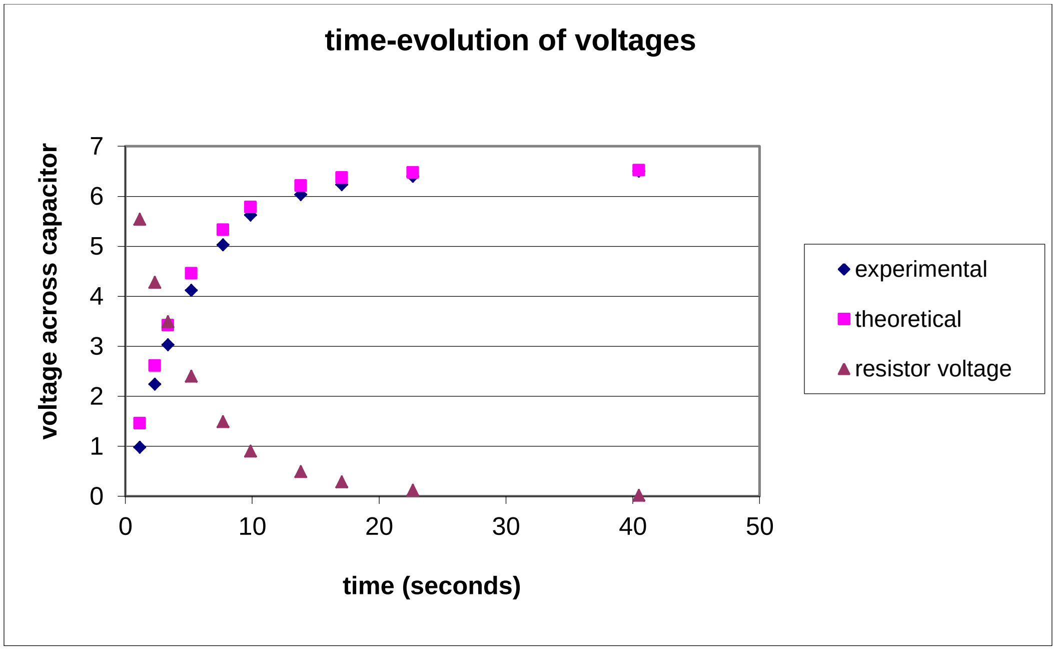
It is important that the students know the solutions to these equations, and that the equation they have chosen is the appropriate one for the data they are taking. Note that the second equation contains an inhomogeneous term (the battery voltage over RC).

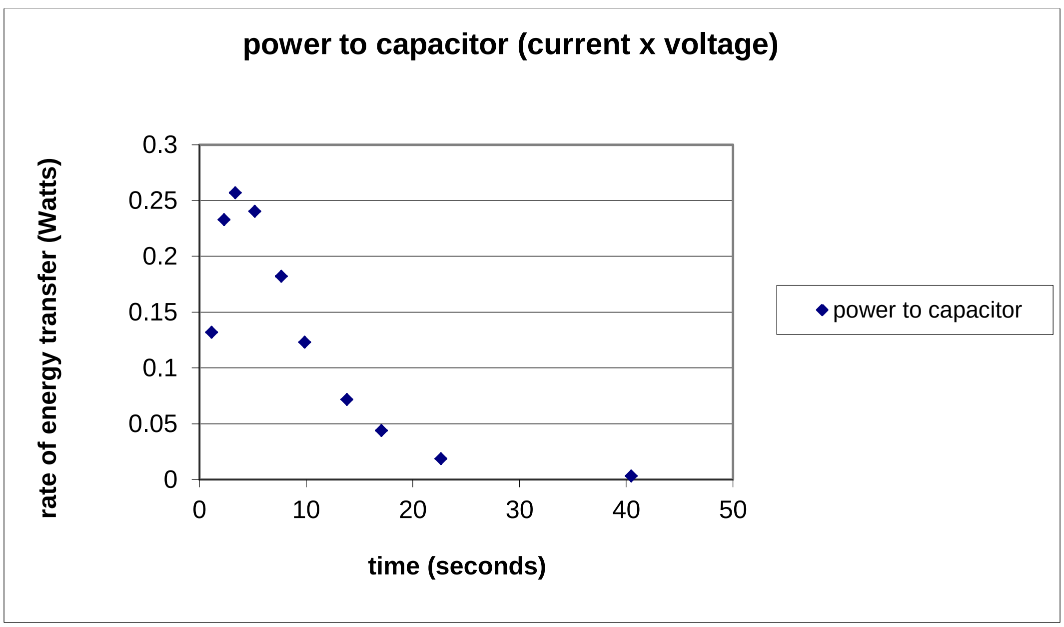
3. Many students will not want to take enough data. Remember, any function can be fit to two points.
4. The resistance of the light bulbs is only a few ohms. You may need to connect a resistor in series with the light bulb to increase the time constant. If the students have done the resistors and light bulbs lab, they will know that resistors and light bulbs are slightly similar.
5. If you have time, it might be interesting to lead a discussion on the connection between the total work done by the battery, the maximum capacitor energy, and the energy dissipated in the resistor. Since a final charge of $Q=CV_B$ is deposited to the capacitor plates, work done by the battery is $QV_B= CV_B^2$. The capacitor stores the amount ½ CV_B^2, so the energy dissipated is also ½CV_B^2; each is just half of the total energy given by the battery.
6. If you have time, you might also like your students to compare the work done by the battery $P=IV_B$ to the rate energy goes into the capacitor. The difference would just be the 'Joule heating' in the resistor.

Data:

The plots below were based on an RC-circuit with R=41.2ohms and C=110,000 μF connected to a battery at 6.52 volts. The theoretical prediction is of course $V = V_B(1-\exp(-t/RC))$. The percentage difference between the predicted and measured voltages is less than 10% except for the first three data points.

Instead of measuring the current independently, the difference between the battery and capacitor voltages was taken and Ohm's law was used. The rate of energy input (power) to the capacitor is just the product of the current (proportional to the resistor voltage) and capacitor voltage. Because the voltage increases (towards a plateau) and the current decays exponentially, the power should exhibit a peak. The students may verify the energy stored in the capacitor by estimating the area under the curve.


time-evolution of voltages
voltage across capacitor
0
1
2
3
4
5
6
7
0
10
20
30
40
50
time (seconds)
experimental
theoretical
resistor voltage

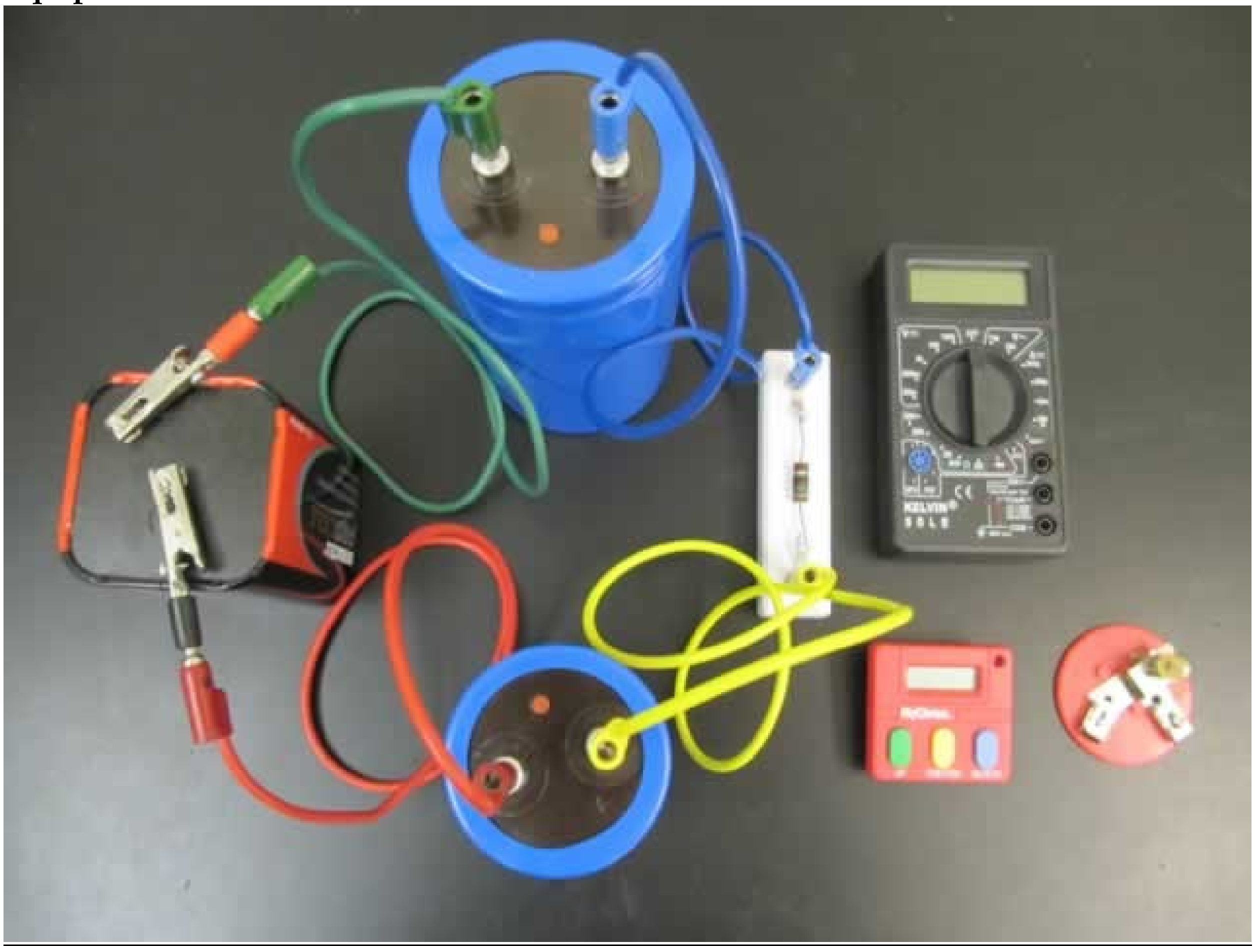

power to capacitor (current x voltage)
rate of energy transfer (Watts)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
10
20
30
40
50
time (seconds)
power to capacitor

Lab 3 Problem #6: Circuits with 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:



****EQUIPMENT NOTES:** All values of capacitance printed on the capacitors have units of microfarads (μF) even though some might be labeled "MF". To find identical bulbs look for markings and check to see that the color of the bead separating the filaments is the same (clear or white).

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.

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.

From above: $E_3 < E_1 < E_2$.

Teaching Tips:

For capacitors in series connected to a battery, the potential divides as follows: $V_1=C_2V/(C_1+ C_2)$, $V_2=C_1V/(C_1+C_2)$.

Discussion Question:

How can the bulb in circuit III 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?

Lab 3 Problem #7: Efficiency of an Electrical Motor

Purpose:

- To show students that capacitors store energy and that this stored energy can be used to do mechanical work, but not all of the energy available does work on the cart.

Equipment:

****EQUIPMENT NOTES:** All values of capacitance printed on the capacitors have units of microfarads (μF) even though some might be labeled "MF".

Teaching Tips:

1. Make sure students connect the capacitors to the battery correctly: + to +, - to - otherwise the capacitors could be damaged (written value will be off from the real capacitance).
2. The capacitance is written on the side of the capacitors. All values are in microfarads (μF). You may need to point these numbers out to students, as they are difficult to find on some capacitors. However, as the students may learn later, these are not accurate. This is not an important issue for this lab.
3. For safety reasons, be sure that all of the capacitors are discharged before your students enter the lab room.
4. The best way to spool the string is to slip the string through the small hole in the side of the spool, then fix it with a small piece of masking tape on the outside edge of the spool.

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 move the block. This is relatively constant over the range of capacitances used in the lab.
6. A good problem for the students to solve is the effective efficiency of the motor, as stated in the conclusion section.

Difficulties and Alternative Conceptions of Students: 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).

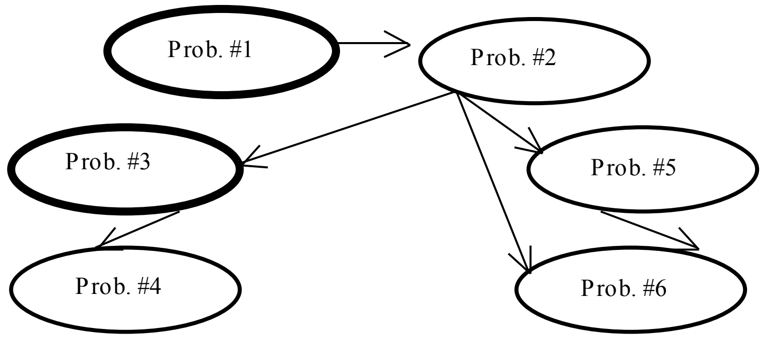
Prediction:

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 cart, there is no external force to do work on the system. Therefore, the change in kinetic energy of the cart will be due entirely to the motor. The final velocity (squared) of the block is directly proportional to the energy change of the capacitor.

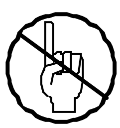
Laboratory 4: Electric Field and Potential

The flow chart for the sequence of problems is:



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. **Students will have had no experience with the field due to charged plates before Problems #5 or #6, and may not realize that they produce a uniform electric field**. You do not need to do Problem #3 or #4 to do Problem #5 or Problem #6.

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



REMINDER: Your students will be working with equipment that generates large voltages. Improper use can cause painful burns. To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply.

Things your students should know by the end of this lab:

- Know 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.
- Be able to map the electric potential based on the geometry of charged objects.
- Relate the electric field to the electric potential.
- Calculate the electric field and potential due to a point charge.
- Calculate the electric field and potential due to multiple charges with the principle of superposition.
- 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 conductive paper set up to convince yourself 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. The best way to check a battery is to see if you can draw current from the battery, or test it's voltage under load.

Lab 4 Simulation Problem #1: Electric Field Vectors

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 Electrostatics 3D needed for the rest of the course.

Equipment: Electrostatics 3D 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 primarily (or exclusively) pay attention to the electric field vector capabilities of Electrostatics 3D. You might want to encourage students to map out the fields by evaluating the electric field vector without clicking the mouse and placing continuous electric field lines.

Difficulties and Alternative Conception of Students:

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. The metaphor of an attractive woman walking into a bar and creating a field that most men in the establishment feel may be a useful example of a "field." 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.

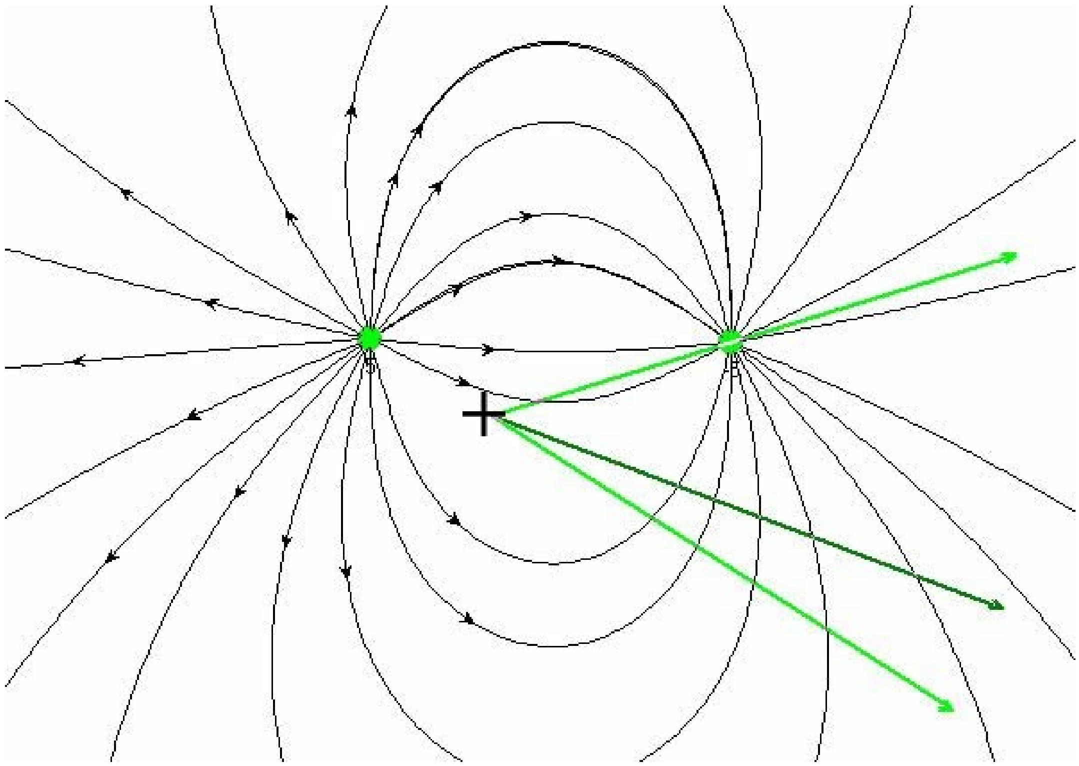
The field idea that objects interact with space and not with each other is a difficult one to understand. This is not a strict Newtonian view of the world. For example, Newton's 3rd law, with which they had so much trouble at the beginning of the course, no longer applies in a straightforward manner.

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 **Electrostatics 3D**. The field lines were inserted using the Manual E Lines option under the **Field menu**. When set to Manual E Lines, the cursor is represented by a + on the screen denoting that point in space with a dark green field vector displayed and two light green vectors representing the partial field from each respective charge. You'll notice that each of the light green vectors always goes towards negative charges and away from positive charges.

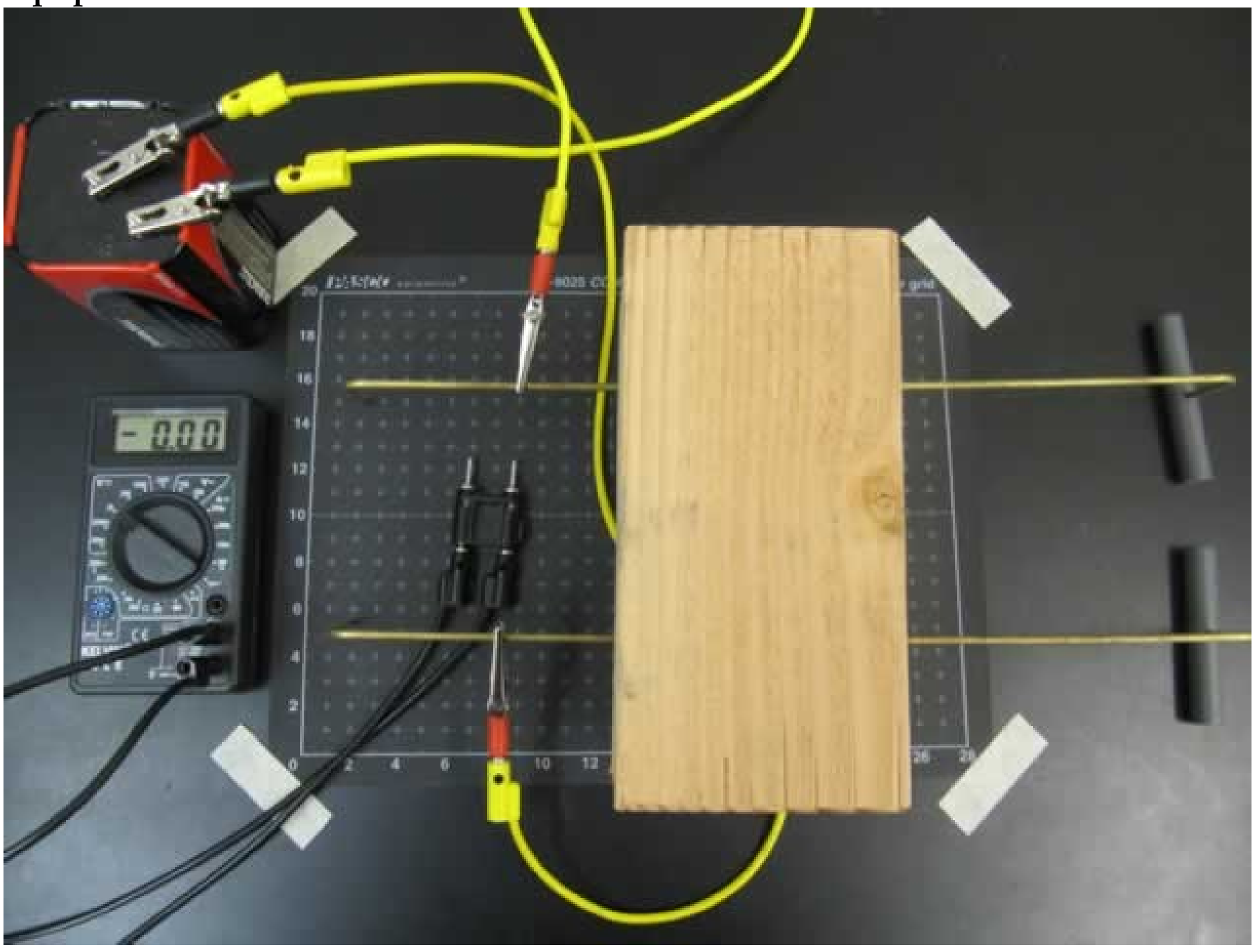


Lab 4 Problem #2: The Electric Field of a Dipole

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 compare to the Electrostatics 3D simulation.
- 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:



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. 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. The relationship is far more complex: we are determining the field, by measuring the

current through a pseudo two-dimensional dielectric material (conductive paper). This is not the field in free space. The role of the conductive paper is complicated, but necessary. Try to avoid discussing it. 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.

3. Batteries or the 18volt/5amp power supply should be used for this exercise. **Make sure you check out all of the batteries before the beginning of class.** Any voltage higher than 16V while using the power supply 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**. If you need new batteries, please send a report to labhelp@physics.umn.edu.
4. Many of the probes give readings with large fluctuations. If a group of students has this problem, get them a new DMM. 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 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, 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:

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: See comments for the previous problem

Data:

The map of the electric field looks much like the Electrostatics 3D result.

Lab 4 Problem #3: The Electric Potential due to Multiple Point Charges

Problem

Find the electric potential at the corner of a square made of charged point objects.

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.

Teaching Tips:

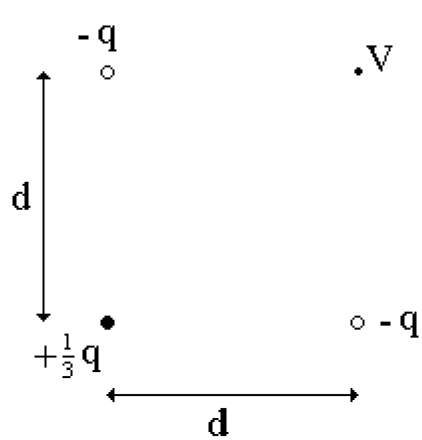
1. The students should focus on the electric potential capabilities of Electrostatics 3D.
2. Make sure that your students pick appropriate charge magnitudes and distances for these problems.
3. When talking about electric potential it is often useful to make an analogy between electric potential energy and gravitational potential energy.

Difficulties and Alternative Conceptions of Students:

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.

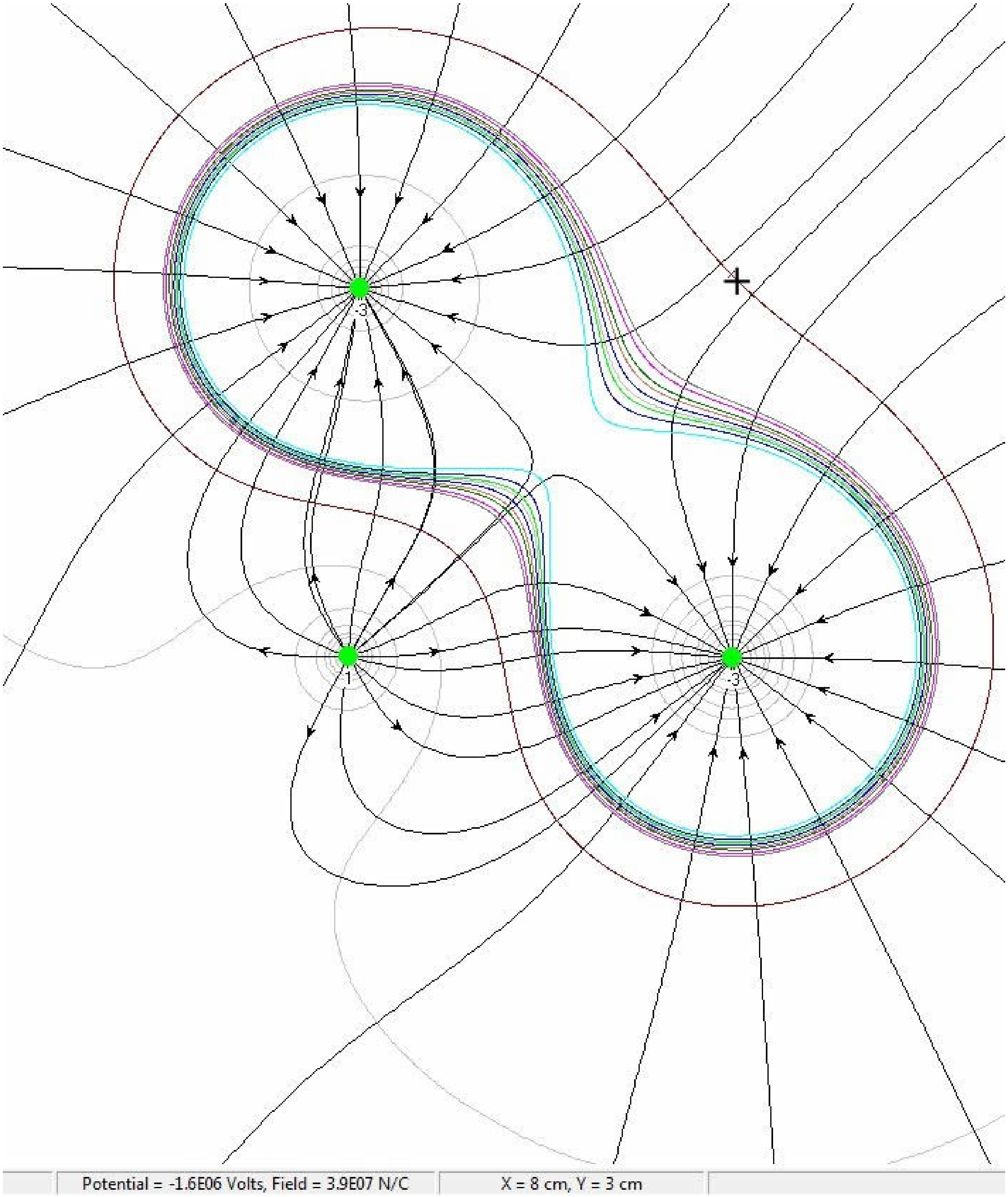
Prediction:



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

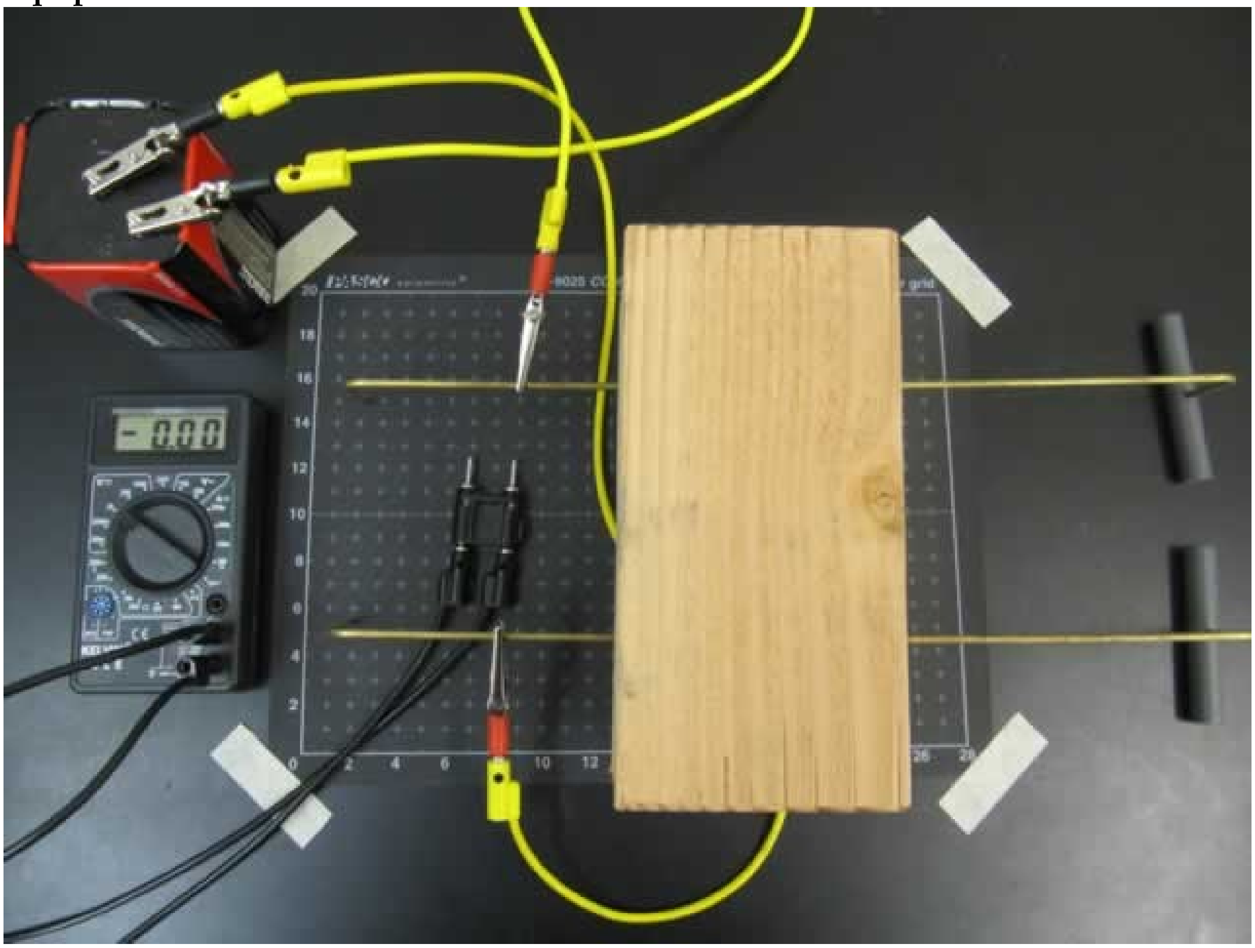
$$V = -\frac{k_e q}{6d}\left(12 - \sqrt{2}\right)$$

Sample Simulation



Lab 4 Problem #4: Electric Field and Potential

Purpose:
To help students make connections between electric fields and electric potentials.

Equipment:


Teaching Tips:
- TRY THE SINGLE PROBE TIP BEFORE TEACHING THIS LAB. DOES IT GIVE RELIABLE RESULTS?
- You can simply use the terminal end of a banana cable as the single tip probe.

Warm-up Questions:
- The potential due to two point charges is the SCALAR sum of the potential due to each charge.

- The electric field is perpendicular to an equipotential line at all points in space, and its magnitude is proportional to the spacing of equipotential lines.

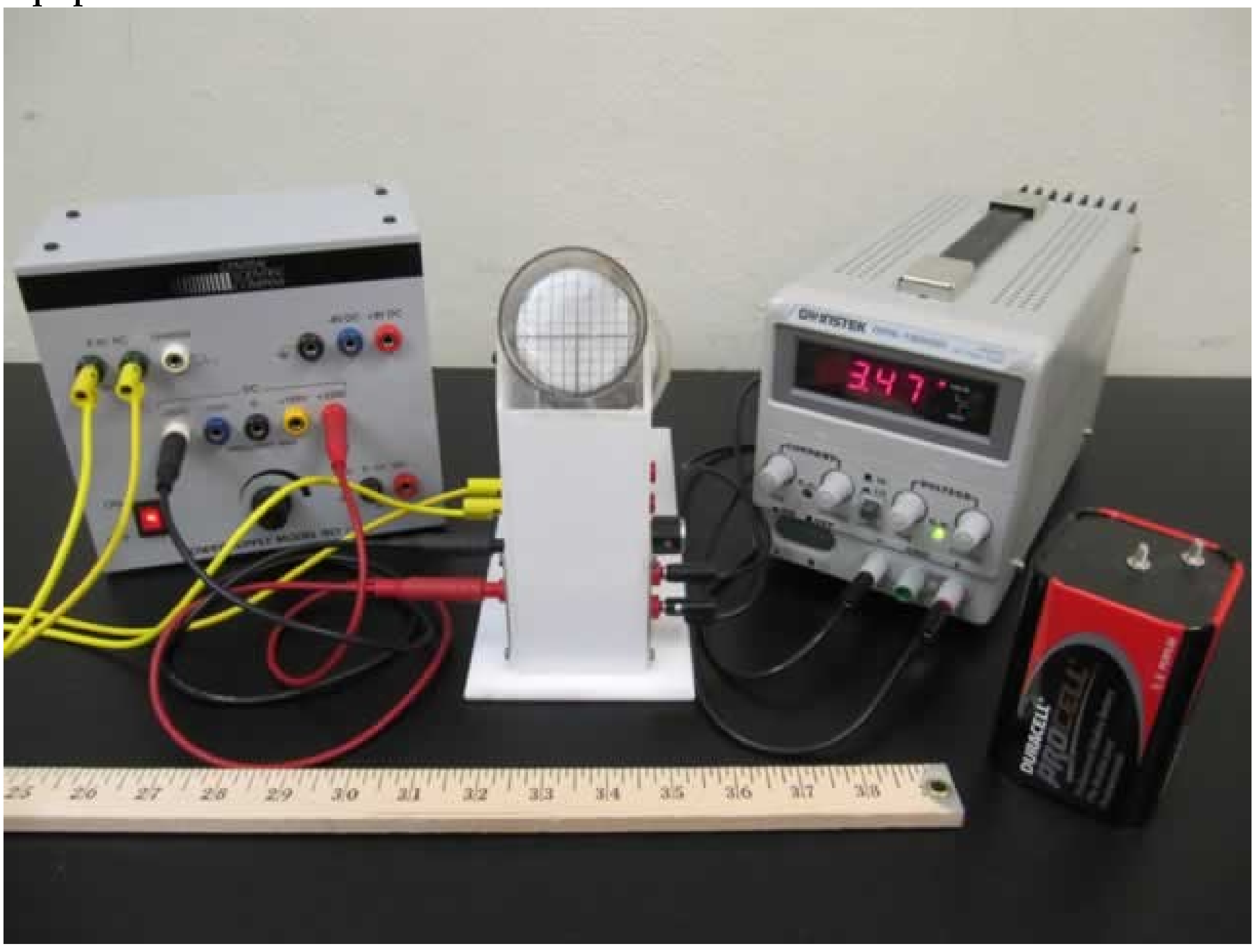
- The perpendicular bisector of the line segment connecting the charges of a dipole is a line of zero potential. The potential should be anti-symmetric across that line, as you can tell from the equation describing the potential for the two charges.

Lab 4 Problem #5: Deflection of an Electron Beam by an Electric Field

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:



- Both the CRT and the CRT power supply are some of our oldest and most used equipment. You will need to be particularly careful using them as they are dangerous and very breakable.
- If one is broken, please send a report to LABHELP immediately.
- The CRT power supply has a resettable fuse on its side near the power cord. Most have a yellow button that resets the unit, some have broken off and might need to be reset using a paper clip or pen tip.

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 "Preamble" in the warm-up questions is intended to remind students about kinematics, which most seem to have forgotten by this part of the term. This exercise is nearly identical (save for its embedding into reality) to the motion of the electron in this lab problem.

3. The students must keep their CRT pointing in the same direction for all measurements. The earth's magnetic field will displace the beam differently for different orientations.
4. 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.
5. **Be sure to warn your students of the danger when connecting the high voltage leads.**
6. This is a difficult problem for students. They need to do it in an organized manner. Drawing a good picture is crucial. ***Students WILL have particular difficulty if they do not already know that the electric field between the plates should be constant.***

Difficulties and Alternative Conceptions of Students:

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 ought to vary linearly with the applied electric field.

Warm-up Questions:

The total deflection is caused by two distinct regions of the CRT. The first part of the deflection is caused by the electric field between the plates; the second part is caused by the straight line path after the electron leaves the plates until it hits the screen. Your final result for the deflection should boil down to:

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

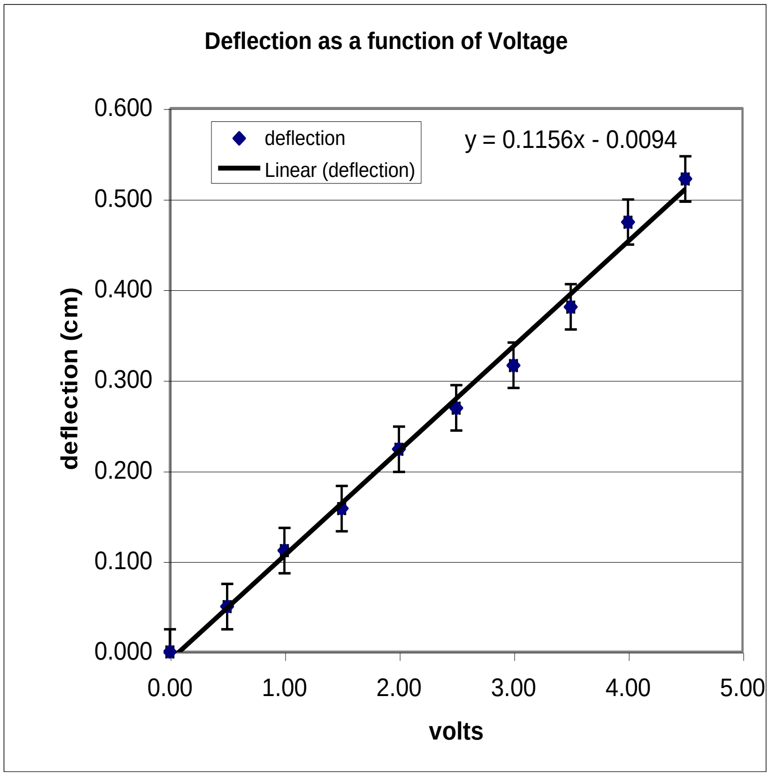
where E is the applied electric field, V_{acc} is the accelerating potential, L is the length of each plate, and D is the distance from the plates to the screen. Remember that the applied electric field is found from $E = V_x / S$, where V_x is the potential across the deflection plates, and S is the 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:

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
L = 2
S = 0.3
V = 250

m = 0.112

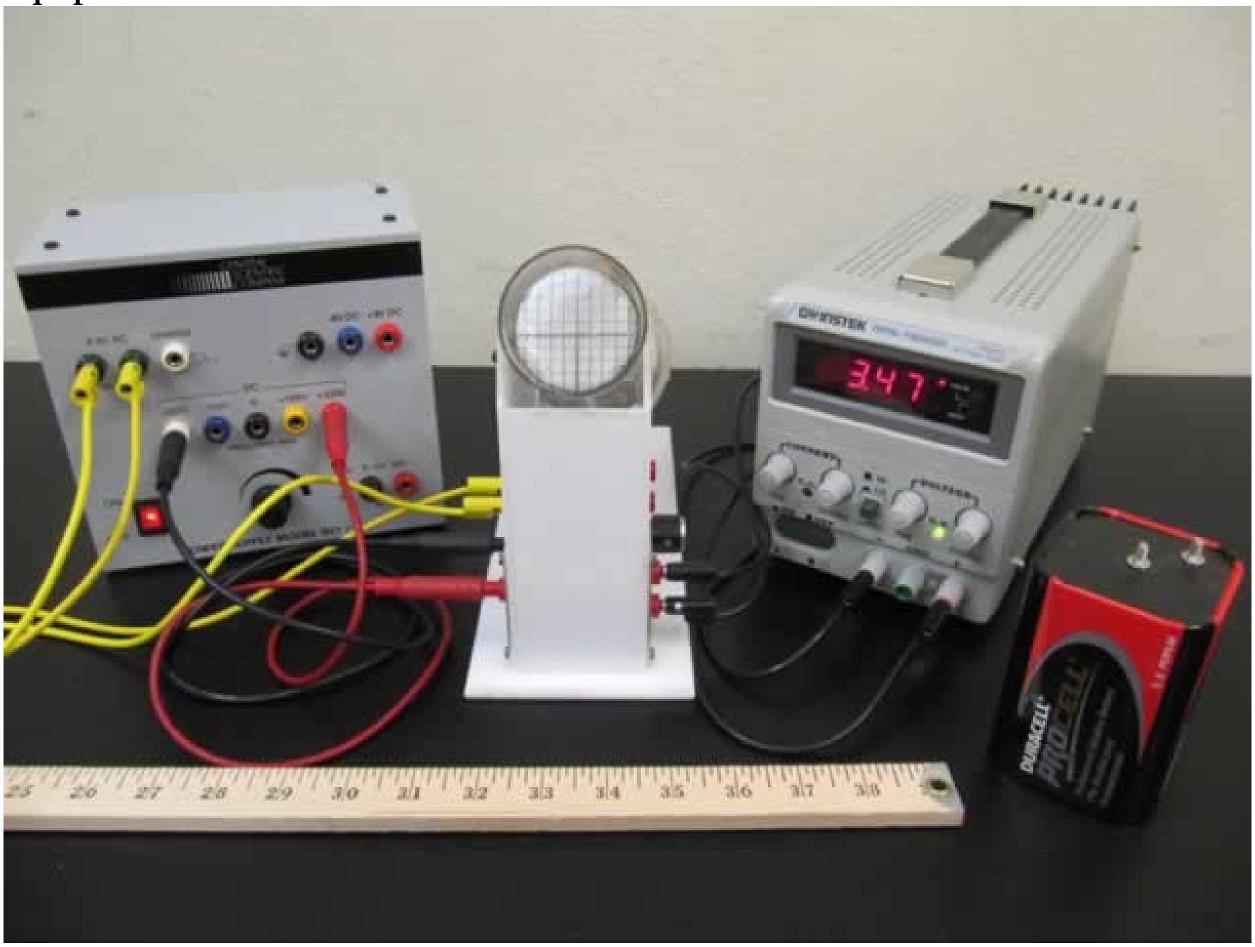


Lab 4 Problem #6: Deflection of an Electron Beam and Velocity

Purpose:

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

Equipment:



- Both the CRT and the CRT power supply are some of our oldest and most used equipment. You will need to be particularly careful using them as they are dangerous and very breakable.

- If one is broken, please send a report to LABHELP immediately.

- The CRT power supply has a resettable fuse on its side near the power cord. Most have a yellow button that resets the unit, however, some have broken off and might need to be reset using a paper clip.

- If you cannot get a CRT to produce a beam at all the required potential differences send a report to LABHELP.

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 #5. 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 of Students:

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:

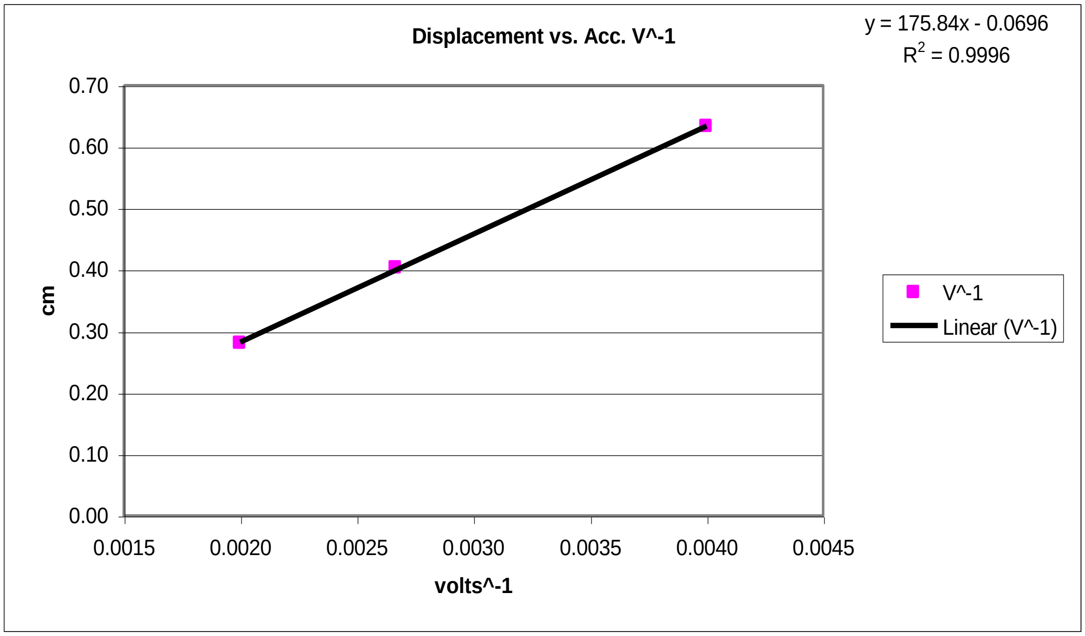
The total deflection is caused by two distinct regions of the CRT. The first part of the deflection is caused by the electric field between the plates; the second part is caused by the straight line path after the electron leaves the plates until it hits the screen. Your final result for the deflection should boil down to:

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

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:

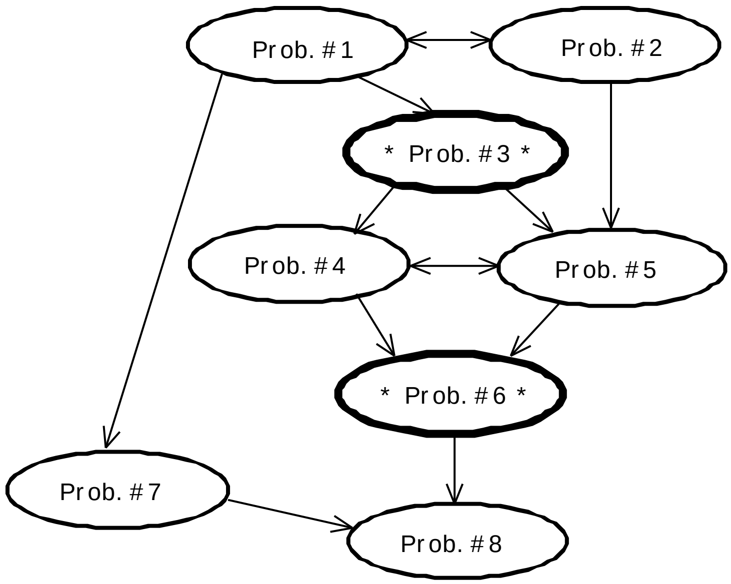
voltage	V^-1	displacement				
			D =	7.4		
250	0.0040	0.63	L =	2	m =	156.24
375	0.0027	0.40	S =	0.3		
500	0.0020	0.28	V =	5.58		



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

Laboratory 5: Magnetic Fields and Forces

The flow chart for this lab is:



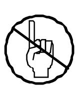
Teaching Tips:

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.



REMINDER: Your students will be working with equipment that can generate large electric voltages. Improper use can cause painful burns. To avoid danger, the power should be turned OFF and your students should WAIT at least one minute before any wires are disconnected from or connected to the power supply.

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 equipment appendix) 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.
- **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.

Lab 5 Problem #1: Permanent 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:

Teaching tips:

1. **Check the magnets!!** They can become oddly magnetized when they are dropped or stored poorly. Magnets are a large source of frustration to the students and bad magnets reinforce many misconceptions. It is necessary to **re-magnetize the magnets before each class period**! Make sure you know how to use the magnetizer! **You need to put the north end of the bar magnet into the hole labeled with the S (& arrow) of the magnetizer, and vice versa for the south end of the bar magnet!!** The chrome square metal bar rest across the top of the magnets to complete a path while you press the button. You should be able to notice a significant increase in quality of the magnets when magnetized properly.
2. This is a field-mapping problem 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.
3. Explore the properties of the 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-ups. Emphasize vector addition of the field from every magnetic pole.
5. The front entrance of Tate faces west. Also, remember that the earth's magnetic field has a large vertical component in Minneapolis. This is not shown on flat compasses.
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 make educated guesses about the magnitude of the magnetic field and add this information to the maps.
7. **If you find a plate that leaks** send a report to labhelp@physics.umn.edu immediately for a replacement. Glycerin is a skin irritant, if it does come in contact with skin, it is suggest that the area is washed immediately.
8. To distribute the taconite, shake the Plexiglas frame. Once distributed, keep the taconite plates flat on the table and don't leave the magnets on plates when finished.
9. DO NOT leave the magnets stuck together! This will demagnetize them.

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). The 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 perpendicularly away from the center of the two magnets and watch what happens.

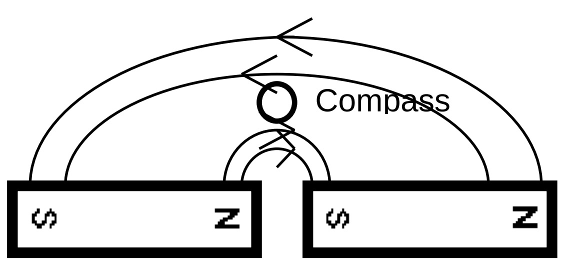


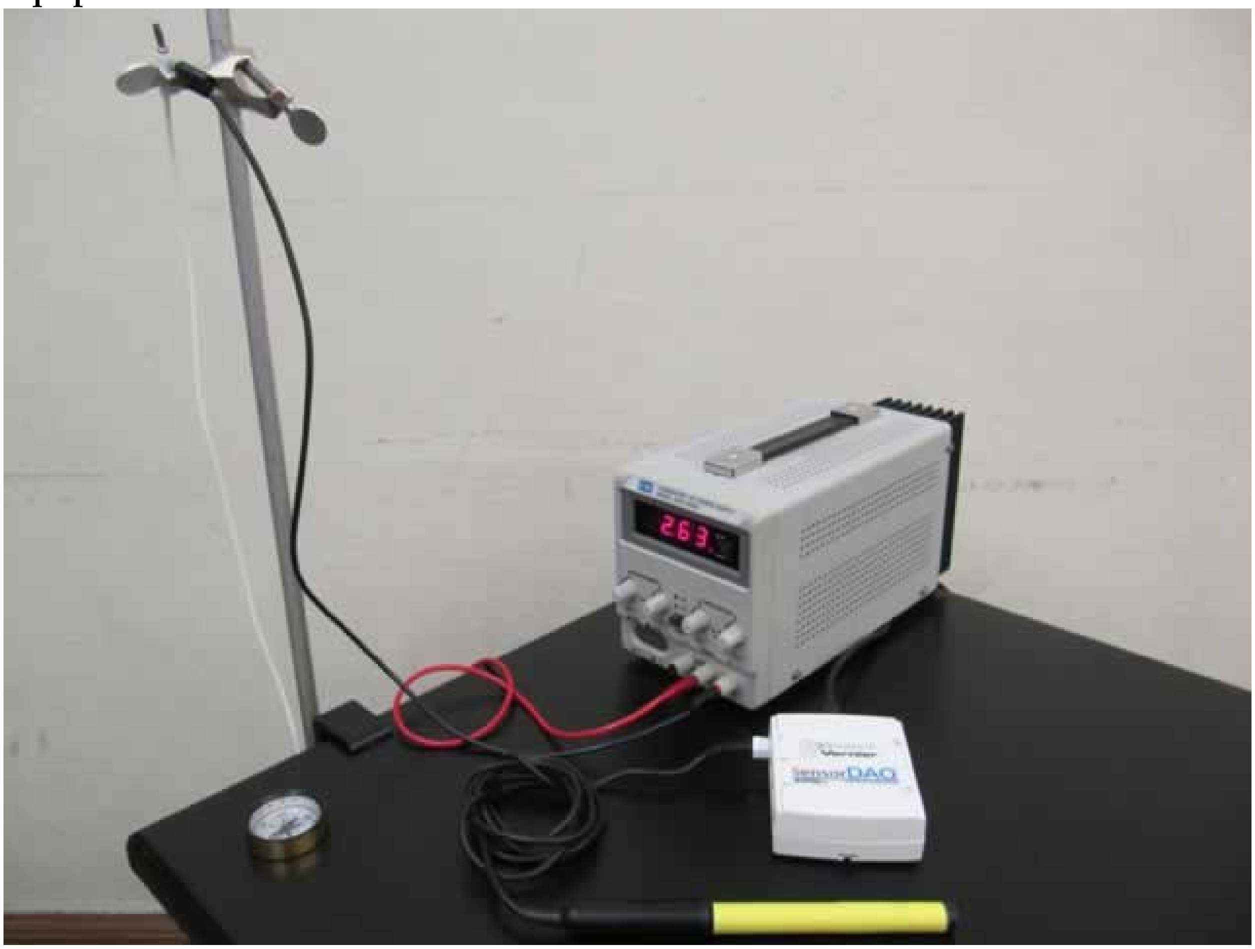
Figure III

Lab 5 Problem #2: Current-Carrying Wire

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:



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 Magnetism 3d 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. 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.

4. 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 generated causes them to break down.

Difficulties and Alternative Conceptions of Students:

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:

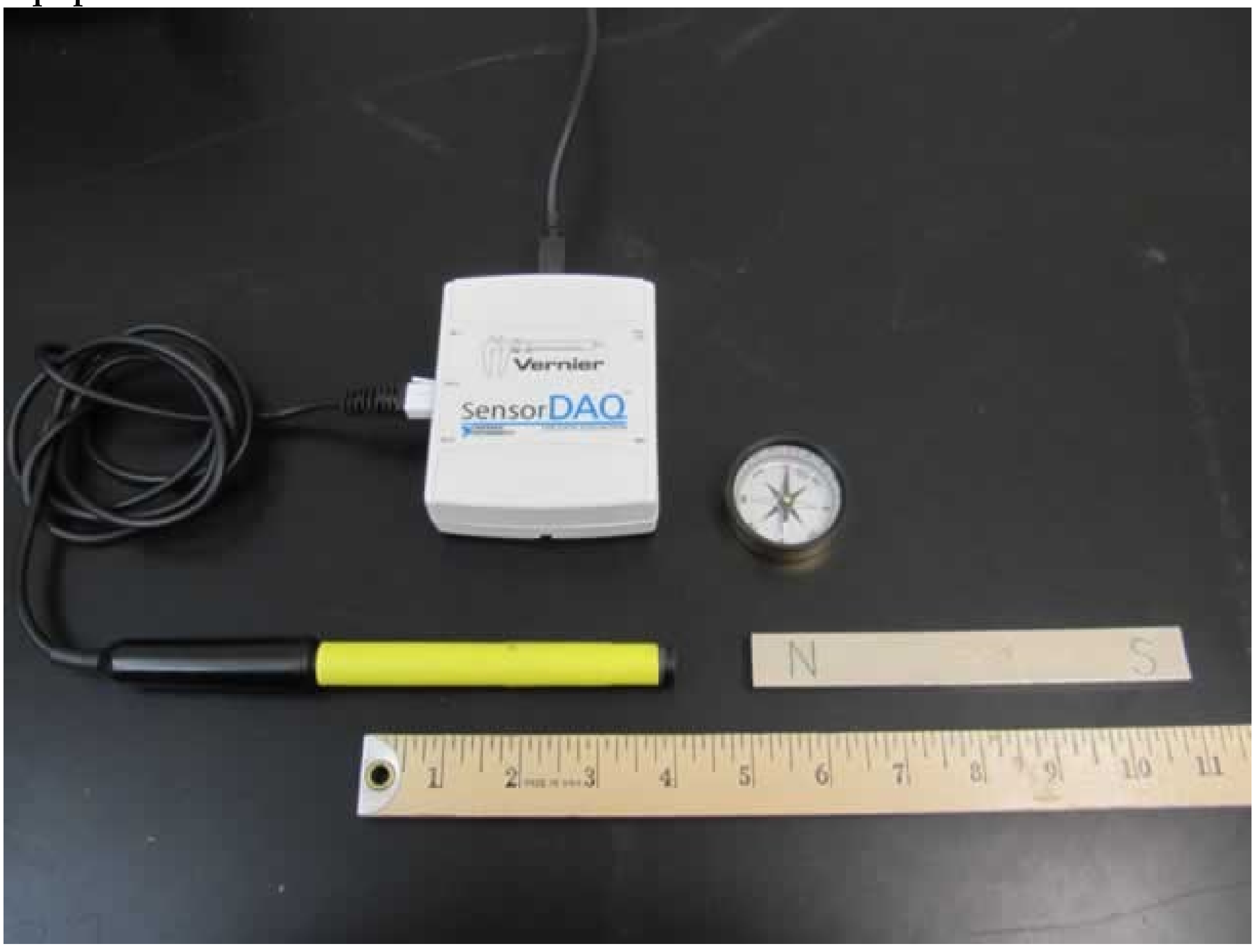
Make sure your students' predictions are magnetic field maps not lines of force.

Lab 5 Problem #3: Measuring the Magnetic Field of Permanent Magnets

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:



Teaching tips:

1. This is mainly an introduction to the Hall probe and MagnetLab application. If you haven't used them 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 in the manuals appendix. The program reads out directly in magnetic field strength.

2. 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. The background fields are different in different parts of the room.

3. Make sure you understand the Hall effect. Students will be frustrated 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.

4. Chances are slim that the Hall effect will be covered in the students' lecture. Refer any of the boisterous ones (and yourself) to (note: the Kane text does not cover this!!)Tipler, section 26-4 (page 904). **Do not lecture on the Hall effect!** For most students it is enough that the Hall probes measure a magnetic field.

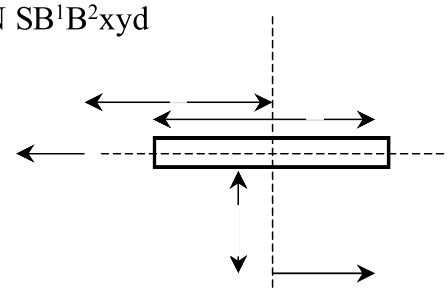
5. You may wish to have your students test the $1/r^3$ behavior of their data (for 'large' distances from the poles).

Difficulties and Alternative Conception of Students:

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:

N SB^1B^2xyd



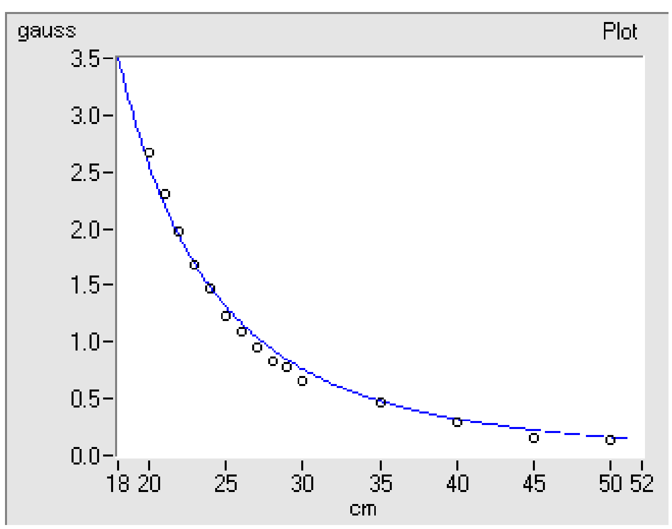
The magnetic field at points along the two axes of the magnet are given by:

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

$$B_2 = \frac{kd}{\left(y^2+\frac{1}{4}d^2\right)^{3/2}},$$

where k is a constant that depends upon the magnet.

Graph shows the magnetic field parallel to the bar magnet. 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.



Lab 5 Problem #4: Magnetic Field of One Coil

If Biot-Savart calculations will not be emphasized on tests, then it is probably best to do Problem #4 instead of Problem #5.

Problem

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

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.

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

Teaching tips

1. The data should show a field similar to that produced by a magnetic dipole.
2. 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. (1T = 10^4 G).

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 (for problem #5)

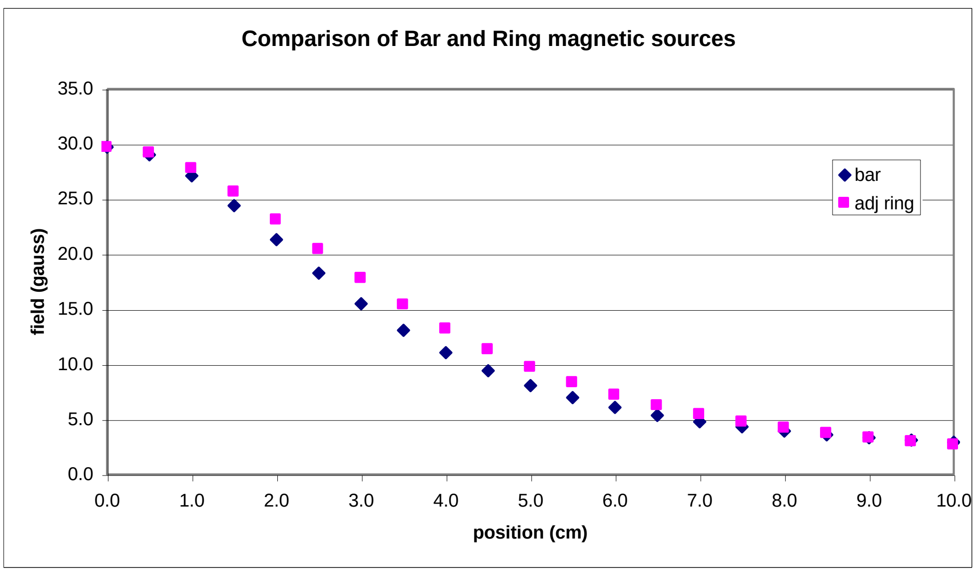
$$B(x) = \frac{\mu_0 INR^2}{2\left(x^2 + R^2\right)^{3/2}},$$

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).

Data

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.



Lab 5 Problem #5: Determining the Magnetic Field of a Coil

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

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.

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 practice using the Biot-Savart Law.

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

Teaching tips

1. 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.

2. 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. ($1T = 10^4$ G).

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

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

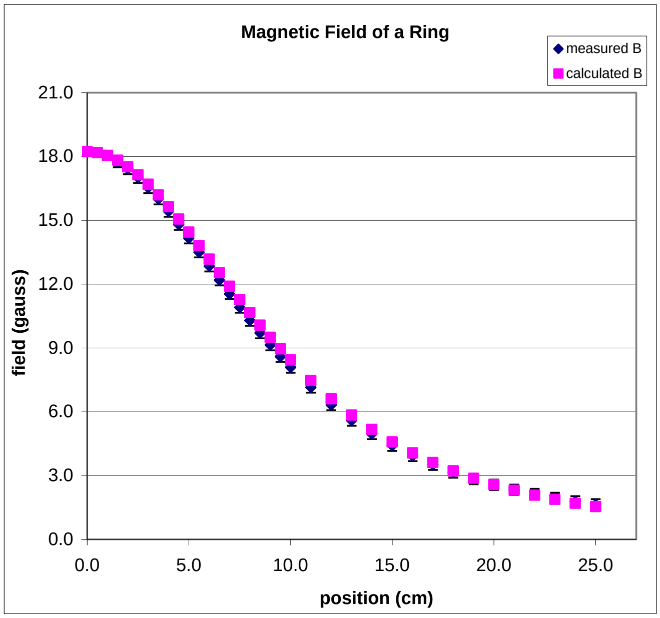
where I is the current in the coil, R is the radius of the coil, x is the distance along the axis of the coil, and N is the number of turns of wire (the Helmholtz coils have 200 turns).

Data

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



Lab 5 Problem #6: Measuring Magnetic Field of Two Parallel Coils

Problem
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 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.

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

Teaching tips
1. 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**.
2. Make your students really measure distance along the axis of the Helmholtz coils.

3. 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 T = 10^4 G).
4. 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.

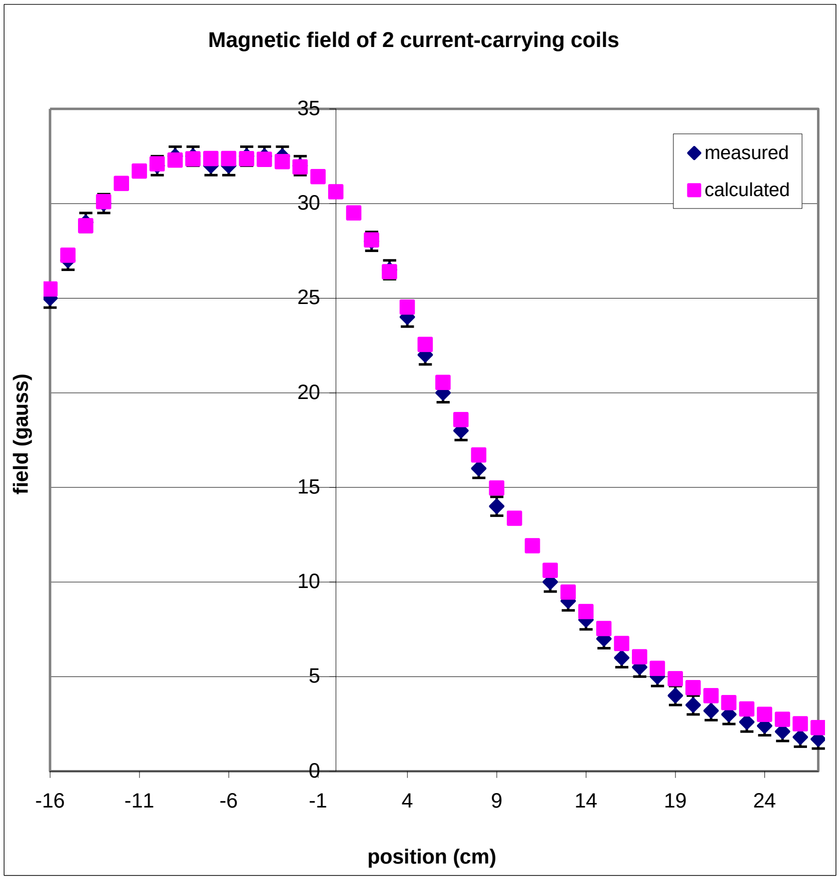
Predictions

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

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

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

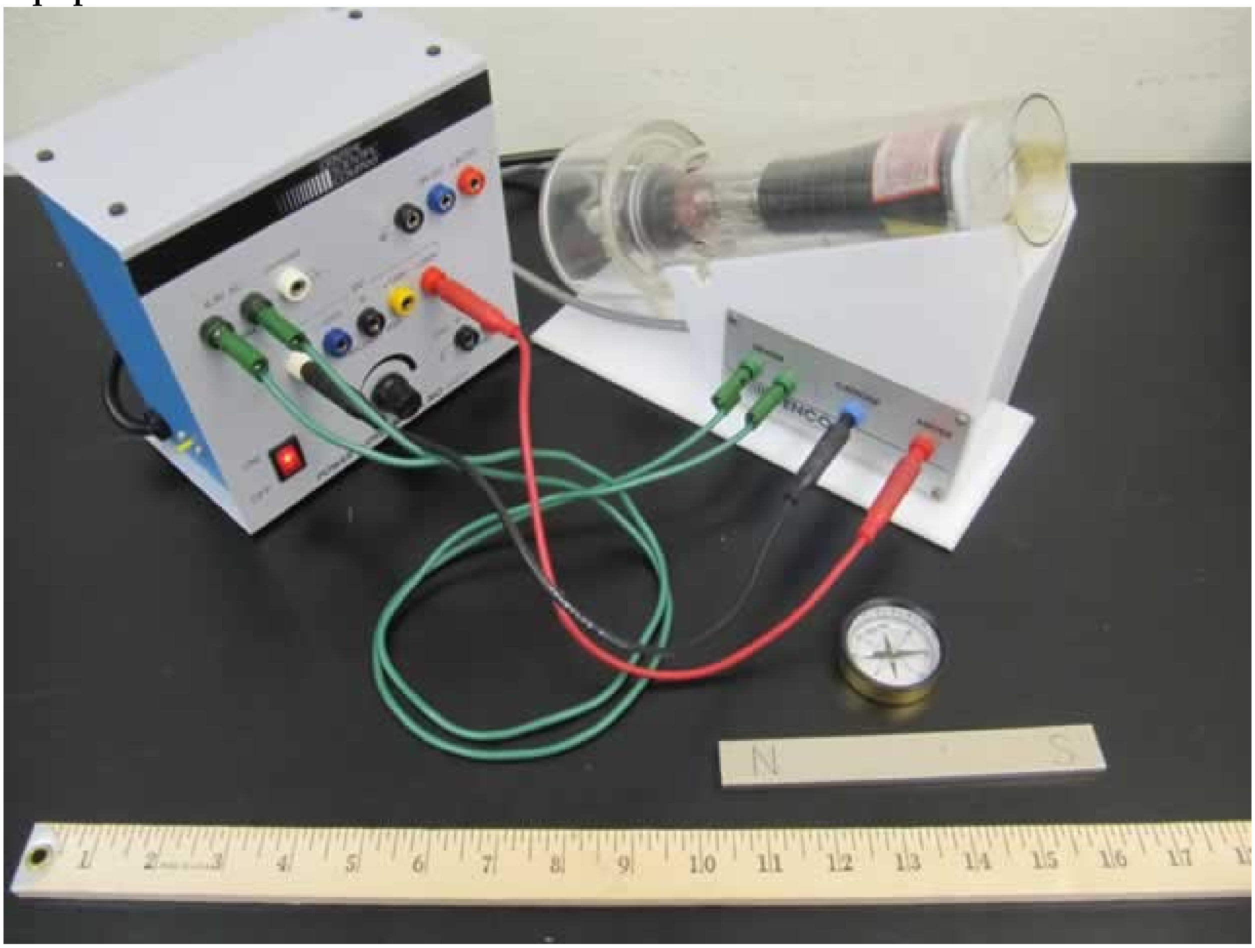


radius =	12.5 cm
separation =	12.5 cm
current =	3 amps
# coils =	200 turns

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

Lab 5 Problem #7: Magnets and Moving Charge

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

Equipment:


- Both the CRT and the CRT power supply are some of our oldest and most used equipment. You will need to be particularly careful using them as they are dangerous and very breakable.

- If one is broken, please send a report to labhelp@physics.umn.edu immediately.

- The CRT power supply has a resettable fuse on its side near the power cord. Most have a yellow button that resets the unit, some have broken off and might need to be reset using a paper clip.

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 devise their own exploration. 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:

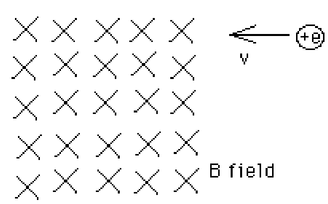
Many of your students believe that if one object exerts a force on another object, that force must point toward (or away from) the object exerting the force. Many of your students will still believe that magnetic poles are the same as electric charges. There are also students who will confuse velocity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

Prediction:

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

???? Discussion Questions: What happens if the groups use multiple magnets? What if they move the magnets along the entire length of the CRT? What if you deflect the beam with the charged plates and a magnet?
???? 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:

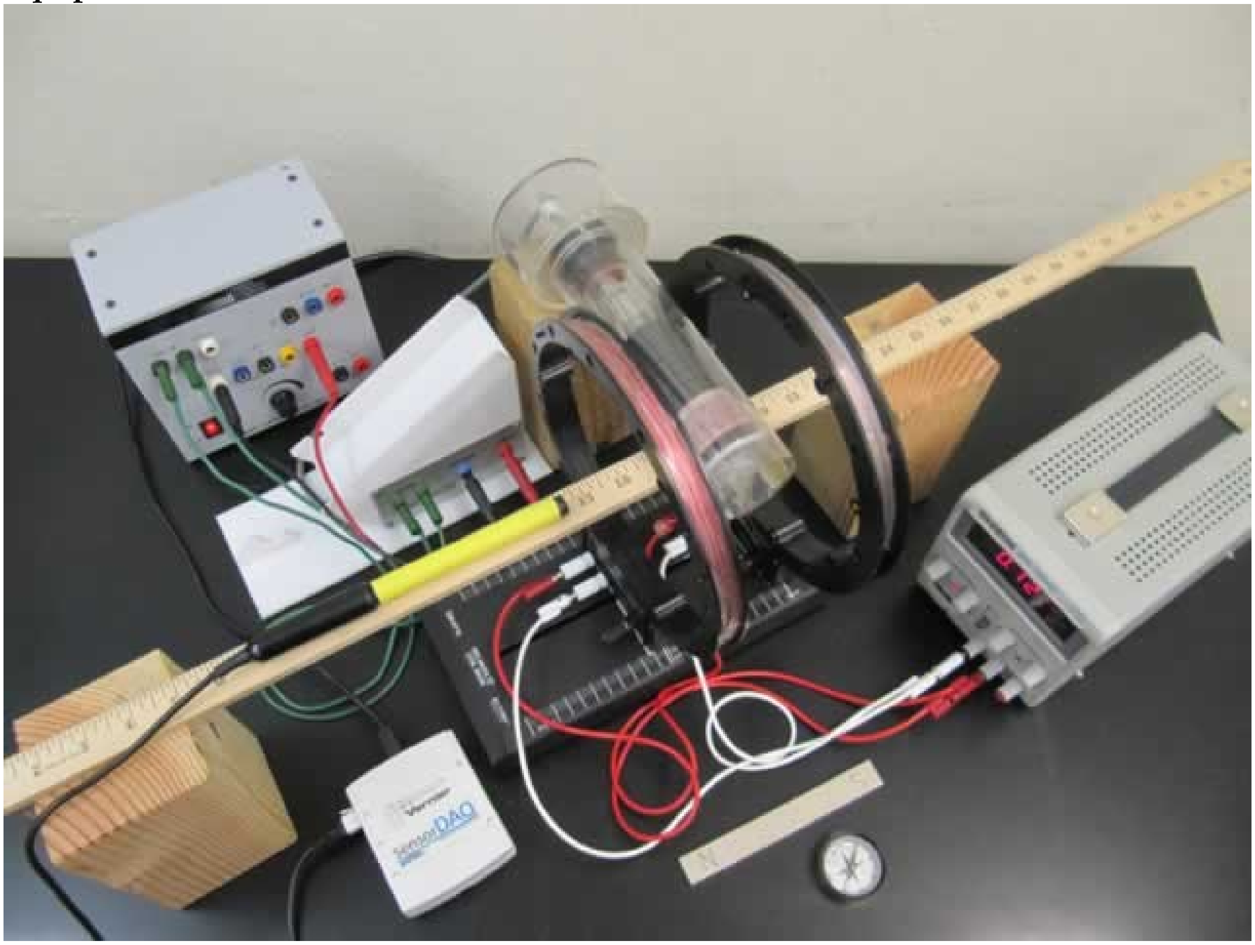


Lab 5 Problem #8: Magnetic Force on a Moving Charge

Purpose:

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

Equipment:



- Both the CRT and the CRT power supply are some of our oldest and most used equipment. You will need to be particularly careful using them as they are dangerous and very breakable.
- If one is broken, please send a report to labhelp@physics.umn.edu immediately.
- The CRT power supply has a resettable fuse on its side near the power cord. Most have a yellow button that resets the unit, some have broken off and might need to be reset using a paper clip.

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 and might hold a residual charge immediately after turning the power supply off.

4. It 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 use the radius of the electron's path to deduce the deflection geometrically. This can be solved exactly, and yields:

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

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 an approximation. This yields:

$$d_2 = \frac{eBL^2}{2mv}$$

(where e is the unit of electric charge, B is the magnetic field strength, L is the length of the CRT, m is the mass of the electron, and v is the velocity of the beam). This solution assumes a parabolic flight path for the electron.

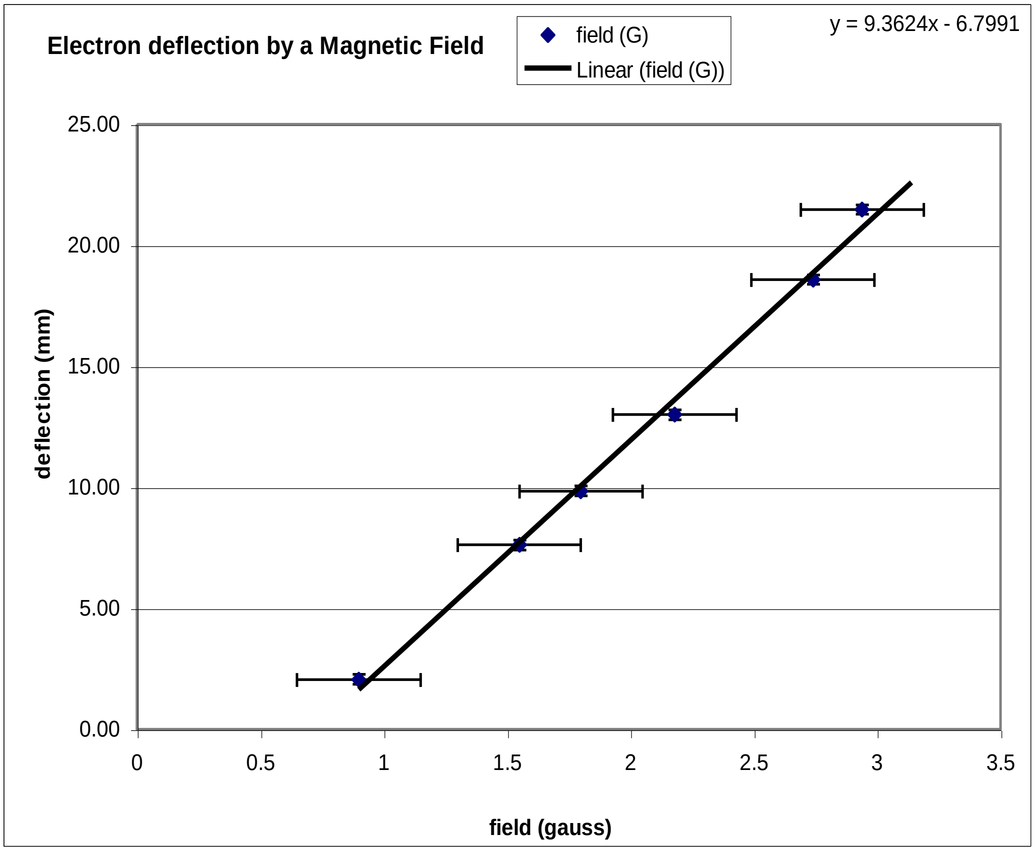
This is not a bad approximation in this case but make sure your students know when they leave that it is an approximation. Make sure they understand how to do this problem correctly and how it differs from the approximation (if they use it).

One can also show that:

$$d_1 = d_2 + \left(\frac{eLB}{mv}\right)^4$$

Data:

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

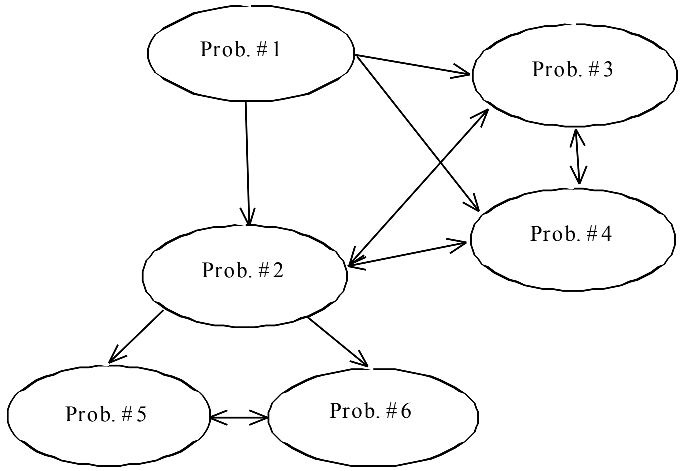


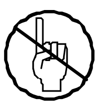
???? Discussion Question: How is the deflection due to a magnetic field different from the deflection due to an electric field?

One answer is that the path of deflection is circular, not parabolic.
Another answer is that magnetic deflection requires motion where electric deflection does not.

Laboratory 6: Electricity from Magnetism

The flow chart for these labs is shown below:





REMINDER: Your students will be working with equipment that can generate large electric voltages. Improper use can cause painful burns and destroy motors. Make sure that your students DO NOT use the higher voltage settings of the power supplies.

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. Another difficulty that students have is that the effect (Induced EMF) depends not on the size of the flux but on its change (time derivative).
- Calculus is still a foreign language to many of your students and they are not confident in its use. That said, this course, if properly taught, should make clear the obvious utility of Calculus. 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. *Dissenting opinion, This is college and students are paying us to learn. Just because a word is “difficult” doesn’t mean it should be avoided at all costs. Nouns and verbs are an essential thing for modern communication. How many children’s toys could be assembled if the directions consisted of instructions like “Put the grey thing in the squiggly hole.”*
- 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. Specifically how to differentiate sine, cosine, and write out what a dot product means.
- 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:

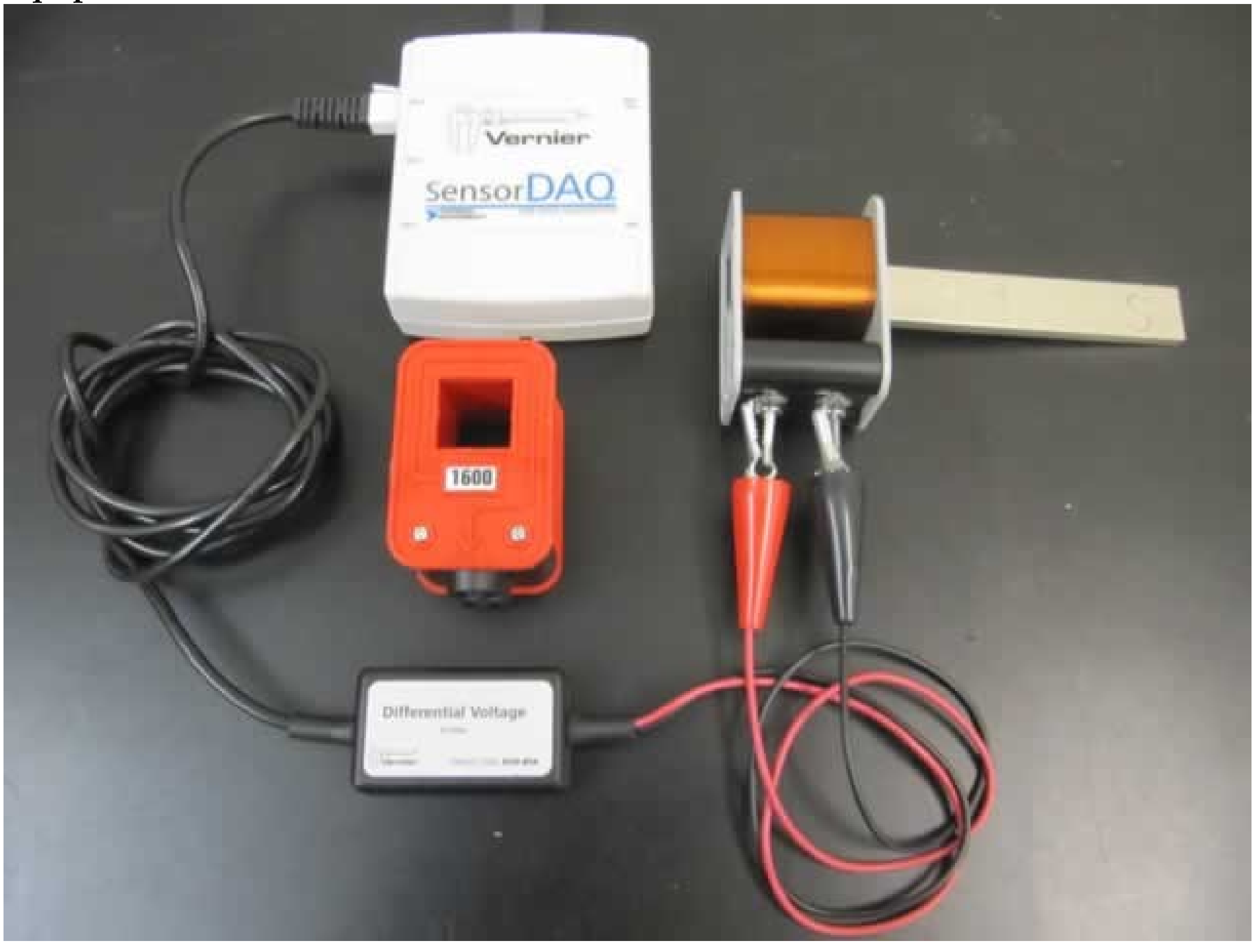
- In order to help your students if they don't notice an effect, determine how fast you must move the magnet through the coil to see a noticeable effect on the VoltageTimeLab screen. How much deflection can you get if the magnet is moved and it does not go through the coil? Try keeping the magnet steady and moving the coil.
- Make sure that you can correctly predict the sign of the induced potential difference as measured by the VoltageTimeLab 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 re-magnetize the magnets just before your lab begins**.

Lab 6 Exploratory Problem #1: Magnetic Induction

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:



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 software 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.

5. VoltageTimeLab should be toggled using the DAQStart and DAQStop buttons to stop the live graph so students can view events. Students will need to work together to achieve this during lab.

6. You might try using the software LoggerPro instead of VoltageTimeLAB. It'll allow you to record data over a designated period of time by clicking the collect button. Whichever software you choose to use, make sure you practice before lab so you can help students having difficulties getting a usable signal.

Difficulties and Alternative Conceptions of Students:

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.

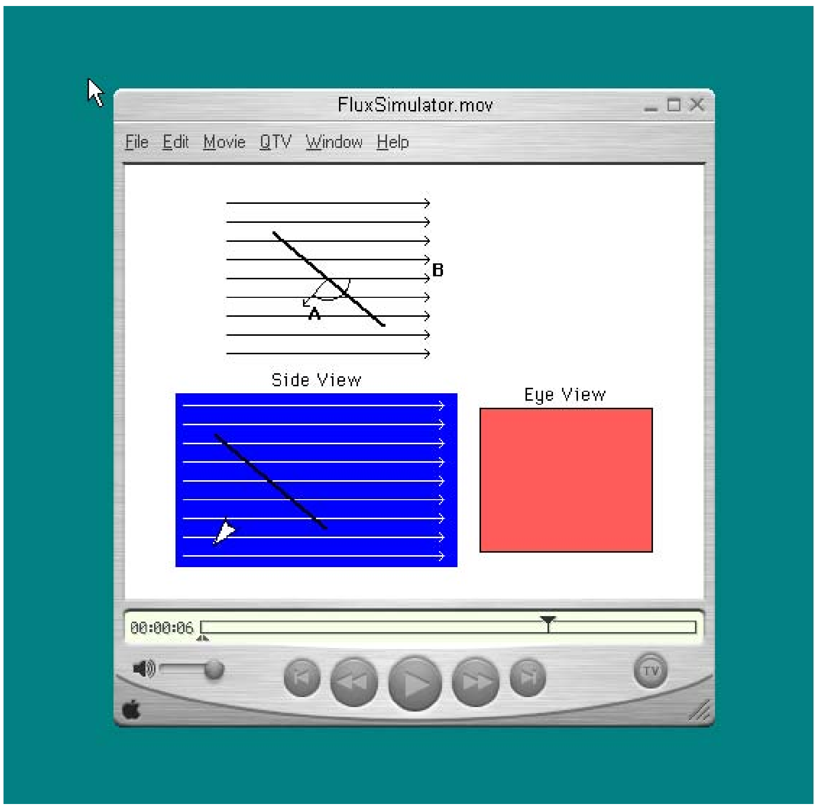
Lab 6 Problem #2: Magnetic Flux

Purpose:

- To use a simple computer simulation to help students visualize how flux depends on the angle of the magnetic field within a coil's area.
- To make the visualization correspond to reality by measuring the amount of magnetic field through a fixed area as the angle between the field vector and the area vector is changed.

Equipment:

The "Flux Simulation" program can be started using the Start menu.   This problem is intended to let the students change the angle of a coil inside a magnetic field and watch how the flux increases or decreases with angle.



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 MagnetLab software, 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 of Students: Many students believe that the flux is the magnitude of the magnetic field. They have difficulty with the concept of adding together all of the magnetic field vectors enclosed by an area. After all, there are an infinite number of points enclosed and each point has a magnetic field vector. To some students, flux implies flow. In this case nothing is changing so how can you have a flux. This misconception may be caused by misinterpreting lines of force. 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.

Warm-up Questions:

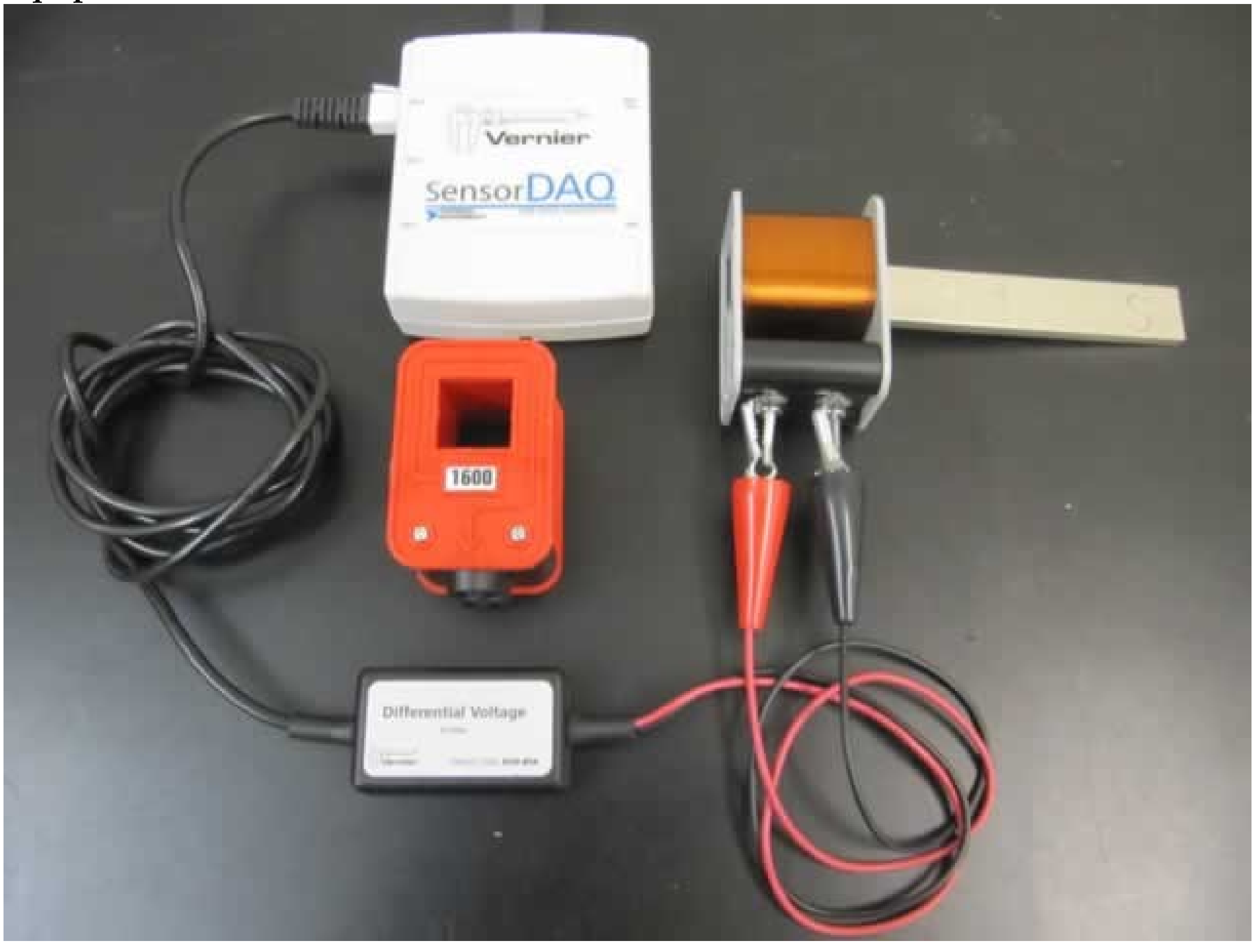
By asking appropriate questions of each group, make sure that the students are making the connection between the objects in the simulation and the objects in the lab.

Lab 6 Problem #3: The Sign of the Induced Potential Difference

Purpose:

- To give students the experience predicting the sign of an electric potential difference produced by changing a 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.

4. VoltageTimeLab should be toggled using the DAQStart and DAQStop buttons to stop the live graph so students can view events. Students will need to work together to achieve this during lab.

1. You might try using the software LoggerPro instead of VoltageTimeLAB. It'll allow you to record data over a designated period of time by clicking the collect button. Whichever software you choose to use, make sure you practice before lab so you can help students having difficulties getting a usable signal.

Difficulties and Alternative Conceptions of Students:

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, students 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:

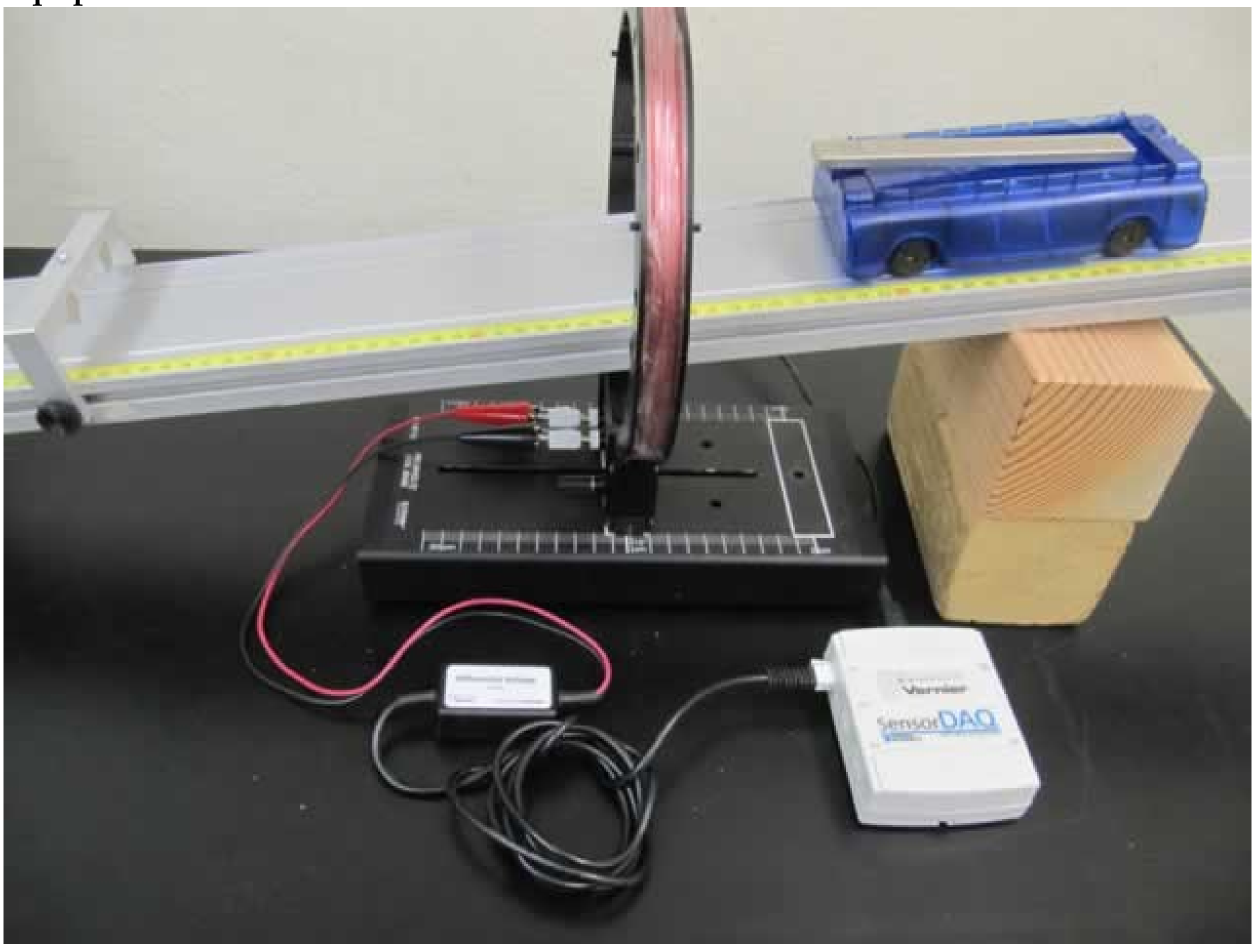
Make sure that students draw good pictures with their predictions. The answer to the prediction is meaningless unless you have a picture showing the arrangement.

Lab 6 Problem #4: The Magnitude of the Induced Potential Difference

Purpose:

- To have students quantitatively connect the magnitude of the produced potential difference to the rate of change of magnetic flux.

Equipment:



Teaching Tips:

1. More than one magnet can be put on the cart for a stronger magnetic field. Magnets should be freshly magnetized for best results.

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. 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.

4. 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).

5. 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 of Students:

Many students will still have many of the misconceptions mentioned in earlier problems. 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:

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

$$\varepsilon = \left[-N\sqrt{2g\sin\theta} \int_A \frac{d\vec{B}}{dx} \square \quad \vec{} \right]$$

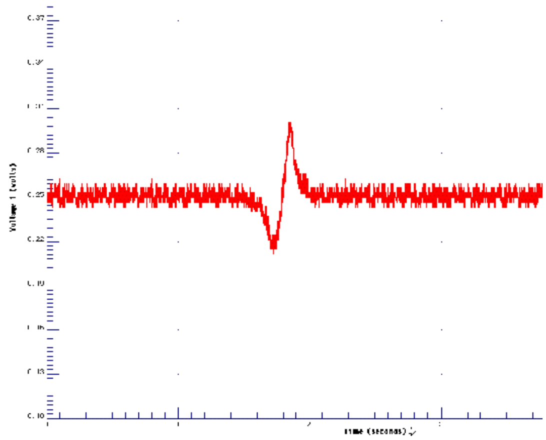
where ε is the induced potential difference across the coil, N is the number of turns in the coil, θ is the angle of inclination of the track, B is the magnetic field of the bar magnet, A is the cross-sectional area of the coil, x is the cart's position as measured from the coil, and d is the cart's 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.

<u>Important Note</u>:

In the exploration section, have the students check if they can read the signal from the LabPro interface.

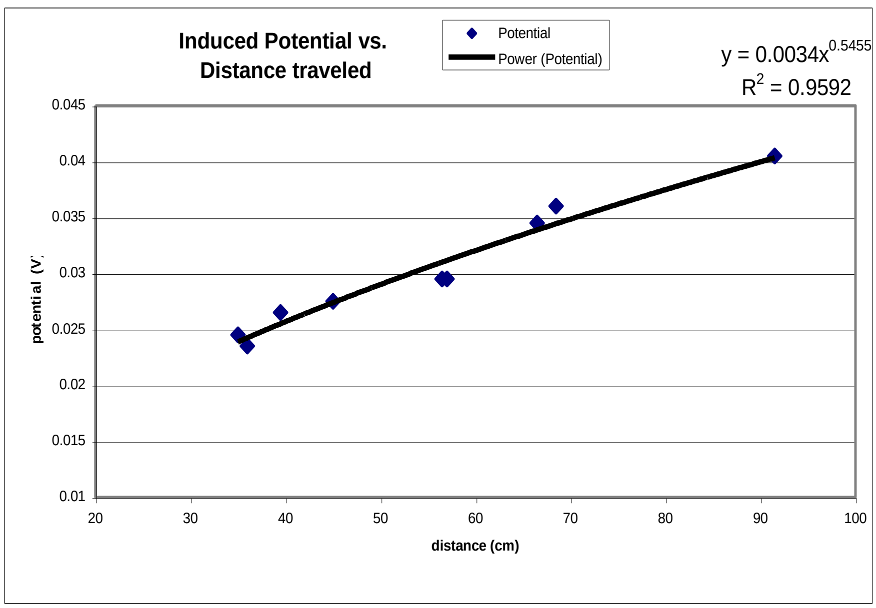
Data:

VoltageTimeLab results:



Graphed 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

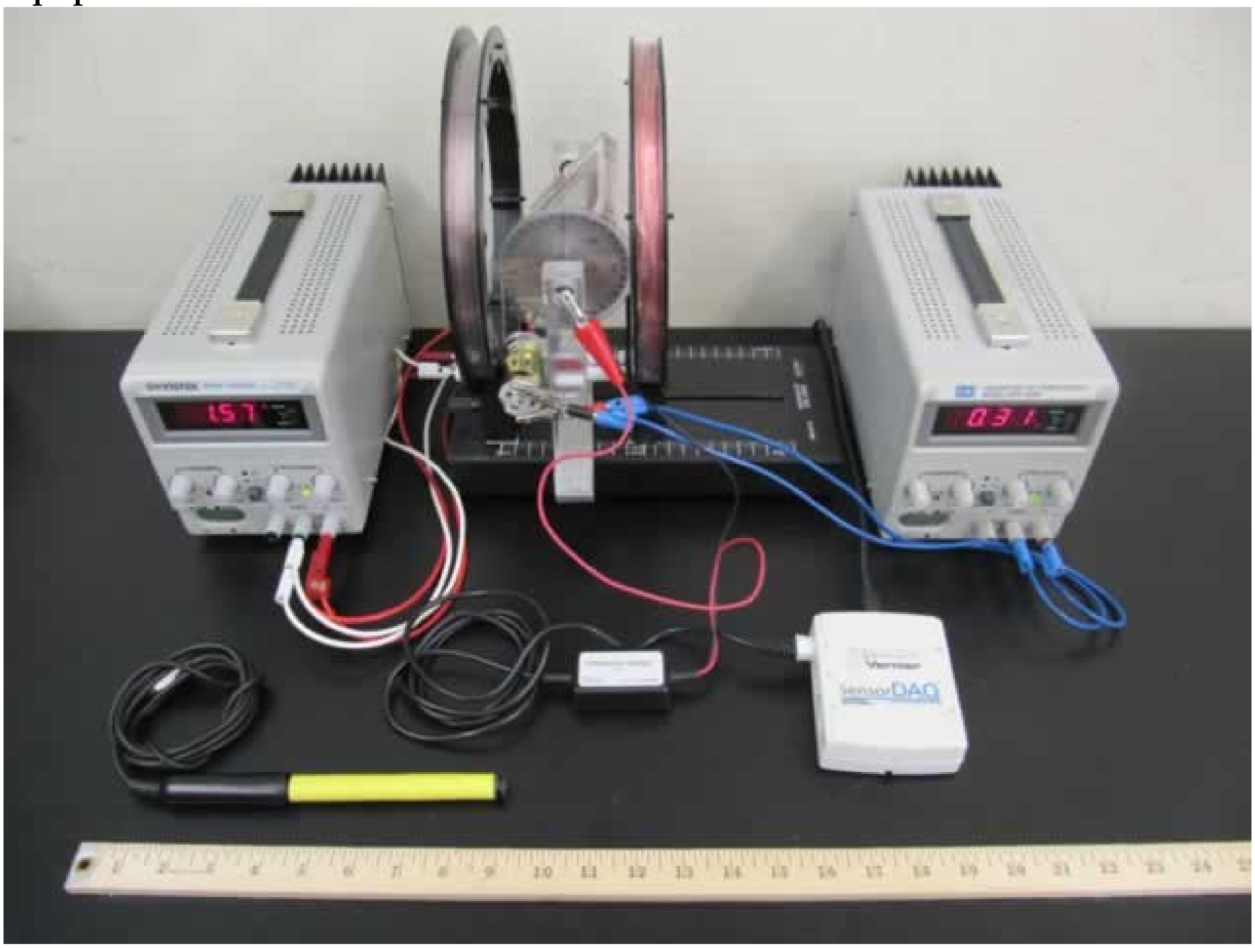


Lab 6 Problem #5: The Generator

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:

1. The motor should be connected to a second 18volt/5amp power supply. The variable 0-5volt DC output of the CENCO CRT supply works, but should be avoided if possible. Increasing the voltage increases the motor speed but too high a voltage could burn out the motor. Keep the motors under 9volts! A rubber belt connects the motor to the spinning coil and is a common point of failure. If you have a bad drive belt, you will need to contact labhelp.

2. The Helmholtz coils should be connected to an 18volt/5amp 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 threaded terminals at the ends along the axis 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. **Make sure the students DO NOT apply any voltage to the small pick-up coil! They will overheat and be destroyed.**

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. 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.

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 of Students:

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. An explanation of "cutting field lines" can lead to additional 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: $\varepsilon = \omega B A n \sin(\omega t)$,

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, 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 (◎) 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.

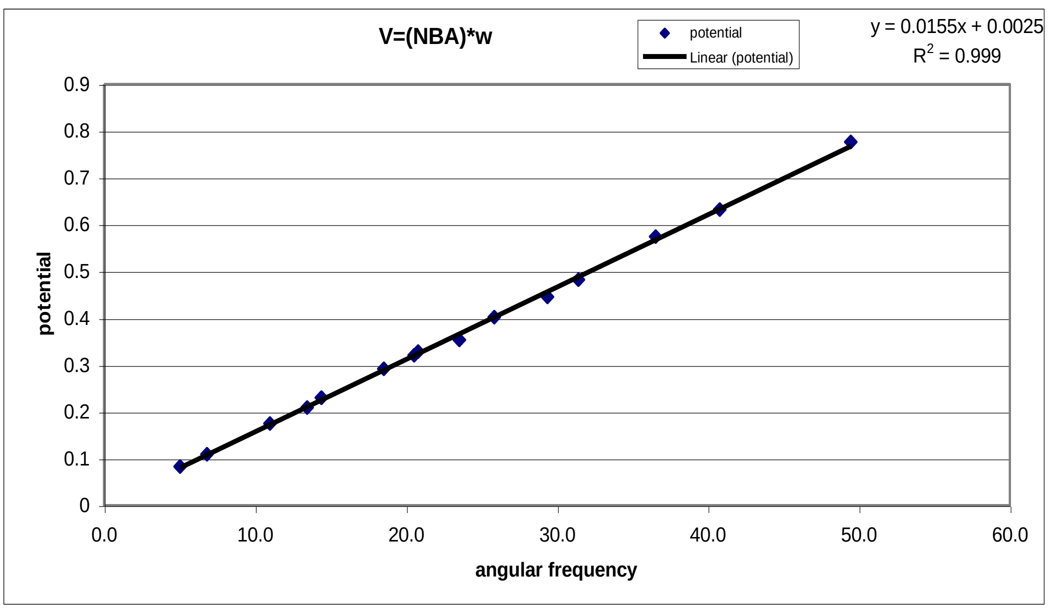
Data:

(data taken with different coils than currently used in the labs!!)

period	w	potential	amplitude	from data pts
0.571	11.0	0.349	0.1745	**NBA=.0155**
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	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:

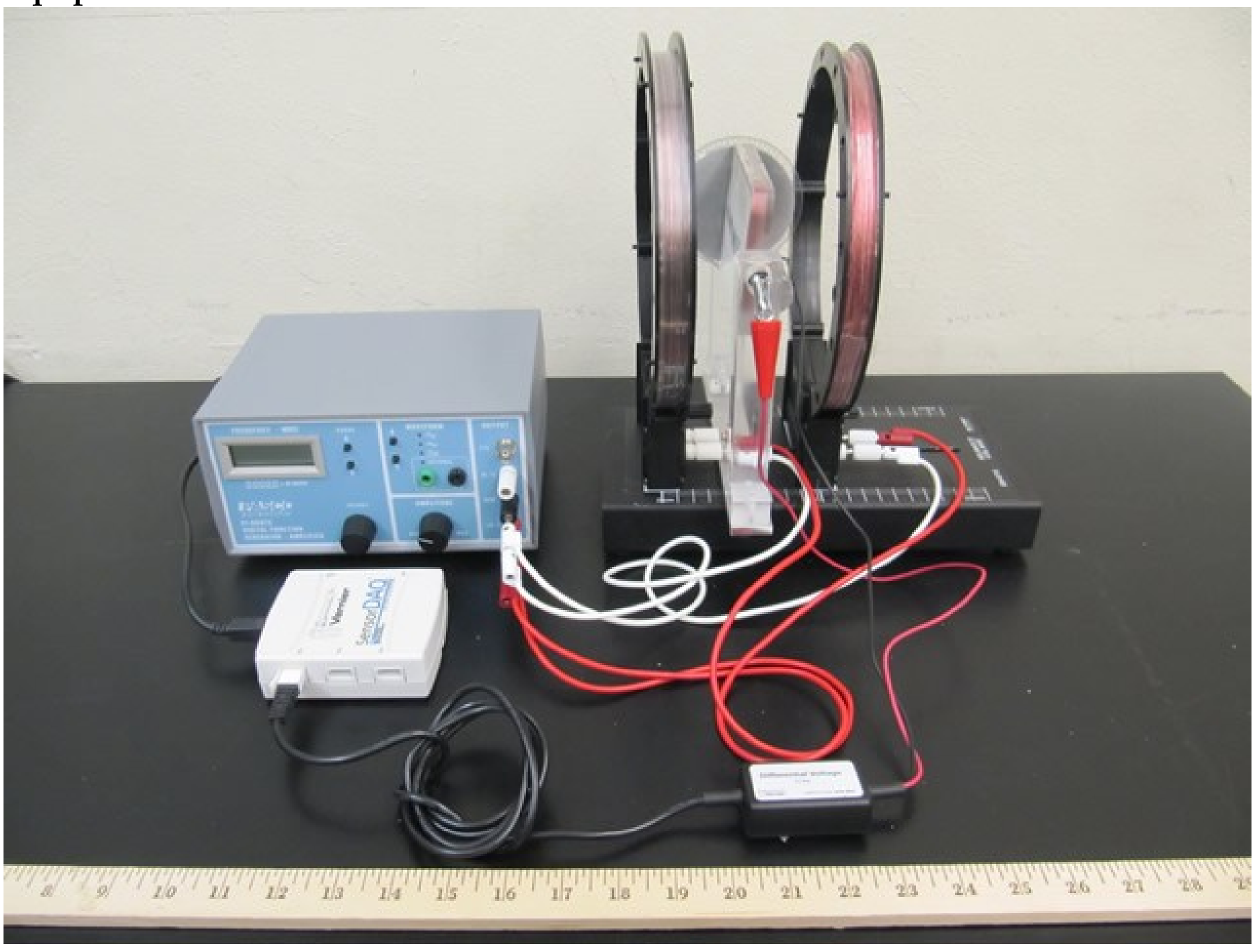
Point out that this generator is the way we get our electricity. You might discuss why turning the coil with an electric motor would not be a useful way of generating electricity. Ask the students if they can think of another energy source that might be used to turn the coil in the magnetic field. One simple answer is a waterfall (hydropower) another is steam (coal or nuclear). Stress that is the fundamental idea of a generator is changing mechanical energy into electrical energy with the use of a magnetic field. Conservation of energy still holds so no energy is gained in the process.

Lab 6 Problem #6: Time-Varying Magnetic Fields:

Purpose:

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

Equipment:



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 an 18volt/5amp 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. There are two threaded terminals at the ends along the axis 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. **Make sure the students DO NOT apply any voltage to the small pick-up coil! They will overheat and be destroyed.**

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 of Students:

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: $\varepsilon = -n\dfrac{d\Phi}{dt}$

The time dependence of the magnetic field is taken to be: $B(t) = B_0 \sin(\omega t + \varphi)$

Hence, the magnetic flux is given by: $\Phi = B_0 A \cos\theta \sin(\omega t + \varphi)$

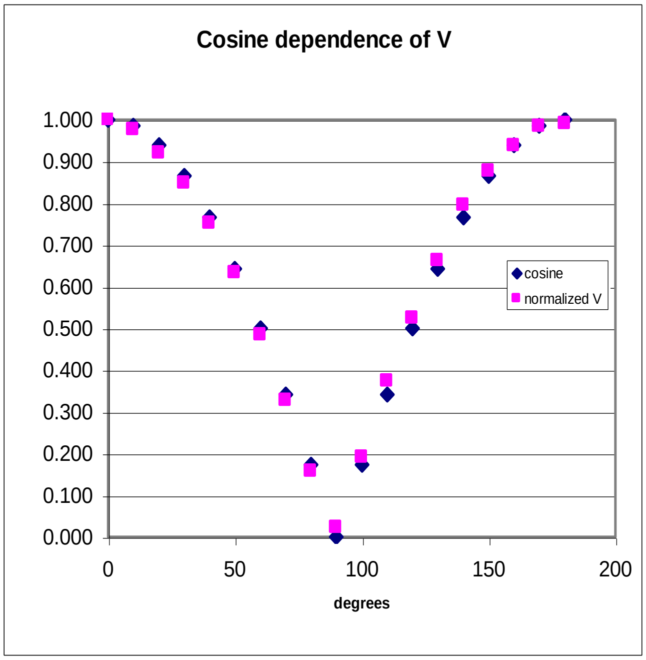
Hence:

$$\boxed{\varepsilon = -B_0 A n \omega \cos\theta \cos(\omega t + \varphi) \text{ and } \varepsilon_{max} = B_0 A n \omega \cos\theta}$$

Data:

(data taken with different coils than currently used in the labs!!)

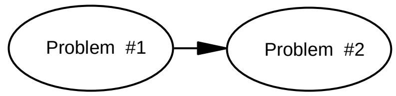
angle	cosine	voltage	normalized V
0	1.000	11.37	1.000
10	0.985	11.091	0.975
20	0.940	10.455	0.920
30	0.866	9.642	0.848
40	0.766	8.547	0.752
50	0.643	7.205	0.634
60	0.500	5.51	0.485
70	0.342	3.709	0.326
80	0.174	1.784	0.157
90	0.000	0.26	0.023
100	0.174	2.172	0.191
110	0.342	4.238	0.373
120	0.500	5.951	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 clearly is proportional to the cosine of the angle its normal makes with the magnetic field

Laboratory 7: Wave Optics

The suggested sequence of problems is:



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

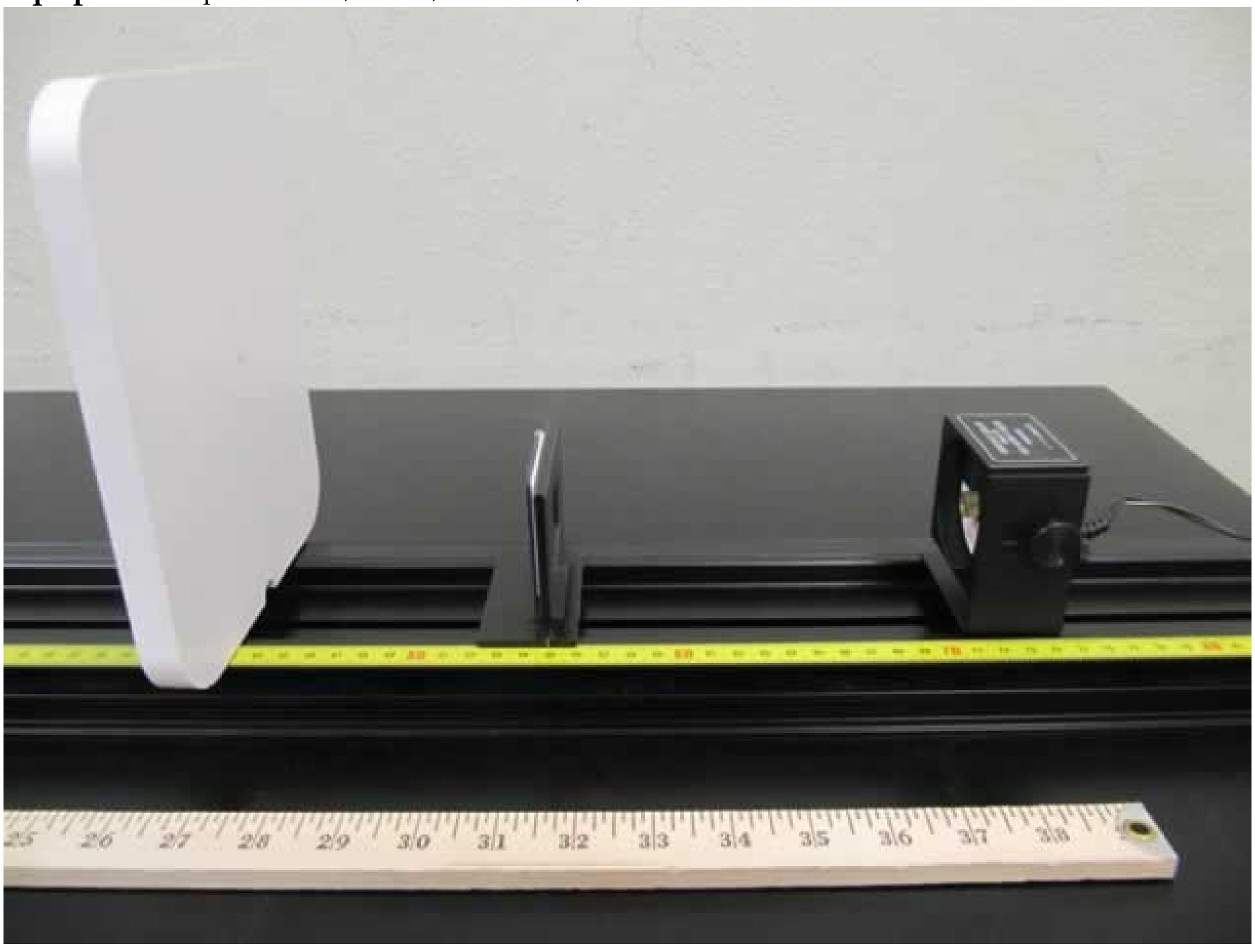
- Qualitatively and quantitatively describe diffraction patterns in terms of constructive and destructive interference and phase differences.
- Predict how changes in the size of an object or slit, or the wavelength of the light, will affect interference patterns.
- Recognize connections between geometrical and wave optics (in problem 1)

Lab 7 Problem #1: Interference Due To a Double Slit

Purpose:

- To explain students the concept of wave interference
- To provide grounds for future explanation of combined picture coming from different wave effects.

Equipment: optical bench, screen, diode laser, slide with double slits and ruler.



Teaching tips:

1. **Laser beams may cause permanent vision impairment or blindness! Warn your students about this. Even laser pointers can cause serious damage. Do NOT allow stray beams in the laboratory – all the beams from lasers should terminate on a screen at all times.**
2. In physics we use terms diffraction and interference interchangeably. In this problem we use the term interference for effects on two slits and diffraction for the ones on individual slits.
3. This is the first lab on wave optics. In the lasers projected image **you will see both** interference from two slits and diffraction on each of them (providing large-scale intensity variations.) It would be helpful if the students notice that (it's seen when slits with the same separation but different slit width are used), but this is not the point of the whole lab. For the first step it would be enough if they understand solidly the formation of diffraction pattern just from double-slit solely.

4. Especially for small distances between the slits and the screen it may be hard to measure the distance between two adjacent maxima. The way around is to count the number of interference maxima within one diffraction maximum (say, the central one), to measure the distance between two outermost of them and divide it by the number of the intervals (# of maxima minus one). This would give a reliable measurement of the displacement of one maximum.
5. One of the possibilities to put a screen farther away is to tape a piece of paper on a neighboring wall and project the fringe on it. (BE CAREFUL! when making marks on the paper one shouldn't turn his head towards the laser!)

Difficulties and Alternative Conception of Students:

- It may seem to students that they are being given a "whole new set of rules" for dealing with light in this set of problems, as opposed to the previous set of geometrical optics problems. It might be helpful for them to discuss similarities and differences between geometrical and wave optics. Such a discussion may serve to bring their confusion into the open, so they can deal with it.
- Students may have problems with the trigonometry and geometry involved in these problems, or with the requirement that "m" is integer (or half-integer) for an interference maximum (or minimum).

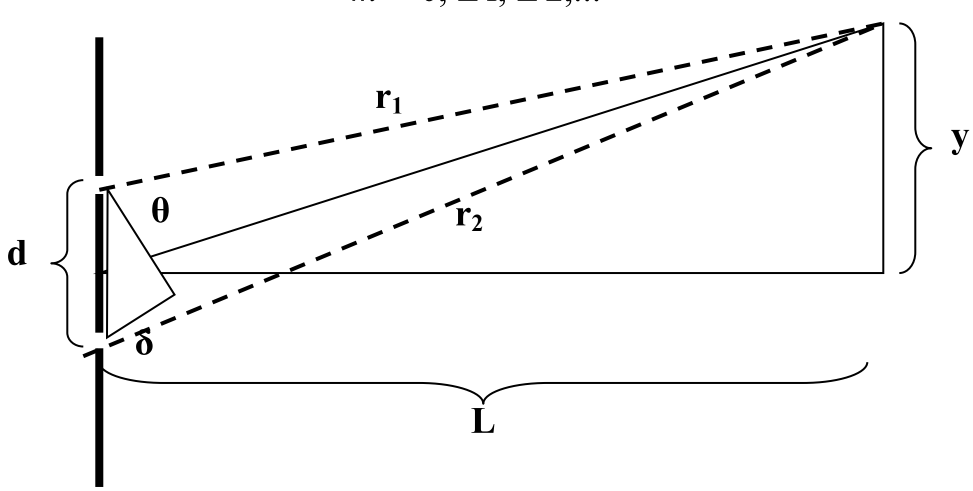
Prediction and Warm-up Questions:

The distance *y* is measured from the center to a point of maximum or minimum brightness ("bright" or "dark" fringes).

$$y_{bright} = \frac{\lambda L}{d} m$$

$$y_{dark} = \frac{\lambda L}{d}\left(m + \frac{1}{2}\right)$$

$$m = 0, \pm 1, \pm 2, \ldots$$



The path difference for the light rays passing through the slit is $\delta = r_2 - r_1 = d\sin\theta$, which is approximately $= d\,y/L$ for a small angle.

This expression works in the limit L>>d, which assumes the light rays are nearly parallel ($\sin\theta$ approximately same as $\tan\theta$).

Sample Data:

HeNe laser - λ = 632.8 nm.

d, mm	a, mm	L, m	$\#_{maxima}$	dist, mm	λ, nm
0.25	0.08	1	5	10.5	656
0.25	0.04	1	10	23.5	653
0.5	0.08	0.5	12	7.5	682
0.5	0.04	0.5	22	13	619
0.25	0.08	0.5	7	7.5	625
0.25	0.04	0.5	13	15	625

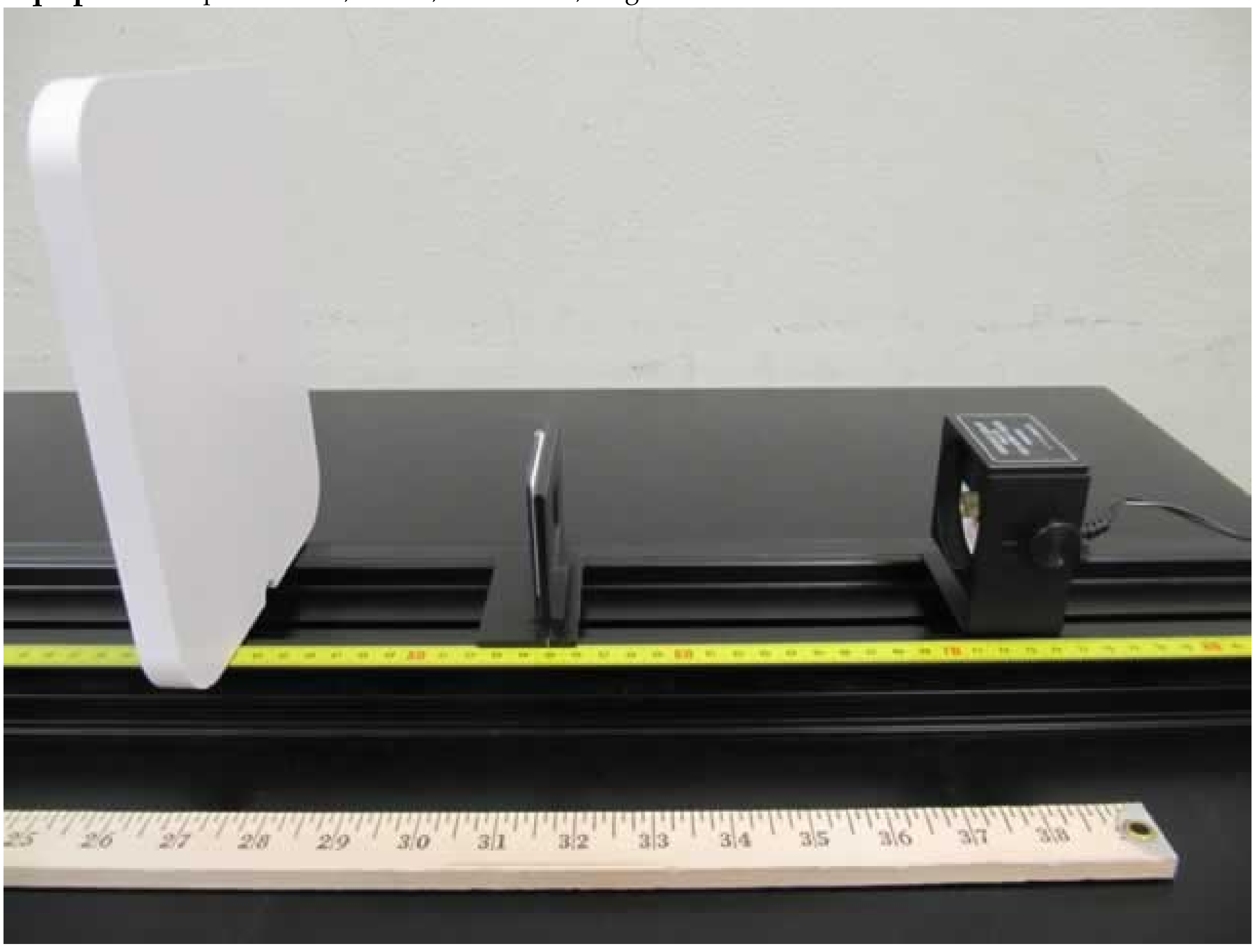
$\#_{maxima}$ is the number of observed interference maxima within central diffraction maximum, dist is the distance between two outermost maxima.

Lab 7 Problem #2: Interference Due to a Single Slit

Purpose:

- To give students an example of diffraction, illustrating the concept of interference of waves arriving with different phases from different points of the wave front.
- To build a connection between diffraction on small holes and diffraction on small objects.
- To teach students how to isolate different effects in a resulting fringe.

Equipment: optical bench, screen, diode laser, single slit slide and ruler.



Teaching tips:

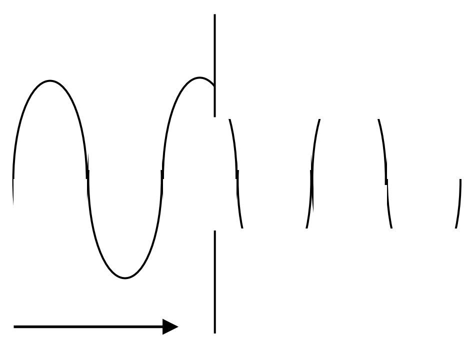
1. **Laser beams may cause permanent vision impairment or blindness! Warn your students about this. Even laser pointers can cause serious damage. Do NOT allow stray beams in the laboratory – all the beams from lasers should terminate on a screen at all times.**
2. The central maximum is a mess. The students should get as many side maxima as possible and measure the distance between the outermost ones (on one side) and divide it by the number of the intervals (# of maxima minus one). This would give an accurate measurement of the displacement of one maximum (since they are equidistant).
3. It is important to get a diffraction pattern from a hair. This would justify the use of diffraction on a slit as a model to the diffraction on small bodies like viruses. It also reinforces the notion that you get

wave effects all the time when the light source is coherent and the size of the object is comparable to the wavelength.

4. For the diffraction on a hair you will see a usual diffraction pattern and a small fringe around the central maximum. This is probably due to the diffraction of the whole beam on a sharp edge (the edge of the hair).
5. It's convenient to put a piece of tape on one side of the hair – to make it heavier and stretch in vertical direction.
6. It is also useful to put a double slit explored in the previous problem and compare the resulting fringes. By now the students should be able to tell which parts of it are coming from interference on the double slit, and which – from the diffraction on each slit individually.

Difficulties and Alternative Conceptions of Students:

- Some students may be confused by a common representation of a wave going through a slit, which they may interpret to show that light with a "wave amplitude" greater than the slit width a would be "chopped off" and somehow not make it through the slit. (See diagram below.) (These students must not understand that the amplitude of the electric or magnetic field is in a completely different dimension than the spatial width of the slit.) Warm-Up question 8 should allow you to diagnose this misconception.
- Students may have difficulty understanding how "objects" and "holes" could cause similar diffraction patterns



Prediction and Warm-Up Questions:

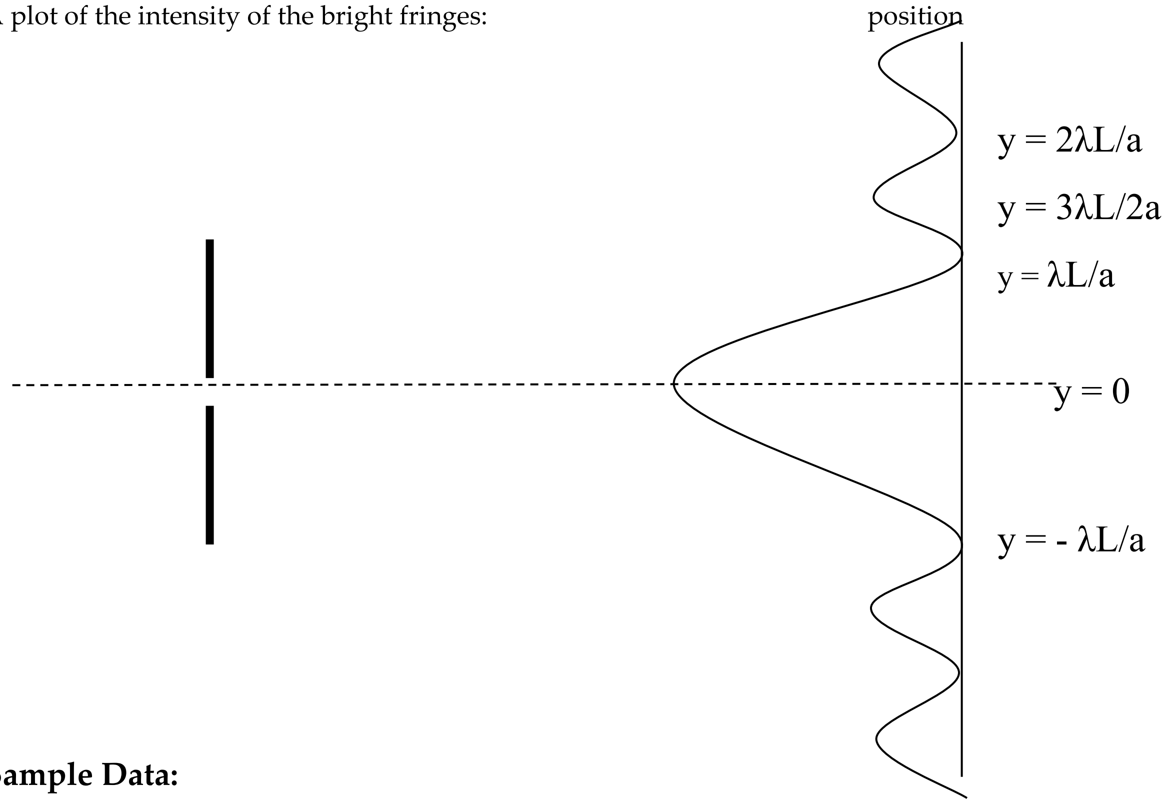
The distance y is measured from the center to a point of minimum brightness ("dark" fringes).

$$y_{dark} = \frac{\lambda L}{a} m$$
$$m = \pm 1, \ \pm 2, \ldots$$

Where a is the width of the single slit.
This expression works in the limit L>>a.

Approximate that each bright fringe peak lies halfway between its bordering dark fringe minima.

For the diffraction on a hair ***a = λmL/y*** .
A plot of the intensity of the bright fringes:



Sample Data:

HeNe laser - λ = 632.8 nm.

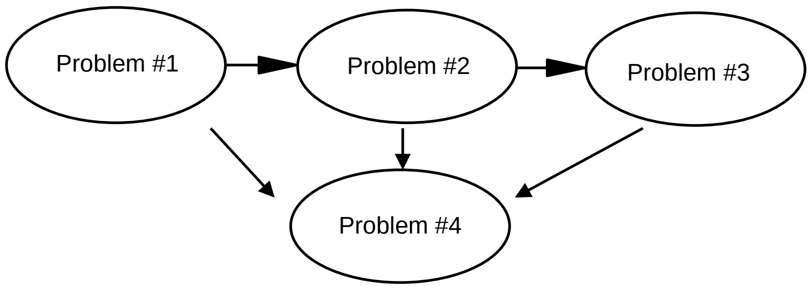
a, mm	L, m	$\#_{maxima}$	dist, mm	λ, nm
0.02	1	3	66	660
0.04	1	2	17	680
0.08	1	3	16.5	660
0.16	1	5	17	680
0.02	0.5	2	17	680
0.04	0.5	3	16	640
0.08	0.5	4	12	640
0.16	0.5	6	10	640

$\#_{maxima}$ is the number of observed diffraction maxima on one side of the central one, dist is the distance between two outermost within one sample.

For the diffraction on a hair, L = 1 m, $\#_{maxima}$ = 5, dist = 24 mm, assuming λ = 633 nm the diameter of the hair is a ≈ 0.1 mm.

Laboratory 8: Radioactive Decay

The suggested sequence of problems is:



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

- Qualitatively and quantitatively describe the process of radioactive decay.
- Understand uncertainty and be able to specify uncertainties for random events.
- Understand the law of radiation decrease with distance.
- Recognize the physics of radiation shielding, knowing the differences for shielding of different types of radiation.
- Understand half-life.

Things to check before teaching the lab:

- It would be useful for you to know how to operate the Radiation Monitor in conjunction with the LabPro interface, and how to access the Logger Pro radiation data acquisition software.

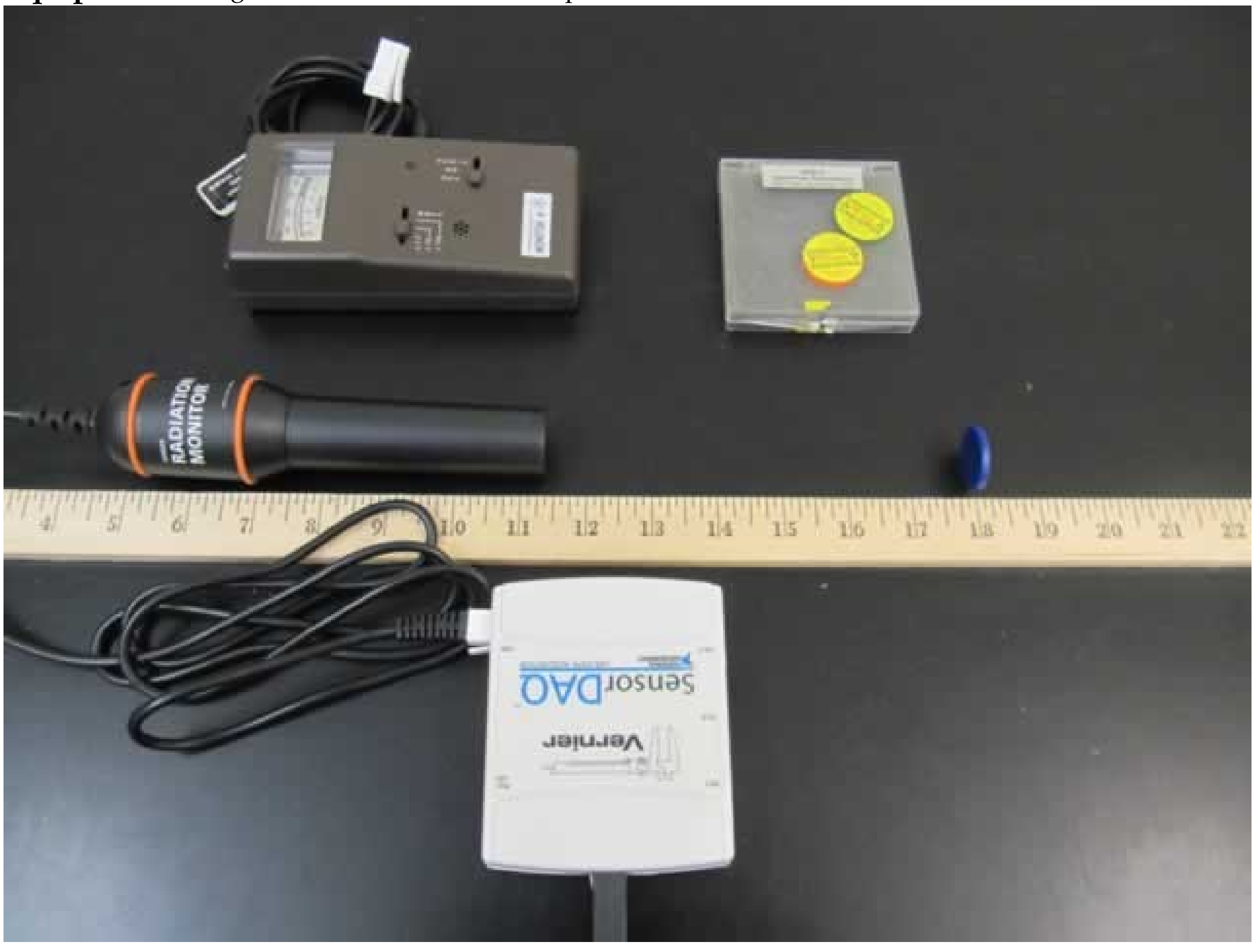
<u>**Caution:**</u> **We are using low-intensity radioactive sources, but they are still radioactive and need proper caution when handled. Don't allow your student to take them out of the room or play with them.**

Lab 8 Problem #1: Distance from Source

Purpose:

- To introduce students to the equipment they will be using later in the lab.
- To make them think about the physics of radiation detection.
- To elucidate the meaning of "error" in a measurement.
- To give an example of the inverse-square behavior.
- To give students some practice with graph analysis.

Equipment: Geiger counter, radioactive samples, ruler.



Teaching tips:

1. The sources of radiation should be put with their label down.
2. When doing all the measurements try to integrate (record counts) long enough, so that the counts level would be well above the background.
3. Don't forget to subtract the background!
4. The software used is Logger Pro. To open the module associated with your experiment go to File->Open, choose the Probes & Sensors folder, choose the Radiation Monitor folder, and then

choose the appropriate module. There are modules for radiation counts vs. distance, counts vs. shielding type, and counts vs. shielding thickness.

Difficulties and Alternative Conception of Students:

- Some students have troubles working with graphs, changing the scale on the axis (usual, log, inverse square, etc) and making sense out of it. This is a good practice for them to get the understanding of how you support or discard specific type of behavior that you expect for the quantity.

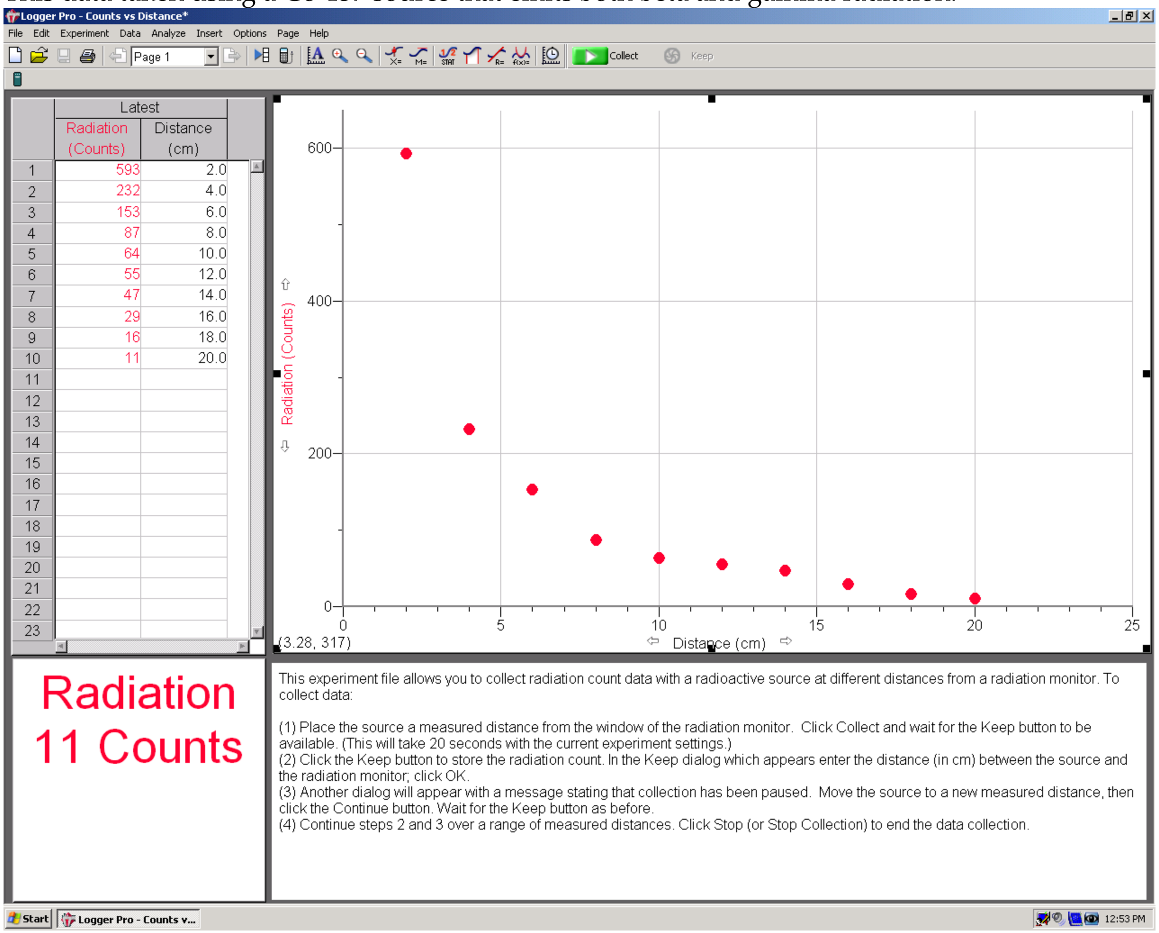
- The inverse square law is common in physics, so this is a good opportunity for the students to understand where it is coming from, and to check it.

Warm-up:

$$\#counts \sim 1/distance^2$$

Sample Data:

This data taken using a Co-137 source that emits both beta and gamma radiation.



Note: the background radiation value should be subtracted from the count values when doing further analysis.

Lab 8 Problem #2: Shield Position

Purpose:

- To make the students think about the physics of radiation shielding.
- To show them the effectiveness of shielding of different types of radiation.

Equipment: Geiger counter, a set of calibrated absorbers, radioactive samples, ruler..

Teaching Tips:

1. This is more or less qualitative lab, but it can give some insights into the physics of shielding process. If it were pure absorption, the flux shouldn't depend on the position of the shield (it's just a multiplicative factor), but there clearly is an effect. It works both for gamma- and beta- radiation, so it should be related either to the particles scattered at large angles that make it to the detector or/and to the secondary radiation (primarily bremsstrahlung soft X-rays).

2. It worth noting for the students (just comparing the counts) how effectively different types of radiation are shielded by different materials.

3. The data points that have been shielded to the background level were excluded from the graph analysis (in the sample data).

4. The software used is Logger Pro. To open the module associated with your experiment go to File->Open, choose the Probes & Sensors folder, choose the Radiation Monitor folder, then choose the appropriate module. There are modules for radiation counts vs. distance, counts vs. shielding type, and counts vs. shielding thickness.

Difficulties and Alternative Conceptions of Students:

- There could be misconceptions about which position of the shield would be more "effective". People may argue it both ways, but if it were to be pure absorption, it shouldn't make any difference at all.
- It may be hard to understand what difference the type of shielding makes (absorption vs scattering).
- It also may be difficult for the students to imagine how the particles are deflected into the detector, as well as how the size of the "emitting spot" on the surface of the shield changes with distance to the detector and to the source.

Warm-up Questions:

For pure absorption the amount of radiation shouldn't depend on the distance to the shield.

$$(I_0 * \alpha) * 1/(d^2) = (I_0/(d^2)) * \alpha$$

where α is a fraction of flux transmitted by the shield, I_0 is the flux at the source, d is the distance between the source and the detector. For scattering you may expect to see some more particles from a remote screen, since the size of the "spot" of scattered particles on the surface of the shield seen by the detector should increase when the distance to the detector increases and the distance to the source decreases (more particles coming at acute glancing angles to the shield, increasing the "depth" of scattering along the travel path and allowing for the large-scatter-angle particles still to make it to the detector).

Sample Data:

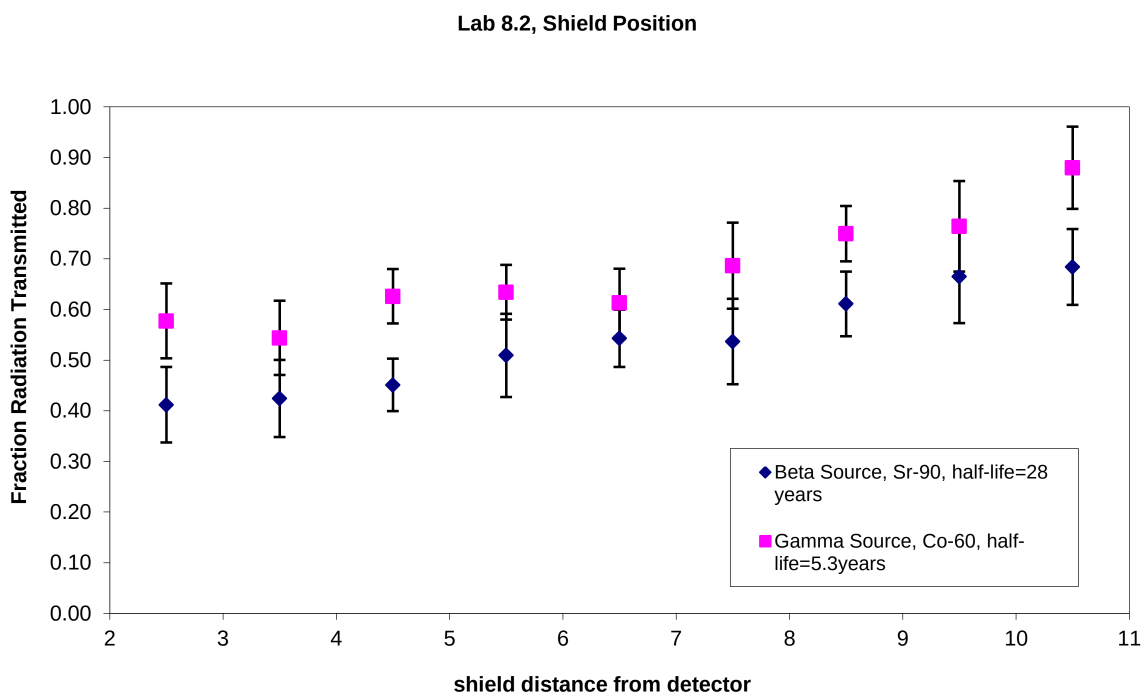
Background sampled at 0.65 counts/second, distance to center again estimated to be 1.5cm.

Beta Source, Sr-90

R	R (corrected)	counts	time	Counts/second	error	fraction transmitted	error
No shield		338	20.13	16.14	1.83	1.00	0.11
1	2.5	146	20.01	6.65	1.21	0.41	0.07
2	3.5	149	19.88	6.85	1.23	0.42	0.08
4	5.5	178	20.07	8.22	1.33	0.51	0.08
6	7.5	188	20.19	8.66	1.36	0.54	0.08
8	9.5	236	20.73	10.74	1.48	0.67	0.09
9	10.5	374	31.99	11.04	1.21	0.68	0.07
7	8.5	418	39.76	9.87	1.03	0.61	0.06
5	6.5	424	45.03	8.77	0.91	0.54	0.06
3	4.5	359	45.28	7.28	0.84	0.45	0.05

Gamma Source, Co-60

R	R (corrected)	counts	Time	counts/second	error	fraction transmitted	error
No shield		2091	245.41	7.87	0.37	1.00	0.05
1	2.5	318	61.25	4.54	0.58	0.58	0.07
2	3.5	293	59.44	4.28	0.58	0.54	0.07
3	4.5	698	125.19	4.93	0.42	0.63	0.05
4	5.5	704	124.86	4.99	0.43	0.63	0.05
5	6.5	431	78.72	4.83	0.53	0.61	0.07
6	7.5	328	54.19	5.40	0.67	0.69	0.08
7	8.5	928	141.71	5.90	0.43	0.75	0.05
8	9.5	360	54.03	6.01	0.70	0.76	0.09
9	10.5	560	73.94	6.93	0.64	0.88	0.08



Lab 8 Problem #3: Shield Thickness

Purpose:

- To show students the underlying physics of radiation shielding, including the difference between shielding of different types of radiation.
- To build a connection with the decay equation – probably, the only equation in the radioactive decay that they will learn from lectures.
- To teach students how to use graphic analysis to support or discard specific hypotheses of quantitative behavior.

Equipment: Geiger counter, radioactive samples, a set of calibrated absorbers

Teaching tips:

1. You may expect to see an exponential for the shielding of gamma-rays, since it is mostly happening locally on electrons. Since the beta-particles (electrons) are charged, they are Coulomb interacting with a big piece of shielding material simultaneously (non-locally) continuously loosing energy and producing the bremsstrahlung (braking radiation). Hence, it should not look exponential, and the data shows the deviation from an exponential behavior.
2. For a good measurement you need a high number of counts..

3. The samples in the calibrated absorbers set (thickness given in inches) are not enough to shield gamma effectively. For gamma the way out is to use extra shields made of sheet lead of 2 mm thickness. You can pile them on something other (we used a thin aluminum shield out of calibrated sample). Just make sure that your "zero-point" would be measured with that extra screen on place.
4. An easy way to see exponential behavior is to take a minus log of a ratio of number of counts over an unshielded value (in this case still including the auxiliary screen).
5. The software used is Logger Pro. To open the module associated with your experiment go to File->Open, choose the Probes & Sensors folder, choose the Radiation Monitor folder, then choose the appropriate module. There are modules for radiation counts vs. distance, counts vs. shielding type, and counts vs. shielding thickness.

Difficulties and Alternative Conceptions of Students:

- Some students may have troubles arriving at the shielding equation (the exponential).
- Many people may have hard time connecting the passage of radiation through absorbing material to the nuclear decay process. This is important, first because it gives a better insight into the derivation of one of the most common laws in physics, and second because it helps them to understand probably the only equation in radioactive decay they are likely get in lectures. Some students may have troubles arriving at the shielding equation (the exponential).

Warm-Up Questions:

For the scattering on individual small centers (not accounting for re-scattering) the intensity should drop as an exponential in thickness:

$$I = I_0 e^{-d/d_o}$$

where *d* is the thickness, *do* is the characteristic length of absorption, related to the scattering probability.

Sample Data:

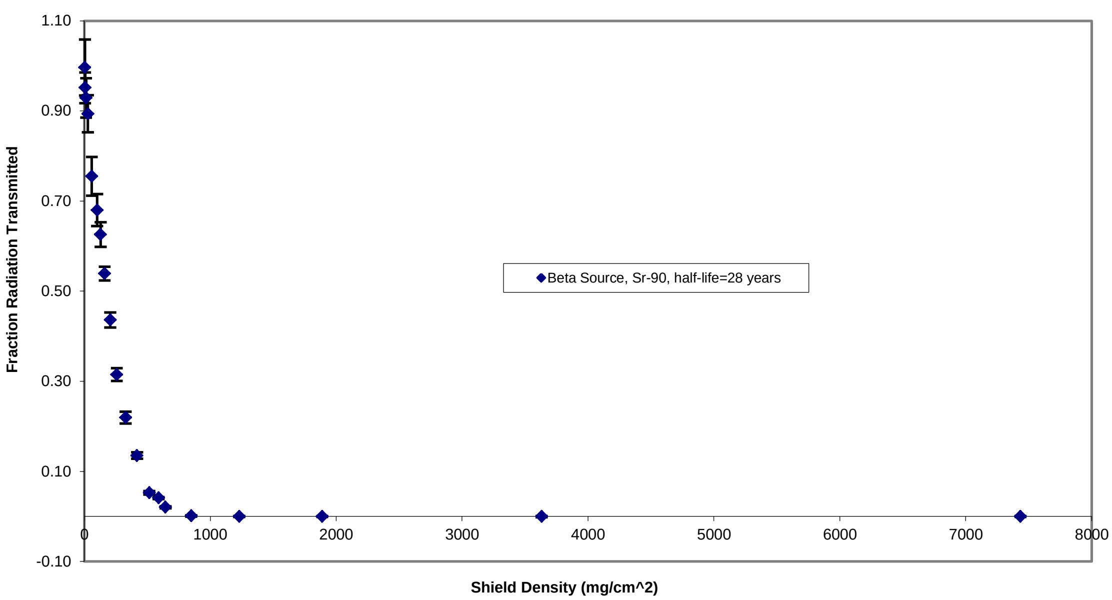
Background estimated 0.69 counts/second. Again use 1.5cm distance to center of detection. Data is from beta source, Sr-90.

Counts	time	counts/second	error	fraction transmitted	error	shield density (mg/cm^2)	shield material
21593	133.18	161.44	2.21	1.00	0.01	0	
77	113.96	-0.02	0.15	0.00	0.00	7435	Pb
36	54.49	-0.04	0.22	0.00	0.00	3632	Pb
57	81.88	0.00	0.18	0.00	0.00	1890	Pb
45	66.33	-0.02	0.20	0.00	0.00	1230	Pb
59	66.08	0.20	0.23	0.00	0.00	849	Al
590	147.7	3.30	0.33	0.02	0.00	645	Al
1530	209.52	6.61	0.37	0.04	0.00	590	Al
772	84.01	8.49	0.66	0.05	0.00	516	Al
1530	68.03	21.79	1.15	0.13	0.01	419	Al
1170	32.38	35.44	2.11	0.22	0.01	328	Al
1957	37.98	50.83	2.33	0.31	0.01	258	Al
2788	39.22	70.39	2.69	0.44	0.02	206	Al
5147	58.68	87.02	2.45	0.54	0.02	161	Al
2122	20.86	101.03	4.42	0.63	0.03	129	Al

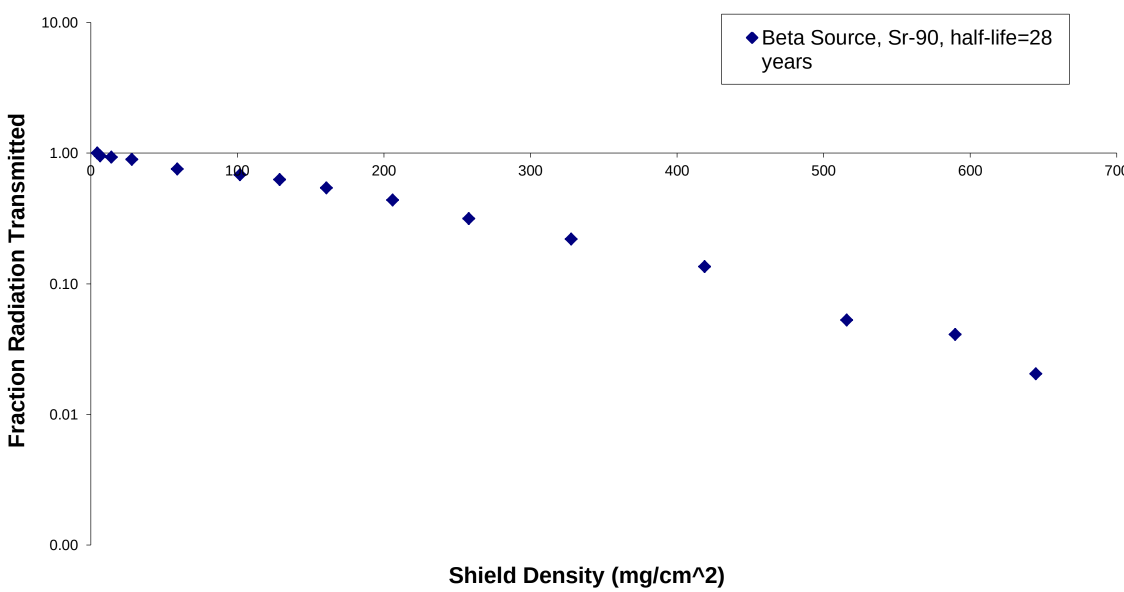
1469	13.3	109.75	5.76	0.68	0.04	102 Plastic
1248	10.18	121.90	6.94	0.76	0.04	59.1 Plastic
1900	13.11	144.23	6.65	0.89	0.04	28.1 Poly
1815	12.05	149.93	7.07	0.93	0.04	14.1 Poly
3160	20.48	153.60	5.49	0.95	0.03	6.5 Foil (Al)
1042	6.45	160.85	10.01	1.00	0.06	4.5 Foil (Al)

Exponential decay is clearly seen, small deviation from re-scattering is apparent at high shield density (>400 mg/cm^2).

Lab 8.3, Shield Thickness



Lab 8.3, Shield Thickness



Lab 8 Problem #4: Half-life

Purpose:

- To explore the concept of half-life.

Equipment:

Teaching Tips:

Discuss the concept of half-life is a bit hard at the start: a good demonstration involves a collection of pennies. Drop the pennies on the table or floor, and roughly half of the pennies will be heads and the rest of them will be tails. Consider the heads radioactive and the tails decayed. Pick up the remaining heads and drop them. Once more, about half of these pennies will be heads and the rest will be tails. Pick up the heads and continue until just one or two of the pennies are heads. This simulates the half-life: with each drop (or each half-life), about half of the pennies decayed to tails. In each of the subsequent drops, about another half of the remaining pennies decayed to tails.

Difficulties and Alternative Conceptions:

The most common difficulty is that some, or if not most, of your students will need assistance with logarithmic calculations and graphing – the use of computers will make this much easier.

Warm-Up Questions:

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

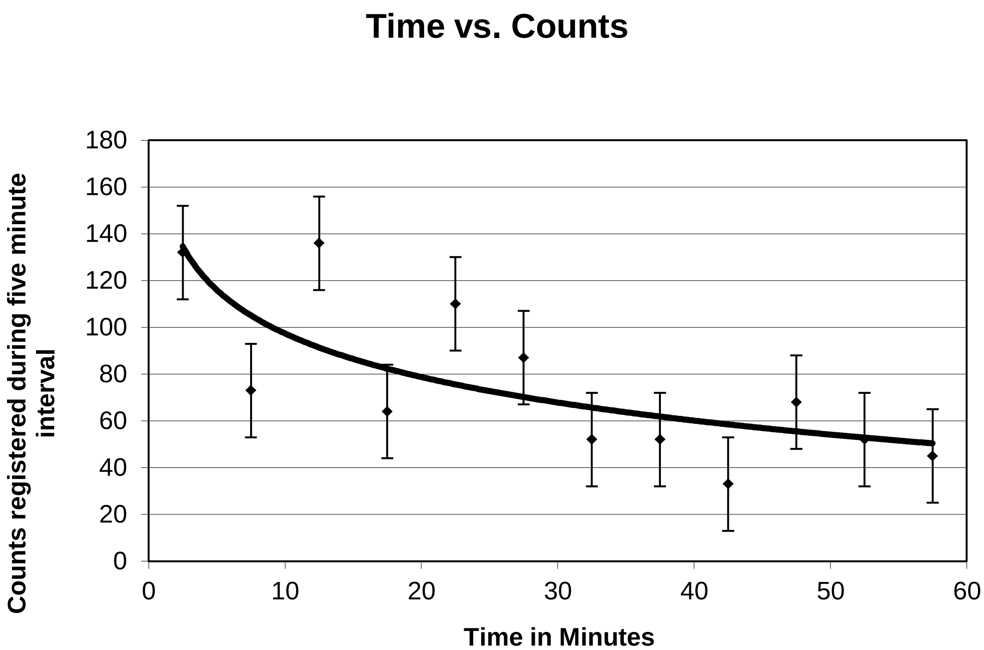
$$N = N_O e^{-kt}$$

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

$$\tau = \frac{\ell n\ 2}{k} \qquad \text{or} \qquad \tau = \frac{0.693}{k}$$

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

Data:



The half life of the

TA Lab Evaluations
Physics 1202 Lab _________

We strongly encourage you to report issues or problems with any aspect of the lab immediately after completing the lab; please email available information to labhelp@physics.umn.edu. Please try and include topics included below when emailing an evaluation. You may also print out and complete this form, then turn into the lab coordinator's mailbox located in rm. 139 if desired.

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?

____

____

____