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Kenneth & Patricia Heller

WELCOME TO THE PHYSICS LABORATORY!

Physics is our human attempt to explain the workings of the world. The success of that attempt is evident in the technology of our society. We are surrounded by the products resulting from the application of that understanding, technological inventions including clocks, cars, and computers. You have already developed your own physical theories to understand the world around you. Some of these ideas are consistent with the accepted theories of physics while others are not. This laboratory is designed to focus your attention on your interactions with the world so that you can recognize where your ideas agree with those accepted by physics and where they do not.

You are presented with contemporary physical theories in lecture and in your textbook. The laboratory is where you can apply those theories to problems in the real world by comparing your application of those theories with reality. This course is rare in the University for that property. In very few departments are you able to test and see if what was heard in lecture is actually truth. Relish this opportunity to be free from interpretation and relative perspective. If you think the TA, the professor, and the book are incorrect, this is your opportunity to demonstrate it conclusively. The laboratory setting is a good one to clarify your ideas through discussions with your classmates. You will also get to clarify these ideas through writing in a report to be read by your instructor. Each laboratory consists of a set of problems that ask you to make decisions about the real world. As you work through the problems in this laboratory manual, remember that the goal is not to make a lot of measurements. The goal is for you to examine your ideas about the real world.

The three components of the course - lecture, discussion section, and laboratory - each serve a different purpose. The laboratory is where physics ideas, often expressed in mathematics, come to grips with the real world. Because different lab sections meet on different days of the week, sometimes you will deal with concepts in the lab before meeting them in lecture. In that case, the lab will serve as a good introduction to the lecture. In other cases, when the lecture about a topic precedes the lab, the lecture will be a good introduction to the lab.

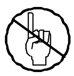
The amount you learn in lab will depend on the time you spend in preparation before coming to lab.

Before coming to lab each week you must read the appropriate sections of your text, read the assigned problems to develop a fairly clear idea of what will be happening, and complete the prediction and warm-up questions for the assigned problems.

Often, your lab group will be asked to present its predictions and data to other groups so that everyone can participate in understanding how specific measurements illustrate general concepts of physics. You should always be prepared to explain your ideas or actions to others in the class. To show your instructor that you have made the appropriate connections between your measurements and the basic physical concepts, you will be asked to write a laboratory report. Guidelines for preparing lab reports can be found in the lab manual appendices and in this introduction. An example of a good lab report is shown in Appendix G. Please do not hesitate to discuss any difficulties with your fellow students or the lab instructor.

Relax. Explore. Make mistakes. Ask lots of questions, and learn what is true!

WHAT TO DO TO BE SUCCESSFUL IN THIS LAB:



Safety always comes first in any laboratory.
If in doubt about any procedure, or if it seems unsafe to you, do not continue. Ask your lab instructor for help.

A. What to bring to each laboratory session:

1. Bring an 8" by 10" graph-ruled lab journal, to all lab sessions. Your journal is your "extended memory" and should contain everything you do in the lab and all of your thoughts as you are going along. As such, your lab journal is a legal document; consequently you should **never** tear pages from it. For this reason, your lab journal **must** be bound, for example, University of Minnesota 2077-S, and **not** of the varieties that allow pages to be easily removed, for example spiral bound notebooks.

2. Bring a "scientific" calculator.

3. Bring this lab manual.

B. Prepare for each laboratory session:

Each laboratory consists of a series of related problems that can be solved using the same basic concepts and principles. Sometimes all lab groups will work on the same problem, other times groups will work on different problems and share results.

1. Before beginning a new lab, you should carefully read the Introduction, Objectives and Preparation sections. Read the sections of the text specified in the *Preparation* section.

2. Each lab contains several different experimental problems. Before you come to a lab, be sure you have completed the assigned *Prediction* and *Warm-Up Questions*. The warm-up questions will help you build a prediction for the given problem. It is usually helpful to answer the warm-up questions before making the prediction. **These individual predictions will be checked (graded) by your lab instructor *immediately* at the beginning of each lab session.**
This preparation is crucial if you are going to get anything out of your laboratory work. There are at least two other reasons for preparing:

   a) There is nothing more dull or exasperating than plugging mindlessly into a procedure you do not understand.

   b) The laboratory work is a **group** activity where every individual contributes to the thinking process and activities of the group. Other members of your group will not be happy if they must consistently carry the burden of someone who isn't doing his/her share.

C. Laboratory Reports

At the end of every lab (about once every two weeks) you will be assigned to write up one of the experimental problems. Your report must present a clear and accurate account of what you and your group members did, the results you obtained, and what the results mean. A report is not to be copied or fabricated. To do so constitutes Scientific Fraud. To make sure no one gets in that habit, such behavior will be treated in the same manner as cheating on a test: **A failing grade for the course and possible expulsion from the University**. Your lab report should describe <u>your</u> predictions, <u>your</u> experiences, <u>your</u> observations, <u>your</u> measurements, and <u>your</u> conclusions. A description of the lab report format is discussed at the end of this introduction. **Each lab report is due within two days of the end of that lab.**

D. Attendance

Attendance is required at all labs without exception. If something disastrous keeps you from your scheduled lab, contact your lab instructor **immediately**. The instructor will arrange for you to attend another lab section that same week. **There are no make-up labs in this course.**

E. Grades

Satisfactory completion of the lab is required as part of your course grade. *Those not completing **all** lab assignments by the end of the quarter at a 60% level or better will receive a grade of F for the <u>entire course</u>.* The laboratory grade makes up <u>15% of your final course grade</u>. Once again, we emphasize that **each lab report is due, without fail, within two days of the end of that lab.**

There are two parts of your grade for each laboratory: (a) your laboratory journal, and (b) your formal problem report. Your laboratory journal will be graded by the lab instructor during the laboratory sessions. Your problem report will be graded and returned to you in your next lab session.

If you have made a good-faith attempt but your lab report is unacceptable, your instructor may allow you to rewrite parts or all of the report. Again, a rewrite must be handed in <u>within two days of the return of the report to you</u> by the instructor, in order to obtain an acceptable grade.

F. The laboratory class forms a local scientific community. There are certain basic rules for conducting business in this laboratory.

1. *In all discussions and group work, full respect for all people is required.* All disagreements about work must stand or fall on reasoned arguments about physics principles, the data, or acceptable procedures, never on the basis of power, loudness, or intimidation.

2. *It is OK to make a <u>reasoned</u> mistake. It is in fact, one of the more efficient ways to learn.* This is an academic laboratory in which to learn things, to test your ideas and predictions by collecting data, and to determine which conclusions from the data are acceptable and reasonable to other people and which are not.

> What do we mean by a "reasoned mistake"? We mean that after careful consideration and after a substantial amount of thinking has gone into your ideas you simply give your best prediction or explanation as you see it. Of course, there is always the possibility that your idea does not accord with the accepted ideas. Then someone says, "No, that's not the way I see it and here's why." Eventually persuasive evidence will be offered for one viewpoint or the other.

"Speaking out" your explanations, in writing or speech, is one of the best ways to learn.

3. *It is perfectly okay to share information and ideas with colleagues. Many kinds of help are okay. Since members of this class have highly diverse backgrounds, you are encouraged to help each other and learn from each other.*

   However, it is never acceptable to copy the work of others. Helping others is encouraged because it is one of the best ways for you to learn, but copying someone else's work and claiming it as your own is completely inappropriate and immoral. Write out your own calculations and answer questions in your own words. It is okay to make a reasoned mistake; it is wrong to copy.

   No credit will be given for copied work. It is also subject to University rules about plagiarism and cheating, and may result in dismissal from the course and the University. See the University course catalog for further information.

4. *Hundreds of other students use this laboratory each week. Another class probably follows directly after you are done. Respect for the environment and the equipment in the lab is an important part of making this experience a pleasant one.*

   The lab tables and floors should be clean of any paper or "garbage." Please clean up your area before you leave the lab. The equipment must be either returned to the lab instructor or left neatly at your station, depending on the circumstances.

A note about Laboratory equipment:
At times equipment in the lab may break or may be found to be broken. If this happens you should inform your TA and report the problem to the equipment specialist using the Problem Report Form found on the desktop. To use the Problem Report Form you will have to login using your University ID and password. Describe the problem, including any identifying aspects of the equipment, and be sure to include your lab room number.

If equipment appears to be broken in such a way as to cause a danger do not use the equipment and inform your TA immediately.

In summary, the key to making any community work is **RESPECT**.

Respect yourself and your ideas by behaving in a professional manner at all times.

Respect your colleagues (fellow students) and their ideas.

Respect your lab instructor and his/her effort to provide you with an environment in which you can learn.

Respect the laboratory equipment so that others coming after you in the laboratory will have an appropriate environment in which to learn.

WHAT IS EXPECTED IN A LAB REPORT? HOW IS IT HANDLED?

1. Before you leave the laboratory, have the instructor assign the problem you will write up and initial your cover sheet.

2. A cover sheet for each problem must be placed on top of each problem report handed in to the instructor. A cover sheet can be found at the end of every lab. *It gives you a general outline of what to include in a report.*

3. A problem report is always due **within two days of the end of the lab**.

4. **A lab report should be an organized, coherent display of your thoughts, work, and accomplishments**. It should be written *neatly* (word processor recommended) in English that is ***clear*, *concise*, and *correct*.** It may help you to imagine that hundreds of people will read your report and judge you by it. **Communication is the goal of the report.** In many cases, communication can be aided greatly by use of tables and graphs.

5. A sample report is included in Appendix G. Listed below are the major headings which most laboratory reports use.

MAJOR PARTS OF A LABORATORY REPORT:

COVER SHEET

See the end of this introduction for a sample cover sheet.

STATEMENT OF THE PROBLEM

State the problem you were trying to solve, and how you went about it. Describe the general type of physical behavior explored, and provide a short summary of the experiment.

PREDICTION

This is a part of the lab where you try to predict the outcome of the experiment based on the general knowledge of Physics. Generally, you start from fundamental laws or principles and derive the theoretical expression for the measured quantity. Later you are going to use your prediction to compare with experimental results.

EXPERIMENT AND RESULTS

Following the problem statement is a Data and Results section, containing a detailed description of how you made your measurements and what results you obtained. This usually involves an organized and coherent display of labeled diagrams, tables of measurements, tables of calculated quantities, and graphs. Explanations of all results must occur in correct grammatical English that would allow a reader to repeat your procedure.

Mathematical calculations connecting fundamental physics relationships to the quantities measured should be given. Any interesting behavior should be explained. Difficulties performing the experiment should be described as well as any subtleties in the analysis.

All data presented must be clearly identified and labeled. Calculated results should be clearly identified. Anybody should be able to distinguish between quantities you measured, those you calculated, and those you included from other sources. Clearly assign uncertainties to **ALL** measured values -- **without uncertainties, the data is nearly meaningless.**

CONCLUSIONS

The Conclusions section should include your answers to the following questions: What generalized behavior did you observe? Was it different from what you expected? Why? (e.g. What were the possible sources of uncertainties? Did you have any major experimental difficulties?) How do your results compare with the theory presented in your textbook or during lectures? Can you think of any other ways to check your theory with your data?

SAMPLE COVER SHEET

PHYSICS 1202 LABORATORY REPORT

Laboratory I

Name and ID#: ____

Date performed: ____________ Day/Time section meets: ______________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: ________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

LABORATORY I:
GEOMETRIC OPTICS

In this lab, you will solve several problems related to the formation of optical images. Most of us have a great deal of experience with the formation of optical images: they can be formed by flat or curved mirrors, water surfaces, movie projectors, telescopes, and many other devices. We can see because the cornea and a flexible lens in each eyeball form images on our retinas (sometimes with the aid of "corrective lenses," in the form of contacts or eyeglasses). Solving the problems in this laboratory should help you explain many of your daily experiences with images with the concept of light rays that travel from sources or illuminated objects in straight lines.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Describe features of real optical systems in terms of ray diagrams.
- Use the concepts of real and virtual images, as well as real and virtual objects, to explain features of optical systems.
- Explain the eye's function in human perception of images.

PREPARATION:

Before coming to lab, read Sections 1-4 of Chapter 25 and Sections 1-4 of Chapter 26 in Serway & Jewett. Keep the objectives of the laboratory in mind as you read the text. It is likely that you will do these laboratory problems before your lecturer addresses this material; the purpose of this laboratory is to introduce you to the material.

Before coming to lab you should be able to:

- Create graphs of measured quantities, and determine mathematical relationships between the quantities based on the graphs.
- Draw a ray diagram to locate the image formed by an object and a convex lens.
- Use the geometrical properties of similar triangles to find unknown quantities.

PROBLEM #1:
IMAGES WITHOUT LENSES OR MIRRORS

Your group is developing an imaging device for use in diagnosing ulcers. Because it will be used inside the human stomach, the device must be small and durable. To meet these criteria, you would like to develop a camera that does not use a lens. While developing an initial presentation about lens-less image formation for your clients, you investigate a model of a lens-less camera: a light source (representing the object to be imaged), a mask with a small hole, and a screen. What are the properties of an image projected on a screen by a small hole?

EQUIPMENT

For this problem, you will be provided with a flashlight, a long filament bulb and stand, masks with various holes and a holder for the masks, an optics bench, and an empty lens holder for attaching a sheet of white paper to serve as a screen.

PREDICTION

Write an equation that relates the size of the image produced on the screen to the size of the light source, the distance between the light source and the mask, and the distance between the mask and the screen.

WARM-UP

Read Serway & Jewett: sections 25.1, 25.2.

1. Suppose you held a point-like light source close to a mask with a small circular hole in it, as shown below. Draw a diagram, showing the light rays that would make it from the light source to the screen. Beside the diagram, sketch a picture of what you expect to see on the screen.

2. What would happen if the light were moved down? On your original diagram, add the light rays that would make it from the light source in its new position to the screen. How would the position of the light spot on the screen change?

3. Draw a new ray diagram for a similar situation with a new light source, in the shape of a vertical arrow that emits light from all parts. Sketch a picture of what you would expect to see on the screen.

4. How would the size of the image on the screen change if you move the screen away from the mask? What if you move the screen closer to the mask? Use your ray diagram to write a relationship among the length of the arrow, the distance from the arrow to the mask, the length of the arrow's image on the screen, and the distance from the mask to the screen.

The ratio of the size of the arrow and the size of the arrow’s image is the magnification of the system. (Note that the length of an inverted image is customarily negative, so that an optical system that results in an inverted image has a magnification < 0.)

5. What would you expect to see on the screen if the top half of the arrow were covered? What would you expect to see on the screen if the hole in the mask were made smaller? What would you expect to see on the screen if the mask were removed altogether, leaving just the arrow-shaped light source and the screen? Draw a sketch to support each of your predictions.

EXPLORATION

Remove the cover from the maglite, so that it acts as a point-like light source. Describe what you see on the screen without the mask. Does this match your prediction from the warm-up questions?

Place the mask with the smallest hole between the maglite and the screen. Describe what you see on the screen in this case. What happens when you move the maglite up? Down? Left? Right? Toward the mask? Away from the mask? Does this match your predictions from the warm-up questions?

Place the mask with the smallest hole between the bulb with a long straight filament and the screen. Describe what you see on the screen in this case. What happens to what you see on the screen when you cover the top part of the light bulb? When you cover the bottom part of the light bulb? Do your observations match your predictions from the warm-up questions?

Describe what you see on the screen when you slowly tip the light bulb to the left or the right. What happens when you move the light bulb toward the mask or away from the mask. What happens when you move the screen toward the mask or away from the mask?

How does the size or shape of the mask's hole affect what you see on the screen?

MEASUREMENT

Make measurements sufficient to quantitatively examine the relationship of the size of the image to the distance between the light source and the mask, and the distance between the mask and the screen. Be sure to measure the length of the bulb's filament.

ANALYSIS

Did your warm-up question responses match the observations you made in the explorations? If not, how can you change the sketches from the warm-up questions to account for your observations? When an image of the long filament of the light bulb appeared on the screen, did it appear erect or inverted? How could you tell?

Compare your predicted values for the size of the image with those you measured. Also compare your predicted values for the magnification with those you measured. Were your predictions accurate? If not, can you adjust your prediction (if so, support with new diagrams) or otherwise account for any discrepancy?

CONCLUSION

In designing a camera with no lens, what factors might be important in your choice of pinhole size, and why would they be important? What factors might be important to the distance between the camera's pinhole and its imaging surface, and why?

PROBLEM #2:
IMAGE FORMATION WITH A PARTIALLY COVERED LENS

Your group, consulting for a drug company that hopes to develop new antibiotics, needs to make a video recording of a bacteria specimen under special conditions. These conditions involve light levels too intense for your recording equipment. One of your colleagues suggests partially blocking the microscope lens with a shutter to reduce the light levels for the recording equipment. Others argue that this would block part of the image, so that some parts of the sample would not be recorded.

You decide to test your co-worker's idea with a simplified optical system. You arrange a light source, a lens, and a screen on an optical bench, so that a focused image of the light source appears on the screen.

EQUIPMENT

For this problem, you will be provided with an optical bench, a convex lens mounted in a lens holder, an empty lens holder for attaching a sheet of white paper to serve as an imaging screen, a long filament bulb and stand, and a ruler.

PREDICTION

Describe how covering part of a convex lens will change the shape and the brightness of the image produced.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

1. Draw a fairly large sketch, showing a convex lens and a source of light that has a defined top and bottom.

2. Sketch the paths of two light rays from the top of the light source to the lens, and continue the sketch for each ray on the other side of the lens. (For the rays you choose, simple rules should tell you the path they take after passing through the lens, if confused, refer to Chapter 26 of Serway.) Do you expect an image to form in this situation? If so, indicate the position of the image in your sketch. Where should you position the screen in order to see the image?

3. Repeat steps 1 and 2, placing the light source at one of the lens's focal points. Do you expect an image to form in this situation?

4. Repeat steps 1 and 2, placing the light source closer to the lens than its focal point. Do you expect an image to form in this situation?

5. What will happen to the image if the top half of the lens is covered? Indicate on your diagram which rays could pass through the lens in this situation, and which would be blocked.

6. Side-by-side, sketch the light source, the image you expect to see when the lens IS NOT covered, and the image you expect to see when the top half of the lens IS covered. Qualitatively compare the sizes, shapes, orientations, and brightness of the source and the two images.

EXPLORATION

Experiment to find a way to estimate the focal length of your converging lens. (Hint: Parallel light, as from a distant object, is focused very close to the focal point of a converging lens.)

Position the light source, the convex lens, and a screen on the optics bench so that a focused image appears on the screen. Does the image still exist if the screen is removed? How could you check?

Can you project an image on the screen when the distance from the light source to the lens is longer than the focal length? When the light source is closer to the lens than its focal length? What happens when the light source is *at* the lens's focal length?

Project a clear image of the light source on the screen. Sketch the shapes of the light source and its image. Is this sketch similar to the one you drew for the warm-up questions? If not, describe the differences.

Cover part of the lens. How does the image change? What changes if you cover different parts of the lens – top, bottom, right, left, middle? What changes if you cover more than half of the lens?

Draw sketches in your lab notebook of what you see on the screen. Indicate which part of the lens was covered for each sketch, as well as the alignment of the image relative to the source. Point out differences among the images formed when different parts of the lens are covered.

Gradually move the cover from the lens to the light source, in such a way that it always blocks about half of the light traveling toward the lens. Describe carefully how the image on the screen changes during this process.

ANALYSIS

Did your prediction and warm-up question responses match your observations? If not, how can you change the sketches from the warm-up questions to account for your observations? Can you use the fact that light travels in straight lines, and sketches similar to your (amended) sketches from the warm-up questions, to explain how the image changed as you moved the cover from the lens to the light source?

CONCLUSION

Do your results rule out use of the method proposed by your colleague for reducing light intensity? How is an image formed by a lens? Which rays "participate" in forming the image for a point on an object?

Do your results suggest any advantages that lenses with large diameters have over small lenses? Do your results suggest any advantages of using lenses instead of pinholes to form images, or advantages of using pinholes instead of lenses?

PROBLEM #3:
IMAGE POSITION I

Your group is working to develop and study new proteins. To analyze the composition of a protein mixture you have produced, the protein solution is placed in an electric field. Proteins with different total charges will drift at different speeds in the solution, and can be separated for further analysis.

Your group needs to focus an optical apparatus at known positions within the protein solution in order to record an image of a small part of the volume. For every point in an image, you must be able to specify the location of the corresponding point in the protein solution. To accomplish this, you must know two relationships: (a) the relationship between an object's distance from the lens and the distance of its image from the lens, along the principal axis; and (b) the relationship between the distance of a point on the object from the principal axis and the distance of the corresponding point of the image from the principal axis. For simplicity, you decide to model your optical apparatus with a single convex lens. Your group will investigate relationships between the positions of points on an object and points in its image in two parts. In the present problem, you will investigate relationship (a). In the next problem, you will investigate relationship (b).

EQUIPMENT

For this problem, you will be provided with an optical bench, a set of convex lenses in lens holders, a light bulb with vertical filament and stand, an empty lens holder for attaching a sheet of white paper to serve as a screen, and rulers.

PREDICTION

Write out an expression that relates the distance of the image from the lens to the distance of the object from the lens and the focal length of the lens. Use this expression to predict features of the graphs of *the distance of the object from the lens vs. the distance of the image from the lens* and (1/*the distance of the object from the lens*) vs. (1/*the distance of the image from the lens*).

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

It is useful to have an organized problem-solving strategy such as the one outlined in the following questions.

1. Draw a fairly large sketch, showing a convex lens and a source of light (a vertical arrow). Label the lens's focal points, and position the source so that an image will be created, which could be projected on a screen.

2. Determine the position of the image, by sketching the paths of two light rays from the top of the light source. Indicate the position of the image in your sketch. Where should you position the screen in order to see the image?

3. Repeat the steps above with a lens of the same focal length, but with the light source farther away from the lens. Has the image moved closer to or farther from the lens?

4. From your ray diagrams and geometrical knowledge of similar triangles, write an equation that relates the distance between the lens and the image, the distance between the lens and the object, and the lens's focal length.

5. Solve the equation in step **4** for (1/ *the distance of the object from the lens*). What do you predict as a shape for a graph of (1/the distance of the object from the lens) vs. (1/the distance of the image from the lens) for a lens of fixed focal length? What are the values of the intercepts where the graph crosses each axis? Draw a sketch of the graph shape you expect and indicate the expected values of the intercepts.

6. Solve the equation in step **4** for *distance of the object from the lens*. What do you predict as a shape for a graph of *the distance of the object from the lens vs. the distance of the image from the lens* for a lens of fixed focal length? Sketch the shape of the graph you expect. Does the graph cross the each axis? If so, what are the values of the intercepts?

EXPLORATION

Estimate the focal length of each convex lens. To do so, take advantage of a convenient source of light that is much more distant than the focal length of each lens. (Where should light from a very distant object be focused?)

Position the light source, the convex lens, and a screen on the optics bench. Align the light source with the principal axis of the lens. Adjust their positions so that a focused image appears on the screen.

Move the source slightly toward and away from the lens, each time adjusting the screen's position to show a crisp image. Does the direction in which you have to move the screen match your responses to the warm-up questions?

Try focusing an image of the vertical filament light bulb on the screen. Can you adjust the position of the screen, lens, or bulb to project an image of the front part of the bulb on the screen? The filament? Other parts of the bulb?

MEASUREMENT

Record the positions of the image, lens and light source for several distances between the lens and the light source. In order to explore features of *the distance of the object from the lens vs. the distance of the image from the lens* and (1/*the distance of the object from the lens*) vs. (1/*the distance of the image from the lens*) graphs, record several measurements and plan your experiment so the data points are not "clumped together" on the graphs. Plot the points on each graph *as you go*. Take measurements for at least two different convex lenses.

ANALYSIS

In the warm-up questions you predicted the shape of two different graphs. Choose one of these graphs to use for your measurements and determine the focal length of each lens. Compare the focal length found on your graphs with the focal length calculated from your prediction equation.

CONCLUSION

How does the image position change as an object is moved along the optical axis? If you know the focal length of a lens and the position of the image, could you use your graphs *and* the relationship you predicted among *the distance of the object from the lens*, *the distance of the image from the lens*, and *the focal length* to determine the position of the object producing that image? Which would be more useful, and why?

Are your results consistent with your predictions? Did your graphs have the shape you expected? Were the estimated and calculated values for the focal length of each lens in agreement? Explain any discrepancies between your predictions and your measurements.

PROBLEM #4:
IMAGE POSITION II (MAGNIFICATION)

Your group is working to develop and study new proteins. To analyze the composition of a protein mixture you have produced, the protein solution is placed in an electric field. Proteins with different total charges will drift at different speeds in the solution, and can be separated for further analysis.

Your group needs to focus an optical apparatus at known positions within the protein solution in order to record an image of a small part of the volume. For every point in an image, you must be able to specify the location of the corresponding point in the protein solution. To accomplish this, you must know two relationships: (a) the relationship between an object's distance from the lens and the distance of its image from the lens, along the principal axis; and (b) the relationship between a point of the object a distance from the principal axis and the distance of its corresponding point of the image from the principal axis. For simplicity, you decide to model your optical apparatus with a single convex lens. Your group will investigate relationships between the positions of points on an object and points in its image in two parts. In the previous problem, you investigated relationship (a). In this problem, you will investigate relationship (b).

EQUIPMENT

For this problem, you will be provided with an optical bench, a set of convex lenses in holders, a Pasco light source with a measurement grating, an empty lens holder for attaching a sheet of white paper to serve as a screen, a long-filament bulb and stand, and rulers.

PREDICTION

Write an expression relating the size of an object to the size of its image, in terms of the distance from the object to the lens and the distance from the lens to the image. Explain how this can be used to relate the position of a point on an object to the position of a corresponding point on the image.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.1, 26.3, 26.4.

1. Draw a fairly large sketch, showing a convex lens and a source of light (such as a vertical arrow). Label the lens's focal points, and position the source so that an image will be created, which could be projected on a screen.

2. Determine the position of the image, by sketching the paths of two light rays from the top of the light source. Indicate the position of the image in your sketch. Where should you position the screen in order to see the image?

3. To your initial diagram, add a second object at the same position, but approximately twice as long. Determine the position and size of the image, as you did for the first object. How do the position and size compare to those of the original object?

4. From your diagrams and geometrical knowledge of similar triangles, write an equation that relates the height of the object to the height of the image, in terms of the *distance of the object from the lens* and *the distance of the image from the lens.*.

5. Write an equation for the magnification in terms of *distance of the object from the lens* and *the distance of the image from the lens*. (*Magnification* is the ratio of image height over *object height.* The magnification is traditionally negative if the image is inverted.)

6. What shape would you predict for a graph of *magnification* vs. *distance of object from lens/distance of image from lens*? What is the significance of the slope of this graph? Where do you expect the graph to intercept the horizontal and vertical axes? How could you use such a graph to determine the distance from a point in an object to the principal axis of the optical system, if you knew the distance from the principal axis to the corresponding point in its image?

EXPLORATION

Position the light source with the transparent grid, the convex lens, and a screen on the optics bench. Align the light source with the principal axis of the lens. Adjust their positions so that a focused image of the grid appears on the screen.

Cover part of the light source. If half of the light source is covered, what fraction of the image disappears?

Shift the light source in a direction *perpendicular* to the principal axis. How does the position of the image change? How does the image change as it moves further from the principal axis? If you double the distance of a point on the object from the principal axis, what happens to the distance of the corresponding point on the image from the principal axis?

MEASUREMENT

Measure the spacing of the lines on the light source.

Arrange the light source so that a clear image of the lines is projected on the screen. Measure *the distance from the object to the lens* and *the distance from the image to the lens*. Make any other measurements necessary to determine the magnification for this arrangement. Repeat with the same lens for at least two more variations in the distance of the object from the lens.

Repeat the above series of measurements with a second convex lens.

ANALYSIS

Did the magnification for each series of measurements agree with your predicted relationship between *magnification*, *the distance of the object from the lens*, and *the distance of the image from the lens*?

CONCLUSION

Is the magnification of an optical system solely a property of the lens in the system, or are other factors important as well?

Are your results consistent with your predictions? If not, explain the sources of any discrepancies. How does the position of a point on an image change as the corresponding point on the object is moved perpendicular to the principal axis?

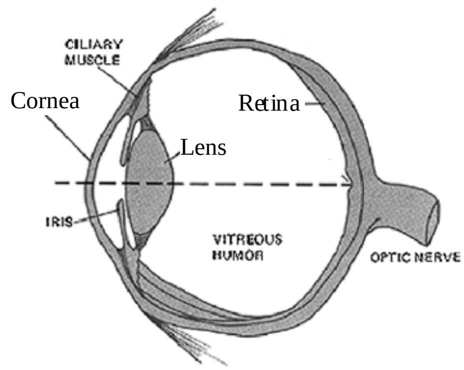
If you know the distances *of the object and the image from the lens*, and the position of a point on an image, can you determine the corresponding position on the object?

If an optical system has a magnification, and the image of an object moves upward a distance X perpendicular to the principal axis, how far did the object move, and in what direction?

PROBLEM #5:
THE EYE -- COMPENSATING FOR AN ARTIFICIAL LENS

A diagram of a human eye is shown below. In an eye with normal vision, the *cornea* and the *lens* can project a focused image of objects at a wide range of distances (not shown in the diagram) on the *retina*. To achieve such flexibility, the *ciliary muscle* in the eye can slightly change the shape of the *lens* to adjust its focal length.

Image of a Human Eye



Your friend's grandmother has just had cataract surgery. During the surgery, the flexible *lens* in one of her eyes was removed, and was replaced with a plastic lens whose focal length cannot be adjusted. As a result, she can only see clear images of objects when they are held at one particular distance from her eyes. Your friend's grandmother has asked you to recommend a set of corrective lenses -- one that will help her see at close range. She already has a good set of corrective lenses for seeing far away. Before making specific recommendations for a corrective lens, you and your group decide to work with a simplified model of her eye.

Your eye model will use a single convex lens to approximate the behavior of the inflexible lens and cornea, and a screen to take the place of the retina. You will use additional lenses to model the effects of corrective lenses. You will be given one concave lens that allows your model to focus on a distant object.

EQUIPMENT

For this problem, you will be provided with convex lenses and a single concave lens in lens-holders, an empty lens holder for attaching a sheet of white paper to serve as a screen, a long-filament light bulb and stand, masking tape, an optical bench, and a ruler.

PREDICTION

Formulate an expression that gives the focal length of a corrective lens, to be used in conjunction with a fixed lens. You may assume that both lenses are on the same plane. The corrective lens should allow an object at a specified distance from the lenses to produce an image at a specified distance from the lenses. You may assume that the corrective lens is "weaker" than the other lens, i.e. $|f_0| < |f_c|$.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

1. Sketch a model representing a surgically repaired eye, use an arrow as the object. Sketch a ray diagram to indicate the optimal position of the retina for "seeing" an object at this distance.

2. Sketch ray diagrams to show what happens to the image position if the object moves *closer* to the "eye," or *farther away* than in the first diagram. If a corrective lens were added in each situation, would it have to be convex or concave to project a clear image on the "retina"?

3. Calculations in this problem will be simpler if you can assume that the distance between the "eye" lens and the corrective lens is small relative to other distances, so that bending due to *both lenses occurs in a single plane*. Sketch a diagram of the eye model (without the "retina") with a corrective lens just in front of the "eye" lens. Indicate the focal points of both lenses.

4. To determine the position of an image produced by the system of two lenses, first draw a ray diagram to show the position of the image (real or virtual) that would be produced by *just the corrective lens*.

5. Then, treat the *image* (real or virtual) that would be produced by the corrective lens alone as the *object* (virtual or real) to be imaged by the "eye" lens. (The object is treated as virtual if it is on the same side of the "eye" lens as the final image will be, or real if it is on the opposite side.) Add rays to show the position of the final image, produced by the "eye" lens.

6. Label each important distance in your sketch. Use the diagram and the results of your work on earlier problems to write down equations relating these distances. (Watch the sign conventions!) Write an equation for the focal length of the corrective lens, in terms of the focal length of the "eye" lens, the distance from the lenses to the object, and the distance from the lenses to the image.

7. What does it mean if your equation predicts a corrective lens with a negative focal length? A positive focal length? An infinite focal length? Is each result possible? Could each of the three cases describe an actual lens?

EXPLORATION

Consider the constraints on an eye with an inflexible lens. Can the focal length of the lens change? Can the distance between the lens and the retina change? With these constraints in mind, construct a model on the optics bench. Experiment to determine the size your model should be. Using the simple eye model without any corrective lens you should be able to demonstrate that an object is out of focus at a large distance, clearly focused at a moderate distance, and out of focus at a short distance. See if you can focus a far away image with the concave corrective lens. Can you focus an image outside the window?

Investigate the effect of increasing distance between the corrective lens and the eye lens. Why is it important for this distance to be minimized? With the equipment available, how can the distance be minimized?

MEASUREMENT

Determine the focal lengths of the convex lenses you will use in this experiment as precisely as possible, using new measurements and/or your results from previous problems.

With the corrective concave lens, determine the size of your model eye (distance from lens to retina) by focusing a far away object. When you have successfully produced a clear image, record the positions and focal lengths of each lens, as well as the positions of the light source and screen.

Repeat with the convex lenses, focusing on close up objects.

ANALYSIS

Compare your measured results for the long distance with the predicted focal length f_c of the required corrective lens given by your prediction. For the short distance, calculate the focal length of the required corrective lens from your measurements, by using the relationship you predicted among *the distance of the object from the lens, the distance of the image from the lens*, the eye focal length and the focal length of a corrective lens.

CONCLUSION

How do your results compare to your predictions? If you made assumptions in the warm-up questions, how well were they met by your physical model of the eye? What effect would the observed deviations from those assumptions have on the comparison between your predictions and the measurements you made? Can you account for differences between your measurements and your predictions?

People with *myopia* are nearsighted, so that they can clearly see objects close to their eyes, while objects far away appear blurry. Use your results to answer the following questions about myopia. Should corrective lenses for nearsighted people be concave or convex? Myopia results from slightly misshapen eyeballs: are the eyes of myopic people too short (placing the retina too close to the lens) or too long (placing the retina too far from the lens)? Support your reasoning with a sketch.

People with *hyperopia* are farsighted, so that they can clearly see objects far away; however, objects that are close appear blurry. Use your results to determine whether corrective lenses for farsighted people should be concave or convex, and whether those people have eyeballs that are too short or too long. Support your reasoning with a sketch.

PROBLEM #6:
MICROSCOPE

While studying bacteria cultures for a medical research laboratory, you are exhausted at the end of each day, which invariably includes hours bent over a microscope. One of your co-workers proposes a solution: projecting magnified images onto a screen, where observations could be made more easily. Your boss claims that this is impossible but is unable to explain why. You and your colleagues decide to investigate the optics in a model microscope, in order to determine whether the suggestion might work.

You decide to model your microscopes with a "simple" compound microscope: the "objective lens" -- a strong (short focal length) convex lens placed near the object to be imaged -- and an "eyepiece lens" -- a weaker (longer focal length) convex lens placed near the eye. If the lenses and object are arranged properly, you should see an inverted and enlarged image of the object when you look through the eyepiece lens. Is it possible to project an image from a microscope onto a screen?

EQUIPMENT

For this problem, you will be provided with an optical bench, a set of convex lenses in lens holders, a Pasco light source with grating lines, a light bulb with vertical filament and a stand, an empty lens holder for attaching a sheet of white paper to serve as a screen, and rulers.

PREDICTION

Given an objective lens and an eyepiece lens with known focal lengths, determine appropriate positions for the two lenses and for an object to be imaged by a model microscope. Determine the position of the image produced, and predict whether or not that image could be projected on a screen.

WARM-UP

Read Serway & Jewett: 25.1, 25.2, 25.4, 26.3, 26.4.

1. Draw a sketch to represent the compound microscope and an object, which meets the following specifications. The two lenses should share the same optical axis. The distance from the object to the objective lens should be between the focal length and 2 times the focal length of the objective lens. The position and focal length of the “eyepiece” lens will be determined in step 3 below.

2. Draw a ray diagram to show the position and size of the image that produced by the objective lens.

3. In a compound microscope, the *image* produced by the objective lens is the *object* for the eyepiece lens. The eyepiece lens will be placed so that the *image* from the objective lens is <u>between</u> the two lenses, and is <u>at a focal point</u> of the eyepiece lens. Add an eyepiece lens to create this arrangement in your sketch.

4. Add rays to show how light will travel after passing through the eyepiece lens. Do the rays converge or diverge? Does the eyepiece lens form a real or virtual image? If so, what is its location?

5. Does the microscope form an image that could be projected on a screen? If so, where should the screen be placed? If not, should it be possible to adjust the microscope so that it could project an image on a screen?

EXPLORATION

Arrange an approximate model of a compound microscope before taking careful measurements. First, estimate the focal lengths of each lens you will use to model the microscope.

Position the light source and a convex lens with short focal length (the "objective") on the bench. Verify that the principal axis of the lens is parallel to the bench and passes through the center of the source. Find the position of the image formed by the objective lens.

Place another convex lens (the "eyepiece") in position so that the image formed by the objective lens is approximately at a focal point of the eyepiece lens.

Look through the eyepiece lens. Can you see an image of the light source? Is it inverted or erect? Does it appear to be enlarged? Can you estimate how much the image is enlarged? Can an image be projected onto a screen? What do you observe if you move the eyepiece lens along the principal axis, or if you adjust the position of the light source or objective lens? How can you tell when you have achieved the conditions described in the warm-up questions for a compound microscope?

Try focusing the microscope on the vertical filament light bulb. (The filament is very bright, so you may wish to focus on some other part of the bulb.) Can you focus on different parts of the bulb?

MEASUREMENT

Carefully determine the focal length of each lens you will use in the model microscope.

Place the light source and the objective lens at a convenient distance apart. Following the methods you developed in the exploration, adjust the position of the eyepiece lens until you have achieved the conditions necessary for a compound microscope. Measure and record the relevant positions and focal lengths.

Will the microscope project an image on a screen, or can it be adjusted to do so? If so, measure image positions, magnification, lens positions and light source positions, and describe the image produced.

Repeat the process for a new distance between the light source and objective lens.

Repeat, if possible with the same two distances between light source and objective lens, for a second eyepiece lens.

ANALYSIS

For each distance between the lamp and objective lens, compare the observed separation of the two lenses with the expected value, from the warm-up questions. Can you account for any discrepancies?

Qualitatively, how did the second eyepiece lens change the magnification of the microscope? Why did you (or why didn't you) expect this change?

CONCLUSION

How does the position of the eyepiece depend on the distance between the object and the objective lens, and on the focal lengths of the lenses?

Is it possible to use a microscope to project an image on a screen for observation, without extra optical equipment? Do you support your boss's claim that it is not possible? If it is possible, explain why or why not you think it could be useful.

☑ CHECK YOUR UNDERSTANDING

1. Use a ray diagram to determine the size and position of the image when a 5 cm tall object is located 18 cm from a converging lens with focal length 9 cm.

2. What would happen if the same object were located 9 cm from a converging lens with focal length 18 cm?

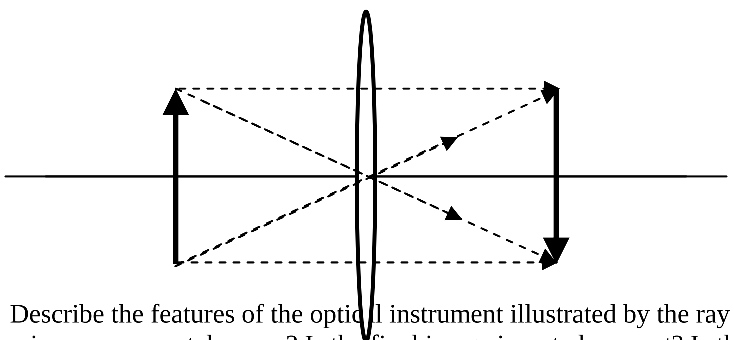
3. What would happen if the same object were located 18 cm from a converging lens with focal length 18 cm?

4. What would happen if the same object were located 18 cm from a diverging lens with focal length -18 cm?

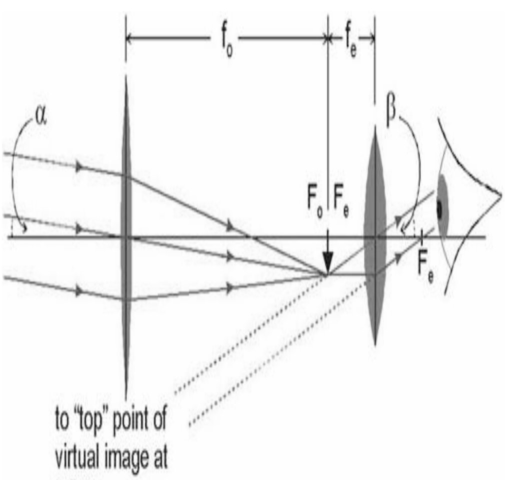
5. In any of the situations above, what would happen if the middle 2/3 of the lens were blocked?

6. In which of the situations above could an image be projected on a screen? In which of the situations above could an image be seen without a screen?

7. Describe the problems with the ray diagram below:



8. Describe the features of the optical instrument illustrated by the ray diagram below. Is this a diagram for a microscope or a telescope? Is the final image inverted or erect? Is the final image magnified?



☑ CHECK YOUR UNDERSTANDING

PHYSICS 1202 LABORATORY REPORT
Laboratory I

Name and ID#: ____

Date performed: ____________ Day/Time section meets: ______________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: ________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

LABORATORY II
ENERGY AND ELECTRIC CIRCUITS

It is often useful to study physical systems to gain insight into biological ones because both obey the same fundamental principles. In addition, physical systems are easier to study because they are less complex than biological systems and can be more easily modified to test a hypothesis. Furthermore, using physical systems bypasses some moral and ethical questions inherent in experimenting with living organisms. Determining the relationships between simple physical systems and complex biological ones requires continually drawing on your knowledge, insight, and imagination to make the connections.

In this first laboratory, you will explore a system that has many features in common with biological systems. An electric circuit illustrates how energy can be transformed within a system, transferred to different parts of the system, and transferred out of the system. As with all biological systems, the source of energy within the system is a complex chemical interaction. In this case that source of energy is a battery. An electric circuit is similar to many biological processes that proceed through a cycle such as the Krebs cycle at the molecular level or the water cycle at the ecosystem level. In this case it is the electric charge that transports the energy from one place in the system to another. The key to understanding any cycle is to identify what is conserved in the process and more importantly what is conserved in any process. In the case of an electric circuit, two conservation principles are important, conservation of energy and conservation of charge. These same two conservation principles also play crucial roles in all biological processes.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Identify what is an electrical circuit and what is not.
- Use the concept of conservation of energy together with the concept of conservation of charge to describe the behavior of an electric circuit.
- Measure the current through an electric circuit element.
- Measure the voltage or potential difference between two points in an electric circuit.
- Use a digital multimeter (DMM) to measure various properties of an electric circuit.

PREPARATION:

Read Serway & Jewett: Chapter 21 sections 1, 2, 5, 7 and 8. It is likely that you will be doing these laboratory problems before your lecturer addresses this material. The purpose of this laboratory is to give you these experiences as an introduction to the material. So, it is very important that, when you read the text before coming to lab, you remember the objectives of the laboratory.

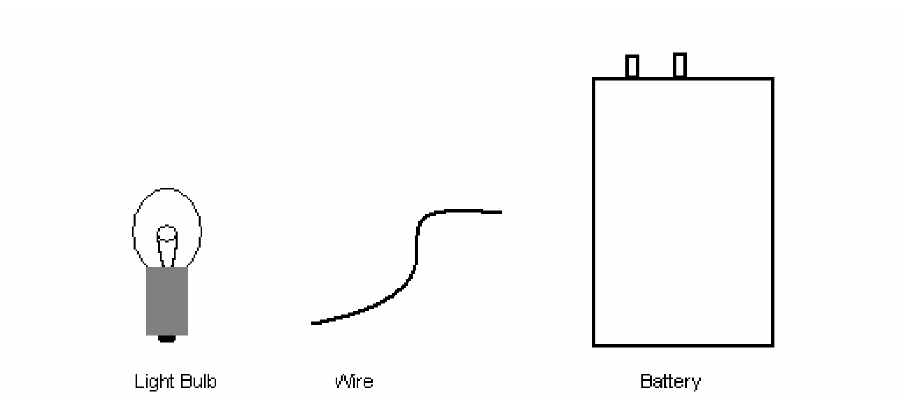
Before coming to lab you should be able to:

- Describe the difference between electrical current and voltage.
- Describe what is meant by a conservation principle.
- Describe the relationship between voltage and energy.
- Be able to write down Ohm's Law and identify all of the terms in the equation with physical quantities in an electric circuit.

PROBLEM #1:
ELECTRICAL CONNECTIONS

You are working for a research group that is studying the nerves in that part of the eye called the retina. It is known that the neurons exchange signals via the flow of ions through junctions called synapses. You are interested in electrical synapses, abundant in the retina but rare everywhere else in the body. Your research group decides to begin by using a battery, a wire, and a light bulb to make the simplest possible model of a single electrical synapse. In this model, chemical reactions in the battery provide the difference in voltage across the synapse that causes ions to flow from one neuron to the next. The flow of ions across the synapse is manifested in the bulb as light and heat. You are interested in modeling the flow of energy and charge, and your first step is to determine the simplest possible conditions under which energy can be transferred using a single battery, a single wire, and a single bulb. To do this you determine all of the possible configurations to light a bulb with a single wire and a single battery. How many different configurations of a single battery, a single wire, and a single light bulb will cause the bulb to light?

EQUIPMENT



PREDICTION

How many ways can you connect the bulb, battery, and wire to make the bulb light?

WARM-UP

Read Serway & Jewett: sections 21.1, 21.2, 21.5, 21.6.

1. Make a drawing of a single light bulb connected to the battery with a single wire so that the bulb will light. What parts of each object must be touching for the light bulb to light? Is this the only configuration possible? If not, make drawings of other possible configurations.

2. What object in the circuit is the source of energy? Using your drawing(s), describe how the energy gets to the light bulb. What happens to the energy after it gets to the light bulb?

3. Along which path is the energy carried? Draw arrows to indicate the path of the energy carriers. Are the energy carriers conserved or do they just disappear at the light bulb? If they are conserved, where do they go after delivering energy to the light bulb?

4. What does the battery voltage have to do with this energy? How are the energy carriers related to the electric charge?

5. Using your drawing, describe how conservation of energy applies to the system defined as the light bulb while the bulb is lit. Identify the initial energy of the system, the final energy of the system, any energy entering the system, and any energy leaving the system.

6. Using your drawing, describe how conservation of charge applies to the system defined as the light bulb while the bulb is lit. Identify the initial charge of the system, the final charge of the system, any charge entering the system, and any charge leaving the system

7. Check the drawing(s) you made in question 1. Does it obey conservation of energy? Does it obey conservation of charge? If the answer to any of these questions is no, change your drawing so that the answers are yes.

8. Write down the general properties of an electric circuit that always obeys conservation of energy and conservation of charge an lights the bulb.

EXPLORATION

Look closely at the inside and the outside of a bulb. Draw what you see. How are parts inside of the bulb connected to the outside of the bulb? If you can't see the connection, make a reasonable guess based on what you do see. What part of the bulb do you think actually lights? What parts of the bulb do you think conduct electricity and what parts do not?

Connect the bulb, battery, and wire as drawn in the warm-up questions. Does the bulb light? If not, try another configuration until you find one that does light. Draw all of the configurations that do not work as well as the ones that do.

Check which part of the bulb lights. Does it agree with what you thought initially?

Can the positive and negative ends of the battery be switched without affecting the operation of the circuit? Can the two ends of the bulb be switched? Are there any parts that cannot be switched? Write down a plan to systematically check all configurations you think might light the bulb.

MEASUREMENT

Connect the battery, bulb, and wire according to the plan that you wrote down in your Exploration section. Carefully make a drawing of each way you connect the items and the result of whether or not the bulb lights. Also write down the comparative bulb brightness for each configuration.

ANALYSIS

Examine your pictures of situations where the bulb lights and compare them with pictures of situations where the bulb did not light. Also compare the brightness of the bulb in each situation. Write down a general rule for connecting the objects together so that the bulb will always light. What is important and what makes no difference? Estimate how well you can determine relative bulb brightness. Can you tell the difference between a bulb lighting and not lighting?

CONCLUSION

What are the necessary conditions for energy transfer in an electric circuit? How many ways were you able to connect the bulb, wire, and battery to make energy transfer possible? What do these connections have in common? What is different among them? What are the general requirements for a simple working circuit? Compare your results to your predictions.

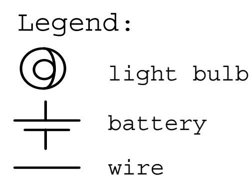
PROBLEM #2
QUALITATIVE CIRCUIT ANALYSIS

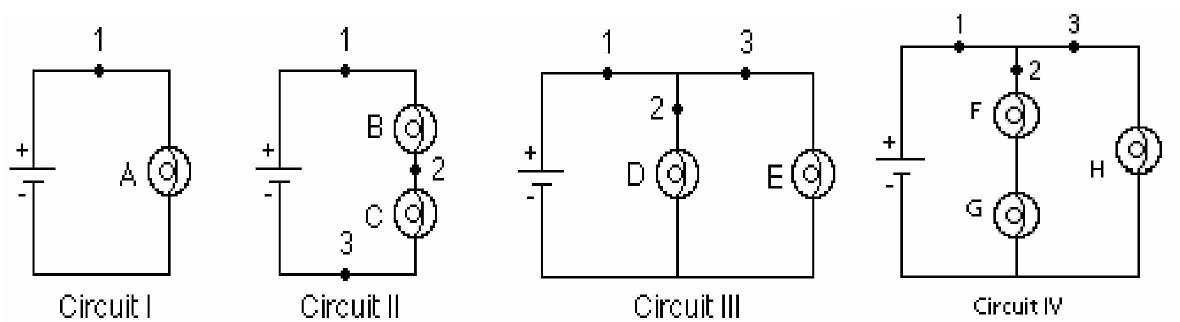
You are working at the Minnesota Arboretum testing the effects of light intensities on apple color. You have one area that you wish to expand so you decide to add another light fixture. However, you are concerned that adding another light may dim the lights that are already in the track. When you proceed with the addition of another light, you notice that none of the lights are dimmer than before. You wonder what type of circuit your track lighting uses. You decide to build models of circuits with two bulbs connected across a battery, and to compare the brightness of the bulbs in these circuits to a reference circuit with a single bulb. The circuit in which each bulb is as bright as the one in your reference circuit is the same type as the circuit in your track lighting.

EQUIPMENT

You will build four simple circuits shown below out of wires, bulbs, and batteries.

Use the accompanying legend to build the circuits.





Note: Some of the light bulbs in the lab may be of different kinds and have different resistances. To find identical light bulbs look for markings and check to see that the color of the plastic bead separating the filament wires is the same.

PREDICTION

Restate the problem. Rank, in order of brightness, the bulbs A, B, C, D, and E from the brightest to the dimmest (use the symbol '=' for "same brightness as" and the symbol '>' for "brighter than"). Write down your reasoning.

EXPLORATION

Reference Circuit I

Connect Circuit I to use as a reference. Observe the brightness of bulb A. Replace the bulb with another one and again observe the brightness. Repeat until you have determined the brightness of all your bulbs when they are connected into the same type of circuit. If the bulbs are identical, they should have the same brightness.

Note: Pay attention to large differences you may observe, rather than minor differences that may occur if two "identical" bulbs are, in fact, not quite identical. How can you test whether minor differences are due to manufacturing irregularities?

Circuit II

Connect Circuit II. Compare the brightness of bulbs B and C. What can you conclude from this observation about the amount of current through each bulb?

Is current "used up" in the first bulb, or is the current the same through both bulbs? Try switching bulbs B and C. Based on your observation, what can you infer about the current at points 1, 2, and 3?

How does the brightness of bulb A (Circuit I) compare to the brightness of bulbs B and C (Circuit II)? What can you infer about the current at point 1 in each of the two circuits?

Circuit III

Connect Circuit III. Compare the brightness of bulbs D and E. What can you conclude from this observation about the amount of current through each bulb?

Describe the flow of current around the entire circuit. What do your observations suggest about the way the current through the battery divides and recombines at junctions where the circuit splits into two branches? How does the current at point 1 compare with the currents at points 2 and 3?

How does the brightness of bulb A (Circuit I) compare to the brightness of bulbs D and E (Circuit III)? What can you infer about the current at point 1 in each of the two circuits?

Circuit IV

Connect Circuit IV. Compare the brightness of bulbs F and G with that of H. What can you conclude from this observation about the amount of current through each bulb?

Describe the flow of current around the entire circuit. What do your observations suggest about the way the current through the battery divides and recombines at junctions where the circuit splits into two branches? How does the current at point 1 compare with the currents at points 2 and 3?

How does the brightness of bulb B and C compare to the brightness of bulbs G and H? What can you infer about the current at point 1 in each of the two circuits?

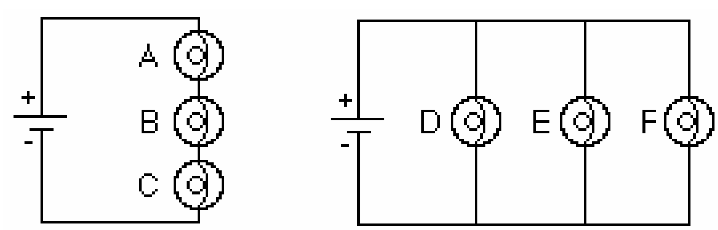
Comparing the four circuits, does the amount of current at point 1 appear to remain constant or to depend on the number of bulbs and how they are connected?

CONCLUSIONS

Rank the actual brightness of the bulbs. How did this compare to your prediction? Make sure you adequately describe what you mean in your comparisons, i.e. “the same brightness as”, “brighter than”, “dimmer than”. What type of circuit is used in your track lighting? Circuit II is called a *series circuit* and Circuit III is called a *parallel circuit*.

Can you use conservation of energy and conservation of current to explain your results? The rate that energy is output from a bulb is equal to the potential difference (voltage) across the bulb times the current through the bulb. Does a battery supply a constant current or a constant potential difference to circuits?

To check your understanding, rank the brightness of the bulbs in the following circuits.



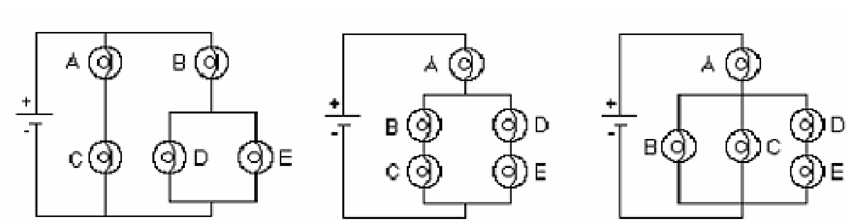
Use the lab equipment to see if your answer is correct.

PROBLEM #3
QUALITATIVE CIRCUIT ANALYSIS B

You have a summer job in a Medical Equipment company. To ensure that the company's products meet safety requirements, you often have to judge current flows through different parts of complex circuits. You have been checking your work by tediously re-calculating each current. A fellow worker suggests that a qualitative analysis of the circuit could allow you to catch some kinds of mistakes very quickly. You decide to try this technique on several circuits for practice, modeling circuit elements with light bulbs. You reason that the relative brightness of bulbs in a circuit indicates the relative sizes currents passing through them.   Compare the brightness of the bulbs in each of the circuits shown below.

EQUIPMENT

You will have batteries, wires, and five identical bulbs that you can connect to make the three circuits shown below.



Circuit XIV   Circuit XV   Circuit XVI

Note: Some of the light bulbs in the lab may be of different kinds and have different resistances. To find identical light bulbs look for markings and check to see that the color of the plastic bead separating the filament wires is the same.

PREDICTIONS

Read Serway & Jewett: sections 21.1, 21.8.

1. Complete the following predictions. For each prediction, state your reasoning.

Circuit XIV:

How will the brightness of bulb A compare with the brightness of bulb B?

How will the brightness of bulb B compare with the brightness of bulb D?

How will the brightness of bulb C compare with the brightness of bulb D?

Circuit XV:

How will the brightness of bulb A compare with the brightness of bulb B?

How will the brightness of bulb B compare with the brightness of bulb C?

How will the brightness of bulb B compare with the brightness of bulb D?

Circuit XVI:

How will the brightness of bulb A compare with the brightness of bulb B?

How will the brightness of bulb B compare with the brightness of bulb C?

How will the brightness of bulb B compare with the brightness of bulb D?

2. Using equations in your text for finding equivalent resistances and your conceptual understanding of circuits, predict the relative brightness of bulb A in the three circuits.

EXPLORATION

Set up each circuit and observe the brightness of the bulbs. How can you test whether minor differences you observe are due to manufacturing irregularities in the "identical" bulbs?

MEASUREMENT

Coordinate with other groups to compare the brightness of bulb A in each of the three circuits.

If necessary, use a DMM to measure the current through bulb A in each of the three circuits (see *Appendix D*).

CONCLUSION

Quantitative circuit analysis results from applying conservation of energy (Kirchhoff's loop rule) and conservation of charge (Kirchhoff's junction rule) to series and/or parallel configurations. For each circuit, write the corresponding equation(s).

PROBLEM #4
RESISTORS AND LIGHT BULBS

Talking with a friend about the role of electric circuits in biological systems, you realize that a light bulb may not be a good model for biological electrical energy transfer. The light bulb is a useful laboratory tool because it is easy to observe differences in the rate of energy transfer by observing its brightness. However, to give off light, the bulb filament must be raised to a temperature well above that of any biological system. There is a common electrical device called a resistor that transfers energy out of the electric circuit without the extreme behavior of a bulb. For this reason, the resistor might be a better object to model biological processes such as those in which an electric current results from the motion of ions through a cellular membrane. As a first step in determining the similarities and differences of the electrical properties of light bulbs and resistors, you draw a graph of the relationship between the voltage across a light bulb to the current through the light bulb and compare it to a resistor. You decide to check your graphs by making the relevant measurements in the laboratory. Determine how the current through a light bulb depends on the voltage across it. How does that relationship compare to that for a resistor?

EQUIPMENT

You will have wires, a power supply, a digital multimeter (DMM), a light bulb, and a resistor. The power supply has the same function as a battery, to supply energy to the circuit by maintaining a constant voltage or potential difference. Because this voltage is not the result of chemical reactions, it is easy to change the voltage across the power supply within some range.

PREDICTIONS

Sketch a graph describing your expectations of the relationship between the voltage across a resistor and the current through the resistor. On your graph also sketch your expectation for the behavior of a light bulb.

WARM-UP

Read Serway & Jewett: sections 21.1, 21.2.

1. Draw a picture of a circuit containing one battery, one resistor, and two wires. On the picture show how you would insert a device to measure the voltage across the resistor. Now redraw the picture of the battery, resistor, and wires showing how you would insert a device to measure the current through the resistor.

2. Draw a graph of voltage across an object vs. the current through the object as given by Ohm's Law. How does one determine the resistance of the object from this graph?

3. As more current goes through a light bulb, it gets brighter because it gets hotter. Do you expect the increasing temperature to change the bulb's resistance? If so, how?   Draw a graph of voltage across a light bulb versus current through a light bulb that shows your expectation of its resistance.

EXPLORATION

WARNING: You will be working with a power supply that can generate large electric currents. 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. Never grasp a wire by its metal end.**

Connect your light bulb to the power supply in a circuit. Go through the range of voltages and observe the brightness change of the bulb. Decide on a range of voltages to use for your measurements. Looking at your prediction graph, determine how many measurements you should take and at what voltages. How many points are necessary to check your prediction when the bulb is dim? When the bulb is bright?

Read *Appendix D* and try out the different functions of the digital multimeter (DMM). Make sure that your DMM is set to measure a current or is set to measure a voltage depending on how it is connected in your circuit. Using a DMM to measure a current in a voltage-measuring configuration may damage the meter.

MEASUREMENT

Follow the measurement plan that you decided upon in the Exploration section for the light bulb and the same plan for your resistor. Make sure that your DMM is connected so that it measures either the voltage across the light bulb (or resistor) or the current through it. To make sure you are making reasonable measurements, check the resistance of your resistor by the following independent techniques. Compare these determinations with each other and with the results of your graph.

1. Use the color code on the resistor (see *Appendix D*) to determine the resistance as calibrated at the factory. What is the uncertainty in this value?

2. Use the DMM set to ohms to directly measure the resistance of the resistor. To do this the resistor must be disconnected form the circuit. What is the uncertainty in this value?

ANALYSIS

Make a graph of voltage versus current for your resistor and light bulb. Use the graph to determine the resistance of the resistor as a function of voltage (or current). Use the graph to determine the resistance of the light bulb as a function of voltage (or current).

CONCLUSION

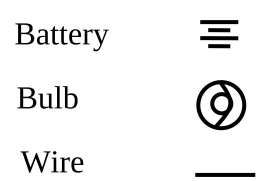
Do the resistor and light bulb have the same electrical behavior? If so, what are their resistances? If not, is there a range of voltages where they have approximately the same behavior? Did your prediction match your results? Explain why or why not. What are possible sources of systematic uncertainty? (see *Appendix C*) Does the equipment contribute any? Do you? Be specific in explaining how and why.

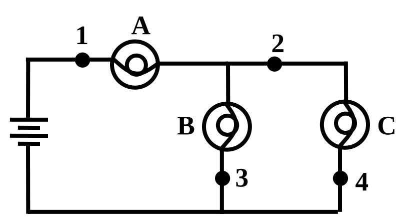
PROBLEM #5
SHORT CIRCUITS

You have a part time job with a company that tests pacemakers. Pacemakers deliver electrical energy to the heart using a number of transducers. One possible failure mode of a pacemaker circuit is developing a low resistive current path, or short circuit, through surrounding tissue after implantation in the body. Your assignment is to see how this failure mode affects the functioning of the pacemaker transducers. First you determine how a low resistance path around a transducer affects the current through that transducer and thus its ability to deliver signals to the heart. You also need to determine how that low resistance path affects the current from the battery and thus the battery lifetime. Since you cannot induce these faults in a living person, you have been asked to make an electric circuit as a model of the process. To make the effects visual, you decide to use light bulbs to model the transducers that deliver energy to the heart. The test circuit consists of a light bulb with one side connected to a battery and the other connected to two light bulbs that are connected in parallel. The other end of the parallel combination is connected back to the battery such that all of the bulbs light. For identical light bulbs you calculate the current through the battery and each bulb for the case of no short circuit and for all other cases where a short circuit develops as specified below. To make your calculations easier, you assume that each light bulb has a constant resistance and that the short circuit path has zero resistance. You will then check your calculations by measuring the relevant voltage differences and currents in your circuit. For the test circuit, determine how a short circuit between two points in the circuit affects the brightness of each bulb. Calculate the current through each bulb and the current output from the battery for each case.

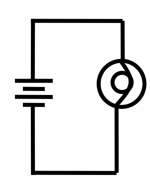
EQUIPMENT

The symbols on the right are used in the circuit diagram shown below.





Test Circuit



Reference Circuit

Note: Some of the light bulbs in the lab may be of different kinds and have different resistances. To find identical light bulbs look for markings and check to see that the color of the plastic bead separating the filament wires is the same.

PREDICTIONS

Determine the brightness of each of the bulbs when a wire is attached from point 1 to point 2 by calculating the current through each bulb in terms of the battery voltage and bulb resistance. Calculate the current output by the battery as a function of the battery voltage and bulb resistance.

Determine the brightness of each of the bulbs when a wire is attached from point 2 to point 3 by calculating the current through each bulb in terms of the battery voltage and bulb resistance. Calculate the current output by the battery as a function of the battery voltage and bulb resistance.

Determine the brightness of each of the bulbs when a wire is attached from point 1 to point 3 by calculating the current through each bulb in terms of the battery voltage and bulb resistance. Calculate the current output by the battery as a function of the battery voltage and bulb resistance.

Determine the brightness of each of the bulbs when a wire is attached from point 2 to point 4 by calculating the current through each bulb in terms of the battery voltage and bulb resistance. Calculate the current output by the battery as a function of the battery voltage and bulb resistance.

WARM-UP

Read Serway & Jewett: sections 21.1, 21.2, 21.6, 21.7, 21.8.

1. Draw the diagram of the test circuit. Compare the potential differences across pairs of points (taken from the four points labeled) with each other and with the voltage across the battery. Label the voltage across each bulb. Compare the voltage across each bulb with the voltage between the labeled points. Explain why you think it is smaller, equal, or larger than the voltage across the battery.

2. Draw and label the current through each wire on the circuit diagram. Use conservation of charge to determine how these currents are related.

3. Using your circuit diagram follow an energy carrier (say a positive charge) from the battery around a complete circuit back to the battery. Use conservation of energy to write down an equation (or equations) relating the voltage differences across each bulb. You may need to consider more than one path for the charge to take.

4. Write down equations relating the voltage difference across each bulb to the current through that bulb using Ohm's law as an approximation

5. Using the equations from questions 2, 3, 4 can you solve for the current through the battery? If not, find a different path around a complete circuit and write down the voltage equation for that path. Continue this process of choosing paths and writing down voltage equations until you have enough equations to solve for the current through the battery.

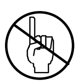
6. How is the brightness of a bulb related to the rate of energy transferred to the bulb? Write down an equation showing how the current through the bulb determines its brightness. Write down an equation showing how the voltage across the bulb determines its brightness.

7. Draw a wire between point 1 and point 2. How does the voltage across each bulb change? How does this voltage change affect the brightness of each bulb?

8. Now repeat questions 2 and 3 with this new circuit.

9. Repeat the above steps for the other short circuit configurations.

EXPLORATION



WARNING: A short circuit is what happens any time a very low-resistance path (like a wire, or other piece of metal) is provided between points in a circuit that are at different potentials, like the terminals of a battery or power supply. **Short circuits can destroy equipment and injure people! Always avoid short circuits in other circuits!** Short circuits damage equipment by causing larger currents in a circuit than they are designed for. These currents can cause intense heat and damage to nearby circuit elements or measuring devices. **Only apply the short circuit for a small amount of time**.

Build the test circuit and make sure all of the bulbs light. Try touching a wire to make a short circuit for a very small amount of time. Determine the shortest time necessary to make a reliable observation of the bulb brightness. Use this technique to make your measurements.

Decide how you will insert a DMM in your circuit to measure the current from your battery. Make sure the DMM has the correct setting before you put it in the circuit to prevent damaging the meter. Does the DMM significantly affect your circuit? Look at the brightness of the bulbs before and after you insert the DMM. Determine how long you will need to keep a short circuit connected to make an accurate measurement with your DMM.

Decide on the best way to make the set of measurements that you need.

MEASUREMENT

Follow the measurement plan that you decided upon in the Exploration section using the reference circuit for brightness comparisons and the DMM for current measurements.

ANALYSIS

Examine your circuit diagrams for the three bulbs with each short circuit and compare the brightness of the bulb in each situation. Estimate how well you can determine relative bulb brightness. Does this qualitative brightness determination agree with your quantitative current measurements?

Does the resistance of your DMM affect the current measurements in each case? Does introducing the DMM to measure the current through a bulb have a noticeable effect on the brightness of that bulb? Estimate the size of this effect.

CONCLUSION

Did your predictions match your observed results? Explain your answers. What effects might such malfunctions have on human patients?

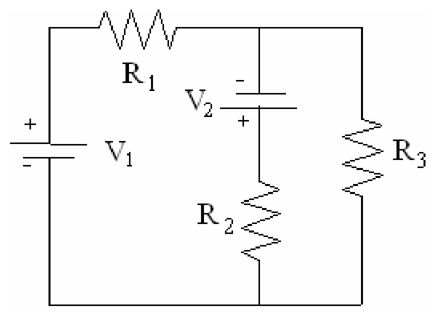
PROBLEM #6
QUANTITATIVE CIRCUIT ANALYSIS

You work with a team building networks of circuits designed to imitate the behavior of networks of neurons in the brain. You are assigned the job of tuning the parameters of a circuit that represents a feedback loop within a single neuron. You run into trouble in your calculations, and decide to test some of your assumptions about variations in the current supplied to your feedback circuit, using the model circuit shown below. Determine the current through each resistor in the circuit shown.

EQUIPMENT

Build the circuit shown to the right with wires, resistors, and a voltage source (batteries or a power supply).

You will have a digital multimeter (DMM) for measuring resistance, voltages, and currents.



Circuit

PREDICTION

Write an expression for the current through each resistor in the circuit, in terms of the resistances and voltages labeled in the circuit diagram.

WARM-UP

Read Serway & Jewett: sections 21.1, 21.2, 21.6, 21.7, 21.8.

1. Draw and label a circuit diagram, showing all voltages and resistors. Sometimes you may need to redraw the given circuit to help yourself see which resistors are in series and which are in parallel. For this problem, the voltages and the resistances are the known quantities and the currents in the resistors are the unknowns.

2. Assign a separate current for each branch of the circuit, indicating each current on the diagram. Identify the number of circuit paths (loops) and label them on the diagram.

3. Apply conservation of current to each point in the circuit at which wires come together (a junction). Use conservation of energy to get the sum of the potential differences across all of the elements in each loop, ensuring your signs are correct. Does the potential difference increase or decrease across each circuit element, in the direction you have chosen to traverse the loop? Use Ohm's law to get the potential difference across each resistor. Check that the number of linear equations that you wrote above matches the number of unknowns.

4. Complete the calculations and write your solution. Simplify your equations as much as possible, but be warned that your final solutions may look quite complicated.

EXPLORATION

If you have not used the digital multimeter (DMM), read *Appendix D* and get familiar with its different operations.

Build the circuit. How can you tell if there is current flowing through the circuit? What happens to the current at each junction? What is the resistance of each resistor? What is the potential difference provided by each of the batteries? What is the potential difference across each resistor? Use the DMM to check your answers to each of these questions.

Complete your measurement plan.

MEASUREMENT

Measure the resistance of the resistors, the current flowing through each resistor, and the potential difference provided by each battery in the circuits. So that you can check your measurements, measure the potential difference across each resistor.

ANALYSIS

Calculate the current through each resistor from your prediction equations, using your measured values of the resistance of each resistor and voltage of each battery. Compare those results to the measured values of each current.

CONCLUSION

Did your measured and predicted values of the currents through the resistors agree? If not, explain the discrepancy.

As a check for the consistency of your measurements, calculate the potential difference across each resistor using the currents that you measured. Compare these values with the potential difference across each resistor that you measured with the DMM.

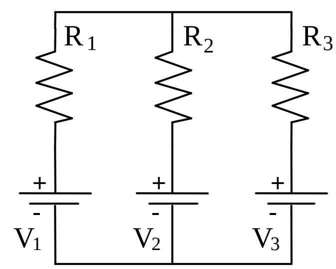
PROBLEM #7
QUANTITATIVE CIRCUIT ANALYSIS B

You again work with a team building networks of circuits designed to imitate the behavior of networks of neurons in the brain. You are assigned the job of tuning the parameters of a circuit that represents a feedback loop within a single neuron. You run into trouble in your calculations, and decide to test some of your assumptions about variations in the current supplied to your feedback circuit, using the model circuit shown below. Determine the current through each resistor in the circuit shown.

EQUIPMENT

You will have wires, resistors, and batteries or a power supply to build a circuit shown to the right.

You will have a digital multimeter (DMM) to measure resistances, voltages, and currents.



Circuit XIII

PREDICTION

Derive formulas to calculate the current through each of resistors in Circuit XIII as a function of voltages of the batteries and resistances involved in the circuit.

WARM-UP QUESTIONS

1. Draw and label a circuit diagram showing all voltages and resistors. Sometimes you may need to redraw the given circuit to help yourself see which resistors are in series and which are in parallel. For this problem, the voltages and the resistors are the known quantities and the currents in the resistors are the unknowns.

2. Assign a separate current for each leg of the circuit, indicating each current on the diagram. Identify the number of circuit paths (loops) and label them on the diagram.

3. Apply conservation of current to each point in the circuit at which wires come together (a junction). Use conservation of energy to get the sum of the potential differences across all of the elements in each loop, ensuring your signs are correct. Does the potential difference increase or decrease across each circuit element, in the direction you have chosen to traverse the loop? Use Ohm's law to get the potential difference across each resistor.

Check that the number of linear equations that you have now matches the number of unknowns.

4. Complete the calculations and write your solution. Simplify your equations as much as possible, but be warned that your final solutions may look quite complicated.

EXPLORATION

To become familiar with a DMM and various modes of its operation, read *Appendix D*.

Build Circuit XIII. How can you tell if there is current flowing through the circuit? What happens to the current at each junction? What is the resistance of each resistor? What is the potential difference provided by each of the batteries? What is the potential difference across each resistor? Use the DMM to check your answers to each of these questions.

Complete your measurement plan.

MEASUREMENT

Measure the resistance of each of the three resistors, as well as the currents flowing through each of them. Measure the potential difference provided by each battery. So that you can check your measurements, measure the potential difference across each resistor.

ANALYSIS

Calculate the current through each resistor from your prediction equations, using your measured values of the resistance of each resistor and voltage of each battery. Compare those results to the measured values of each current.

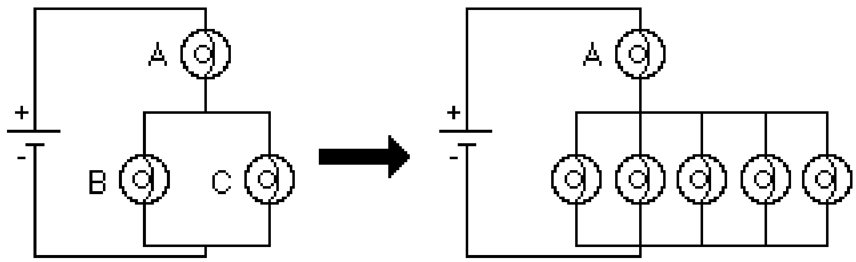
CONCLUSIONS

Did your measured and predicted values of the currents through the resistors agree? If not, explain the discrepancy.

As a check for the consistency of your measurements, calculate the potential difference across each resistor using the currents that you measured. Compare these values with the potential difference across each resistor that you measured with the DMM.

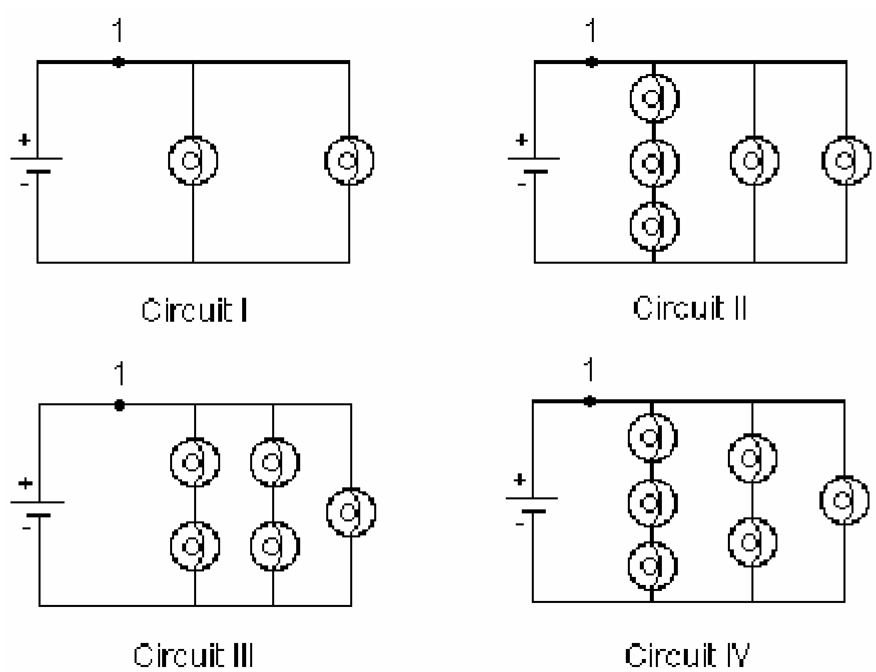
☑ CHECK YOUR UNDERSTANDING

1. What would happen to the brightness of bulb A in the circuit below if more bulbs were added parallel to bulbs B and C?

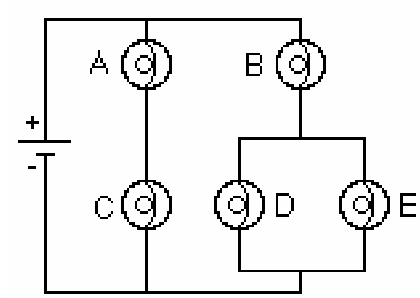


In household circuits, a fuse or circuit breaker is in the position occupied by bulb A, why?

2. Rank Circuits I through IV from the largest current at point 1 to the smallest current at point 1. Explain your reasoning.

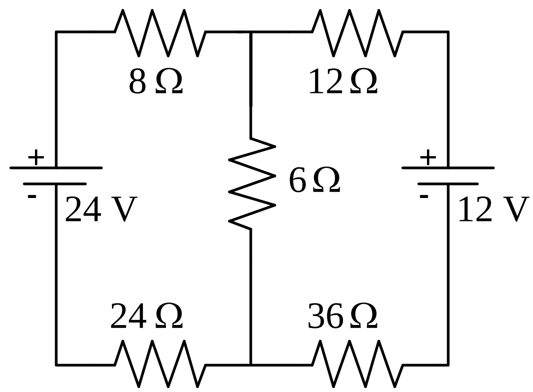


3. Predict what will happen to the brightness of bulbs A, B, C and D if bulb E were removed from its socket. Explain your reasoning.

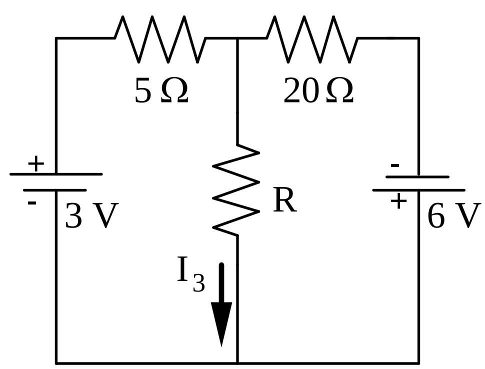


☑ CHECK YOUR UNDERSTANDING

4. For the circuit below, determine the current in each resistor.



5. For the circuit below, determine the value for R such that the current I_3 is 0.1A with the indicated direction.



What is the value for R that will give a current $I_3 = 0.1$ A, but in the opposite direction to what is shown?

PHYSICS 1202 LABORATORY REPORT
Laboratory III

Name and ID#: ____

Date performed: ________________ Day/Time section meets: ________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: ________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

LABORATORY III
ENERGY AND CAPACITORS

All biological systems rely on the ability to store and transfer electrical energy. One feature that many of these systems have in common is a structure that behaves like a capacitor, the simplest device that stores electrical energy. By studying the way capacitors store and transfer energy, you can gain insight into the way many biological systems store and transfer energy. In this laboratory you will investigate the storage and transfer of energy in capacitors.

The problems in this lab involve transferring stored electrical energy as work or as light.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Apply the concept of conservation of energy to solve problems involving electrical phenomena.
- Describe the energy stored in a capacitor based on how it is connected to other capacitors and to sources of potential differences.
- Describe the rate at which a capacitor loses or gains energy based upon the system in which it is involved.

PREPARATION:

Read Serway & Jewett: Chapter 20, sections 7, 8, and 9 and Chapter 6 section 5.

Before coming to lab you should be able to:

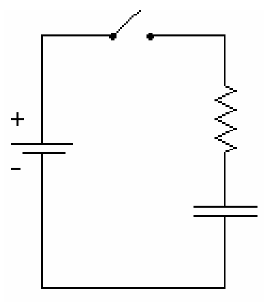
- Calculate the energy stored in a capacitor as a function of its capacitance and its voltage.
- Calculate the energy of an object given its speed and mass.
- Solve the rate equation, $\frac{dN(t)}{dt} = A \cdot N(t)$, and understand all quantities involved.

PROBLEM #1:
CHARGING A CAPACITOR

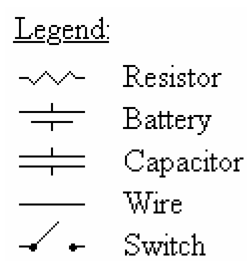
One summer you volunteer at a summer biology camp for high school students. You plan to demonstrate the effect of lightning on the creation of organic substances. To imitate the lightning, you will use a capacitor to be discharged in the atmosphere. Each time the capacitor is discharged, it must be recharged for the next demonstration. To save time, you want to charge the capacitor as fast as possible. However, you are not sure whether the resistance in series with the capacitor should be small or large to achieve quick recharging of the capacitor. To find the answer, you model the circuit with a capacitor, a resistor, and a battery in series. In a circuit consisting of a battery, a capacitor (initially uncharged), and a resistor, all in series, how does the time taken for the current in the circuit to fall to 1/8 of its initial value depend upon the resistance of the resistor?

EQUIPMENT

Build the circuit shown below using wires, resistors, capacitors, and batteries. Use the accompanying legend to help you build the circuits. You will also have a stopwatch, a light bulb, and a digital multimeter (DMM).



Circuit



PREDICTIONS

How does the time taken for the current in the circuit to fall to 1/8 of its initial value depend upon the resistance of the resistor?

Sketch a graph of the time taken for the current to fall to 1/8 of its initial value against the resistance of the resistor.

WARM-UP

Read Serway & Jewett: sections 21.1, 21.2, 21.8, 21.9.

1. Draw a circuit diagram, similar to the one shown above. Decide on the properties of each of the elements of the circuit that are relevant to the problem, and label them on your diagram. Label the potential difference across each of the elements of the circuit. Label the current in the circuit and the charge on the capacitor.

2. Recall from Kirchhoff's loop rule that the sum of potential differences across each element around any closed circuit loop is zero. Write an equation relating the potential difference across each of the elements of the circuit.

3. What is the relationship between the potential difference across the capacitor plates and the charge stored on its plates? What is the relationship between the current through the resistor and the voltage across it? Are these equations always true, or only for specific times?

4. Use these relationships to rewrite your Kirchhoff loop equation in terms of the voltage of the battery, the capacitance of the capacitor, the resistance of the resistor, the current through the circuit, and the charge stored on the capacitor.

5. Explain how each of the quantities labeled on your diagram changes with time. What is the voltage across each of the elements of the circuit (a) at the instant the circuit is closed, (b) when the capacitor is fully charged? What is the current in the circuit at these two times? What is the charge on the capacitor at these two times?

6. Write an equation relating the rate that charge accumulates on the capacitor to the current through the circuit. To do this, determine how the rate at which the charge on the capacitor is changing relates to the rate at which charge comes from the battery. Then, determine how the rate at which charge comes from the battery relates to the current in the circuit.

7. The unknown quantity in your loop equation is the current in the circuit and the charge on the capacitor. You need to eliminate the charge on the capacitor from your equations to obtain an equation for the current in the circuit in terms of the known quantities. You may find it helpful to differentiate both sides of the equation with respect to time and use the relationship from step 6 to eliminate the charge.

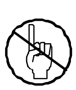
8. Solve the equation from the previous step for current by using one of the following techniques: (a) Guess the current as a function of time, which satisfies the equation, and check it; (b) Get all the terms involving current on one side of the equation and time on the other side and solve. Solving the equation may require an integral.

9. Complete your solution by determining any arbitrary constants in your solution, using the initial value of the current obtained above (what is the current when t=0?)

10. Using your equation for the current, write an expression for the time taken for the current to fall to half its initial value. Now find an expression for the time taken for the current in the circuit to halve again, and so on. How does the time for the current to halve change as the time since the circuit was closed increases?

11. How does the time it takes for the current to drop to 1/8 of its original value compare to the time it takes for the current to drop to 1/2 of its original value? How does that time depend on the resistance in the circuit? Sketch a graph of that time vs. the resistance.

EXPLORATION



WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Note: Make sure the + terminal of the battery is connected to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

Examine each element of the circuit **before** you build it. How do you know if the battery is "good"? Is the capacitor charged? Carefully connect the two terminals of the capacitor to ensure it is uncharged. How can you determine the resistance of the resistor? Is there a way to confirm it?

After you are convinced that all of the circuit elements are working and that the capacitor is uncharged, build the Circuit **with a light bulb in place of the resistor**, but leave the circuit open.

Close the circuit and observe how the brightness of the bulb changes with time. What can you infer about the way the current in the circuit changes with time? From what you know about a battery, how does the potential difference (voltage) across the battery change over time? Check this using the DMM set for potential difference (Volts). From your observations of the brightness of the bulb, how does the potential difference across the bulb change over time? Check this using the DMM. What can you infer about the change of voltage across the capacitor over time? Can you check with a DMM? Use the concept of potential difference to explain what you observe.

Now, discharge the capacitor, and reconnect the DMM in such a way that it measures the current in the circuit. Close the circuit and observe how the current changes with time? Is it as you expected? How long does it take for the current to fall to zero?

Replace the light bulb with a resistor. Qualitatively, how will changing the resistance of the resistor and the capacitance of the capacitor affect the way the current in the circuit changes with time? How can you test this experimentally?

Build the circuit, including a DMM in the circuit to measure the current. Close the circuit and observe how long it takes for the current in the circuit to halve. How does changing the capacitance of the capacitor or the resistance of the resistor affect this time? Choose a value of the capacitance of the capacitor and a range of resistances that allow you to most effectively construct a graph to test your prediction.

Complete your measurement plan.

MEASUREMENT

Measure the time taken for the current in the circuit to drop to 1/8 of its initial value for different resistance of the resistor. Do this at least twice for each resistor for averaging.

ANALYSIS

Using the measured values of the capacitance of the capacitor, the resistances of the resistors, and the voltage of the battery, construct a graph of your prediction of the time it takes the current to drop to 1/8 of its initial value vs. resistance. Using your data, construct a graph of the measured times versus resistance.

CONCLUSION

How does the time taken for the current in the circuit to drop to 1/8 of its initial value depend upon the resistance of the resistor?

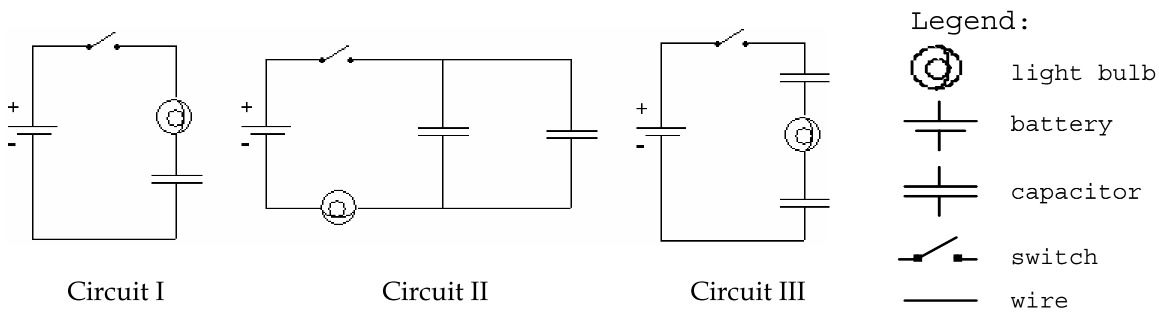
Compare your prediction result with your measurement result. Explain any differences.

PROBLEM #2:
CONNECTION OF TWO CAPACITORS

You are working in a research group of the University, which is studying the effect of sudden currents on protein suspensions. The method used in the research is to charge a capacitor and discharge it to provide a large current. One day, you need to increase the capacitance of the capacitor to get larger discharging current. However, no larger capacitor is available. Fortunately, you have another capacitor with smaller capacitance than the original. You wish to use both capacitors at the same time, but you are not sure how to connect the two capacitors together to achieve maximum capacitance. To model the situation, you set up three kinds of circuits with the capacitors. For each, you will investigate how long it takes for the bulb to dim after the circuit is closed. You think that the longer the time, the larger the capacitance. How does the capacitance of two capacitors in parallel compare to that of two capacitors in series?

EQUIPMENT

Build the circuits shown below out of wires, resistors, capacitors with equal capacitance, and batteries. You will also have a stopwatch and a digital multimeter (DMM).



Note: Some of the light bulbs in the lab may be of different kinds and have different resistances. To find identical light bulbs look for markings and check to see that the color of the plastic bead separating the filament wires is the same.

PREDICTION

Graph the current in each of Circuits I, II, and III as functions of time, assuming each capacitor has the same capacitance. Rank the total time it takes for the bulbs in Circuits I, II, and III to turn off from shortest to longest.

WARM-UP

Read Serway & Jewett: sections 20.7, 20.8, 21.1, 21.2, 21.8, 21.9.

1. For each of the circuits, draw a circuit diagram. Decide on the properties of each of the elements of the circuit that are relevant to the problem, and label them on your diagram. Label the potential difference across each of the elements of the circuit. Label the current in the circuit and the charge on each capacitor. What about the two capacitors of Circuit III? When will the bulb go out?

2. Recall from Kirchhoff's loop rule that the sum of potential differences across each element around any closed circuit loop is zero. Write an equation relating the potential difference across each of the elements of Circuit II. Do the same for two closed circuit loops in Circuit III. What is the relationship between the charges on the two capacitors in Circuit II? What is the relationship between the charges on the two capacitors in Circuit III?

3. What is the relationship between the potential difference across the plates of each capacitor and the charge stored on its plates? What is the relationship between the current through the bulb and the voltage across it? Are these equations always true, or only for specific times?

4. Use these relationships to rewrite your Kirchhoff loop equations in terms of the voltage of the battery, the capacitance of each of the capacitors, the resistance of the bulb, the current through the circuit, and the charge stored on each of the capacitors.

5. Explain how each of the quantities labeled on your diagram changes with time. What is the voltage across each of the elements of the circuit (a) at the instant the circuit is closed, (b) when the capacitor is fully charged? What is the current in the circuit between these two times? What is the charge on each of the capacitors between these two times?

6. Write an equation relating the rate that charge accumulates on each of the capacitors to the current through the circuit. To do this, determine how the rate at which the charge on each of the capacitors is changing relates to the rate at which charge comes from the battery. Then, determine how the rate at which charge comes from the battery relates to the current in the circuit.

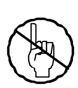
7. The unknown quantities in your loop equations are the current in the circuit and the charge on each of the capacitors. You need to eliminate the charge on each of the capacitors from your equations to obtain an equation for the current in the circuit in terms of the known quantities. You may find it helpful to differentiate both sides of each equation with respect to time and use the relationship from step 6 to eliminate the charge.

8. Solve the equation from the previous step for current by using one of the following techniques: (a) Guess the current as a function of time, which satisfies the equation, and check it; (b) Get all the terms involving current on one side of the equation and time on the other side and solve. Solving the equation may require an integral.

9. Complete your solution by determining any arbitrary constants in your solution, using the initial value of the current obtained above (what is the current when $t=0$?).

10. Complete the above steps for the all of the circuits. How does the equation for current as a function of time compare for Circuits I, II, and III? Sketch a graph of current versus time for all three circuits (plot them on the same graph). In which circuit do you expect the bulb to go out first?

EXPLORATION



WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Note: Make sure the + terminal of the battery is connected to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

Review your exploration from the previous problem. Examine each element of the circuit **before** you build it. How do you know if the battery is "good"? Are the capacitors charged? Carefully connect the two terminals of each capacitor to ensure it is uncharged. Make sure your two capacitors have the same capacitance. Begin your observations by using bulbs instead of resistors.

Build Circuit II, but do not close the circuit. Do you think the bulb will light when the circuit is closed? Record your reasoning. Close the circuit. Record your observations and explain what you saw using conservation of charge and the concept of potential difference

Build Circuit III, but do not close the circuit. Do you think the bulb will light when the circuit is closed? Record your reasoning in your journal. Close the circuit. Record your observations and explain what you saw using conservation of charge and the concept of potential difference. Does the order that you connect the two capacitors and the bulb in the circuit matter? Try following one capacitor with the other capacitor and then the bulb.

Now, replace the light bulbs in your circuits with resistors. How can you determine the resistance of the resistor? Is there a way to confirm it?

Connect a DMM in each of the circuits and observe how the current changes with time. For each circuit, decide how many measurements you will need to make in order to make a graph of current against time, and what time interval between measurements you will choose. Complete your measurement plan.

MEASUREMENT

Measure the current in each circuit for as many different times as you deem necessary. Make your measurements using resistors, not bulbs. What are the uncertainties in each of these measurements?

ANALYSIS

Draw graphs of the measured values of the current as a function of time for each of the circuits I, II, and III.

CONCLUSION

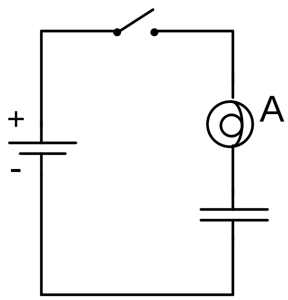
How well do your graphs drawn from your data compare to those drawn from your prediction? Explain any difference.

PROBLEM #3:
CAPACITORS I

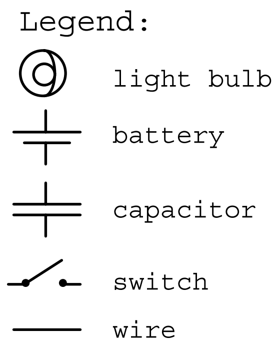
You and a friend are discussing how ion concentrations on either side of a cell membrane change with time. In particular you want to investigate how ions (say Na+) migrate and how voltage across the membrane builds up over time. To clarify this, you model the cell membrane very crudely as a capacitor in series with a light bulb and battery. A capacitor can be thought of as a device used to hold separated charges (similar to the cell membrane).Your friend claims that when the switch is closed the capacitor charges up and the bulb gets brighter and brighter until the brightness levels off. The bulb then stays on until the switch is opened. Do you agree? In a circuit consisting of a battery, a bulb, and a capacitor, determine how the brightness of the bulb changes with time.

EQUIPMENT

You can build the circuit shown below out of wires, bulbs, capacitors and batteries. Use the accompanying legend to help you build the circuits. You will also have a stopwatch and a digital multimeter (DMM).



Circuit I



PREDICTION

Read Serway & Jewett: sections 20.7, 21.1, 21.2, 21.5, 21.9.

How do you think the brightness of the light bulb changes over time?
What is it that makes the light bulb glow? Explain.

Sketch a graph of the brightness of the bulb, as a function of time, assuming the capacitor to be initially uncharged. Is there a limit as to how much charge the capacitor can hold?

EXPLORATION

WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** touch the metal terminals of the capacitors or the exposed metal of any wires connected to them. **Always discharge a capacitor with a wire when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Note: Make sure the + terminal of the battery is connected to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

Examine each element of the circuit **before** you build it. How do you know if the battery is "good"? How do you check if the capacitor is charged? How can you tell if the capacitor is completely charged? How can you be sure the capacitor is not charged?

After you are convinced that all of the circuit elements are working and that the capacitor is not charged, build the circuit but do not make the final connection yet.

Now, close the circuit and observe how the brightness of the bulb changes over time. How long does it take for any variation to cease?

From your observation of the bulb's brightness, how does the current going through the bulb change over time? You can check this using the DMM set for current (Amperes). See *Appendix D* for the use of the DMM. How does the charge on the capacitor change over the same time? Can you measure this with the DMM? Use conservation of energy to explain what you observe.

From what you know about a battery, how does the voltage across the battery change over time? Check this using the DMM set for Volts. From your observations of the brightness of the bulb, how does the voltage across the bulb change over time? Check this using the DMM. What can you infer about the change of voltage across the capacitor over time? Can you check with a DMM? Use the concept of energy to explain what you observe.

After a few moments, open the circuit. Is the capacitor charged or not? To determine if the capacitor is charged, carefully (and safely) remove the battery from the circuit and reconnect the circuit without the battery. With only the capacitor, and bulb (no battery) in the circuit, will the bulb light if you close the circuit and the capacitor is charged? Uncharged? Try it. Was the capacitor charged before you closed the circuit? Was the capacitor still charged long after the circuit was closed? Use conservation of energy to explain your results.

CONCLUSION

Was your friend right about how the brightness of the bulb changed over time?

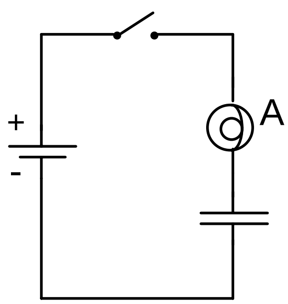
Sketch a qualitative graph of the brightness of the bulb as a function of time after you complete the circuit. How does this compare to your prediction?

PROBLEM #4:
CAPACITORS II

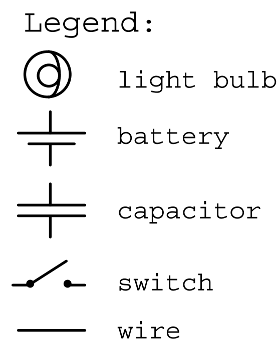
You and a friend are discussing how ion concentrations on either side of a cell membrane change with time. In particular you want to investigate how ions (say Na+) migrate and how voltage across the membrane builds up over time. Now you are wondering how the properties of the membrane affect the migration process. You decide to model the cell membrane, very crudely, as a capacitor in series with a light bulb and a battery. A capacitor can be thought of as a device used to hold separated charges (similar to the cell membrane). You decide to get a qualitative understanding of the rate at which a capacitor charges by using a capacitor in series with a light bulb and battery. How does the time that the light bulb is lit depend on the capacitance of the capacitor connected in series with it?

EQUIPMENT

You have the materials to build the circuit below. You will also have a stopwatch and a digital multimeter (DMM). Use the accompanying legend to help you build the circuit.



Circuit I



PREDICTION

Read Serway & Jewett: sections 20.7, 20.8, 21.1, 21.2, 21.5, 21.9.

From your experience, make an educated guess about how the time that the light bulb is lit depends on the capacitance of the capacitor.

Sketch a graph of the time it takes for the light bulb to turn completely off as a function of the capacitor's capacitance. Assume the capacitor is initially uncharged. Write down what you mean when you say the light bulb is completely off.

EXPLORATION

WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor before you use it and after you are finished using it.**

Note: Make sure the + terminal of the battery is connected to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

Examine each element of the circuit **before** you build it. How do you know if the battery is "good"? Be sure the capacitors are not charged.

After you are convinced that all of the circuit elements are working and that the capacitor is not charged, connect the circuit but do not close it yet.

Now, close the circuit and observe how the brightness of the bulb changes over time. How long does it take for the bulb to turn off?

From what you know about a battery, how does the voltage across the battery change over time? Check this using the DMM set for volts. From your observations of the brightness of the bulb, how does the voltage across the bulb change over time? Check this using the DMM. What can you infer about the change of voltage across the capacitor over time? Can you check with a DMM? Use the concepts of voltage and energy to explain what you observe.

Develop a measurement plan that will allow you to determine the time it takes a bulb to turn off as a function of capacitance. You will want to decide how many different capacitors you need to use, how many time measurements to take for each capacitor, and what you mean by the light bulb being 'off'.

MEASUREMENT

Use your measurement plan to record how long it takes for the light bulb to turn off for each capacitor in the circuit.

ANALYSIS

Graph the time it takes for the light bulb to turn off, as a function of capacitance, assuming the capacitor is initially uncharged.

CONCLUSION

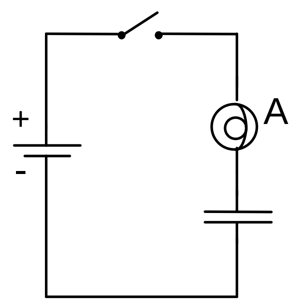
How did your measurement compare with your prediction? Using conservation of charge and conservation of energy, explain how the capacitance affects the time it takes for the bulb to turn off.

PROBLEM #5:
RATES OF ENERGY TRANSFER IN RC CIRCUITS

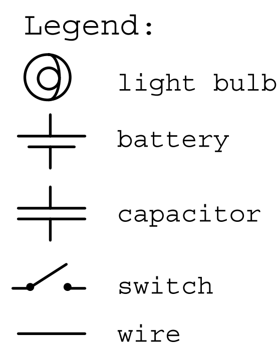
For a class project in biomedical electronics, you thought of developing a simple 'stun gun' for use in self-defense. The 'stun gun' has a capacitor charged to a high voltage. When a pair of electrodes at the tip of the 'gun' touch the skin of an attacker the capacitor discharges (ouch!). Being cautious, you also imagine a scenario in which the gun misses the attacker the first time, so you are concerned about how fast the gun can 'reload'. To shed light on this issue, you assembled together a circuit containing a capacitor in series with a battery and light bulb. You are interested in determining the rate and therefore the time it takes for the capacitor to charge. Can you characterize the rate at which energy enters the capacitor? What determines the time it takes for a capacitor to charge (or discharge)? In this problem you are interested in not just the total charge time but also in how energy enters the capacitor during the charging process. Determine how the energy stored in the capacitor changes as a function of time while charging.

EQUIPMENT

You have the materials to build the circuit below. You will also have a stopwatch and a digital multimeter (DMM). Use the accompanying legend to help you build the circuit.



Circuit I



PREDICTION

Which equation(s) will you use to determine the rate at which energy enters the capacitor?

WARM-UP

Read Serway & Jewett: sections 20.7, 20.8, 20.9, 21.1, 21.2, 21.5, 21.9.

1. In this experiment, you are looking at rates of change. Make a list of the things that are changing in the circuit while a capacitor is charging.

2. Write down appropriate rate equation(s) for properties of the circuit that change with time. Write down the meaning of each letter in the rate equation(s).

3. List the terms (letters) in the rate equation you can measure with tools in the lab. Which terms in the rate equation will you need to calculate as a result of your experiment? How many of these terms are there?

4. Explain the role of the capacitor in the rate equation.
5. Explain the role of the battery in the rate equation
6. Solve the rate equation. Are there any unknown quantities in this equation? Write them down. How about initial conditions?
7. How are the time-varying quantities, which you can measure directly and which you have written rate equation(s) for, related to the capacitor's energy? To the rate of energy input to the capacitor?
8. How is the energy stored in a capacitor related to the voltage across the capacitor terminals?

EXPLORATION

WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor before you use it and after you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Note: Make sure the + terminal of the battery is connected to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

You are interested in rates of change, so you will need to time things. Begin with the smallest capacitor available. You will need to take measurements at several times as the capacitor charges. What do you need to measure? What is the best way to coordinate data taking? You may find the "split" feature of the stopwatch to be useful. Does this capacitor charge too quickly for you to measure?

You might want to connect a resistor in series with the light bulb (or use a resistor in place of the bulb) to reduce the charging rate to something measurable. How can you measure the resistance of this combination? How much resistance does the light bulb contribute? What role does the bulb play? How are the light bulb and resistor similar? How are they different?

Try using different capacitors and resistor sizes until you find a few combinations that will allow you to get some good sets of data.

MEASUREMENT

Measure the voltage across the capacitor as a function of time. Take several measurements as the capacitor charges - you will find it easier to fit your prediction equation to a larger number of data points.

For each circuit, remove the resistor/light bulb combination and measure its resistance using the digital multimeter. Take data for a few capacitor/resistor sizes. The capacitor value written on the capacitor might not be accurate.

ANALYSIS

Using a graphing program or a spreadsheet, plot your data for voltage (and perhaps also for current) as a function of time. Plot the solution to your rate equation for the voltage. You may adjust the 'fit' parameters (e.g. the capacitance) until your measured and calculated graphs match.

From the time-evolution of the voltage across the capacitor, construct a plot of the rate at which energy is transferred to the capacitor.

CONCLUSION

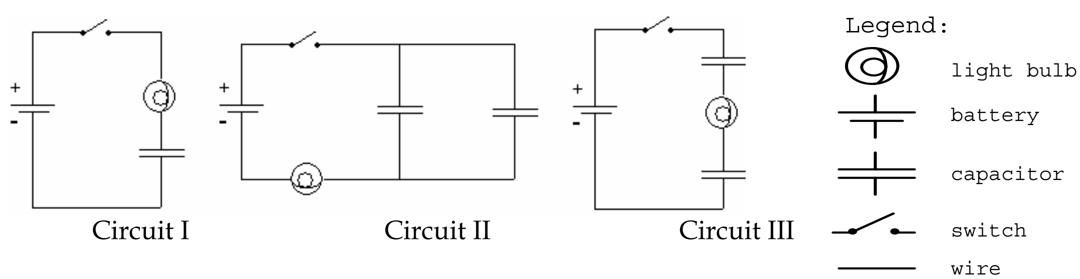
Knowing the rate at which energy enters the capacitor, what determines the time for the capacitor to charge?

PROBLEM #6:
CIRCUITS WITH TWO CAPACITORS

You have a job in a research group studying nocturnal fish. Your task is to photograph the creatures at certain intervals using a camera with an electric flash. After taking a roll of pictures you are disappointed that the flash isn't bright enough. You look in the camera and notice that the flash works by slowly charging a capacitor with a battery and then quickly releasing the stored energy through a light bulb when a photo is taken. You think that the problem with your camera may be that not enough energy is stored in the capacitor to properly light the flash bulb. You have another capacitor, of different capacitance, but aren't sure if you should connect it in series or in parallel with the original capacitor in order to store the most energy. First you calculate which of the two ways of connecting the two capacitors results in the most stored energy. Next you decide to test your calculation by seeing which one takes longest to charge through a bulb. You reason that the more the stored energy, the longer it will take to charge. Which circuit consisting of a bulb, a battery, and two capacitors takes the longest time for the bulb to dim?

EQUIPMENT

Build the circuits shown below out of wires, *identical* bulbs, two *different* capacitors, and batteries. Use the accompanying legend to help you build the circuit. You will also have a stopwatch.



Note: Some of the light bulbs in the lab may be of different kinds and have different resistances. To find identical light bulbs look for markings and check to see that the color of the plastic bead separating the filament wires is the same.

PREDICTION

Rank the total time it takes for each of the bulbs in Circuits I, II, and III to turn off (use the symbol '**=**' for "same time as"; the symbol '**>**' for "more time than"; and the symbol 'Ø' if the bulb never lights). Explain your reasoning.

WARM-UP

Read Serway & Jewett: sections 20.7, 20.8, 20.9, 21.1, 21.2, 21.5, 21.9.

1. Draw a picture of each arrangement of the capacitors, light bulb, and battery. On each picture, label the capacitance of each capacitor, remembering that you only have two capacitors, with different capacitances. Also, label the electric potential difference across each circuit element and the charge stored on each capacitor.

2. Decide on the physics principles you will use. In the case of a circuit, conservation of charge is usually useful, as is conservation of energy. What is the relationship between the total energy stored in each circuit and the energy stored on each capacitor in that circuit?

3. For each capacitor, determine an equation that relates the energy stored on its plates, the charge stored in it, and its capacitance.

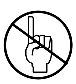
4. For each capacitor, write an equation that relates the charge on each capacitor, the potential difference across the capacitor, and the capacitance of the capacitor.

5. When the current stops flowing through the circuit, is the charge on the two capacitors in Circuit II the same? Circuit III? At that time, what is the potential difference across the bulb in each circuit? At that time, what is the relationship between the potential difference across the battery and the potential difference across each capacitor?

6. The target quantity is the energy stored in the capacitors of each circuit. To determine which is larger, you must find the energy stored in terms of common quantities such as the potential difference across the battery and the capacitance of each capacitor.

7. From step 6, you have the total energy stored in the capacitors in each circuit in terms of the potential difference across the battery and the capacitance of each capacitor. Now compare them to determine which is largest. Check your equations by making the comparison when both capacitors have the same capacitance. Does this make sense?

EXPLORATION



WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or connected wires by their metal ends. **Always discharge a capacitor before you use it and when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Note: Make sure the + terminal of the battery is connected to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

Make sure all of your capacitors are uncharged before starting the exploration.

Examine each element of the circuit **before** you build it. How do you know if the battery and the bulb are "good"?

Connect Circuit I to use as a reference. Close the circuit and observe how the brightness of the bulb changes over time. How long does it take for the bulb to turn off?

Connect Circuit II using the capacitor from Circuit I along with a capacitor with a different capacitance. Do not close the circuit yet. Do you think the bulb will light when the circuit is closed? Record your reasoning in your journal. Now, close the circuit. Record your observations and explain what you saw using conservation of charge and the concept of potential difference. Does the order that you connect the two capacitors and the bulb in the circuit matter? Try following one capacitor with the other capacitor and then the bulb. Try switching the two capacitors.

After the brightness of the bulb no longer changes, what is the relationship between the potential differences across the elements of the circuit? Check this using the DMM set for potential difference (Volts). Use the concept of potential difference to explain what you observe.

Connect Circuit III using the two capacitors you used in Circuit II. Do not close the circuit yet. Do you think the bulb will light when the circuit is closed? Record your reasoning in your journal. Now, close the circuit. Record your observations and explain what you saw using conservation of charge and the concept of potential difference. Use the DMM to check the relationship between the potential differences across the elements of this circuit. Explain what you observe.

Develop a plan for measuring the time that it takes for the bulbs in Circuits I, II, and III to turn off, if they light at all.

MEASUREMENT

Use your measurement plan to record how long it takes for the light bulb to go off for each circuit. Use 0 seconds for bulbs that did not light. What are the uncertainties in these measurements?

ANALYSIS

Rank the actual time it took each bulb to turn off. Do all the bulbs initially light? Do all the bulbs go off?

CONCLUSION

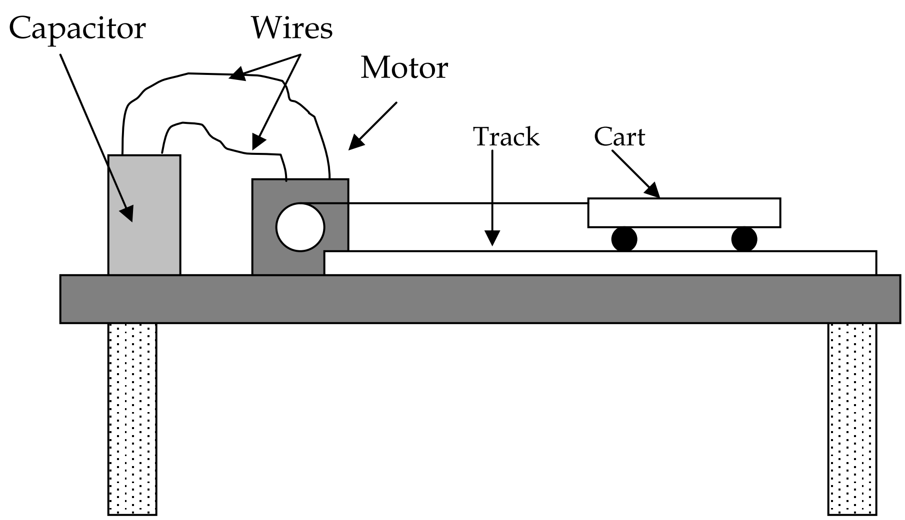
How did your initial ranking of the time it would take for the bulbs to go out compare with what actually occurred? Use conservation of charge and the concept of potential difference to explain your results.

PROBLEM #7:
EFFICIENCY OF AN ELECTRIC MOTOR

You have a job in a University research group investigating locomotion of prokaryotes such as the bacteria *Escherichia Coli*. These organisms 'swim' by rotation of rigid helical flagellum[1] like a propeller (similar to the underwater vessel in *Star Wars: Episode I*). A tiny molecular motor situated at its base drives the flagellum. The energy to drive this motor comes from hydrolysis of ATP molecules. You would like to measure the efficiency of this energy conversion process, but since the equipment for this experiment is expensive and the measurements time consuming, you would like to understand a simpler physical model first. You decide to model the energy source using a (charged) capacitor and the tiny molecular motor with a DC electric motor. A cart is pulled when the motor runs. What fraction of the energy that can be stored in a capacitor is converted into energy of the cart?

EQUIPMENT

You will have a cart that can be pulled along a track as shown. The cart will be connected with a string to a motor. You will also have several different capacitors, an aluminum track, a battery or power supply, several banana cables, a meter stick, a video camera, a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL), and a digital multimeter (DMM).



PREDICTION

Calculate the efficiency of the electric motor by determining the energy transferred from the capacitor and the final energy of the cart.

WARM-UP

Read Serway & Jewett: sections 6.4, 6.5, 20.7, 20.9.
Review Forces and Energy if necessary: Read Serway & Jewett: sections 6.1, 6.2, Chapter 4.

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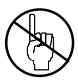
[1] R. Cotterill, *Biophysics: An Introduction*, Wiley, 2002, pp. 215-216.

1. Draw a picture of the situation. Label all relevant distances, masses, speeds, and energies.
2. Decide on your system and the initial and final times at which you will consider your system. Write down the initial energy of your system. Write down the final energy of your system.
3. Make a list of items in the equipment that are not part of the system defined in step 2. Identify any energy transferred into or out of your system in the time interval you are using.
4. Efficiency is defined as the ratio of useful energy output divided by the energy input. Write down the energy input to the electric motor. Write down the energy output of the electric motor.

EXPLORATION



WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** touch the metal terminals of the capacitors or the exposed metal of any wires connected to them. **Always discharge a capacitor with a wire when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Note: Make sure you connect the + terminal of the battery to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

Charge the capacitor by connecting it to a battery. How can you use the DMM to tell if the capacitor is fully charged? What do you mean by fully charged? Try charging it for different amounts of time. How long does it take the capacitor to fully charge?

Connect the cart to the motor with the string. Without touching the capacitor leads to anything else connect one lead to one terminal of the motor and the other lead to the other terminal of the motor. Which direction does the motor spin? Does the direction that the motor spins depend on how you connected the terminals to the motor?

How far is the cart pulled along the track? When the cart leaves the frame of the camera, is it still gaining energy? What implications does this have for your measurements? How can tell when energy is still being transferred to the cart? What happens when energy is no longer being transferred to the cart?

Write down your measurement plan.

MEASUREMENT

Use the camera to take a video of the cart as it travels a known distance. By looking at the clarity of the video picture, estimate the measurement accuracy as the speed of the cart increases.

Measure the speed of the cart after it travels a known distance. What was the speed of the cart initially? What was the energy stored in the capacitor at this time? What was the speed at the final position? What was the energy of the capacitor at the final position?

Was it necessary for the cart to be stationary initially? If the cart was not stationary, what additional information did you need to collect? How could you collect this information? Was it necessary for the capacitor to be completely discharged at the final position? If it was not, what implications does this have for your experiment? What is more important, the total energy the capacitor is able to store, or the amount of energy the capacitor transfers?

Is there a way you can visually determine that the capacitor is no longer transferring energy to the cart? What are the obvious changes to your system when energy is no longer being supplied to the cart from the capacitor?

Once you have used the analysis software on your video, which graph can you use to determine the final speed of the cart? What are the uncertainties associated with this measurement? Try to think of any possible sources of uncertainty and quantify them.

ANALYSIS

Calculate the initial energy of the cart. Calculate the final energy of the cart.

Calculate the initial energy of the capacitor. Calculate the final energy of the capacitor.

Combine the quantities you decided to be energy input and output to determine the efficiency of the electric motor. What are the implications if this number is equal to one? What if it is less than one? Greater than one?

CONCLUSION

Did your results match your predictions? Explain any differences.

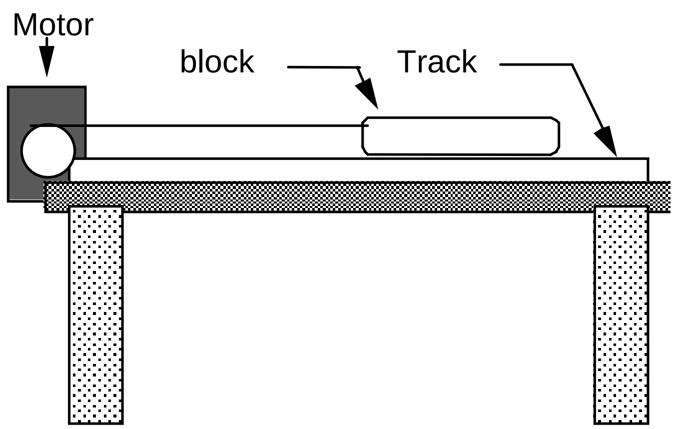
How efficient is the electric motor?

PROBLEM #8:
ELECTRICAL AND MECHANICAL ENERGY

You have a job in a University research group investigating the effect of a low gravity environment on protein synthesis. Your team is designing a small, experiment that will be carried into orbit by a satellite. As part of the experiment you need an automated pipette to add a small volume of ATP solution to a prepared protein and enzyme mixture in order to provide the energy for the protein assembly. Your team must design a lightweight power source for powering the automated pipette. You have been asked to investigate the use of capacitors. You decide to calculate how the mechanical energy transferred to a device powered by a capacitor depends on the capacitance. You will test your calculation using a laboratory model in which a capacitor provides power for a motor that drags a block of wood across a table. You calculate how far the block will move as a function of the capacitance of the capacitor, the efficiency of the system, and other properties of the block and table. You assume that you know the initial voltage on the capacitor.

EQUIPMENT

A block of wood, a track, a motor, string, several different capacitors, a battery or power supply, a meter stick, and a digital multimeter (DMM).



PREDICTION

Restate the problem. What are you trying to calculate? Express the result as both an equation and a graph.

WARM-UP

Read Serway & Jewett: sections 6.4, 6.5, 6.7, 20.7, 20.9.
Review Forces and Energy if necessary: Read Serway & Jewett: sections 6.1, 6.2, Chapter 4.

1. Draw pictures of the situation before the block moves, while the block is in motion, and after the block has come to rest. Label all relevant distances, masses, forces, and potential differences. Describe the physics principles you need to solve this problem.

2. Define the initial and final times of interest in this problem. Describe (perhaps with your diagrams) what happens to energy in the situation between those times. Indicate interactions that transform energy from one form to another or from one object to another.

3. Are there objects in the problem whose potential or kinetic energy is relevant, and that you can calculate directly in terms of quantities measurable in the lab? If so, write down expressions for their initial and final (potential or kinetic) energies.

4. Draw a force diagram for the block while it is in motion. Are there any relevant forces with magnitudes you *can* calculate, in terms of quantities you can measure in the lab? Write equations for those forces. Are there any relevant forces you *can't* calculate in terms of easily measured quantities? Indicate which forces those are.

5. What is the energy transferred to the block, in terms of the forces exerted on it and the distance it slides? Use this equation and equations from previous steps to write the amount of energy transferred from the capacitor to the block, during the entire process, as a function of the distance the block slides and properties of the block and track.

6. How would you define "efficiency" for this situation? Choose a system. Write an energy conservation equation for your system that relates the efficiency, the situation's initial conditions, and properties you can measure in the lab, to the distance the block slides.

7. Use the principal of energy conservation to write an equation for the amount of energy dissipated in this situation, in terms of measurable quantities and the efficiency. Be sure this equation is consistent with your description from step 2.

8. Sketch a graph of the distance the block slides as a function of the capacitor's capacitance. Assume constant efficiency, and that the capacitor is charged to the same potential difference for each trial. (You can check the "constant efficiency" assumption in the lab.)

EXPLORATION

WARNING: A charged capacitor can discharge quickly producing a painful spark. **Do not** handle the capacitors by their electrical terminals or handle connected wires by their metal ends. **Always discharge a capacitor with a wire when you are finished using it.** To discharge a capacitor, use an insulated wire to briefly connect one of the terminals to the other.

Note: Make sure you connect the + terminal of the battery to the + terminal of the capacitor! Like some biological capacitors, these capacitors are only designed to charge one way. If you connect the capacitors up the wrong way, the capacitance will change in an unpredictable manner.

Take the capacitor with the smallest capacitance. Give the capacitor plates a potential difference of 6 volts. Disconnect the capacitor from the battery. Explain how you can use the DMM to tell if the capacitor is fully charged or fully discharged. Explain what you mean by fully charged. Try charging for different amounts of time. Determine how long it takes the capacitor to fully charge.

Connect the block to the motor with the string. Without touching the capacitor leads to anything else connect one lead to one terminal of the motor and the other lead to the other terminal of the motor. Which direction does the motor spin? Does the direction that the motor spins depend on how you connect the motor and the capacitor? Decide the best way to connect the motor and the capacitor.

How far is the block pulled along the track? Try it for the largest capacitor as well. Does the efficiency appear to be constant? If not, can you make it more constant, or will you have to average over several trials, or is the assumption of constant efficiency simply not realized by this system? Choose a range of capacitors to give you a good range of distances (too much energy will cause the block to collide with the electric motor. If this is the case, you might try adding some mass to the block).

Write down your measurement plan.

MEASUREMENT

Measure the distance that each fully charged capacitor pulls the block. Be sure to take more than one measurement for each capacitor.

ANALYSIS

Graph the distance the block is pulled versus the capacitance of the capacitor. Show the estimated measurement uncertainty on your graph.

CONCLUSION

Did your results match your predictions? Explain any differences.

How efficient is this energy transfer? Define what you mean by efficient. How good was the assumption of constant efficiency for this situation?

You have heard that energy is always conserved. Is it appropriate to say that energy was conserved in this situation? Why or why not?

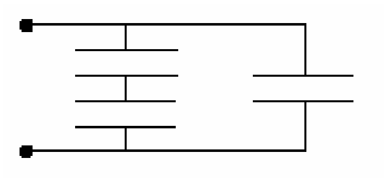
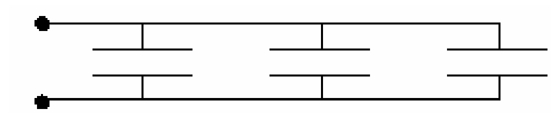
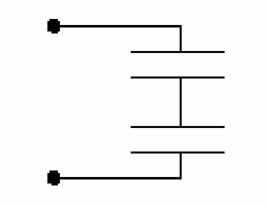
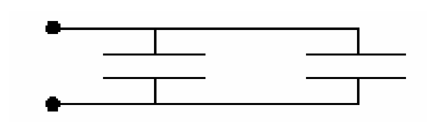
☑ CHECK YOUR UNDERSTANDING

For each of the arrangements of identical capacitors shown below:

1) Rank them in terms of the amount of time they can light a light bulb. Assume that the leads shown have been connected to a 6 Volt battery and then removed from the battery and connected to a light bulb.

2) Calculate the potential difference between the terminals of each capacitor. Assume that the leads shown have been connected to a 6 Volt battery and that the capacitance of each capacitor is 10 μF.

3) Calculate the amount of energy stored in each capacitor and the total energy stored in each arrangement of capacitors. Assume that the leads shown have been connected to a 6 Volt battery and that the capacitance of each capacitor is 10 μF.

 Arrangement 1	 Arrangement 2
 Arrangement 3	 Arrangement 4

PHYSICS 1202 LABORATORY REPORT

Laboratory III

Name and ID#: ______________________________

Date performed: ____________ Day/Time section meets: ______________________

Lab Partners' Names: ______________________________

____

____

Problem # and Title: ______________________________

Lab Instructor's Initials: ________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.

LABORATORY IV:
ELECTRIC FIELD AND POTENTIAL

Many forces in nature cannot be modeled as contact forces, such as those you have used to describe collisions or friction interactions. Forces sometimes characterized as "action-at-a-distance" involve an objects exerting forces on each other although not in physical contact. The gravitational force, in fact, fits this characterization. You are just now learning about another action-at-a-distance force: the electric force. Action-at-a-distance can be difficult to fit into our physics framework for two reasons. First, it is hard to conceive of objects interacting when they are not touching. Second, objects that interact by these action-at-a-distance forces form systems that can have potential energy. The concept of action-at-a-distance does not satisfactorily describe where this potential energy resides.

The notion of a "field" solves these problems. In a field theory, an object affects the space around it, creating a field. Another object entering this space is affected by that field and experiences a force. In this picture the two objects do not directly interact with each other; one object creates a field and the other object interacts directly with that field. The magnitude of the force on an object is the magnitude of the field at the space the object occupies (caused by other objects) multiplied by the property of that object that causes it to interact with that field. In the case of the gravitational force, that property is the mass of the object. In the case of the electrical force, it is the electric charge. The direction of the electrical or gravitational force on an object is along the direction of the field (at the object's position). The potential energy of the system can be envisioned as residing in the field.

Thinking of interactions in terms of fields solves the intellectual problem of action-at-a-distance. It is, however, a very abstract way of thinking about the world. We use it only because it leads us to a deeper understanding of natural phenomena and inspires the invention of new devices. The problems in this laboratory are primarily designed to give you practice visualizing fields and their associated potentials, and in using the field concept to solve problems.

In this laboratory, you will first explore electric fields by building different configurations of charged objects (physically and with a computer simulation) and mapping their electric fields and potentials. In the last two problems of this lab, you will measure the behavior of electrons moving through an electric field and compare this behavior to your calculations.

As you progress through the problems in this laboratory, pay particular attention to learning about relationships among (and differences between) the oft-confused concepts of *field*, *force*, *potential*, and *potential energy*.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Qualitatively determine the electric field at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Calculate the electric field at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Qualitatively determine the electric potential at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Calculate the electric potential at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Relate the electric field caused by charged objects to the electric potential caused by charged objects.

PREPARATION:

Read sections 19.1-19.7 and 20.1-20.4 in Serway & Jewett.

You may find the supplementary text, "There Are No Electrons" by K. Amdahl, (ISBN 096 278 1592), a useful resource for conceptual understanding of electricity.

Before coming to lab you should be able to:

- Apply the concepts of force and energy to solve problems.
- Calculate the motion of a particle with a constant acceleration.
- Write down Coulomb's law and understand the meaning of all quantities involved.
- Add vectors in two dimensions.
- Calculate the electric field due to a point charge.
- Calculate the electric potential due to a point charge.

PROBLEM #1:
ELECTRIC FIELD VECTORS

As part of your internship with a local power company, you have been assigned to a team reviewing published research about the effects of electric fields on human health. To evaluate the merits of apparently conflicting research, you need a computer program to simulate the electric field due to complicated charge configurations. Your team leader has assigned you the task of evaluating such a program. To test the program, you will compare its predictions to your own understanding of the electric field created by a few simple charge configurations. You start with the very simple configuration of a single positive charge. You then try a single negative charge. Finally, you consider a positive charge near a negative charge of equal magnitude (a dipole configuration.) Qualitatively, determine the electric field distributions of a single positive charge, a single negative charge and a dipole.

EQUIPMENT

You will use the computer application EM Field. This program will draw the electric field vector at any point near any given charge distribution. Instructions for use of the program are in the program.

PREDICTION

Using your knowledge of the forces exerted by charged objects, draw vectors representing the electric field around the following charge distributions: (i) A positively charged point object; (ii) A negatively charged point object; (iii) A dipole (two equal but oppositely charged point objects separated by a small distance). As usual, the length of the vector should represent the magnitude of the field. In each case, draw enough vectors to give a qualitative idea of the behavior of the field. Where do you think the electric field will be the strongest? The weakest?

WARM-UP

Read Serway & Jewett: sections 19.2, 19.5, 19.6.

To solve this problem it is useful to have an organized problem-solving procedure such as the one outlined in the following questions.

1. Draw a positively charged point object. What does the electric field look like surrounding a positive charge? How is this different from the field surrounding a negative charge?

2. At a point in space some distance from the positively charged point object, imagine you have another positively charged point object. The force on such a "test charge" (1 Coulomb) is the electric field at that point due to the charge configuration. Draw a vector representing the magnitude and direction of the force on the test charge due to the other charge.

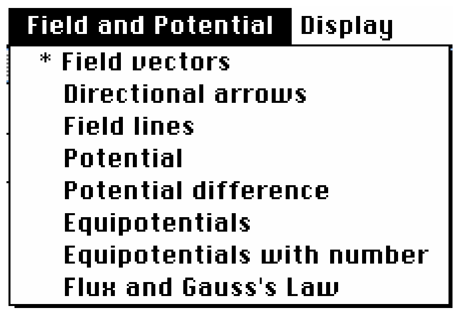
3. Now move your test charge to another point and draw the vector representing the force on it. (How does the magnitude of the force on the test charge depend on its distance from the positively charged point object? Make sure the length of your vector represents this dependence.) Continue this process until you have a satisfactory map of the electric field in the space surrounding the positively charged point object.

4. Repeat the above steps for a negatively charged point object and a dipole. (Should your test charge have a positive or negative charge in these cases?) For the dipole, remember that if two objects exert a force on a third object, the force on that third object is the **vector sum** of the forces exerted by each of the other objects.

EXPLORATION

Before beginning to use the computer simulation, do a quick check to see if the program works the way you think it should.

Open EM Field and click anywhere in the window for the instructions. From the *Sources* pull-down menu, select *3D point charges*. Drag any positively charged point object to the center of the window of EM Field. Select *Field vectors* from the *Field and Potential* pull-down menu (as shown)



Move the cursor to where you would like to place a field vector and click the mouse button. An electric field vector should appear. Repeat this procedure until you have created a reasonable map of the electric field. To clear the EM Field window, select *Clean up screen* from the *Display* pull-down menu.

You can get a second visual representation of the electric field by selecting *Directional arrows* from the *Field and Potential* menu. In this representation all arrows are the same length and the magnitude of the field is given by its color. Try this out for a single positively charged point object. If you switch to *Field vectors* without clearing the screen, you can see how the representations correspond to each other. Unfortunately, the *Directional arrows* representation is poor for printing on black and white printers.

Repeat your favorite electric field representation for a single negatively charged point object. How does the direction and magnitude of the electric field compare to that for the positively charged point object? Try clearing the screen and selecting a larger charge. What happens to the electric field?

Clear the screen and create a dipole by dragging two equal, but oppositely charged point objects onto the window of EM Field. You may want to use the *Show grid* and *Constrain to grid* features in the *Display* pull-down menu to position your dipole. Using your favorite electric field representation, make a map of the electric field caused by a dipole. Make sure that you carefully map the electric field at points along all axes-of-symmetry of the dipole.

Try a different spacing between the two charged objects in the dipole to see how that changes the electric field map. Try larger charges.

If you are very far away from the dipole, how does the field compare to that due to a single charged point object? How about when you are *very* close to one of the charged objects in the dipole?

MEASUREMENT

Use EM Field to get the electrical field distributions of a positive charge, a negative charge and a dipole. Print out the result of vector representation (select *Print Screen* from the *File* pull-down menu).

You should experiment with and print out other electric field representations. Specifically, try to understand what role symmetry plays in the creation of electric fields.

ANALYSIS

Look at the electric field graphs of the single positive charge and the single negative charge. What is the same about the two graphs, and what is different?

Qualitatively, can you re-create the electric field vector due to the dipole at any point by *adding* the electric field vectors due to the positive charge and the negative charge? Select several points and try. Explain why this technique does or does not work.

Looking at the electric field map of your dipole, imagine a positively charged point object at the tail position of each vector. Where is the force on the "imaginary" object the greatest? The least? How would the force change if the "imaginary" object were negatively charged?

CONCLUSION

How does each of the printed field maps compare with your prediction? Investigate both direction and magnitude of the electric field vectors on these printouts. How does the magnitude of the electric field change with position in each case? Where is the field strongest in each case? How is this shown in your map? Where is the field weakest in each case?

For the dipole, how does the magnitude of the electric field change with the position change along (a) the line passing through both charged objects of the dipole, and (b) the line passing through the dipole's center and perpendicular to the first line. Can you generalize this observation?

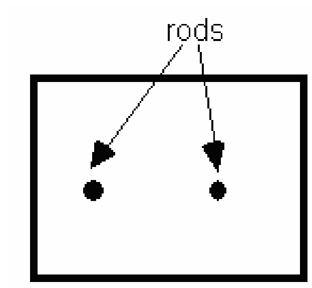
Suppose the objects making up your dipole were fixed in space, and that you placed a positively charged mobile object nearby. If the mobile object started at rest, how would it move? (Be careful not to confuse the object's acceleration with its velocity!) Does the way the mobile object moves depend on where you start it?

PROBLEM #2:
ELECTRIC FIELD OF A DIPOLE

In your summer job with a bioengineering company you have been studying the electric fields generated by Amazonian Electric Eels. Your specific assignment is to test a portable instrument designed to measure electric fields underwater. To find out if it works correctly, you decide to use it to determine the electric field created by a simple pattern of charged objects. You create a two-dimensional dipole field by giving two parallel metal rods opposite charges with a battery while their tips are touching conductive paper (meant to simulate a thin layer of water).. You then measure the electric field on the paper. Determine what electric field pattern is created by the tips of two metal rods with opposite charge.

EQUIPMENT

You will be using the conductive paper setup described in Appendix D. There is a coordinate grid drawn on the conductive paper. Two brass rods (electrodes) stand upright with their tips in contact with the conductive paper and connected to opposite terminals of a battery or power supply. The electric field probe (Pin Tip Probe) should be connected to a digital multimeter (DMM) set to read volts. You will also have the EM Field program. A white sheet of paper with a grid similar to the grid on the conducting paper is useful for recording the field (**do not write on the conductive paper**).



Overhead view of conductive paper for this problem.

PREDICTION

Based on your knowledge of the strength and direction of the electric force, sketch a map of the electric field created in a plane perpendicular to two parallel metal rods with opposite charges. Where do you think the electric field will be the strongest? The weakest? Do you anticipate any symmetry in the strength and/or direction of the field vectors?

When you get to lab, check your sketch by making a field map of *2D charged rods* using the EM Field simulation.

WARM-UP

Read Serway & Jewett: sections 19.2, 19.5, 19.6.

1. Draw a picture of the dipole similar to the one shown in the equipment section. Label one of the charged point objects "+" and the other "-".

2. At a point in space some distance from one charged object, imagine you have another positively charged point object. Draw a vector representing the force on that "imaginary" object. How does the magnitude of the force on the "imaginary" object depend on its distance from the positively and negatively charged objects that you drew originally? Make sure the length of your vector represents this dependence. Remember that if two objects exert a force on a third object, the force on that third object is the vector sum of the force exerted by each of the other objects.

3. Now move your "imaginary" object to another point in space and draw the vector representing the force on it. Continue this process until you have a satisfactory map of the electric field in the space surrounding the dipole.

EXPLORATION

You may compare your prediction with a field map of *2D charged rods* produced by the EM Field simulation program, located on the desktop. For instructions on how to use this program see the Exploration section of Problem 1.

Set up the conductive paper as instructed in *Appendix D*. For use of the DMM and power supply, see *Appendix D*.

Once the rods are connected to the battery, set the digital multimeter (DMM) to volts and turn it on. Place the tips of the probe on the conductive paper midway between the tips of the two rods. Does the probe measure the electric field? What does the probe measure? Based on your warm-up questions, what is the direction of the electric field at that position? Rotate the probe so that the center of the probe stays in the same spot. Record the meter readings as you rotate the probe. Do the values change (pay attention to the sign)? Is there a minimum or maximum value? Are there any symmetries in this data? If there are large fluctuations, determine how you will measure consistently. Describe how you will use the probe to determine the field **direction** at other points.

Now place the field probe near, but not touching, one of the rods and rotate the probe as you did before. Record your data. Determine the direction of the electric field. Compare the maximum DMM reading at this point to the one you found at the midway point. Compare your measurements to your prediction; does the value displayed on the DMM become larger or smaller when the electric field becomes stronger? Describe how you will use the probe to determine the electric field **strength** at other points.

Where on the conductive paper is the electric field strongest / weakest? Does this match your prediction?

Complete your measurement plan for mapping the electric field on the conductive paper. How will you record the magnitude and direction of the electric field at each point?

MEASUREMENT

Select a point on the conductive paper where you wish to determine the electric field. Place the probe on the conductive paper at that point and rotate until you have found the direction of the electric field. Record the magnitude and direction of the field at that point by drawing a vector in your lab journal or on a sheet of white paper with a grid pattern similar to that on the conductive paper. At each point, take at least two measurements of magnitude and direction to gain a measure of your uncertainty.

Repeat for as many points as needed to check your prediction. When you have taken enough data, you will have a map of the electric field.

CONCLUSION

How does your map compare to your prediction? How does it compare to the simulation program? Where is the field the strongest? How do you show this in your map? Where is the field the weakest? How do you show this in your map?

PROBLEM #3:
ELECTRIC POTENTIAL DUE TO MULTIPLE CHARGED OBJECTS

You are a member of a team designing a compact particle accelerator in which ions of low-Z atoms will be directed at radio resistant malignant tumors. Charged atomic nuclei will be accelerated when they pass through a charged electrode structure. The team must determine the effect of several electrode configurations on the final speed of various nuclei. The charged electrode configuration will be extremely complicated, so your team has decided to use a computer simulation. The first step is to calculate the electric potential that will affect the nuclei.

Your immediate task is to determine if the simulation can be trusted. You decide to calculate the electric potential caused by a set of charged objects complex enough to test the simulation, but simple enough for direct calculation. The first configuration that you try is a square with two equal negatively charged point objects in opposite corners and a positively charged point object of $\frac{1}{3}$ the magnitude of the negative charges in a third corner. You will calculate the electric potential at the remaining corner of the square and compare your result to that of the computer's simulation of the same configuration. What is the electric potential at the corner of a square made of charged point objects?

EQUIPMENT

You will use the computer program EM Field.

PREDICTION

Two equal negatively charged point objects are in opposite corners of a square. A positively charged point object, with a charge of $\frac{1}{3}$ the magnitude of the negative objects, is located in a third corner of the square. Calculate the electric potential at the fourth corner of the square.

WARM-UP

Read Serway & Jewett: sections 19.2, 19.5, 19.6, 20.1, 20.2, 20.3.

The following questions should help with your prediction.

1. Make a picture of the situation. Label the objects and their charges. Draw and label all relevant distances and angles. Draw appropriate right triangles so that you can use the Pythagorean theorem to find needed distances.

2. What variables affect the potential at the unoccupied corner of the square? For each charged object, write down a formula expressing the electric potential from that object at the point of interest.

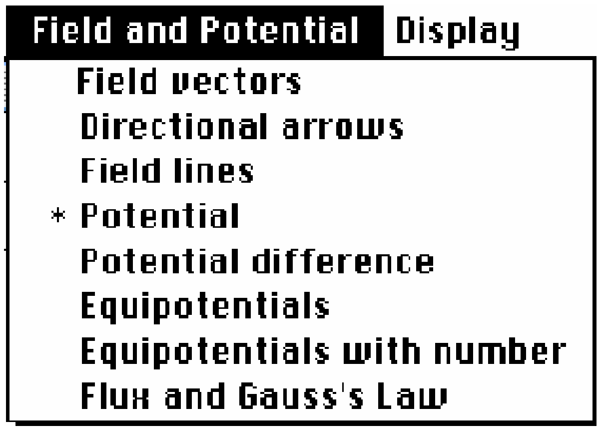
3. Add the electric potentials due to each of the charged objects to find the potential at the unoccupied corner due to all three of them. This "adding" up of different charges is possible by the principle of "Linear Superposition."

EXPLORATION

Before beginning to use the computer simulation, do a quick check to see if the program works the way you think it should.

Open EM Field and click anywhere in the window for the instructions. From the *Sources* pull-down menu, select *3D point charges*. Drag any positive charge to the window of EM Field.

From the *Field and Potential* pull-down menu (as shown to the right), select *Potential*. Move the cursor where you would like to determine the electric potential and click the mouse button.



When using the program quantitatively, use the *show grid* and *constrain to grid* features of the program (from the *display* pull-down menu). To expand the display window to fill the entire screen, click the small box in the top-right corner of the window.

Another useful way of viewing the electric potential is using equipotential surfaces. Select *Equipotentials with number* from the *Field and Potential* pull-down menu. Move the cursor where you would like to determine the electric potential and click the mouse button. How is this different from the *potential* setting?

Try using different magnitudes of charge. What range of charge values allows you to accurately measure the electric potential at a large number of locations on the screen?

Try using negative charges. How does this change the electric potential?

Check to see if you get the correct behavior of the electric potential from a point charge:

- Make a graph of the electric potential as a function of the distance from the center of the charged point object. What features of the graph help you determine if the simulation displays potential correctly, for a point charge?
- Re-graph the same electric potential values versus the inverse distance from the point charge, $\frac{1}{r}$. What shape do you expect for this graph? Why? Does the graph match your expectation? For more on this topic, see *Appendix C*, "How do I linearize my data?"

Now, qualitatively check to see if the program combines the electric potentials from two charged point objects correctly. First examine the potential at several points due to a dipole configuration. Does it behave as you expected? Does it go to zero where you would expect it to? Second, examine the potential at several points due to two identical charges (positive or negative). Does it behave as expected?

You may notice that the potential measurements given by the computer are in a foreign set of units. You will have to translate the computer-generated measurement into an actual electric potential in appropriate units. To do so, you must calibrate the computer simulation program using a charge distribution whose actual electric potential can easily be determined:

- You have already collected a set of electric potentials for different distances from a single charged point object (of different magnitudes).
- Calculate the actual electric potential for this set of charges and distances.
- Graph the set of simulated electric potentials vs. the corresponding calculated electric potentials. Knowing the slope of this curve, you can translate a number the *computer gives* for the electric potential into an *actual* electric potential in the appropriate units. (What are the units of the slope?) Be sure you can explain the translation procedure to your teammates. Record information for translation, as you will need it later.

MEASUREMENT

Place charges on the screen to simulate the situation described in the problem. Measure the electric potential of an object at the point of interest.

ANALYSIS

For the situation in the problem, compare your calculated electric potential to that from the computer simulation.

CONCLUSION

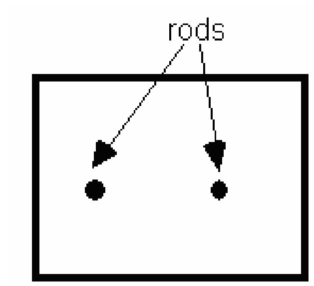
Did your results match your predictions? Explain any differences.

PROBLEM #4:
ELECTRIC FIELD AND POTENTIAL

You work for a team consulting with a company that produces technology for medical education. A school has asked the company to produce cheap, durable equipment that can measure and depict the electric field and the electric potential distribution inside a human body. The equipment will be used in the education of EKG technicians. Because the electric field and electric potential are related, you know that it is not necessary to measure both the field and potential directly. To convince yourself and the company that it is appropriate to measure only the potential distribution, you decide to investigate a method of determining the electric field from the electric potential. You decide to investigate a single dipole first, since many electric fields and electric potentials can be modeled in terms of dipole combinations. Determine the electric field and electric potential near a dipole and how the field and potential are related.

EQUIPMENT

You will be using the conductive paper setup described in Appendix D. There is a coordinate grid drawn on the conductive paper. Two brass rods (electrodes) stand upright with their tips in contact with the conductive paper and connected to opposite terminals of a battery or power supply. The **single-tip probe** is connected to the DC voltage socket of a digital multimeter (DMM) set to read DC volts. The GND socket of the DMM is connected to the ground of the power supply or the cathode of the battery. You will also have the EM Field program.



Overhead view of conductive paper for this problem.

NOTE: The probe is *not* the one used in problem #2.

PREDICTION

Qualitatively sketch equipotential lines for the dipole. Potential differences between adjacent pairs of equipotential lines in the sketch should be approximately equal. Based on the equipotential lines, sketch electric field vectors at several points. Explain your method.

WARM-UP

Read Serway & Jewett: sections 19.2, 19.5, 19.6, 20.1, 20.2, 20.3, 20.4.

1. On a piece of paper, draw a horizontal axis and a vertical axis. Place two charged objects on the horizontal axis so that they create a dipole centered around the vertical axis. (Leave enough space between the objects so that at least five equipotential lines will fit between them.)

2. How is the electric potential due to the two point-like charged objects of a dipole related to the potential due to each of the objects? Write an equation describing the dipole electric potential on your paper. Clearly identify all variables.

3. Calculate the electric potential at the point where the axes intersect, and label the point with its potential. What other points have the same potential? Draw the line connecting those points (an equipotential line). Select another point on the horizontal axis between the two charges, label it with its electric potential, find other points with the same electrical potential, and sketch the equipotential line associated with that point. Repeat for at least three more equipotential lines. (Be sure to keep a constant potential difference between adjacent lines.) You may be able to intuitively see where the equipotentials lie, but better results can be obtained with the equation formed in **(2)**.

4. What symmetry would you expect to see in the equipotential lines? Do your equipotential lines exhibit that symmetry? Since pairs of adjacent lines have equal potential differences, would you expect them to be equally spaced on the paper? Why or why not?

5. What is the relationship between electric potential differences between two points and the electric field? How would you find the direction of the electric field vector at a point on an equipotential line? How would you find the magnitude of the electric field vector at a point on an equipotential line? Qualitatively sketch the electric field vectors at several points on each equipotential line. (The relative lengths of the lines should indicate the relative magnitudes of the electric field at the points.)

EXPLORATION

Set up the conductive paper as instructed in *Appendix D*. For use of the DMM and power supply, see *Appendix D*.

If you use the power supply, set it to provide no more than 15 Volts DC.

Connect the two rods representing a dipole to the battery or power supply. Connect the single-tip probe to the DC voltage socket of the digital multimeter (DMM). Use a wire to connect the GND socket of the DMM to the cathode of the battery or the GND of the power supply.

Turn on the power supply. Be careful to avoid a short circuit. Place the tip of the probe against the paper. The DMM displays a value of voltage. What does it mean? Move the tip to other places. Observe whether the value displayed in DMM changes. What does the change mean?

Try to stabilize the tip on the paper. Can you get a stable value from the DMM? Is there a fluctuation due to the small shaking of your hand? If there is large fluctuation, how will you make your measurement consistently? Estimate the uncertainty in your measurements of electric potential.

Select a point between the two rods of the dipole. Put the tip at this point and read the value from DMM. On your copy of the grid, record the voltage reading for that point. Find more points that produce the same voltage reading, and mark your copy of the grid to indicate their positions. Connect your marks with a smooth curve. What does the curve mean?

Practice the above process and find more similar curves.

MEASUREMENT

Record the voltage reading given by the DMM at the point midway between the two rod-points that form the dipole. As in the exploration, find other points that produce the same reading and connect them with a smooth curve.

Make a voltage reading at a second point, and repeat the process of producing a curve of constant voltage readings. Calculate the difference in voltages between points on this curve and points on the first one.

Repeat the process for at least three more points (curves). Be sure that the voltage difference between adjacent curves is constant.

ANALYSIS

What is the significance of the curves of constant voltage readings you have created? How are they related to the warm-up questions?

Write down the equation that expresses the electric field in terms of spatial variation in the electric potential. Based on the equation, develop a technique to estimate the direction and magnitude of the electric field for a point on a curve of constant voltage readings. (Hint: What are the units of electric field and potential?) What assumptions must you make to estimate electric fields based on the limited amount of data you have collected about voltage in the water tank?

Use your technique to estimate the magnitude of the electric field at several points along curves of equal voltage readings. Create a map of the electric field on your copy of the grid, by drawing arrows to represent the direction and magnitude of the field at each of those points.

CONCLUSION

What parts of your measured map correspond to parts of your predicted map of electric potential and field for a dipole? Can you account for any differences? How do these maps of electric field compare to your dipole results in problems 1 and 2? Can you account for any differences?

Symmetries should be apparent in your map of potential. Can you explain these symmetries with your prediction equation?

Use the EM Field program to simulate a dipole, and use the software to draw equipotential lines (with constant potential difference between adjacent lines). Select several points on the equipotential lines, and show electric field vectors for those points. Print out the result.Compare the simulation result with your measured result.

Is the method used here, deriving the electric field from electric potential, reasonable? How could you improve its accuracy? *Is it possible to determine the electric potential from the electric field? Do you think it would be better or worse (for the team's medical education project) to measure the electric field directly and derive the electric potential, or to measure the electric potential directly and derive the electric field?*

PROBLEM #5:
DEFLECTION OF AN ELECTRON BEAM BY AN ELECTRIC FIELD

As in problem #3, you are a member of a team designing a compact particle accelerator in which ions of low-Z atoms will be directed at radio resistant malignant tumors. Charged atomic nuclei will be accelerated when they pass through a charged electrode structure. The team has moved on to the problem of aiming the atoms that emerge from the accelerator. You plan to add controls to the accelerator that will aim the beam by passing it through a region with an adjustable electric field. You decide to use a cathode ray tube (CRT) to model the particle accelerator and study the plan. In the CRT, electrons are emitted at one end of an evacuated glass tube and are detected by their interaction with a phosphorous screen on the other end. Inside the tube, the electrons pass between two sets of parallel plates: one set oriented horizontally, and another oriented vertically. If an electron beam passes through a perpendicular electric field, how does the deflection of the beam depend on the strength of the perpendicular field?

EQUIPMENT

You will be using the Cathode Ray Tube described in Appendix D. The fluorescent screen has a centimeter grid in front of it so you can measure the position of the beam spot. The applied electric field is created by connecting the internal parallel plates to a battery or power supply. **Note that you will be using the deflection plates as described in Appendix D, "Cathode Ray Tube (CRT) and accessories".**

PREDICTIONS

Calculate how the electric field between the horizontal deflection plates affects the position of the electron beam spot. Use this equation to make a graph of deflection as a function of the strength of the electric field between the plates.

WARM-UP

Read Serway & Jewett: sections 19.2, 19.5, 19.7.
Review Kinematics if neccessary: Read Serway and Jewett: Chapters 3 and 4.

Preamble: *This problem involves kinematics, which many students have forgotten about by this time of the semester. It is suggested that you complete the following problem before starting on the rest of the warm-up questions.* A herd of Holsteins in Montana has been snowbound for several days by an early October snowstorm. Their owner decides to drop bales of hay to the starving cows from his crop duster. If the rancher is flying at an altitude h, with horizontal speed V_{ox}, how soon, in distance and time, before he flies over them should he drop the bales of hay? Ignore crosswinds and air resistance. Answer: horizontal distance = $V_{ox}t = V_{ox}\sqrt{\frac{2h}{g}}$, time = $\sqrt{\frac{2h}{g}}$

1. Draw a picture of the important components of the CRT. Only include one set of the deflection plates shown in Appendix D. Draw a coordinate axis on this picture. Draw the trajectory the

electron would take if there were no electric field between the plates. If there is an electric field between the deflection plates, will there be *regions* where different forces act on the electron? Label these regions. Draw the trajectory the electron would take if there were an electric field between the plates. On the trajectory, draw and label arrows representing the electron's velocity and acceleration for each region. The distance between where these two trajectories hit the CRT screen is the *deflection*.

2. What forces cause electrons to accelerate in each region? On your picture, draw an arrow representing each force. (Are there any forces you can assume to be negligible?) For each region, sketch a motion diagram showing the electron's trajectory and the electron's velocity and acceleration as it enters the region, while it is in the region, and when it leaves the region. Qualitatively describe the shape of the electron's trajectory in each region.

3. The magnitude of the electric field (in Newtons per Coulomb) between two equally charged parallel plates is equal to the voltage between the two plates (in Volts) divided by the distance between the plates (in meters). What is the direction of the electric field between the two accelerating plates? How much energy is transferred to the electron by this accelerating field? Using conservation of energy, write an equation for the electron's velocity as it leaves the electron gun in the CRT. What is the direction of the electron as it leaves the accelerating field? What assumptions have you made?

4. What is the net force exerted on an electron as it travels through the region between the deflecting plates? Use Newton's second law to write an equation for the acceleration of an electron as it travels through this region. Is the electric field constant in the region between the deflecting plates? What does that tell you about the acceleration of the electron in that region?

5. Use your drawing from step 1 and kinematic equations for constant acceleration motion to determine the position and direction of the electron as it enters the region between the deflection plates and when it leaves that region. Write down an equation giving the electron's change in position as it emerges from the deflecting plates (how much it was deflected while traveling between the plates). Write another equation giving the electron's direction.

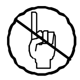
6. Use your drawing from step 1, the position and direction of the electron as it leaves the deflection plates, and geometry to write down an equation giving the position of the electron when it hits the screen. Use the deflection distance from each region to write an expression for the total deflection during the electron's motion through all regions of the CRT.

7. Examine your equations giving the electron's position at the screen. You want an expression for the total deflection in terms of the accelerating voltage, length of the deflecting plate region, distance from the plates to the screen, separation distance of the plates, and potential difference across the plates. Are there any other variables in your equation? You can solve them if the number of unknowns in your equations is equal to the number of equations. Is it? If it is, solve your equations algebraically for the deflection of an electron. If it is not, write down additional equations that relate some of the unknown quantities in your equations to quantities that you know.

8. Complete your solution by using the actual numbers that describe your situation. Refer to the distances shown on the diagram of the CRT in the Appendix.

   Does your solution make sense? If not, check your work for logic problems or algebra mistakes.

EXPLORATION



WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. One unfortunate student in a past year had a hole burned through his finger from improper use of the lab equipment. **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. Never touch the conducting metal of any wire.**

Follow the directions in Appendix D for connecting the power supply to the CRT. Check to see that the connections from the power supply to the high voltage and the filament heater are correct, *before* you switch on the power supply. The electric potential difference between the cathode and anode should be in the range of 250V-500V. After a moment, you should see a spot that you can adjust with the knob labeled "Focus". If your connections are correct and the spot still does not appear, inform your lab instructor.

Before you turn on the electric field between the deflection plates, find the CRT orientation that gives no deflection of the electron beam. In this position the effect of all of the outside forces on the electron is negligible.

Now apply a voltage across one set of deflection plates, noting how the electron beam moves across the screen as the voltage is increased. How will you adjust the voltage level and how will you measure it? Write down the range of voltages for which you can make a good measurement. Repeat this procedure for the perpendicular set of deflection plates.

If you cannot make the electron spot sweep entirely across the screen, try changing the voltage between the anode and the cathode that you originally set somewhere between 250 and 500 volts. This voltage changes the electron's velocity entering the deflection plates. Select a voltage between the anode and cathode that gives you a useful set of measurements for your deflections.

Devise a measuring scheme to record the position of the beam spot. Be sure you have established the zero deflection point of the beam spot.

How will you determine the strength of the electric field between the deflection plates? What quantities will you hold constant for this measurement? How many measurements do you need?

Write down your measurement plan.

MEASUREMENT

Measure the position of the beam spot as you change the electric field applied to the deflection plates. Make sure you take at least 2 measurements at each point for averaging.

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix A) and with your estimated uncertainty (see Appendix B). Otherwise, the data is virtually meaningless.

ANALYSIS

Draw a graph of your prediction equation of the deflection of the electron beam as a function of the voltage applied to the deflecting plates.

Draw a graph using your measurements of the deflection of the electron beam as a function of the voltage applied to the deflection plates.

CONCLUSION

How does the graph based on your data compare to the graph based on your prediction? If they are different, explain why.

How does the deflection of the electron beam vary with the applied deflection plate voltage? How does it vary with the applied electric field? State your results in the most general terms supported by your data.

PROBLEM #6:
DEFLECTION OF AN ELECTRON BEAM AND VELOCITY

You are continuing your attempt, from problem #5, to control the direction of charged particles emerging from a particle accelerator, and are still using a cathode ray tube (CRT) as a model. In the CRT, electrons are emitted at one end of an evacuated glass tube and are detected by their interaction with a phosphorous screen on the other end. While inside the tube, the electrons pass between pairs of charged deflecting plates that create an electric field, which changes the path of the electron beam. To refine your model for aiming charged particles with electric fields, you wish to determine how the velocity of the electrons leaving the electron gun region of the CRT affects the position of the beam spot. How does the deflection of the electron beam vary with initial electron velocity?

EQUIPMENT

You will be using the Cathode Ray Tube described in Appendix D. The fluorescent screen has a centimeter grid in front of it so you can measure the position of the beam spot. The applied electric field is created by connecting the internal deflecting plates to a battery pack or power supply.

PREDICTION

Calculate how the deflection of the electron beam spot changes as the initial velocity of the electrons changes.

Use this equation to make a graph of the deflection of the beam spot as a function of the initial velocity of the electrons.

WARM-UP

Read Serway & Jewett: sections 19.2, 19.5, 19.7.
Review Kinematics if neccessary: Read Serway and Jewett: Chapters 3 and 4.

The prediction for this lab requires the derivation of the prediction equation described in the previous lab problem. If you have not yet completed Problem 5, do the warm-up questions for Problem 5 and then follow the steps below.

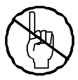
Use conservation of energy to write an equation for the velocity of the electrons as they leave the electron gun in the CRT. This velocity should be determined using the voltage across the accelerating plates in the CRT. The relationship between the initial electron velocity and the accelerating voltage can be used to rewrite your already derived deflection equation in terms of the electron velocity.

Sketch the shape of a graph of your prediction equation's dependence on initial electron velocity for a fixed, non-zero transverse electric field.

Sketch the shape of a graph of your prediction equation's dependence on accelerating voltage for a fixed, non-zero transverse electric field.

Does your solution make sense? If not, check your work for logic problems or algebra mistakes.

EXPLORATION



WARNING: You will be working with equipment that generates large electric 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. Never touch the conducting metal of any wire.**

Follow the directions in Appendix D for connecting the power supply to the CRT. Check to see that the connections from the power supply to the high voltage and the filament heater are correct, *before* you turn the power supply on. Apply between 250 and 500 Volts across the anode and cathode. After a moment, you should observe a spot on the screen that can be adjusted with the knob labeled “Focus”. If your connections are correct and the spot still doesn’t appear, inform your lab instructor.

TAKING EXTREME CARE, change the voltage across the accelerating plates, and determine the range of values for which the electrons have enough energy to produce a spot on the screen. Changing this voltage changes the velocity of the electrons as they enter the deflection plates. What is the range of initial electron velocities corresponding to this range of accelerating voltages? Which of these values will give you the largest deflection when you later apply an electric field between the deflection plates?

The electric field between two equally charged parallel plates (in Newtons per Coulomb) is equal to the voltage between the two plates (in Volts) divided by the distance between the plates (in meters).

Before you turn on the electric field between the deflection plates, find the CRT orientation that gives no deflection of the electron beam. In this position the effect of all of the outside forces on the electron is negligible.

Now apply a voltage across one set of deflection plates, noting how the electron beam moves across the screen as the voltage is increased. Find a voltage across the deflection plates that allows the deflection for the entire range of initial electron velocities to be measured as accurately as possible.

Devise a measuring scheme to record the position of the beam spot. Be sure you have established the zero deflection point of the beam spot.

How will you determine the strength of the electric field between the deflection plates? How will you determine the initial velocity of the electrons? What quantities will you hold constant for this measurement? How many measurements do you need?

Write down your measurement plan.

MEASUREMENT

Measure the deflection of the beam spot as you change the initial velocity of the electrons in the beam but keeping the electric field between the deflection plates constant.

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix A) and with your estimated uncertainty (see Appendix B).

ANALYSIS

Calculate the initial electron velocity for each accelerating voltage you used. Use a spreadsheet program (such as Excel on your lab workstation computer) to make a graph of your average measurements of the deflection of the electron beam as a function of the initial electron velocity. How do your uncertainties affect your graph?

Use your prediction equation to calculate the predicted values for the deflection of the electron beam as a function of the accelerating voltage. Plot these values on the same graph as your measurements and compare.

Make a graph of your average measurements of the deflection of the electron beam as a function of the accelerating voltage. How do your uncertainties affect your graph?

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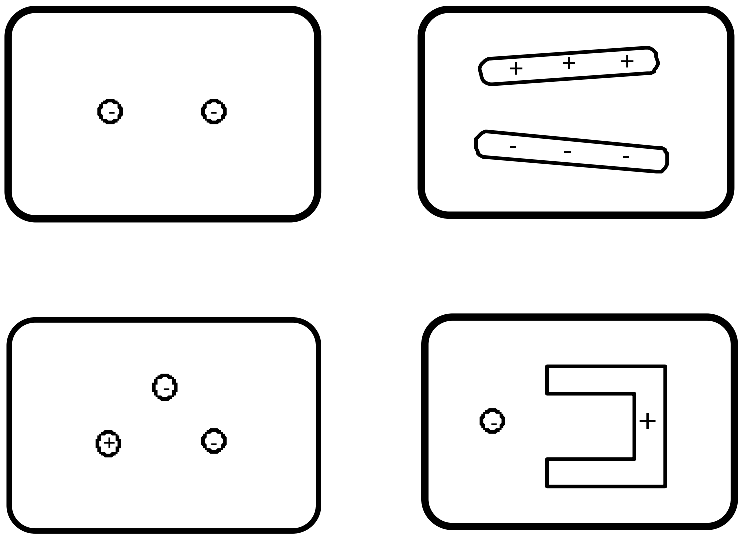
CONCLUSION

Did your data agree with your prediction of how the electron beam would deflect due to the initial electron velocity? If not, why not?

How does the deflection of the electron beam vary with initial electron velocity? How does it vary with accelerating voltage? State your results in the most general terms supported by your data.

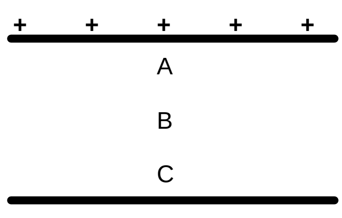
☑ CHECK YOUR UNDERSTANDING

1. For each of the charge configurations below, map the electric field. Assume that each object is made of metal and that the trays are filled with water.



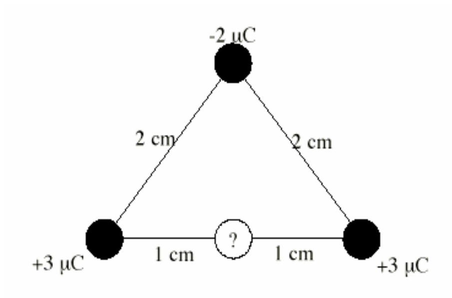
2. For a CRT with the same plates and electron gun as you used in lab, assume that the distance from the center of the Vx plate to the fluorescent screen is 10 cm and the distance from the center of the Vy plate to the screen is 8 cm. If V_{acc} is 300V, Vx = -8V and Vy = 3V, what is the displacement of the electron beam?

3. Assume you have two infinite parallel planes of charge separated by a distance d as shown below. Use the symbols <,>, and = to compare the force on a test charge, q, at points A, B, and C.

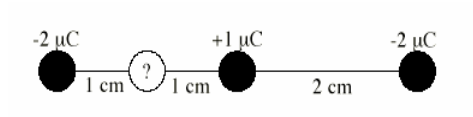


☑ CHECK YOUR UNDERSTANDING

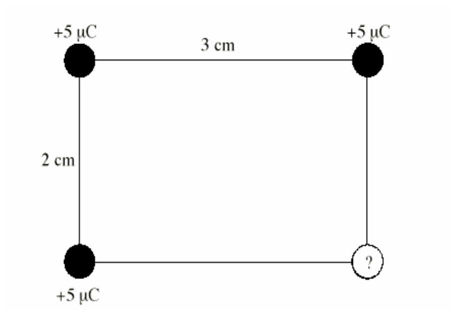
4. For each of the charge configurations below, find the electric field and the electric potential at the point marked with the "?".



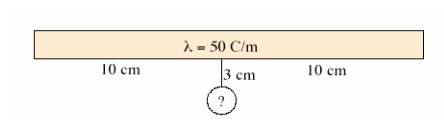
Configuration 1



Configuration 2



Configuration 3



Configuration 4

PHYSICS 1202 LABORATORY REPORT

Laboratory IV

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ______________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: __________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.

LABORATORY V
MAGNETIC FIELDS AND FORCES

Magnetism plays a large part in our modern world's technology. Magnets are used today to image parts of the body, to explore the mysteries of the human brain, and to store data for computers. Magnetism also allows us to explore the structure of the Universe, the atomic structure of materials, and the quark structure of elementary particles.

The magnetic interaction can best be described using the concept of a field. For this reason, your experiences exploring the electric field concept are also applicable in this lab. There are similar activities in both labs; so you can experience the universality of the field concept. Although they are related, the magnetic force is not the same as the electric force. You should watch for the differences as you go through the problems in this lab.

In this set of laboratory problems, you will map magnetic fields from different sources and use the magnetic force to deflect electrons. The activities are very similar to the first lab of this semester dealing with electric fields and forces.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Explain the differences and similarities between magnetic fields and electric fields.
- Describe the pattern of magnetic fields near various sources, such as permanent "bar" magnets, straight current-carrying wires, and coils of wire.
- Calculate the magnetic force on a charged particle moving in a uniform magnetic field and describe its motion.

PREPARATION:

Read Serway & Jewett: Chapter 22, sections 1-4. Review your notes from Lab III (Electric Field and Potential).

Before coming to lab you should be able to:

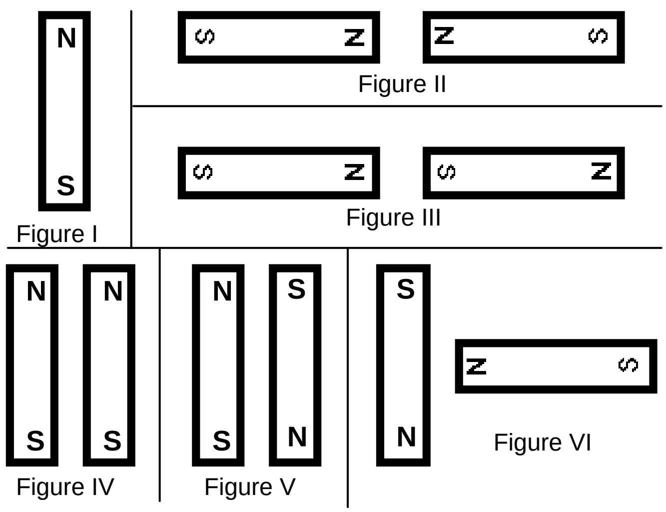
- Add fields using vector properties.
- Use the vector cross product.
- Calculate the motion of a particle with a constant acceleration.
- Calculate the motion of a particle with an acceleration of constant magnitude perpendicular to its velocity.
- Write down the magnetic force on an object in terms of its charge, velocity, and the magnetic field through which it is passing.

PROBLEM #1:
PERMANENT MAGENTS

You have a job working with a company that designs magnetic resonance imaging (MRI) machines. The ability to get a clear image of the inside of the body depends on having precisely the correct magnetic field at that position. In a new model of the machine, the magnetic fields are produced by configurations of permanent magnets. You need to know the map of the magnetic field from each magnet and how to combine magnets to change the magnetic field at any point. You must determine the map of the magnetic field created by each of the distributions of permanent magnets shown below.

EQUIPMENT

You will have two permanent magnets and a clear plate filled with a viscous liquid along with small pieces of Taconite, an iron-rich ore found in northern Minnesota. When a magnet is placed on top of one of these plates, the Taconite pieces align themselves with the magnetic field. You will also have a compass. The magnet configurations you need to consider are as follows:



PREDICTION

Sketch a map of the magnetic field for each magnet configuration in the figures above. Assume that the different magnet configurations in each figure do not interact with the magnets in the other figures.

WARM-UP

Read Serway & Jewett: sections 22.1, 22.2.

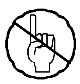
1. Make a sketch of all the magnets in each figure. Be sure to label the poles of the magnets.

2. Choose a point near the pole of a magnet. At that point draw a vector representing the magnetic field. The length of the vector should give an indication of the strength of the field. Keep in mind that:

- The field can have only one value and direction at any point.
- The direction of the magnetic field points away from a North pole, and towards a South pole.
- The field at a point is the vector sum of the fields from all sources.

3. Move a short distance away in the direction of the vector and choose another point. At that point draw another magnetic field vector. Continue this process until you reach another magnetic pole. Choose another point near a pole and start the process again. Continue until you can see the pattern of the magnetic field for all parts of the configuration.

EXPLORATION



WARNING: The viscous liquid (glycerin) in the Taconite plate may cause skin irritation. **If a plate is leaking, please notify your lab instructor immediately.**

Check to make sure your Taconite plate is not leaking. Gently shake the plate until the Taconite is distributed uniformly (the transparent bar inside the plate will help redistribute the flecks when moved).

Properties of magnets can change with handling. Check the poles of the magnet with your compass. Inform your lab instructor if the magnet does not behave as you would expect.

Place a permanent magnet on the Taconite plate. If the flecks are difficult to see, put a piece of white paper behind the plate. How long must you wait to see the effect of the magnetic field? Is it what you expected? Try some small vibrations of the Taconite plate. How does the pattern in the Taconite relate to the direction that a compass needle points when it is directly on top of the Taconite sheet?

Try different configurations of magnets and determine how to get the clearest pattern in the Taconite. What can you do to show that the poles of a magnet are not electric charges? Try it.

MEASUREMENT AND ANALYSIS

Lay one bar magnet on the Taconite plate. In your journal, draw the pattern of the magnetic field produced. Repeat for each figure in the predictions.

CONCLUSION

How did your predictions of the shape of the magnetic field for each configuration of magnets compare with your results? What influence does the field have on the Taconite filings? Does the field cause a net force? Does the field cause a net torque? If so, in what direction?

PROBLEM #2:
CURRENT CARRYING WIRE

Your friend's parents, who run an organic dairy farm, have high-voltage power lines across their property. They are concerned about the effect that the magnetic field from the power lines might have on the health of their dairy cows. They bought a device to measure the magnetic field. The instructions for the device state that it must be oriented perpendicular to the magnetic field. To measure the magnetic field correctly, they need to know its direction at points near a current carrying wire. They know you have taken physics, so they ask you for help. First, you decide to check a simulation of the magnetic field of a current carrying wire. Next, to confirm your prediction and simulation, you decide to use a compass along with a current carrying wire to determine the map of the magnetic field caused by the current carrying wire.

EQUIPMENT

You will have a magnetic compass, a length of wire, a meter stick, a power supply, and the EMField application. Make sure to use the correct power supply – **do not** use the Cenco CRT power supplies!

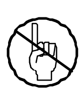
PREDICTIONS

Read Serway & Jewett: sections 22.1, 22.2, 22.7. Sketch your best guess of the map of the magnetic field near a current carrying wire when the wire is (a) stretched straight, and (b) formed into a loop.

EXPLORATION

To open the EMField application, just click on the EMField icon on your desktop. Click anywhere for instructions. To study magnetic fields of current carrying wires, you will want to choose the *2D Line Currents* option in the *Sources* menu. At the bottom of the window, there will be a list of various line currents of different magnitudes. Choose one by clicking and dragging it into the screen. Under the *Field and Potential* menu, you should choose the *Field Vector* option. This option for magnetic fields behaves exactly like that for electric fields. Hence, it is useful to review the EMField instructions from labs 1 and 2. Once you have a clear picture of what the direction of the field is, print it out using the *Print* command under *File*. You might also find it useful to play around with different sizes of current to note any changes.

Once you are finished with EMField, it is time to move to the physical apparatus. Keep in mind that a compass needle, because it is a small magnet, aligns itself parallel to the local magnet field. Attach enough wires together to give a total length of at least half a meter. Is there any evidence of a magnetic field from a non current-carrying wire? To check this, stretch the wire vertically and move your compass around the center of the wire. Does the compass always point in the same direction?



WARNING: You will be working with a power supply that can generate large electric 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. NEVER GRASP A WIRE BY ITS METAL ENDS!**

Connect the wire to the power supply and turn the power supply on (**do not use the Cenco CRT power source**). The circuit breaker built into the power supply minimizes the hazard of this short circuit.

Stretch the wire vertically and move your compass around the wire. Start where you expect the magnetic field to be largest. Is there any evidence of a magnetic field from a current carrying wire? Watch the compass as you turn the current on and off. Does the compass always point in the same direction? How far from the wire can the compass be and still show a deflection? Develop a measurement plan.

Now make a single loop in the wire through which you can easily move the compass. Move the compass around the loop. In which direction is the compass pointing? How far away from the loop can you see a deflection? Is this distance larger along the axis of the loop or somewhere else?
Set up your Hall probe as explained in Appendices D and E. Before you push any buttons on the computer, locate the magnetic field strength window. You will notice that even when the probe is held away from obvious sources of magnetic fields, such as your bar magnets, you see a non-zero reading. From its behavior determine if this is caused by a real magnetic field or is an electronics artifact or both? If you notice an ambient field, can you determine its cause?

Go through the Hall probe calibration procedure outlined in *Appendix E*. Be sure the sensor amplification switch on the Hall probe is set to the correct range. **The Hall Probe application detects the setting of the probe when started, in order to switch settings you must restart Hall Probe.** Why do you rotate the probe 180 degrees for the calibration process? Does the Hall probe ever read a zero field?

Hold the Hall probe next to the wire; how can you use the information from your compass to decide how to orient the probe? Read the value displayed by the Hall probe program. What will happen when you move the probe further from the wire? Will you have to change the orientation of the probe? How will you measure the distance of the probe from the wire?

MEASUREMENT

Use your measurement plan to create a map of the magnetic field around the stretched wire and the looped wire. Include the magnitude and direction of the magnetic field for each distance.

ANALYSIS

The direction of the magnetic field at a point near a current-carrying wire can be found by using the "right-hand rule" that is described in your text. How does the "right-hand rule" compare to your measurements?

CONCLUSION

How did your predictions of the map of the magnetic field near current-carrying wires compare with both physical and simulated results? How do they compare with the "right-hand rule"?

PROBLEM #3:
MEASURING THE MAGNETIC FIELD OF PERMANENT MAGENTS

Still working on retainer for your friend's parents, the organic dairy farmers, you are now ready to measure the magnetic field near high-voltage power lines. Before making this measurement, you decide to practice by using your Hall probe on a bar magnet. Since you already know the map of the magnetic field of a bar magnet, you decide to use the Hall probe to determine how the magnitude of the magnetic field varies as you move away from the magnet along each of its axes. While thinking about this measurement you wonder if a bar magnet's magnetic field might be the result of the sum of the magnetic field of each pole. Although, to date, no isolated magnetic monopoles have ever been discovered, you wonder if you can model the situation as two magnetic monopoles, one at each end of the magnet. Is it possible that the magnetic field from a single magnetic pole, a monopole, if they exist, has the same behavior as the electric field from a point charge? You decide to check it out by studying how the magnitude of the magnetic field from a bar magnet along each of its axes depends on the distance from the magnet. Is the behavior of the magnetic fields with respect to the distance from a magnetic pole similar to the behavior of an electric field with respect to the distance from a point charge?

EQUIPMENT

You will have a bar magnet, a meter stick, a Hall probe (see *Appendix D*), and a computer data acquisition system (see *Appendix E*). You will also have a Taconite plate and a compass.

PREDICTION

Calculate the magnetic field strength as a function of distance along each axis of a bar magnet. Make a graph of this function for each axis. How do you expect these graphs to compare to similar graphs of the electric field along each axis of an electric dipole?

WARM-UP

Read Serway & Jewett: sections 19.4, 22.1, 22.2

1. Draw a bar magnet as a magnetic dipole consisting of two magnetic monopoles of equal strength but opposite sign, separated by some distance. Label each monopole with its strength and sign. Label the distance. Choose a convenient coordinate system.

2. Select a point along one of the coordinate axes, outside the magnet, at which you will calculate the magnetic field. Determine the position of that point with respect to your coordinate system. Determine the distance of your point to each pole of the magnet, using your coordinate system.

3. Assume that the magnetic field from a magnetic monopole is analogous to the electric field from a point charge, i.e. the magnetic field is proportional to g/r^2 where g is a measure of the strength of the monopole. Determine the direction of the magnetic field from each pole at the point of interest.

4. Calculate the magnitude of the each component of the magnetic field from each pole at the point of interest. Add the magnetic field (remember it is a vector) from each pole at that point to get the magnetic field at that point.

5. Graph your resulting equation for the magnetic field strength along that axis as a function of position along the axis.

6. Repeat the above steps for the other axis.

EXPLORATION

Using either a Taconite plate or a compass check that the magnetic field of the bar magnet appears to be a dipole. Start the Hall probe program and go through the Hall probe calibration procedure outlined in *Appendix E*. **The Hall Probe application detects the setting of the probe when started, in order to switch settings you must restart Hall Probe**

Take one of the bar magnets and use the probe to check out the variation of the magnetic field. Based on your previous determination of the magnetic field map, be sure to orient the Hall probe correctly. Where is the field the strongest? The weakest? How far away from the bar magnet can you still measure the field with the probe? Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength against position that will include all of the points you will measure. Decide whether you should set the amplifier to high or low sensitivity.

Choose an axis of the bar magnet and take measurements of the magnetic field strength in a straight line along the axis of the magnet. Be sure that the field is always perpendicular to the probe. Make sure a point appears on the graph of magnetic field strength versus position each time you enter a data point. Use this graph to determine where you should take your next data point to map out the function in the most efficient manner. Repeat for each axis of the magnet.

ANALYSIS

Compare the graph of your calculated magnetic field to that which you measured for each axis of symmetry of your bar magnet. Can you fit your prediction equation to your measurements by adjusting the constants?

CONCLUSION

Along which axis of the bar magnet does the magnetic field fall off faster? Did your measured graph agree with your predicted graph? If not, why? State your results in the most general terms supported by your analysis.

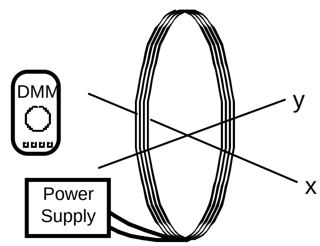
How would the shape of the graph of magnetic field strength versus distance for the magnetic dipole compare to the shape of the graph of electric field strength versus distance for an electric dipole? Is it reasonable to assume that the functional form of the magnetic field of a monopole is the same as that of an electric charge? Explain your reasoning.

PROBLEM #4:
THE MAGNETIC FIELD OF ONE COIL

You read in your text that a coil of wire carrying a current gives the same magnetic field as a bar magnet: a magnetic dipole field. This seems strange, so you decide to check it using a large coil of wire and a Hall probe, as well as a simulation. You decide to measure the strength of the magnetic field as a function of position along the central axis of the coil and compare it to the measurements you have for a bar magnet. As a qualitative check you also use the Hall probe to make a map of the magnetic field everywhere near the current carrying coil, and compare that to what the simulation predicts.

EQUIPMENT

You will have a Pasco coil of 200 turns of wire, a power supply, a compass, a meter stick, a digital multimeter (DMM), a Hall probe, and a computer data acquisition system. You will also have the EMField application. Do not use the Cenco CRT power supply for this problem.



PREDICTION

Compare the magnitude of the magnetic field as a function of distance along central axis of a coil of known radius and carrying a known electric current to that of a bar magnet.

Also compare the field map of the current carrying coil with that of a bar magnet.

WARM-UP

Read Serway & Jewett: 21.1, 21.2, 22.7 (and see example 22.6.)

If you have done Problem #3, you already have the equation that describes the magnetic field strength of a magnetic dipole along an axis of symmetry. If not, answer the warm-up questions in Problem #3.

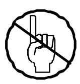
Draw the coil and label the current through it. Using the right hand rule, determine the direction of the magnetic field along the central axis of the coil. Using this information, which symmetry axis of a magnetic dipole corresponds to this central axis?

EXPLORATION

First, see what the simulation gives you. If you do not remember how to use EMField, review lab 5, or the second problem of this lab.

Once you are in the *2D Line Currents* mode, you will need to figure out how to model a coil. You should think of the fact that a coil and its field are symmetric about the coil's central axis and the simulation plots fields in a plane perpendicular to the current flow. Once you have your model of a simple coil input into the program, use the *Field Vectors* option in the *Field and Potential* menu to study the field. You should pick points both inside and outside the coil for a complete map of the magnetic field. Once you have done this, print it out, using *Print* under *File*. **Note that you will use this for qualitative comparisons only!**

Now you should start working with the physical apparatus.



WARNING: You will be working with equipment that generates large electric 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. Never grasp a wire by its metal ends.**

Connect a large coil to the power supply using the adjustable voltage. Using your compass, make a qualitative map of the magnetic field produced. To get the most obvious effect on the compass, should the central axis of the coil be oriented N-S or E-W?

Using your compass an indicator, adjust the current up and down to determine the sensitivity of the magnetic field to the current. For a reasonable current in the coil, use the compass to determine how far a measurable magnetic field along the axis of the coil extends. Also check out the magnetic field outside the coil. Is it large or small? Compared to what?

Try reversing the current through the coil. What happens to the magnetic field at each point?

Connect the Hall probe according to the directions in Appendices D and E. Explore the strength of the magnetic field in the plane of the coil. Is the field stronger inside or outside the coil? Where is the field the strongest inside the coil? Decide whether you should set the amplifier to high or low sensitivity.

How far from the center of the coil along the axis can you measure the field? Is it the same on both sides of the coil?

How can you tell by your magnetic field reading if you are on the axis? How far from the axis can you move the Hall probe without introducing additional uncertainty in your measurement?

Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength as a function of position that will include all of the points that you will measure.

Use the Hall probe to measure the magnitude and direction of the magnetic field as a function of position along the axis of the coil. Measure the field on both sides of the coil. Be sure your Hall Probe is calibrated and has the correct orientation to accurately measure the magnetic field.

Use the Hall probe to complete the field map for the coil.

Use the DMM to measure the current in the coil. Try measuring the field along the axis at several different currents.

Don't forget to measure the diameter of the coil and record the number of turns. What considerations need to be made when measuring the diameter?

ANALYSIS

Graph the magnetic field of the coil along its axis as a function of position and compare to the magnetic field of the bar magnet along the comparable axis. The graphical comparison is easier if you normalize the function describing the bar magnet's magnetic field to that of the coil. You can do this by dividing the largest magnetic field strength of the coil by the largest magnetic field strength of the bar magnet. Use the resulting number to multiply the function representing the bar magnet's magnetic field strength. You may also need to use the same process on the x-values. You can then put both functions on the same graph.

CONCLUSION

Is the graph of magnetic field strength as a function of position along the central axis similar to that for a bar magnet? Does the magnetic field map for a current-carrying coil have the same pattern as for a bar magnet? Do you believe that this coil gives a magnetic dipole field? Is this true everywhere? Why or why not?

How does the magnetic field strength of a current-carrying coil depend on the current? What measurements justify your statement?

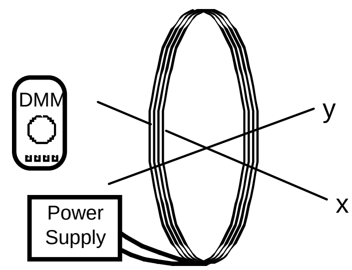
PROBLEM #5:
DETERMINING THE MAGNETIC FIELD OF A COIL

You are a member of a research team studying magnetotactic bacteria. Magnetotactic bacteria from the southern hemisphere preferentially swim to the south along magnetic field lines, while similar bacteria from the northern hemisphere preferentially swim to the north along magnetic field lines. Your team wishes to quantify the behavior of magnetotactic bacteria in closely controlled magnetic fields. You know from your physics class that a coil of wire can be used to produce a magnetic field, which can be varied by changing the current through it. You set yourself the task of calculating the magnetic field along the axis of the coil as a function of its current, number of turns, radius, and the distance along the axis from the center of the coil. To make sure you are correct, you decide to compare your calculation to measurements.

EQUIPMENT

If you have done Problem #4, you can use those measurements for this Problem. If not, you will use the following equipment.

You will have a large, 200 turn coil of wire, a power supply, a digital Multimeter (DMM), a compass, a meter stick, a Hall probe, and a computer data acquisition system.



PREDICTION

Calculate the magnitude of the magnetic field as a function of the position along the central axis of a coil of known radius, the number of turns of wire, and the electric current in the coil.

Use this expression to graph the magnetic field strength as a function of position along the central axis of the coil.

WARM-UP

Read Serway & Jewett: 21.1, 21.2, 22.7 (and see example 22.6.)

1. Make a sketch of a coil of radius R. Define a coordinate axis, label the relevant quantities, and indicate the direction of the current through the coil.

Select a point along the axis at which you will calculate the magnetic field.

2. Select a small element of current along the coil, which will cause a small fraction of this magnetic field. Label the length of that current element. Draw a position vector from that current element to the selected point along the axis of the coil.

Use the Biot-Savart law, (phonetically, “Bee-Oh Saw-Varr”), to draw a vector representing the direction of the small part of the magnetic field from your current element at the position of interest. Determine the components of this vector along the axes of your coordinate system.

Are there any symmetries that rule out one or more components of the magnetic field at the point of interest?

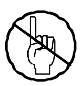
3. Use the Biot-Savart law to calculate the small part of the desired component of the magnetic field, at the selected point, from the small element of current. Now add up (using an integral) all of the small fractions of that component of the magnetic field from all of the small elements of current around the coil.

Determine the magnitude of the magnetic field at that point along the axis for one loop of wire, writing your answer as a function of the distance along the axis of the coil. What will be the effect of N identical loops on the magnitude of the magnetic field?

4. Graph the magnitude of magnetic field strength as a function of the position along the central axis of the coil of wire.

EXPLORATION

If you have the data from Problem #4 you do not need to make any additional measurements. Go directly to the analysis section. If you have not done Problem #4, continue with the exploration.



WARNING: You will be working with equipment that generates large electric 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. Never grasp a wire by its metal ends.**

Connect a large coil to the power supply using the adjustable voltage. Using your compass, make a qualitative map of the magnetic field produced. To get the most obvious effect on the compass, should the central axis of the coil be oriented N-S or E-W? Decide whether you should set the amplifier to high or low sensitivity.

Using your compass as an indicator, adjust the current up and down to determine the sensitivity of the magnetic field to the current. For a reasonable current in the coil, use the compass to determine how far a measurable magnetic field along the axis of the coil extends. Also check out the magnetic field outside the coil. Is it large or small? Compared to what?

Try reversing the current through the coil. What happens to the magnetic field at each point?

Connect the Hall probe according to the directions in Appendices D and E. Explore the strength of the magnetic field in the plane of the coil. Is the field stronger inside or outside the coil? Where is the field the strongest inside the coil?

How far from the center of the coil along the axis can you measure the field? Is it the same on both sides of the coil?

How can you tell by your magnetic field reading if you are on the axis? How far from the axis can you move the Hall probe without introducing additional uncertainty to your measurement?

Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength against position that will include all of the points you will measure.

Use the Hall probe to measure the magnitude and direction of the magnetic field as a function of position along the axis of the coil. Measure the field on both sides of the coil. Be sure your Hall probe is calibrated and has the correct orientation to accurately measure the magnetic field. Make sure you take at least two measurements for averaging.

Use the Hall probe to complete the field map for the coil.

Use the DMM to measure the current in the coil. Try measuring the field along the axis at several different currents.

Don't forget to measure the diameter of the coil and record the number of turns. What considerations need to be made when measuring the diameter?

ANALYSIS

Graph the measured magnetic field of the coil along its axis as a function of position and compare with your prediction.

CONCLUSION

Does the graph of magnetic field strength as a function of distance agree with your prediction? Is this true everywhere? Why or why not?

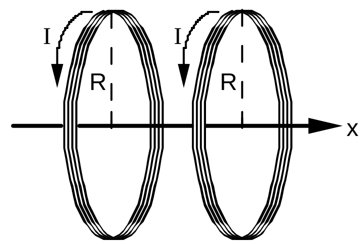
PROBLEM #6:
MEASURING THE MAGNETIC FIELD OF TWO PARALLEL COILS

As in the previous problem, you are a member of a research team studying magnetotactic bacteria, which preferentially swim along magnetic field lines. Your team now wishes to quantify the behavior of magnetotactic bacteria in magnetic fields which are uniform. However, the magnetic field from one coil varies strongly with position; that configuration is not suitable for the test, and the group needs something that can produce a more uniform field. The laboratory has two nearly identical large coils of wire mounted so that the distance between them equals their radii. You have been asked to determine the magnetic field between them to see if it is suitable for the test.

EQUIPMENT

Connect two large coils to a power supply so that each coil has the same current. Each coil has 200 turns. The coil base has markings showing correct spacing for a uniform field.

You will have a digital Multimeter (DMM), a compass, a meter stick, and a Hall probe. A computer is used for data acquisition with the HallPROBE program.



PREDICTION

Calculate the magnitude of the magnetic field for two coils as a function of the position along their central axis, for the special case where the distance between the coils is the same as the radius of the coils. Use this expression to graph the magnetic field strength versus position along the axis.

WARM-UP

Read Serway & Jewett: 21.1, 21.2, 22.7 (and see example 22.6.), 22.10

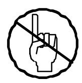
1. Draw a picture of the situation showing the direction of the current through each coil of wire. Establish a single convenient coordinate system for both coils.

Label all of the relevant quantities.

2. Select a point along the axis of the two coils at which you will determine an equation for the magnetic field. In the previous problem, you measured the magnetic field due to one coil as a function of the position along its axis. To solve this problem, add the magnetic field from each coil at the selected point along the axis. Remember to pay attention to the geometry of your drawing. The origin of your coordinate system for this problem cannot be at the center of both coils at once. Also remember that the magnetic field is a vector.

3. Use your equation to graph the magnetic field strength as a function of position from the common origin along the central axis of the coils. Describe the qualitative behavior of the magnetic field between the two coils. What about the region outside the coils?

EXPLORATION



WARNING: You will be working with a power supply that can generate large electric 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. Never grasp a wire by its metal ends.**

Connect the large coils to the power supply with *the current flowing in the opposite direction in both coils*, using the adjustable voltage. Using your compass, explore the magnetic field produced. Be sure to look both between the coils and outside the coils.

Now connect the large coils to the power supply *with the current flowing in the same direction in both coils*, using the adjustable voltage. Using your compass, explore the magnetic field produced. Be sure to look both between the coils and outside the coils.

Based on your observations, should the currents be in the same direction or in opposite directions to give the most uniform magnetic field between the coils?

Connect the Hall probe according to the directions in Appendices D and E. For the current configuration that gives the most uniform magnetic field between the coils, explore the strength of the magnetic field along the axis between the coils. Follow the axis through the coils. Is the field stronger between or outside the coils? Where is the field strongest between the coils? The weakest?

See how the field varies when you are between the two coils but move off the axis. How far from the axis of the coils can you measure the field? Is it the same on both sides of the coils? Decide whether you should set the amplifier to high or low sensitivity.

When using the Hall probe program, consider where you want your zero position to be, so that you can compare to your prediction.

Write down a measurement plan.

MEASUREMENT

Based on your exploration, choose a scale for your graph of magnetic field strength against position that will include all of the points you will measure.

Use the Hall probe to measure the magnitude of the magnetic field along the axis of the coils of wire. Be sure to measure the field on both sides of the coils.

What are the units of your measured magnetic fields? How do these compare to the units of your prediction equations?

Use the DMM to measure the current in the two coils. As a check, repeat these measurements with the other current configuration.

ANALYSIS

Graph the measured magnetic field of the coil along its axis as a function of position and compare to your prediction.

CONCLUSION

For two large, parallel coils, how does the magnetic field on the axis vary as a function of distance along the axis? Did your measured values agree with your predicted values? If not, why not? What are the limitations on the accuracy of your measurements and analysis?

Does this two-coil configuration satisfy the requirement of giving a fairly uniform field? Over how large a region is the field constant to within 20%? This very useful geometric configuration of two coils (distance between them equals their radius) is called a Helmholtz coil.

PROBLEM #7:
MAGNETS AND MOVING CHARGE

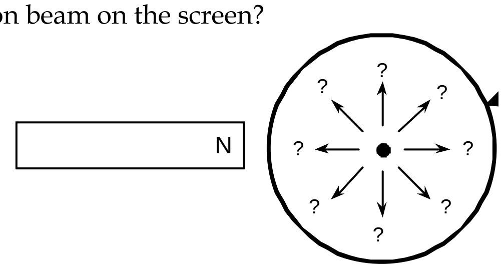
You are leading a technical team at a company that is redesigning the electron linear accelerators used in cancer therapy. Your team is developing a steering mechanism that uses magnetic fields to precisely guide the electrons to their target, where they suddenly slow down and emit high energy photons that can control tumors. To introduce this project to a group of stockholders, you wish to demonstrate how a magnetic field can guide an electron beam across a CRT screen. You decide to use an ordinary bar magnet held outside of the CRT to deflect the electrons. Before you do the demonstration, you need to know the qualitative effect of bringing a bar magnet up to a CRT. In the laboratory you determine how the direction and size of the electron deflection is related to the magnetic field direction, the magnetic field strength, and the velocity of the electron.

EQUIPMENT

For this problem you will need a cathode ray tube (CRT) and accessories, a bar magnet, a meter stick, and a compass. Review the information from Laboratory IV and *Appendix D* regarding the design of the CRT and the proper way to use it.

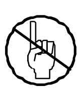
PREDICTION

Read Serway & Jewett: sections 22.1, 22.2, 22.3.
If you bring the north end of a magnet near the side of the CRT, which arrow represents the deflection of the electron beam on the screen?



Does the size of the deflection increase or decrease as the magnet gets closer to the CRT? As you increase the size of the magnetic field? Does the size of the deflection depend on the speed of the electrons? Explain your reasoning.

EXPLORATION



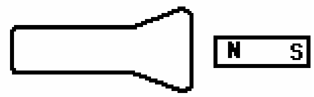
WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply. Never grasp a wire by its metal ends.**

Connect the CRT according to the directions in *Appendix D* and your lab journal from Lab IV. Select the accelerating voltage that gave the largest deflection for the smallest electric field based on your explorations from Lab IV. Record the location of the non-deflected beam spot.

Determine which pole on your bar magnet is the north magnetic pole. Make a qualitative field map of your magnet to make sure it is a simple dipole. If it is not, ask your instructor to replace it. Describe the magnetic field at the end of the magnet.

Place the magnet near the side of the CRT. Did the deflection match your prediction? Why or why not? Repeat this procedure for the south pole. Should there be any difference? In which direction did the beam spot deflect?

Put the bar magnet perpendicular to the screen of the CRT, do you see a deflection? Try this with both poles of the magnet. Record your results. Were they what you had expected?



Can you orient the bar magnet so that it attracts or repels the electron beam? Place the north pole of your magnet a fixed distance away from the side of the CRT near the screen. Record the deflection. Increase the speed of the electrons by increasing the accelerating voltage as much as possible. Calculate the increase in speed. How does the deflection change? Try this with both poles of the magnet. Record your results. Were your results what you had anticipated?

Place the north pole of your magnet a fixed distance away from the side of the CRT near the screen. Record the deflection. Increase the magnetic field by adding more magnets. How does the deflection change? Try this with both poles of the magnet. Record your results. Were your results what you had anticipated?

What effect does the Earth's magnetic field have on the electron beam of a CRT? What is the direction of the Earth's magnetic field in your laboratory room? Arrange the CRT to see the maximum effect. Arrange it to observe the minimum effect. By measuring the electron deflection, what would you say is the relative strength of the magnet and the Earth's magnetic field in the lab? Remember to take account of the distance that the electron travels through each magnetic field. What is the effect of the Earth's magnetic field on the CRT beam relative to the Earth's gravitational field?

Devise your own exploration of the effect of a magnetic field on electrons using the CRT and the bar magnets. What variables can you control with the magnets and the CRT? Record your questions that will guide your exploration and check it with your lab instructor for safety before starting

ANALYSIS

Draw a picture relating the three vectors representing the velocity of the electron, the magnetic field, and the force on the electron consistent with your results.

CONCLUSION

Did the electron beam deflection in the presence of a magnetic field agree with your prediction? Why or why not? What was the most interesting thing you learned from this exploration?

PROBLEM #8:
MAGNETIC FORCE ON A MOVING CHARGE

You are attempting to design a better electron microscope; in particular, you wish to improve the mechanism that guides the electron beam across a sample. To precisely control the beam of electrons, your research team decides to try a magnetic field. For your study of electron control you decide to use a Cathode Ray Tube (CRT) with a magnetic field perpendicular to its axis. From your work with Helmholtz coils in Problem #5, you know that the magnetic field between these parallel coils is fairly uniform, so you decide to use them for your test. Before you can evaluate the sensitivity of the electron microscope design, you need to determine how the magnitude of a constant magnetic field affects the position of the beam spot.

EQUIPMENT

You will be using the cathode ray tube (CRT) described in *Appendix D*. The magnetic field will be provided by connecting the Helmholtz coils to the power supply and placing the CRT between the coils. You will also have a digital multimeter (DMM), a compass, a meter stick, and a Hall probe connected to a computer data acquisition system.

PREDICTION

Write an equation for the deflection of an electron as a function of the strength of a constant magnetic field and the velocity of the electron when the direction of the magnetic field is such as to give maximum deflection. Use this equation to graph the deflection as a function of magnetic field strength for a typical electron velocity in the CRT.

WARM-UP

Read Serway & Jewett: sections 22.1, 22.2, 22.3.

Review Kinmatics if necessary: Read Serway & Jewett: Chapters 3 and 4.

1. Draw a picture of the CRT in the Helmholtz coils. Since you will not be using electric fields, do not include the deflection plates in your sketch. Be sure you have all the other components in your sketch. Draw a coordinate axis on this sketch and show the magnetic field direction and the region occupied by the magnetic field. Draw the electron trajectory through all regions of the CRT together with its velocity and acceleration. Draw the electron trajectory if there were no magnetic field. The difference between where these two trajectories hit the CRT screen is the deflection.

2. What path does an electron follow while traveling through a constant magnetic field? The magnetic force is always perpendicular to the electron's velocity. Are there any forces other than the magnetic force that need to be considered?

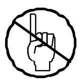
3. Determine the velocity of the electrons as they leave the electron gun in the CRT. (See your notes from Lab 1V, Problem #5.)

4. Determine the position, direction, and velocity of an electron entering the region of constant magnetic field. Determine the position, direction, and velocity of an electron as it leaves the region of constant magnetic field. What type of curve is the electron's trajectory in that region?

5. Determine the path of the electron as it travels after it leaves the magnetic field region until it strikes the screen. Use geometry to determine how far from the center the electron strikes the screen.

EXPLORATION

Review your notes from your exploration in Problem #7.



WARNING: You will be working with equipment that generates large electric 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. Never touch the conducting metal of any wire.**

Check to see that the connections from the power supply to the high voltage accelerating plates and the filament heater of the CRT are correct, then turn the power supply on. You should have between 250 and 500 volts between the cathode and anode. After a moment, you should see a spot that you can adjust with the knob labeled “Focus”. If your connections are correct and the spot still does not appear, inform your lab instructor.

Devise a measuring scheme to record the position of the beam spot. Record your zero deflection position and do not move the CRT once you have started taking measurements.

Review the magnetic field map from the Helmholtz Coils. How will you orient the CRT with respect to the coils? Would the deflection be the same if the magnetic field were reversed? Try it. How will you determine the length of the CRT within the magnetic field? Is the field uniform throughout the flight of the electrons?

Write down a measurement plan.

MEASUREMENT

Measure the position of the beam spot as you change the magnetic field. Make at least two measurements for averaging.

Use the Hall Probe to Measure the magnetic field between the Helmholtz coils.

ANALYSIS

Graph your measurements of the deflection of the electron beam for the different values of the magnetic field at a fixed electron speed and compare to your prediction. Repeat for deflection as a function of electron speed for a fixed magnetic field.

CONCLUSION

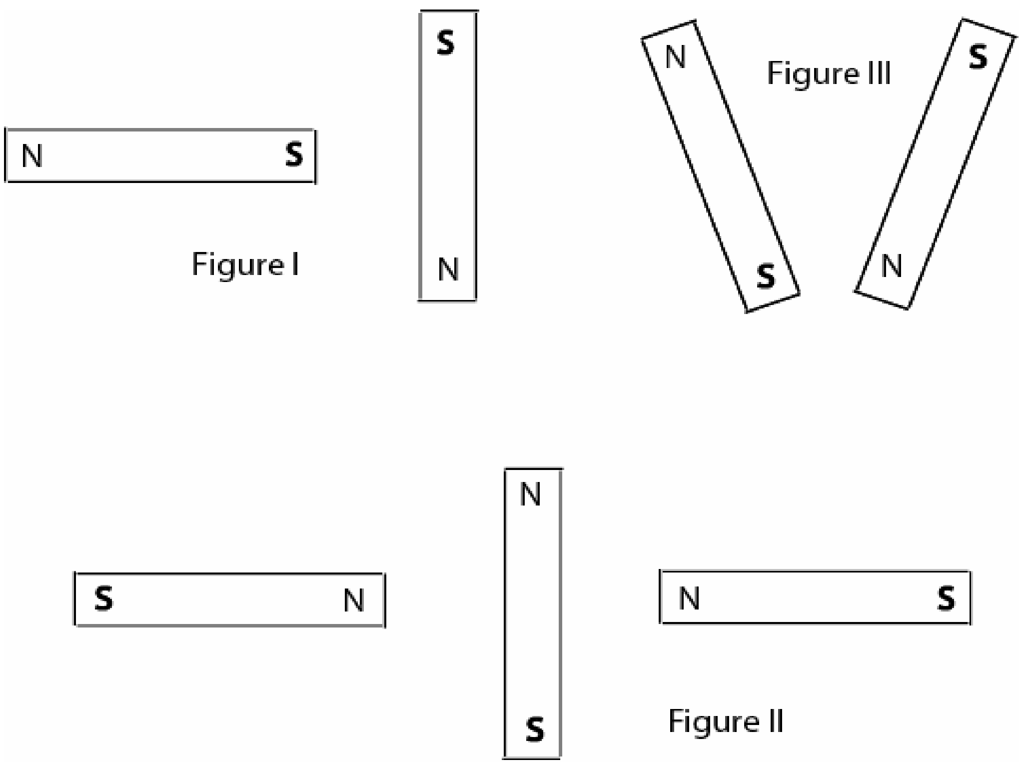
How does the deflection of the electron beam depend on the magnetic field? Did your data agree with your prediction? If not, why? What are the limitations on the accuracy of your measurements and analysis?

How does the deflection of the electron beam depend on the electron speed? Did your data agree with your prediction? If not, why? What are the limitations on the accuracy of your measurements and analysis?

Is controlling the deflection of an electron beam easier with a magnetic field or an electric field? Write down what you mean by easier.

☑ CHECK YOUR UNDERSTANDING

1. For each of the configurations of magnets below, sketch the magnetic field map. Assume that the figures do not interact with each other.



2. You and your friends are watching an old Godzilla movie. In one scene, a scientist broke a magnet in half because he needed a monopole for his experiment. You cringe and start laughing, but your friends don't understand what you found so funny. Explain the joke.

3. For a cathode ray tube (CRT) with the same electron gun as you used in lab, assume that the distance from the center of the V_X plate to the fluorescent screen is 10 cm, V_{acc} is 500V and V_X = 6V. The CRT is then placed between the large parallel coils (also used in this lab) which have a current of 1 ampere flowing through them. Assume that the CRT is oriented in the large parallel coils such that the electric field between the V_X plates and the magnetic field are <u>in the same direction</u>. What is the displacement of the electron beam on the screen? This is a difficult problem!!

TA Name:______________________________

PHYSICS 1202 LABORATORY REPORT

Laboratory V

Name and ID#: ____

Date performed: _______________ Day/Time section meets: ______________________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: __________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

LABORATORY VI
ELECTRICITY FROM MAGNETISM

In the previous problems you explored the magnetic field and its effect on moving charges. You also saw how magnetic fields could be created by electric currents. This lab will carry that investigation one step further, determining how changing magnetic fields can give rise to electric currents. This is the effect that allows the generation of electricity, which powers the world's technology.

The problems in this laboratory will explore different aspects of changing the magnetic flux through a coil of wire to produce an electric current. You will investigate the current produced in a coil of wire by moving the coil, moving the magnet causing the magnetic field, changing the area of the coil perpendicular to the magnetic field, and changing the magnetic field.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Explain what conditions are necessary for a magnetic field to produce an electric current.
- Determine the direction of a current induced by a magnetic field.
- Use the concept of magnetic flux to determine the electric effects of a changing magnetic field.
- Use Faraday's law to determine the magnitude of a potential difference across a wire produced by a change of magnetic flux.

PREPARATION:

Read Serway & Jewett: Chapter 23, sections 1-4.

Before coming to lab you should be able to:

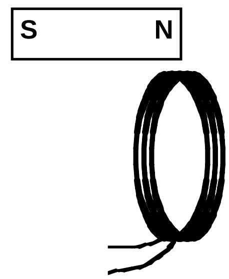
- Use a DMM to measure current, potential difference, and resistance.
- Sketch the magnetic fields from permanent magnets and current carrying coils of wire.
- Use vector addition to combine magnetic fields from several sources.
- Use the right-hand rule to determine the direction of the magnetic fields from circuit loops and wires.
- Use a Hall probe to determine the strength of a magnetic field.
- Use the definition of magnetic flux.

PROBLEM #1:
MAGNETIC INDUCTION

One of the great technical problems in modern society is how to generate enough electricity for our growing demand. You have been assigned to a team that is investigating efficiency improvements for electric generators. Before becoming involved with a lot of math and computer simulations, you decide to get a feel for the problem by seeing how many different ways you can generate a potential difference using a bar magnet and a coil of wire, and how you can influence the size of that potential difference.

EQUIPMENT

You will have a small coil of wire and a bar magnet. You will use the LabPro interface and the Faraday Probe (*Appendix D*) to convert the potential difference into a digital signal suitable for your computer data acquisition program (see *Appendix E*) which records time varying potential differences.



PREDICTION

Read Serway & Jewett: sections 23.1, 23.2, 23.3.

How can you use the magnetic field of the bar magnet to induce a potential difference across the ends of a coil of wire? How many different ways can you think of? What influences the size of the potential difference? For each method, draw a picture of your procedure(s) to induce the current in the coils.

EXPLORATION

If necessary, disconnect the magnetic field probe from the LabPro interface. Plug the Faraday Probe into the LabPro interface (*Appendix D*). Attach the clips to the two ends of the coil and start the FaradayPROBE program (*Appendix E*).

Use the magnet and the coil to make sure that the apparatus is working properly and that you are getting appropriate potential difference graphs on the screen.

From your predictions, how many different motions did members of your group think of to induce a potential difference across the ends of the coil? List them in your journal. Test each method and record the results. Did any method not produce a potential difference? For each method, what factors affect the magnitude and sign of the induced potential difference? *Make sure everyone gets a chance to manipulate the magnet and coil and control the computer.*

Can you discover any methods you didn't think of earlier? What is the largest potential difference you can generate?

CONCLUSION

How do your results compare with your predictions? Explain any differences.

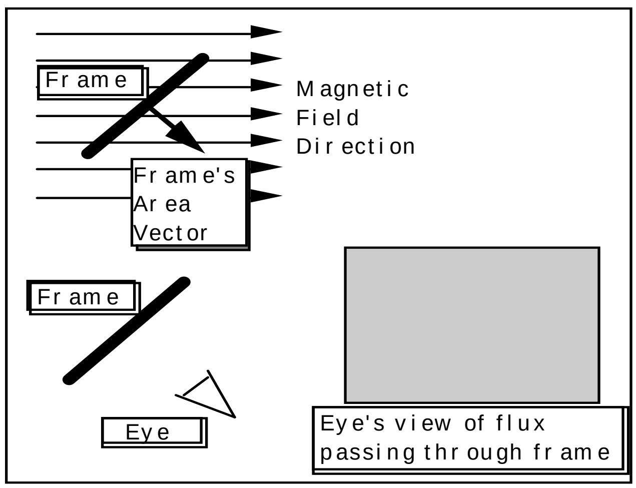
List the important characteristics for inducing a potential difference in the coil of wire. Explain how they are related to the magnitude and sign of the induced potential difference (the sign of your measured induced potential difference will depend on how your Faraday Probe is hooked up to the coil). How do you get the largest potential difference?

PROBLEM #2:
MAGNETIC FLUX

You have produced a potential difference in a coil of wire by changing the amount of magnetic field passing through it. However, a literature search on the web shows that most existing generators use mechanical means such as steam, water, or airflow to rotate coils of wire in a constant magnetic field. To continue your design of a generator, you need to calculate how the potential difference depends on the change of orientation of the coil with respect to the magnetic field. A colleague suggests you use the concept of magnetic flux that combines both the magnetic field strength and the orientation of the coil with respect to the magnetic field direction. You decide that you need to calculate the magnetic flux through the coil as a function of the angle between the coil and the magnetic field. To help you qualitatively check your calculation, you use a computer simulation program. You then quantitatively test your calculation by modeling the situation in the laboratory.

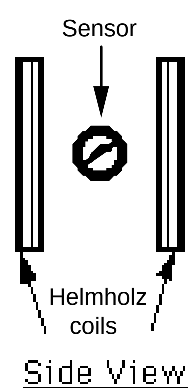
EQUIPMENT

See <u>Flux</u> <u>Simulator</u> in *Appendix E*.



Picture of <u>Flux Simulation</u> Screen

To make the measurement, a magnetic field sensor (Hall probe) is placed midway between two Helmholtz coils as shown to the right. The sensor can be rotated about a vertical axis and the angle of rotation measured. The sensor measures the amount of magnetic field perpendicular to the area of the Hall effect chip (white dot).



The magnetic field application written in LabVIEW™ will be used to analyze the measurements obtained with the magnetic field sensor (HallPROBE).

WARNING: You will be working with equipment that generates large electric currents. 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.**

PREDICTION

Calculate the magnetic flux through an area (the frame of the simulation or the Hall effect transducer chip for the measurement) as a function of the angle that the area makes with the direction of the magnetic field. Use this expression to graph the magnetic flux versus angle.

In the simulation program, under what conditions will the "eye see" the most intense blue color? The most intense red color? Will there ever be no color, or white? As the Frame is slowly rotated, will the transitions in intensity be sudden, or gradual? Is the change in intensity linear or something else?

WARM-UP

Read Serway & Jewett: sections 23.1, 23.2, 23.3.

1. Draw the coil of wire at an angle to a magnetic field.

2. Draw and label a vector that you can use to keep track of the direction of the coil. The most convenient vector is one perpendicular to the plane of the coil, the area vector. Label the angle between the area vector and the magnetic field.

3. The magnetic flux for a constant magnetic field is the component of the magnetic field perpendicular to the plane of the coil times the area of the coil. Write an equation for the magnetic flux through the coil as a function of the strength of the magnetic field and the angle between the area vector and the magnetic field direction. For what angle is this expression a maximum? Minimum?

EXPLORATION

Open the Flux Simulator movie. Use the control bar with slider, which advances through the movie, to control the rotation of the frame. Try it.

Slider

As you rotate the frame, observe both the angle that the frame's area vector makes with the magnetic field and the color seen by the eye. Is this what you expected the eye to see? Why or why not?

Now examine the apparatus with which you will make your measurement. Don't forget to calibrate the Hall probe before you turn on the coils. Decide whether you should set the amplifier to high or low sensitivity. You will want as large a magnetic field as you can produce safely with the equipment available.

Check to see if the magnetic field varies in time. Move the sensor slightly without changing its orientation to see if the magnetic field changes with position in the region of the sensor. If it does, this will add to the uncertainty of your measurement.

Slowly rotate the Hall Probe sensor through a complete circle noting the size of the readings. What is the best way to read the angle? When you return to the same angle, do you get the same reading? For what orientation is the magnetic flux largest? Smallest? Is that as you expected?

Make sure you understand the correspondence between the simulation program, the measurement apparatus, and the objects in the problem statement.

MEASUREMENT

Use the Hall probe to measure, for a particular angle, the magnitude of the magnetic field between the Helmholtz coils. Rotate the probe through 360 degrees, making measurements at whatever angle intervals you think are appropriate. Include uncertainties with your data.

ANALYSIS

Describe the color and intensity change seen by the eye as the frame rotates. What does this represent?

After the Hall probe measurement, choose an equation, based upon your prediction, that best represents your data points and adjust the coefficients to get the best correspondence with the data.

CONCLUSION

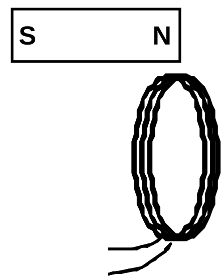
How is the magnetic flux through the coil dependent on the angle it makes with the magnetic field? Is the flux ever zero? When is the flux a maximum? How did the results compare to your prediction?

PROBLEM #3:
THE SIGN OF THE INDUCED POTENTIAL DIFFERENCE

To continue your investigation of how to improve the efficiency of electric generators, you decide to determine how the sign of the induced potential difference across the ends of a coil of wire depends on the physical arrangement and relative motions of your materials. You decide to start your investigation with the simplest situation possible – a coil of wire and a bar magnet.

EQUIPMENT

You will have a small coil of wire and a bar magnet. You will also have a computer data acquisition system with an application written in LabVIEW™ to display potential difference as a function of time (see Appendix E).



PREDICTION

Draw a coil of wire wrapped either clockwise or counterclockwise with the two ends of the wire protruding as shown in the above diagram. Add a bar magnet being pushed through the center of the coil in one direction.

Given the orientation of coil and magnet you have chosen, which of the protruding wires would you expect to be at a higher potential when :

i) The north pole of a bar magnet is pushed through the coil in the direction you've chosen.
ii) The south pole of a bar magnet is pushed through the coil in the direction you've chosen.

WARM-UP

Read Serway & Jewett: sections 23.1, 23.2, 23.3.

1. Draw a picture of each situation. Draw and label the velocity vector of the magnet relative to the coil. Also draw the direction of the magnetic field vectors in the coil.

2. Use Lenz's Law to relate the changing flux through the coil to the sign of the potential difference induced across the ends of the coil? How does the induced potential difference across the ends of the coil relate to the induced current in the coil?

EXPLORATION

If necessary, disconnect the magnetic field probe from the LabPro interface. Plug the Faraday Probe into the LabPro interface. Attach the clips to the two ends of the coil and start the FaradayPROBE program.

Use the magnet and the coil to make sure that the apparatus is working properly and that you are getting appropriate graphs of potential difference as a function of time on the screen.

Push one end of the magnet into the coil and note the sign of the induced potential difference. Is the sign of the induced potential difference the same if you hold the magnet steady and instead move the coil? How does changing the velocity of the moving magnet (or the moving coil) change the magnitude and sign of the induced potential difference?

How does the sign of the induced potential difference change when you (i) push the magnet into the coil; (ii) leave it in the coil without moving, and iii) pull it out of the coil?

What happens if you move the magnet next to the coil? Try it.

MEASUREMENT

Determine the sign of induced potential difference across the ends of the coil when you push the north pole of the magnet through the coil and when you push the south pole of the magnet through the coil.

Repeat the measurements, but this time keep the magnet still and move the coil.

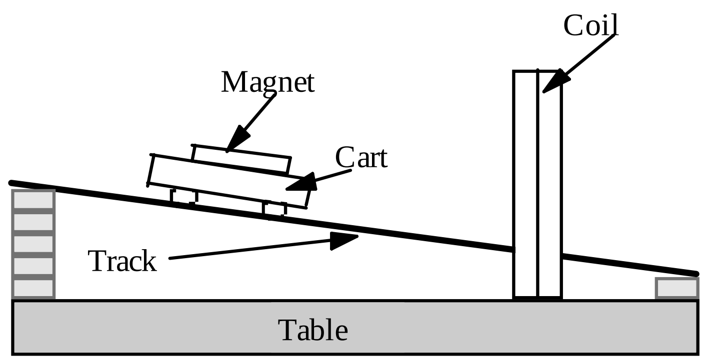
CONCLUSION

Did your results agree with your predictions given the way the coil is wrapped and the way you hooked up your Faraday Probe? Explain any differences.

PROBLEM #4:
THE MAGNITUDE OF THE
INDUCED POTENTIAL DIFFERENCE

To continue investigating how to improve the efficiency of electric generators, you decide to calculate how the induced potential difference across the ends of a coil of wire depends on the velocity with which a magnet is thrust through it. To check your calculation, you set up a laboratory model in which you can systematically vary the speed of the magnet. You mount a magnet on a cart and roll the cart down a ramp. At the end of the ramp, the cart passes through the center of a coil of wire. You can calculate the speed of the magnet as it goes through the coil from where it is released on the ramp.

EQUIPMENT



You will have a large coil of 200 turns of wire, a magnet, a meter stick, a cart, and a track. The track can be raised at an incline using wooden blocks. You will also have a computer data acquisition system with an application written in LabVIEW™ to display potential difference as a function of time (see *Appendix E*).

PREDICTION

Calculate the induced potential difference in the coil as a function of the distance from the coil at which the cart is released and other quantities that are not changed. Make a graph of this function.

WARM-UP

Read Serway & Jewett: sections 22.1, 22.2, 23.1, 23.2, 23.3.

1. Draw a picture of the situation. Label important distances and kinematic quantities. Decide on an appropriate coordinate system and add it to your picture.

2. Use Faraday's Law to relate change of magnetic flux to the magnitude of the induced potential difference in the coil.

3. Draw a magnetic field map of a bar magnet. Draw the coil of wire on the magnetic field map. As the bar magnet passes through the coil, when is the flux change the strongest? What is the relationship between the velocity of the bar magnet and the change of the magnetic flux through the coil? This tells you, qualitatively how the flux changes with time.

4. Look at the time rate change of the magnetic flux. How is it related to the velocity of the cart? It is important to note whether or not the quantities of interest vary with time or with the cross-sectional area of the coil.

5. What physics principles can you use to determine the velocity of the magnet as it passes through the coil to the starting position of the cart?

6. Write an equation giving the induced potential difference across the ends of the coil of wire as a function of the velocity of the magnet through the coil.

7. Write an expression for the velocity of the cart through the coil as a function of its starting distance from the coil. Substitute that into the equation for the induced emf.

EXPLORATION

Before you begin exploring, consider what the signal displayed by the FaradayPROBE program will look like. Will you be able to tell by the signal when the cart has not passed through the ring, and when it has? Will the peaks be sharp or rounded? Will there be many peaks or only one? How will the signal look different from background noise? Draw on your experiences from problems 1 and 3 in this lab.

If necessary, disconnect the magnetic field probe from the LabPro interface. Plug the Faraday Probe into the LabPro interface. Attach the clips to the two ends of the coil and start the FaradayPROBE program.

Push the magnet through the coil to make sure that the apparatus is working properly and that you are getting appropriate potential difference graphs on the screen. How does the graph compare to your expectations?

Set up the track at an incline so that a rolling cart will go through the center of the coil. Try different angles to get the most reproducible situation in which you can change the velocity of the cart over the widest range without damaging the equipment. Be sure to have someone catch the cart when it reaches the end of the incline.

How often does the FaradayPROBE program update the screen? How long of a signal does it display? You may find that not all of the signal captured by the program is displayed; in that case, you will have to time your release of the cart to coincide with the part of the signal being displayed.

Securely attach a magnet to the cart and let it roll down the track while observing the potential difference displayed by the computer. Check that the release position does affect the potential difference graph on the computer. Try different time scales over which the computer makes the measurement. Are the differences large enough to measure reliably?

Does the orientation of the magnet matter? Try it.

Does the display of the potential difference as a function of time on the computer look as you expected? Be sure you can qualitatively explain the behavior that you see displayed. You might want to move the magnet by hand to see if your understanding is correct.

Try adding another magnet to the cart to increase the magnitude of the induced potential difference. Does it matter how the second magnet is oriented?

Develop a measurement plan to take the data you need to answer the question.

MEASUREMENT

Follow your measurement plan and record the maximum potential difference across the ends of the coil of wire as a function of the velocity of the magnet through the coil.

ANALYSIS

From your data construct a graph of maximum induced potential difference in the coil as a function of the distance from the coil at which the cart is released.

Add the graph of your prediction to the same plot and compare. You may need to normalize the graphs.

CONCLUSION

Did your results agree with your predictions? Explain any differences.

From the computer screen, make a sketch of the shape of the induced potential difference across the ends of the coil as a function of time for one pass of the magnet. Label each feature of the graph and indicate where the magnet is in the coil at that time and why the graph looks like it does at that time.

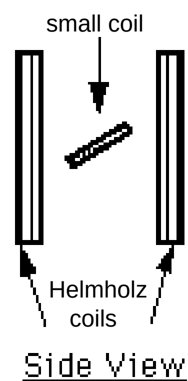
PROBLEM #5:
THE GENERATOR

To begin investigating how to improve the efficiency of electric generators, your supervisor assigns you the task of building a working model of a generator from which it is easy to take measurements. Your model consists of Helmholtz coils to generate a well-defined magnetic field and a small coil of wire, mounted in between the Helmholtz coils, to generate the current. The small coil is mounted to a motor so that it spins at a uniform speed.

Before presenting the model to your supervisor you calculate the potential difference you expect and then take some measurements to make sure that the results correspond to your understanding of the situation.

EQUIPMENT

The small coil sits between the Helmholtz coils, as shown to the right. The Helmholtz coils are connected to a power supply. The small coil has 4000 turns of wire, and can be rotated by a motor. The Cenco supply's 0-5volt is used to power the small coil.



You will have a Hall probe, a DMM, and a meterstick. You will also have a computer data acquisition system with an application written in LabVIEW™ to display potential difference as a function of time (see *Appendix E* - Measuring Time-Varying Voltage).

PREDICTION

Calculate the potential difference produced by a coil of wire spinning in a uniform magnetic field as a function of its angular speed.

WARM-UP

Read Serway & Jewett: sections 22.7 (and example 22.6), 23.1, 23.2, 23.3.

1. Draw a picture of the equipment labeling the direction of the magnetic field and the orientation of the small coil. Choose a coordinate system on the small coil.

2. Use Faraday's Law to relate the changing magnetic flux through the coil to the potential difference across the ends of the coil of wire. The changing magnetic flux is caused by the angular speed of the coil.

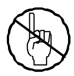
3. Draw a diagram showing only the small coil, a vector giving the direction of the magnetic field, and the area vector for the coil.

4. Write an equation for the magnetic flux through the small coil when it is stationary and at some angle to the magnetic field.

As the small coil is rotated, how does the angle its area vector makes with the magnetic field vary with time? That variation is related to its angular speed.

5. Write an expression for the change in magnetic flux through the small coil as it turns.

EXPLORATION



WARNING: You will be working with equipment that generates large electric currents. 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.**

You will want as large a magnetic field as you can produce safely with the equipment available. Develop a plan for measuring the magnetic field using the Hall probe. Where will you want to measure the magnetic field? Over what region do you need the magnetic field to be reasonably constant? Check to see if it is. Decide whether you should set the amplifier to high or low sensitivity.

Before connecting the motor to a power supply (or batteries), disconnect the Hall probe from the LabPro interface (if necessary). Plug the Faraday Probe into the LabPro interface and attach the clips to the two ends of the small coil. The ends of the small coil are attached to terminals (small wires sticking up) located near the bearings on opposite ends of the axle about which the coil spins. Use the time varying voltage LabVIEW™ application to get an on-screen display of the small coil's potential difference versus time.

With the Helmholtz coils generating a magnetic field, align the small coil such that its area vector is parallel to that magnetic field. What does the display of potential difference versus time read? Is this what you expected? Repeat by moving the small coil so that its area vector is perpendicular to the field.

Now connect the motor to a battery (or 0-5 V DC variable voltage on a power supply) and note the appearance of the potential difference versus time display. Determine how you will measure the rotational period of and the potential difference across the small coil. How can you determine the angular speed of the coil from its rotational period?

Try changing the motor’s speed by connecting it to a different number of batteries or increasing the power supply voltage. How does changing the speed affect the display?

Determine the range of potential differences and rotational periods that you will use for your measurements so that you can set the scale for your graph of maximum potential difference as a function of rotational period.

MEASUREMENT

Note that the area of the small coil enclosed by the inner loops of wire is smaller than that enclosed by the outer loops of wire. Decide how to determine the effective area for the coil.

Measure the strength of the magnetic field produced by the Helmholtz coils in the region of interest.

From the computer display of potential difference as a function of time, measure the maximum potential difference induced in the small coil and the rotational period of the small coil (see *Appendix E*).

Do several trials, rotating the coil at a different constant speed for each. How can you check your computer display to ensure that the coil is rotating at constant speed?

ANALYSIS

Determine the equation that best represents your collected data. What physical quantities do the constants in your equation represent? What do the variables in your equation represent?

CONCLUSION

What is the potential difference induced in a coil spinning in a uniform magnetic field? Did your measured potential difference agree with the predicted potential difference? Did the period of the signal agree with your predictions? If not, why not? What are the limitations on the accuracy of your measurements and analysis?

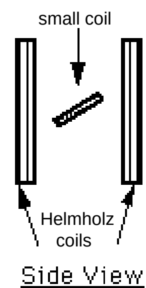
How does the amount of potential difference produced by the generator depend on the angular speed at which the generator rotates?

PROBLEM #6:
TIME-VARYING MAGNETIC FIELDS

You are working for a research team at the University of Minnesota that is developing a new method to electronically detect cancer cells in the lining of a patient's intestine. The patient swallows a small probe, which works its way through the intestine gathering data. Naturally you can't have the probe connected to external wires and you don't want to use a battery inside the person. Instead you plan to power the probe by using an external time-varying magnetic field and a small pick-up coil of wire inside the probe. Your boss is concerned that it won't work because you have no control over the orientation of the probe within the patient's intestine. Specifically, you can't control the angle dependence between the coil and the magnetic field. You have been asked to investigate the magnitude of this problem. You decide to study how the induced potential difference depends on the angle the coil makes with the external magnetic field.

EQUIPMENT

A small "pick-up coil" is mounted between Helmholtz coils, as shown to the right. The small coil has 4000 turns of wire.



A function generator outputs an electrical current, which changes with time as a sine function. When the Helmholtz coils are connected to a function generator, an alternating current goes through the coils. *Use only frequencies of less than 100 Hz.*

You will have a DMM, a magnetic compass, a meter stick, and a protractor. You will also have a computer data acquisition system with an application written in LabVIEW™ to display potential difference as a function of time (see *Appendix E* - Measuring Time-Varying Voltage).

PREDICTION

Calculate the potential difference across the pick-up coil, for a magnetic field changing with a known period, as a function of the angle the coil makes with the magnetic field. From this expression, make a graph of the maximum potential difference as a function of the angle.

WARM-UP

Read Serway & Jewett: sections 22.7 (and example 22.6), 23.1, 23.2, 23.3.

1. Draw a picture of the equipment, labeling the direction of the magnetic field and the orientation of the small coil. Choose a coordinate system on the small coil.

2. Use Faraday's Law to relate the changing magnetic flux through the coil to the potential difference across the ends of the coil of wire. The changing magnetic flux is caused by the angular speed of the coil.

3. Draw a diagram showing only the small coil, a vector giving the direction of the magnetic field, and the area vector for the coil.

4. Write an equation for the magnetic flux through the small coil when it is stationary and at some angle to the magnetic field.

5. Write an equation for the magnetic field produced by the current in the Helmholtz coils.

6. Write an expression for the change in magnetic flux through the small coil, as the current changes with time as a sine function.

EXPLORATION

Use the function generator to drive a low frequency alternating current through the large parallel coils of the Helmholtz coils:

- Set the function generator to create a sinusoidal voltage.
- Use the output labeled LOΩ on the function generator to drive the current through the coils.
- Connect the Helmholtz coils in series so that they carry the same current. Should the current go in the same direction or the opposite direction in the two parallel coils to give the most uniform magnetic field between them?

Set the frequency from the function generator to less than 1 Hertz. If you placed a compass in the magnetic field near the pick up coil, what would you expect to see? Try it. Slowly increase the frequency of the current in the Helmholtz coils. What happens to the compass needle? Is this consistent with what you expected?

Orient the small coil so that the largest magnetic flux passes through it. Attach the DMM to the small coil to read the potential difference across it. Set the DMM to read AC voltage. Slowly change the orientation of the small coil to get the maximum potential difference.

Adjust the amplitude of the signal generator to give the maximum reading on the DMM. At the lowest frequency compare the AC voltage reading to the DC voltage reading. Slowly increase the frequency and observe the results for both AC and DC settings. Decide on the best frequency to use.

Use a Hall probe and the LabVIEW™ application to determine how the magnetic field between the Helmholtz coils varies as a function of time at the frequency you have selected. Note how much time it takes for the computer display to react to any adjustment you make. Try different data sampling times on computer display and select the best one for your situation.

Adjust the amplitude of the function generator to give a magnetic field reading that looks like a sine (or cosine) function. Select the best amplitude for your measurements. How does the magnetic field period on the computer display compare to the frequency of the function generator? What happens to the amplitude of the magnetic field as you change the frequency of the function generator?

Select a range of angles to use in your measurement and note the range of magnetic field amplitudes you expect for the signal generator frequency and amplitude you have chosen to use.

The magnetic field is just the Hall probe reading (a voltage) times a calibration constant. Determine this calibration constant.

MEASUREMENT

For a fixed function generator output, measure how the potential difference across the pick up coil varies with time as a function of its angle with the magnetic field. Take enough data to convince others of your findings.

ANALYSIS

Using your measurements, graph the potential difference across the pick up coil as a function of time, for a fixed function generator output. What is the period of the potential difference? The frequency? How does this behavior change as the angle between the pick up coil and the magnetic field changes?

How does the time structure of the potential difference across the pick up coil compare to the output of the function generator?

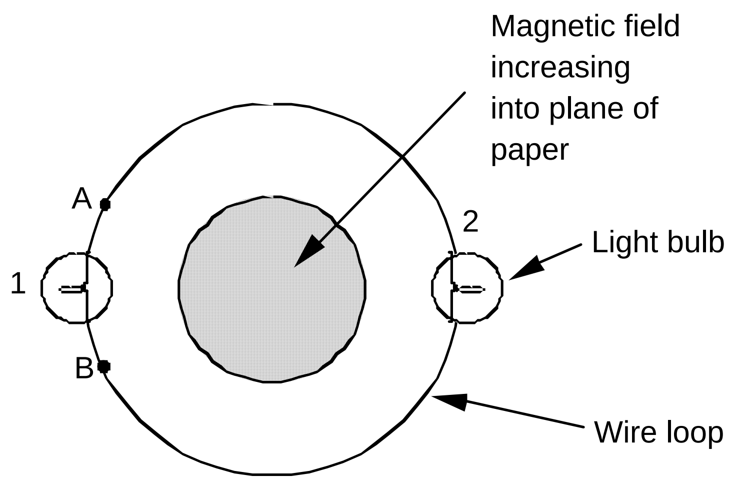
Graph the maximum potential difference across the pick up coil as a function of the angle the coil's area vector makes with the magnetic field.

CONCLUSION

Does the time variation of the potential difference across the pick up coil agree with your prediction? If not, why?

☑ CHECK YOUR UNDERSTANDING

1. A long solenoid, with the axis perpendicular to the plane of the paper, carries a current that continually increases with time. A loop of wire with two light bulbs is connected around the solenoid. What is the direction of the induced current in the wire loop? Compare the brightness of light bulbs 1 and 2.



If a wire was connected from point A to point B, compare the brightness of bulbs 1 and 2.

2. A coil with 50 turns, a diameter of 8 cm, and a resistance of 9 Ω is placed perpendicular to a uniform magnetic field of 2.0 T. The magnetic field suddenly reverses direction. What is the total charge that passes through the coil?

PHYSICS 1202 LABORATORY REPORT

Laboratory VI

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ______________________

Lab Partners' Names: ____________________________________

____

____

Problem # and Title: ____________________________________

Lab Instructor's Initials: __________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

LABORATORY VII:
WAVE OPTICS

In this lab, you will solve problems in ways that take advantage of light interference, a phenomenon most easily understood in terms of the wave nature of light. Like waves, light can interfere constructively and destructively with itself. Under some conditions, this causes distinctive patterns of light and dark fringes that would not be seen if light had no wave-like behavior. These conditions may be less familiar to you than the conditions for which geometrical optics is useful. The results of interference can, however, be seen in common situations such as the colored fringes that form in parking lot puddles where a thin layer of oil floats on the water, or the colored light patterns that reflect from a compact disc.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Describe interference patterns in terms of constructive and destructive interference.
- Predict how changes in the size of an object or slit, or the wavelength of the light, will affect interference patterns.

PREPARATION:

Before coming to lab, read Sections 2 and 3 of Chapter 13, Sections 1 and 2 of Chapter 14, and Sections 1-3 and 6-9 of Chapter 27 in Serway & Jewett. Keep the objectives of the laboratory in mind as you read the text. It is likely that you will do these laboratory problems before your lecturer addresses this material; the purpose of this laboratory is to introduce you to the material.

Before coming to lab you should be able to:

- Find unknown quantities using trigonometric relationships.
- Relate constructive and destructive interference of two waves to phase differences between the two waves.
- Describe why laser light is described as coherent.
- Create graphs of measured quantities and determine the equation describing linear relationships between graphed quantities.

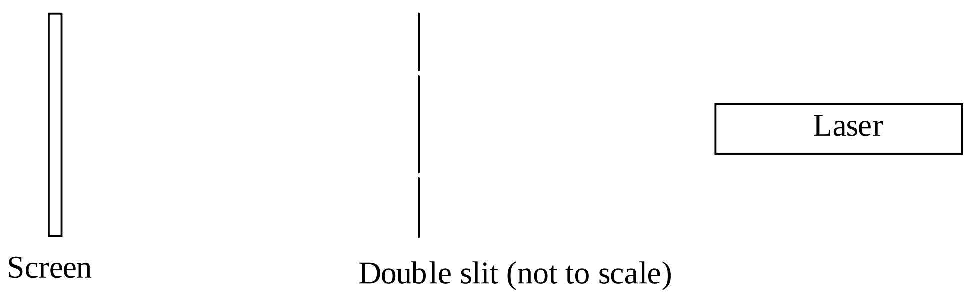
PROBLEM #1:
INTERFERENCE DUE TO A DOUBLE SLIT

Your group is involved in a project investigating some properties of viruses. You need to categorize viruses by size, but have found that they are too small to view with any microscope that uses visible light. You know, however, that for a small object illuminated by coherent light, a diffraction pattern will be formed rather then an image. The size of an object can be determined from its diffraction pattern, and you would like to try a diffraction technique with viruses.

Two issues occur to you. The first issue is, of course, how to determine the size of an object from its diffraction pattern. The second issue has to do with the form in which the viruses will be studied. Your group can isolate a single *type* of virus, but cannot isolate a single *example* of the virus. As a result, you will be forced to study the pattern produced by several viruses in very close proximity to one another. You hope that some information about the size of a single virus can be extracted from the pattern formed by many viruses. If the technique is to be useful, you must be able to distinguish the diffraction pattern due to a *single virus* from the pattern that results from *several copies* of the same type of virus.

In this problem and the next one, you will study light interference in a simplified system to explore how these two issues can be dealt with. You will deal with the second issue first. In this lab problem, you will investigate the interference pattern due to more than one object. In the next lab problem, you will develop a technique for determining the size of an object from its diffraction pattern. In this lab problem, a Helium Neon laser will be the light source, and pairs of closely spaced slits will represent the viruses. In this model you are interested in what pattern is formed on a screen by coherent light that passes through a pair of narrow slits and how that pattern depends on the separation of the slits.

EQUIPMENT



For this problem, you will be provided with a Helium Neon laser, a slide with four sets of double slits, a magnetic slide holder, a screen, an optical bench, and a ruler.

PREDICTION

Write an expression describing the double-slit interference pattern that relates the vertical positions of interference maxima on the screen to: the distance between the slits, the distance between the slide and the screen, and the wavelength of the laser's radiation. (For this prediction, do not include the effects of single slit diffraction. You will deal with those effects in the next lab problem.)

WARM-UP

Read Serway & Jewett: sections 27.1, 27.2, 27.3.

1. Draw a sketch of the arrangement you will use to project a interference pattern on the screen. Include laser, laser beam, slits, and screen.

2. Draw another diagram with an enlarged view of the slits and the screen. Show a laser beam wave front reaching the slide. Are the parts of the wave front that reach the two slits in phase? If they are out of phase, determine the phase difference between them.

3. Indicate the point on the screen that is equidistant from the two slits. Label this as *O*. Are the parts of the wave front that reach *O* from the bottom slit and the top slit in phase? If they are out of phase, determine by how much. Choose another point *P* on the screen. Are the parts of the wave front that reach *P* from the two slits in phase? If they are out of phase, determine the relative phase difference. Is this determination simplified if you assume that the distance between the slide and the screen is much larger than the distance between the slits? If so, explain.

4. What condition must the phase difference meet to produce a bright spot in the interference pattern? Use your diagram to write an expression for the vertical distances (above or below *O*) to the points where interference maxima should be produced. What condition must the phase difference meet to produce a dark spot in the interference pattern? Write an expression for the distances to interference minima.

5. Should the minima (or maxima) be equally spaced from one another? Write an expression for the wavelength of the incident light, in terms of the spacing between minima (maxima).

6. Sketch a graph, showing light *intensity vs. position* on the screen. Identify positions of interference maxima and minima.

7. What should happen to the distances between bright spots if the spacing between the slits is doubled? What should happen if the distance from the slits to the screen is doubled?

8. What pattern would you expect to see on the screen if light from the two slits did not interfere? Could you distinguish between this pattern and the one shown in your graph?

EXPLORATION

Warning: ***Laser beams may cause permanent vision impairment or blindness.***

Do NOT allow the laser beam (or its reflection) to point into anybody's eye. To avoid stray beams in the laboratory, make sure beams from your laser terminate on a screen at all times.

Laser beams are extremely intense compared to light from any common light source (even compared to sunlight, as viewed from earth). While it might seem that the beam is not very bright, it is well parallel. Your eye lens will focus all of the beam's power into a small spot on your eye's retina. Before your blink reflex functions, enough energy will be absorbed to temporarily damage the spot. Permanent blindness may result from prolonged exposure to any laser beam, even those from small laser pointers.

Turn on the laser and open the shutter. Let it warm up for a few minutes to achieve a stable beam. Arrange the laser and the slide with double slits on the optics bench. The laser should be parallel to the optics bench and perpendicular to the slide, and its beam should be aimed at one of the pairs of slits. The screen should be vertical and perpendicular to the optics bench.

By inspection, make sure both slits are illuminated approximately equally. Adjust the positions so that you clearly observe an interference pattern on the screen.

How does the interference pattern compare with your predictions? Which features did you predict, and which ones did you not predict?

Some of the features you see may be the effect of light from one slit interfering with light from the other slit. Other features may be the effect of light from one part of a slit interfering with light from another part of the same slit. There are four pairs of slits on the slide, with different slit widths and different separations between the slits. Use these to make a judgment about which features of the interference pattern are due to each type of interference.

How does the interference pattern change for different slit separations? How does the pattern change when you adjust the distance from the slits to the screen? Do your observations match your predictions?

How important do you think is laser light for this problem? If possible, try illuminating the slits with an alternative light source. Do you still see the interference/diffraction picture? Record your results.

MEASUREMENT

Continuing your exploration, sketch the interference patterns for two pairs of slits with the same slit widths and different slit separations.

Place a sheet of paper on the screen as a recording device. On the paper, label positions of the maxima you can observe. Be sure to record the distance from the slits to the screen. Repeat this operation, for the two pairs of slits, for at least two different distances between the screen and the slits. (Be sure to record the distance from the slits to the screen each time, and the widths and separations of the slits reported on the slide.)

Measure the positions of the interference maxima for each trial.

ANALYSIS

Compare the sketches you prepared during measurement to the graphs from your warm-up questions answers. Do the patterns match?

Use your measurements from each trial and your predicted relationships to determine the wavelength of the laser light. Do you obtain a consistent value across different trials? If so, is it comparable to the accepted value for the wavelength of light produced by a Helium Neon laser?

CONCLUSION

Can you tell which features of a two-slit interference pattern are caused by light from one slit interfering with light from the other slit? Can you distinguish them from the features due to light from part of one slit interfering with light from another part of the same slit? Explain.

Do your results allow you to *rule out* the possibility of determining the size of a single virus from the pattern due to several copies of the same virus in close proximity to one another? Explain.

The size of common viruses is on the order of 10^{-6} m to 10^{-8} m. When determining virus size with an interference technique, would it be helpful to use light with a different wavelength from the one you used for this problem? If so, explain why.

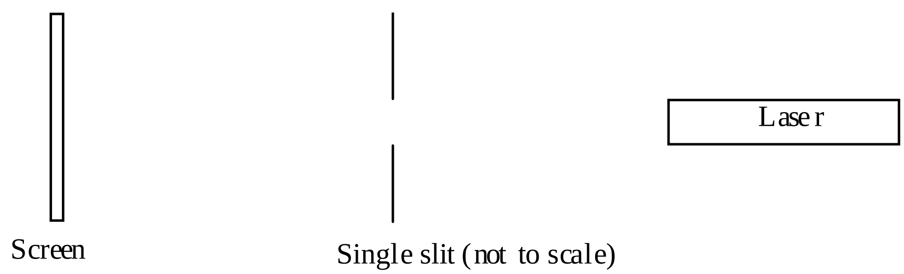
PROBLEM #2:
INTERFERENCE DUE TO A SINGLE SLIT

Your group is involved in a project investigating some properties of viruses. You need to categorize viruses by size, but have found that they are too small to view with any microscope that uses visible light. You know, however, that for a small object illuminated by coherent light, a diffraction pattern will be formed rather then an image. The size of an object can be determined from its diffraction pattern, and you would like to try an interference technique with viruses.

Two issues occur to you. The first issue is, of course, how to determine the size of an object from its diffraction pattern. The second issue has to do with the form in which the viruses will be studied. Your group can isolate a single *type* of virus, but cannot isolate a single *example* of the virus. As a result, you will be forced to study the pattern produced by several viruses in very close proximity to one another. You hope that some information about the size of a single virus can be extracted from the pattern formed by many viruses. If the technique is to be useful, you must be able to distinguish the diffraction pattern due to a *single virus* from the pattern that results from *several copies* of the same type of virus.

In the previous problem and this one, you study light interference in a simplified system to explore how these two issues can be dealt with. You dealt with the second issue first, in the previous problem. In the present lab problem, you will develop a technique for determining the size of a single object from its diffraction pattern. A Helium Neon laser will be the light source, and a narrow slit will represent a virus. You are interested in what type of diffraction pattern is formed and how the pattern depends on the width of the slit.

EQUIPMENT



For this problem, you will be provided with a Helium Neon laser, a slide with four individual slits of different widths a second slide with four pairs of double slits, a magnetic slide holder, a screen, an optical bench, and a ruler.

PREDICTION

Write an equation describing the single slit diffraction pattern that relate the positions of diffraction maxima on the screen to: the width of the slit, the distance between the slide and the screen, and the wavelength of the laser's radiation.

WARM-UP

Read Serway & Jewett: 27.1, 27.2, 27.3, 27.6, 27.7.

1. Draw a sketch of the arrangement you will use to project a diffraction pattern on the screen. Include laser, laser beam, slit, and screen.

2. Draw another diagram with an enlarged view of the slit and the screen. Show a laser beam wave front reaching the slide. Are the parts of the wave front that reach different parts of the slit in phase? If they are out of phase, determine the phase difference between them.

3. What condition must be met for a maximum to occur in the diffraction pattern for a single slit? What condition must be met for a minimum to occur? How can these conditions be understood in terms of the situation's geometry and the properties of light waves?

4. Indicate the point on the screen that is equidistant from the two slits. Label this as *O*. Is *O* a diffraction maximum or minimum? Choose another point *P* on the screen. Indicate on your diagram how you would determine if *P* were a diffraction maximum or minimum. Is this determination simplified if you assume that distance from the slide to the screen is much larger than the slit width? If so, explain.

5. Use your diagram to write an expression for the distances (above or below *O*) to the points where diffraction maxima should be produced. Write another expression for the distances to diffraction minima. Write a third expression for the wavelength of the incident light, based on positions of maxima or minima.

6. Sketch a graph, showing *light intensity vs. position* on the screen. Identify positions of diffraction maxima and minima.

7. What should happen to the distances between bright spots if the width of the slit were doubled? What should happen if the distance from the slits to the screen is doubled?

8. Does the width of the slit place a restriction on the maximum amplitude or wavelength of a light wave that could pass through the slit? If so, illustrate the limits below your diagram, and describe how you expect this might affect the observed diffraction pattern.

EXPLORATION

Warning: ***Laser beams may cause permanent vision impairment or blindness.***

Do NOT allow the laser beam (or its reflection) to point into anybody's eye. To avoid stray beams in the laboratory, make sure beams from your laser terminate on a screen at all times.

Laser beams are extremely intense compared to light from any common light source (even compared to sunlight, as viewed from earth). While it might seem that the beam is not very bright, it is well parallel. Your eye lens will focus all of the beam's power into a small spot on your eye's retina. Before your blink reflex functions, enough energy will be absorbed to temporarily damage the spot. Permanent blindness may result from prolonged exposure to any laser beam, including those from small laser pointers.

Turn on the laser and open the shutter. Let it warm up for a few minutes to achieve a stable beam.

Arrange the laser and the slide with single slits on the optics bench. The laser should be parallel to the optics bench and perpendicular to the slide, and its beam should be aimed at one slit. The screen should be vertical and perpendicular to the optics bench. Adjust the positions so that you clearly observe a diffraction pattern on the screen.

How does the diffraction pattern compare with your predictions? Which features did you predict, and which ones did you not predict?

How does the diffraction pattern change for different slit widths? How does the pattern change when you adjust the distance from the slit to the screen? What happens if you rotate the slit from a vertical to a horizontal position? Do your observations match your predictions?

How does the diffraction pattern of a single slit compare with the diffraction pattern of a pair of slits with the same width? Does this bode well for the virus project? Do you think the laser is important for this problem? Do you have any other sources of light to try instead of laser? What do you see?

MEASUREMENT

Continuing your exploration, sketch the diffraction patterns for two different slit widths.

Fix a sheet of paper on the screen. Mark maxima of diffraction pattern on the screen. (If the maxima are difficult to locate visually, mark some positions so that the central part of each spot can be precisely determined from the marks.) Be sure to record the slit width and the distance from the slit to the screen.

Repeat this operation for at least two different distances and at least two different slit widths.

Remove the slit from the system, and observe the pattern produced when laser light shines on a human hair. Do you see a diffraction pattern? Measure and record the distance from the hair to the screen, as well as the positions of the diffraction maxima.

ANALYSIS

Compare the sketches you prepared during measurement to the graphs from your warm-up questions answers. Do the patterns match?

Use your measurements and the relationships from the prediction to determine the wavelength of the laser light from each trial. Do you obtain a consistent value across different trials? If so, is it comparable to the accepted value for the wavelength of light produced by a Helium Neon laser?

The diffraction pattern due to a solid object (a hair, for example) is the same as that due to a hole of the same shape. Use your measurements to determine the width of your hair.

CONCLUSION

Do the expressions you predicted match the diffraction patterns you observed? If they do not match perfectly, identify some sources of error, and explain how they could result in the observed errors.

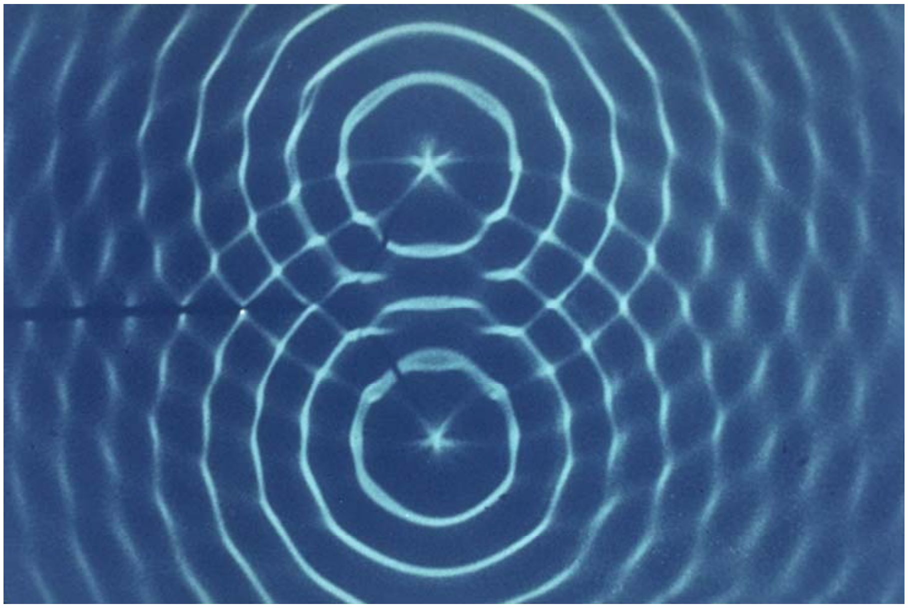
Do your observations provide evidence for the wave nature of light?

Does your measurement of hair thickness match an order-of-magnitude estimate of hair thickness based on direct observation? Explain your estimate.

What do you need to know to determine an object's size from the diffraction pattern it produces?

Compare the results of this problem to the results of the previous problem. How closely connected are the features of a single slit diffraction pattern to those of a double slit interference pattern?

☑ CHECK YOUR UNDERSTANDING



The picture above shows a series of circular water waves emanating outward from two points. The waves interfere with one another. Refer to the picture for questions 1-5 below.

1. On the picture, indicate the wavelength of these waves.

2. Draw lines to show where the waves are *constructively* and *destructively* interfering. How many interference *maxima* are there along the right edge of the picture?

3. What are the phase-difference requirements for constructive or destructive interference? Demonstrate at several points how these requirements are met in the picture above.

4. How would the interference pattern change if the wavelength were shortened?

5. How would the interference pattern change if the wave sources were moved closer together? What would happen if the wave sources were located on top of each other – at a single point?

PHYSICS 1202 LABORATORY REPORT

Laboratory VII

Name and ID#: ____

Date performed: ________________ Day/Time section meets: ______________________________

Lab Partners' Names: ____

____

____

Problem # and Title: ____

Lab Instructor's Initials: __________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.

LABORATORY VIII
NUCLEAR PHENOMENA

Radioactive decay is the emission of particles such as photons, electrons, neutrons, or even other nuclei when atomic nuclei go from a high energy state to a lower energy state. This lower energy state is usually a nucleus of a different element. The particles emitted from the nucleus, given the generic name of radiation, often have a high enough energy to penetrate materials such as organic tissue. This energy is transferred to any object with which the particles collide, including the cells of your body. Radioactive materials are used to kill diseased cells inside a living organism that cannot be reached by other means, as tracers to analyze fluid flow in the body, and in imaging the body's interior. They are also used in industry to examine potential defects in materials. When the particles from radioactive decay collide with cells in a living organism, the resulting collision damages the cell. If enough cells are damaged, the effect can be to overwhelm the organism's repair mechanisms or to cause a mutation. Some food products are treated with radiation to kill existing microorganisms without altering the molecular structure of the food as would happen with heating or chemical treatment.

We live in an environment of particles with energies as high or higher than those produced by radioactive decay. Our bodies are built of some naturally occurring radioactive nuclei such as potassium 40. In addition the earth is bombarded by high energy protons which collide with the atmosphere and produce showers of high energy particles which continuously collide with our cells. Almost all of the common materials in our environment, e.g. carbon or iron, contain radioactive nuclei. This sea of radiation in which we live is usually called background. This radiation constantly kills or alters the cells in our body and our bodies have evolved to handle the repair at the cellular level. Significantly higher levels of radiation however can overwhelm this cellular self-repair mechanism.

In this laboratory, you will solve problems related to the nature of interactions between particles produced by radioactive decay and matter. You will also determine the rate of background radiation for comparison.

OBJECTIVES:

Successfully completing this laboratory should enable you to:

- Quantitatively determine the level of background radiation.
- Understand the statistical nature of radioactive decay and the process of counting.
- Predict the relationship between distance from a radioactive source and the count rate.
- Determine the different types of particles emitted by radioactive decay by the effects of different shielding material.
- Understand how the effectiveness of radiation shielding depends on the shielding thickness, for different shielding materials and different types of radiation.
- Test for relationships among measured quantities by producing a linear graph with data with an non-linear functional dependence.

PREPARATION:

Before you come to lab, read Sections 3-5 of Chapter 30 in Serway and Jewett. You should:

- Set up and solve the equation that describes the lifetime of a radioactive nucleus.
- Use graphical techniques to determine the parameters in that equation.

PROBLEM #1:
DISTANCE FROM THE SOURCE

You have a job working in a cancer treatment facility that prepares radioactive isotopes. Although you take great care to handle them properly, you know that some body parts are more sensitive to radiation than others. After all, you may want to have children some day. To address your worry, you decide to use geometry to calculate how the rate of particles emitted from a radioactive source going through a sensitive area of your body depends on the distance from the source. You will test your calculation in the laboratory using a small radioactive source and a Geiger counter to detect the emitted particles. Is this relationship different for different types of particles?

EQUIPMENT

The equipment consists of a Radiation Monitor, also called a Geiger counter, connected to the LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro.

You will also have three different radioactive sources: an alpha source, a beta source, and a gamma source.

PREDICTION

Use geometry to calculate how the particle count rate varies with distance from a small radioactive source. On what assumptions is your calculation based?

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

1. Draw a large sphere centered on a small radioactive source. Write down the fraction of the particles produced by the source that pass through the surface of that sphere. Write down the equation for the surface area of that sphere.

2. On the surface of the sphere you've drawn, sketch an area representing a small particle detector. If the source emits radiation evenly in all directions, write an equation for the fraction of its radiation that would pass through the particle detector as a function of the area of the detector and the radius of the sphere.

3. Now draw another even larger sphere still centered on the radioactive source. Draw the same particle detector on the surface of the larger sphere. Now write an equation for the fraction of the source's radiation that would pass through the particle detector as a function of the area of the detector and the radius of the new sphere. Is the rate of particles passing through the detector when it is on the surface of the larger sphere higher or lower than its rate when it is on the smaller sphere?

4. Write an equation for the relationship of a detector's counting rate and its distance from radioactive source. Sketch a graph of this relationship. What assumptions does this relationship require?

EXPLORATION

WARNING: The radioactive sources available for this problem provide low intensity radiation, and are safe if handled with respect for short amounts of time. Do not remove them from the laboratory, and do not attempt to open the plastic disks containing the sources. **If a disk breaks open inform your TA immediately, do not touch it.**

Make sure you read *Appendix D* to understand the operation of the Geiger counter before trying to operate it. Place a radioactive source near the detector, turn on the counter. Try the controls, and make sure every group member understands how to operate it. Try each of your sources to make sure the equipment is functioning

.

With the detector working you now need to determine how to make your measurement uncertainty as small a practical. Start by using the detector to measure the number of counts from a radioactive source in some short time interval, say 10 or 15 seconds. Repeat this measurement several times, recording the number of counts occurring in each fixed time interval. Compute the average number of counts per second and the difference of each trial from that average. Calculate the average of these differences for all of your trials. That average difference represents your counting uncertainty for the measurement. Now increase your time interval by a factor of 4 and repeat the same number of trials and the same calculation. In which case is the measurement uncertainty a smaller fraction of the measurement? By approximately what factor did the average measurement change when you increased the counting time by a factor of 4? What does this tell you about the time period necessary when taking data? Keep measurement uncertainty in mind when deciding how much time is "enough" to allow comparisons among count rates under different conditions.

Since we live in a “sea” of radiation, you need to determine how that effects your measurements. Remove all radioactive sources from the vicinity of your detector. Record the count rate from the detector for a significant amount of time. You will need to subtract the count rate due to this background radiation from your future measurements. Measure the background rate, and estimate the uncertainty in your measurement.

Try different orientations of each source relative to the detector. Do you achieve a greater counting rate with the label facing up or facing down? Repeat this test for each type of radioactive source.

Come up with a measurement plan that will allow you to accurately determine the relationship between counting rate and the distance between the detector and the source. Your plan should take background radiation into account and a plan to minimize the measurement uncertainty.

MEASUREMENT

Carry out your measurement plan, and adjust if necessary to obtain useful data for each source. You may find Microsoft Excel (available on the computer at your lab station) to be a very useful tool for recording data, doing calculations, and making plots. Be sure to keep copies of your measurements as electronic files (or on paper printouts).

ANALYSIS

Make a plot to show how the particle rate through the detector depends on the distance from the source. If this is not a linear relationship, use your prediction to determine a set of axes that should make your graph as straight line. Make this graph (see *Appendix C*).

To see if your predicted relationship fits the data better than some other possibilities, try at least one other linearization that you think might also fit the data.

Whenever your graph is a straight line, record the equation of the best fit line for that graph. Solve that equation for the counting rate as a function of distance from the detector.

CONCLUSION

Describe the relationship between the particle rate from a radioactive source and distance from that source to the detector.

Does your predicted relationship match the relationship you found? If not, can you explain why not?

PROBLEM #2:
SHIELD POSITION

As a member of a radiation medicine research group, you are constantly reminded that it is important to limit your dose of radiation. One day while at Starbucks for a coffee break you overhear your coworkers discussing shielding efficacy. One person says that radiation shielding is most effective when it is placed near the radiation source. Another person contends that shielding is most effective when it is worn on the body, which places it as far from the radiation source as possible. Yet a third person states that material of a particular thickness should absorb a certain fraction of incident radiation so the shield's distance from the source is irrelevant. Based on your ideas of what happens when a particle passes through material, you decide which person you believe and explain why. You also decide to test your idea in the laboratory. Since the result might depend on the type of radiation, you use three different sources which each emit alpha (He nuclei), beta (electrons), or gamma (photons) radiation. It is also possible that result depends on the type of shielding so you try several different kinds of material.

EQUIPMENT

The equipment consists of a Radiation monitor, also called a Geiger counter (see *Appendix D*) connected to a LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro. You will also have three different radioactive sources: an alpha source, a beta source, and a gamma source., as well as a variety of shielding materials.

PREDICTION

Do you think that radiation is shielded more effectively by material that is closer to the radiation source or closer to the detector? How does your conclusion depend on the type of radiation? How does it depend on the type of shielding material? On what do you base your prediction?

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

1. Sketch two pictures showing a radioactive source that emits radiation in all directions. Add a detector at the same distance from the source in each diagram. Finally, add identical shielding material in each diagram; place the shield near the source in one picture, and near the detector in another diagram. The shielding material should be wider than the detector, so that radiation emitted in a range of directions from the source will have a chance to interact with the shield.

2. Imagine that each shield absorbs half of the radiation incident on it. Show the paths of some example radiation particles in your pictures for this case. How should the count rates for the situations shown in each picture compare to one another? How should the count rates compare to a situation in which no shielding is present?

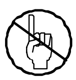
3. Imagine a situation in which some particles that interact with the shielding material are scattered (leave the shield in a new direction). Add examples of scattered radiation particles to

your pictures. Could scattering affect count rates, compared to the situations in which particles are only absorbed? Could scattering cause the count rates to depend on the position of the detector?

4. Imagine a situation in which some particles that interact with the shielding material produce several new particles. Add this example to your pictures. Could this cause the count rates to depend on the position of the detector?

5. If no scattering or particle production occurs, do you expect the count rate to change when the position of the shield is changed? If not, why not? If so, do you expect the count rate to be greater when the shield is closer to the source or closer to the detector? Explain.

EXPLORATION



WARNING: The radioactive sources available for this problem provide low intensity radiation, and are safe if handled with respect for short amounts of time. Do not remove them from the laboratory, and do not attempt to open the plastic disks containing the sources. **If a disk breaks open inform your TA immediately, do not touch it.**

Make sure you read *Appendix D* to understand the operation of the Radiation Monitor before trying to operate it. If you did not do Lab VII, Problem 1 today, do the exploration section of that problem to make sure you can get meaningful results from this specific Radiation Monitor equipment.

For each source, try different shielding materials and thicknesses until you can reduce the counting rate by a significant fraction. Devise a plan to qualitatively determine whether the position of the shielding material (closer to the radiation source or closer to the detector) has an effect on the counting rate.

MEASUREMENT

Carry out your measurement plan, and adjust if necessary to obtain useful data for each source. Measure counting rates for at least three different shield positions for each source.

ANALYSIS

Compare your results for different types of radiation and different types of shielding. Be careful with your logic since there are a lot of materials, radiation types, and distances. To be able to reach any conclusion make sure that only one quantity changes at a time.

Be sure to take the statistical uncertainty in your data into account. If you graph your data (regardless of whether you used a spreadsheet), don't forget to add error bars!

CONCLUSION

Does your data support your prediction? Why or why not?

Does your data support the assertion that the position of a radiation shield has no effect on the count rate? If there is an effect, how does it depend on the type of incident radiation? Does your data allow you to make any firm statements about whether scattering or particle production occurs for each type of radiation?

PROBLEM #3:
SHIELD THICKNESS

You are working for a company interested in irradiating turkeys for long-term storage. The management has asked your team for preliminary estimates of the minimum dose of the radiation necessary to kill enough of the microorganisms to retard spoilage. You quickly realize that the radiation dose to be determined is the minimum necessary at the center of the turkey. Of course, turkeys come in different sizes so your first task is to calculate how the radiation dose varies with depth inside the turkey. Your team decides to test your calculation in the lab by modeling the turkey with sheets of shielding material, as they are easier to handle than slabs of raw turkey meat. Since the company has not decided between using beta or gamma radiation for the process, you will have to test your idea on both types of radiation.

EQUIPMENT

The equipment consists of a Radiation monitor, also called a Geiger counter (see *Appendix D*) connected to a LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro.

You will also have a beta source and a gamma source, as well as a variety of shielding materials.

PREDICTION

Write down a mathematical function that describes the effect of material thickness on the intensity of radiation that passes through that material. Describe the reasoning that leads you to that function.

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

1. Draw a diagram with a source of radiation, a detector, and several identical sheets of equal thickness material between them.

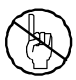
2. Imagine that you measure the amount of radiation incident on the first sheet of material and the fraction that passes through that sheet. The surviving radiation now passes through a second sheet of material. Based on your first set of measurements, write an expression for the amount of radiation that passes through the second sheet. Continue this procedure for a third sheet. You should be able to continue for any number of sheets.

3. Try some numbers. Suppose that the initial radiation was 1000 particles and only half of the incident particles pass through each sheet of material, calculate the number of particles that survive the first sheet. How many survive the second sheet? The third sheet? On what quantity(ies) does the number of particles surviving a sheet of material depend? Make a graph of the number of surviving particles versus the number of sheets of material. Since each sheet is a specific thickness of material, you now have a graph of how the surviving amount of radiation depends on the thickness of material. Try to guess what functions could represent this graph. Check your guesses by graphing them to see if they match your points.

4. Imagine that all of the sheets of material are very thin and are pushed together to make one thick piece of material. As the particles pass through a thin sheet, the number entering the next sheet is reduced. On what quantity(ies) does this change in the number of particles depend? Write an equation for the change of the number of radiation particles per small amount of thickness (dN/dT). Solve this equation for the surviving number of particles as a function of material thickness. Check to see if this function matches your graph in question 3.

5. Compare the mathematics for your hypothetical description of the shielding of radioactive particles by material to that of radioactive decay described in your textbook. How are they similar? Different?

EXPLORATION



WARNING: The radioactive sources available for this problem provide low intensity radiation, and are safe if handled with respect for short amounts of time. Do not remove them from the laboratory, and do not attempt to open the plastic disks containing the sources. **If a disk breaks open inform your TA immediately, do not attempt to touch it.**

Make sure you read *Appendix D* to understand the operation of the Radiation monitor before trying to operate it.

If you did not do Lab VIII, Problem 1 today, do the exploration section of that problem to make sure you can get meaningful results from this specific equipment.

Take a new background count rate.

Try different types and thicknesses of material for the beta and gamma sources while noting the counting rates. Find a material that gives a noticeably different counting rate as you add more sheets? How many sheets will you need to get a good enough graph to check your prediction?

Some of the material, such a lead sheets, may not be able to support themselves when you stack them. If you use such material, be sure that the support system you devise will not significantly affect your measurement.

Decide as a group how long you will count for each increment of material thickness.

Come up with a measurement plan that will allow you to do this.

MEASUREMENT

Carry out your measurement plan, and adjust if necessary to obtain useful data. Don't forget to include measurements that will help you determine your uncertainties.

ANALYSIS

Make a graph of the number of particles entering your detector (corrected for background count rate) vs. material thickness for each source. Match the data to your prediction for each type of radiation on a graph.

If it is difficult to tell whether or not a graph supports your predicted function, linearize the graph (see *Appendix C*) based on your prediction. Also try at least one other linearization of another function that might represent the data.

CONCLUSION

Describe the relationship between radiation survival and material thickness. Does this relationship hold for both types of radiation?

Does your data support your prediction? Why or why not?

PROBLEM #4:
HALF LIFE

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

EQUIPMENT

The equipment consists of a Radiation monitor, also called a Geiger counter (see *Appendix D*) connected to a LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro.

You will also have a Cs/Ba-137m isotope generator kit.

PREDICTION

Write down a mathematical function that describes the half life of a radioactive sample.

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

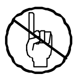
1. Write an expression that represents the number of counts for a source with an unknown decay constant and a specified number of radioactive nuclei to start with.

2. Set the number of counts equal to half the original amount. Can you solve for the decay constant? Can you think of a way to determine the decay constant from the actual counts of a sample?

3. Solve your decay equation for the time when the number of counts is half the original amount. This is referred to as the “half-life” of the radioactive material.

4. How is the half-life of a material related to its decay constant? If a material has a very long half-life, is the decay constant large or small?

EXPLORATION



WARNING: The radioactive sources available for this problem provide low intensity radiation, and are safe if handled with respect for short amounts of time. Do not remove them from the laboratory, and do not attempt to open the plastic disks containing the sources. **If a disk breaks open inform your TA immediately, do not attempt to touch it.**

Make sure you read *Appendix D* to understand the operation of the Radiation monitor before trying to operate it.

MEASUREMENT

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

When you and your partners are done taking measurements, you must ascertain how many radioactive events occurred in each one-minute interval.

ANALYSIS

Plot your results on a graph of counts vs. time. You should discover that, as you took your measurements, the radioactivity of the sample decreased. Also make a graph of (*ln* counts) vs. time. From your prediction equation, what does the slope of this line represent? Record this value. Is the value of this slope positive or negative?

Use your prediction equation to calculate the half-life of the radioactive sample.

CONCLUSION

Report the value for the half-life you measured. How certain are you of the result? What is the uncertainty in your measurements and analysis? How does the half-life of this compare to other radioactive wastes?

PHYSICS 1202 LABORATORY REPORT

Laboratory VIII

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ______________________

Lab Partners' Names: ______________________________________

____

____

Problem # and Title: _______________________________________

Lab Instructor's Initials: __________

Grading Checklist	Points
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PROBLEM REPORT:*	
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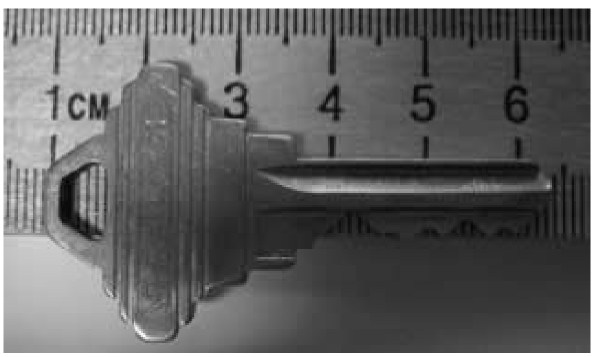
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

Appendix A: Significant Figures

Calculators make it possible to get an answer with a huge number of figures. Unfortunately, many of them are meaningless. For instance, if you needed to split $1.00 among three people, you could never give them each exactly $0.333333 ⋯ The same is true for measurements. If you use a meter stick with millimeter markings to measure the length of a key, as in figure A-1, you could not measure more precisely than a quarter or half or a third of a mm. Reporting a number like 5.37142712 cm would not only be meaningless, it would be misleading.

Figure A-1



In your measurement, you can precisely determine the distance down to the nearest millimeter and then improve your precision by estimating the next figure. It is always assumed that the last figure in the number recorded is uncertain. So, you would report the length of the key as 5.37 cm. Since you estimated the 7, it is the uncertain figure. If you don't like estimating, you might be tempted to just give the number that you know best, namely 5.3 cm, but it is clear that 5.37 cm is a better report of the measurement. An estimate is always necessary to report the most precise measurement. When you quote a measurement, the reader will always assume that the last figure is an estimate. Quantifying that estimate is known as **estimating uncertainties**. Appendix B will illustrate how you might use those estimates to determine the uncertainties in your measurements.

What are significant figures?

The number of significant figures tells the reader the precision of a measurement. Table A-1 gives some examples.

Table A-1

Length (centimeters)	Number of Significant Figures
12.74	4
11.5	3
1.50	3
1.5	2
12.25345	7
0.8	1
0.05	1

One of the things that this table illustrates is that not all zeros are significant. For example, the zero in 0.8 is not significant, while the zero in 1.50 is significant. Only the zeros that appear after the first non-zero digit are significant.

A good rule is to always express your values in scientific notation. If you say that your friend lives 143 m from you, you are saying that you are sure of that distance to within a few meters (3 significant figures). What if you really only know the distance to a few tens of meters (2 significant figures)? Then you need to express the distance in scientific notation 1.4×10^2 m.

Is it always better to have more figures?

Consider the measurement of the length of the key shown in Figure A-1. If we have a scale with ten etchings to every millimeter, we could use a microscope to measure the spacing to the nearest tenth of a millimeter and guess at the one hundredth millimeter. Our measurement could be 5.814 cm with the uncertainty in the last figure, four significant figures instead of three. This is because our improved scale allowed our estimate to be more precise. This added precision is shown by more significant figures. The more significant figures a number has, the more precise it is.

How do I use significant figures in calculations?

When using significant figures in calculations, you need to keep track of how the uncertainty propagates. There are mathematical procedures for doing this estimate in the most precise manner. This type of estimate depends on knowing the statistical distribution of your measurements. With a lot less effort, you can do a cruder estimate of the uncertainties in a calculated result. This crude method gives an overestimate of the uncertainty but it is a good place to start. For this course this simplified uncertainty estimate (described in Appendix B and below) will be good enough.

Addition and subtraction

When adding or subtracting numbers, the number of decimal places must be taken into account.

*The result should be given to as many decimal places as the term in the sum that is given to the **smallest** number of decimal places.*

Examples:

Addition	Subtraction
6.24**2**	5.87**5**
+4.2**3**	-3.3**4**
+0.01**3**	2.5**35**
10.4**85**	
10.4**9**	2.5**4**

The uncertain figures in each number are shown in **bold-faced** type.

Multiplication and division

When multiplying or dividing numbers, the number of significant figures must be taken into account.

*The result should be given to as many significant figures as the term in the product that is given to the **smallest** number of significant figures.*

The basis behind this rule is that the least accurately known term in the product will dominate the accuracy of the answer.

As shown in the examples, this does not always work, though it is the quickest and best rule to use. When in doubt, you can keep track of the significant figures in the calculation as is done in the examples.

Examples:

Multiplication

15.8**4**	17.2**7**
x 2.**5**	x 4.**0**
7920	69.**080**
316**8**	
3**9.600**	
4**0**	6**9**

Division

11**7**	2**5**
2**3**)269**1**	7**5**)187**5**
2**3**	15**0**
39	**375**
23	**375**
161	
161	
1.**2** x 10^2	2.**5** x 10^1

PRACTICE EXERCISES

1. Determine the number of significant figures of the quantities in the following table:

Length (centimeters)	Number of Significant Figures
17.87	
0.4730	
17.9	
0.473	
18	
0.47	
1.34×10^{2}	
2.567×10^{5}	
2.0×10^{10}	
1.001	
1.000	
1	
1000	
1001	

2. Add: 121.3 to 6.7×10^{2}:

[Answer: $121.3 + 6.7 \times 10^{2} = 7.9 \times 10^{2}$]

3. Multiply: 34.2 and 1.5×10^{4}

[Answer: $34.2 \times 1.5 \times 10^{4} = 5.1 \times 10^{5}$]

Appendix B: Accuracy, Precision and Uncertainty

How tall are you? How old are you? When you answered these everyday questions, you probably did it in round numbers such as "five foot, six inches" or "nineteen years, three months." But how true are these answers? Are you exactly 5' 6" tall? Probably not. You estimated your height at 5′ 6" and just reported two significant figures. Typically, you round your height to the nearest inch, so that your actual height falls somewhere between 5' 5½" and 5' 6½" tall, or 5' 6" ± ½". This ± ½" is the **uncertainty,** and it informs the reader of the precision of the **value** 5' 6".

What is uncertainty?

Whenever you measure something, there is always some uncertainty. There are two categories of uncertainty: **systematic** and **random**.

(1) **Systematic uncertainties** are those that consistently cause the value to be too large or too small. Systematic uncertainties include such things as reaction time, inaccurate meter sticks, optical parallax and miscalibrated balances. In principle, systematic uncertainties can be eliminated if you know they exist.

(2) **Random uncertainties** are variations in the measurements that occur without a predictable pattern. If you make precise measurements, these uncertainties arise from the estimated part of the measurement. Random uncertainty can be reduced, but never eliminated. We need a technique to report the contribution of this uncertainty to the measured value.

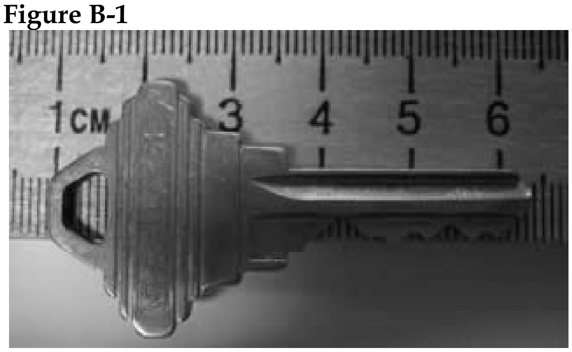
How do I determine the uncertainty?

This Appendix will discuss two basic techniques for determining the uncertainty: **estimating the uncertainty** and measuring the **average deviation.** Which one you choose will depend on your need for precision. If you need a precise determination of some value, the best technique is to measure that value several times and use the average deviation as the uncertainty. Examples of finding the average deviation are given below.

How do I estimate uncertainties?

If time or experimental constraints make repeated measurements impossible, then you will need to estimate the uncertainty. When you estimate uncertainties you are trying to account for anything that might cause the measured value to be different if you were to take the measurement again. For example, suppose you were trying to measure the length of a key, as in Figure B-1.

Figure B-1



If the true value were not as important as the magnitude of the value, you could say that the key's length was 5cm, give or take 1cm. This is a crude estimate, but it may be acceptable. A better estimate of the key's length, as you saw in Appendix A, would be 5.37cm. This tells us that the worst our measurement could be off is a fraction of a mm. To be more precise, we can estimate it to be about a third of a mm, so we can say that the length of the key is 5.37 ± 0.03 cm.

Another time you may need to estimate uncertainty is when you analyze video data. Figures B-2 and B-3 show a ball rolling off the edge of a table. These are two consecutive frames, separated in time by 1/30 of a second.

Figure B-2

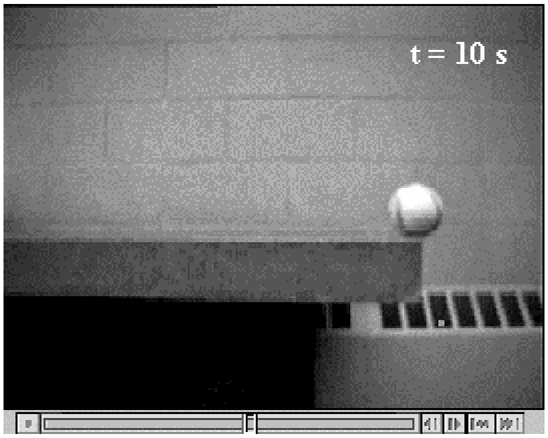
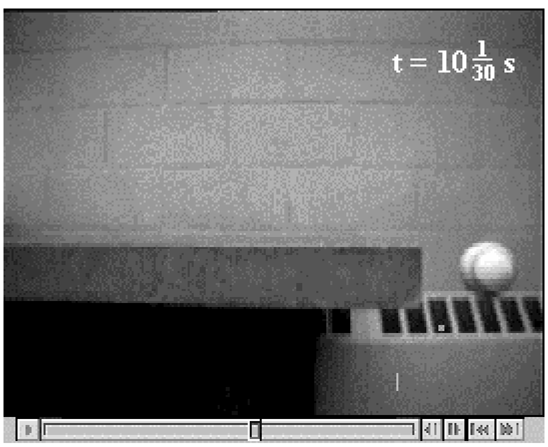


Figure B-3



The exact moment the ball left the table lies somewhere between these frames. We can estimate that this moment occurs midway between them ($t = 10\frac{1}{60}s$). Since it must occur at some point between them, the worst our estimate could be off by is $\frac{1}{60}s$. We can therefore say the time the ball leaves the table is $t = 10\frac{1}{60} \pm \frac{1}{60}s$.

How do I find the average deviation?

If estimating the uncertainty is not good enough for your situation, you can experimentally determine the un-certainty by making several measure-ments and calculating the average deviation of those measurements. To find the average deviation: (1) Find the average of all your measurements; (2) Find the absolute value of the difference of each measurement from the average (its deviation); (3) Find the average of all the deviations by adding them up and dividing by the number of measurements. Of course you need to take enough measure-ments to get a distribution for which the average has some meaning.

In example 1, a class of six students was asked to find the mass of the same penny using the same balance. In example 2, another class measured a different penny using six different balances. Their results are listed below:

Class 1: Penny A massed by six different students on the same balance.

Mass (grams) 3.110 3.125 3.120 3.126 3.122 3.120 3.121 average.
The deviations are: 0.011g, 0.004g, 0.001g, 0.005g, 0.001g, 0.001g
Sum of deviations: 0.023g
Average deviation: (0.023g)/6 = 0.004g
Mass of penny A: 3.121 ± 0.004g

Class 2: Penny B massed by six different students on six different balances

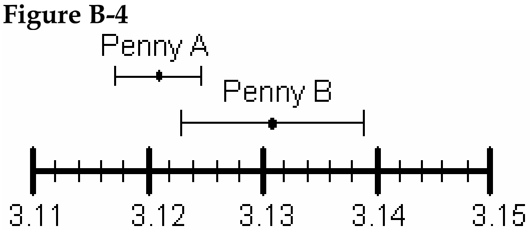
Mass (grams) 3.140 3.133 3.144 3.118 3.126 3.125 3.131 average
The deviations are: 0.009g, 0.002g, 0.013g, 0.013g, 0.005g, 0.006g
Sum of deviations: 0.048g
Average deviation: (0.048g)/6= 0.008g
Mass of penny B: 3.131 ± 0.008g

However you choose to determine the uncertainty, you should always state your method clearly in your report. For the remainder of this appendix, we will use the results of these two examples.

How do I know if two values are the same?

If we compare only the average masses of the two pennies we see that they are different. But now include the uncertainty in the masses. For penny A, the most likely mass is somewhere between 3.117g and 3.125g. For penny B, the most likely mass is somewhere between 3.123g and 3.139g. If you compare the ranges of the masses for the two pennies, as shown in Figure B-4, they just overlap. Given the uncertainty in the masses, we are able to conclude that the masses of the two pennies could be the same. If the range of the masses did not overlap, then we ought to conclude that the masses are probably different.

Figure B-4



Mass of pennies (in grams) with uncertainties

Which result is more precise?

Suppose you use a meter stick to measure the length of a table and the width of a hair, each with an uncertainty of 1 mm. Clearly you know more about the length of the table than the width of the hair. Your measurement of the table is very precise but your measurement of the width of the hair is rather crude. To express this sense of precision, you need to calculate the percentage uncertainty. To do this, divide the uncertainty in the measurement by the value of the measurement itself, and then multiply by 100%. For example, we can calculate the precision in the measurements made by class 1 and class 2 as follows:

Precision of Class 1's value:
(0.004 g ÷ 3.121 g) x 100% = 0.1 %
Precision of Class 2's value:
(0.008 g ÷ 3.131 g) x 100% = 0.3 %

Class 1's results are more precise. This should not be surprising since class 2 introduced more uncertainty in their results by using six different balances instead of only one.

Which result is more accurate?

Accuracy is a measure of how your measured value compares with the real value. Imagine that class 2 made the measurement again using only one balance. Unfortunately, they chose a balance that was poorly calibrated. They analyzed their results and found the mass of penny B to be 3.556 ± 0.004 g. This number is more precise than their previous result since the uncertainty is smaller, but the new measured value of mass is very different from their previous value. We might conclude that this new value for the mass of penny B is different, since the range of the new value does not overlap the range of the previous value. However, that conclusion would be **wrong** since our uncertainty has not taken into account the inaccuracy of the balance. To determine the accuracy of the measurement, we should check by measuring something that is known. This procedure is called calibration, and it is absolutely necessary for making accurate measurements.

Be cautious! It is possible to make measurements that are extremely precise and, at the same time, grossly inaccurate.

How can I do calculations with values that have uncertainty?

When you do calculations with values that have uncertainties, you will need to estimate (by calculation) the uncertainty in the result. There are mathematical techniques for doing this, which depend on the statistical properties of your measurements. A very simple way to estimate uncertainties is to find the *largest possible uncertainty* the calculation could yield. **This will always overestimate the uncertainty of your calculation**, but an overestimate is better than no estimate. The method for performing arithmetic operations on quantities with uncertainties is illustrated in the following examples:

<table>
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Addition:

(3.131 ± 0.008 g) + (3.121 ± 0.004 g) = ?

First, find the sum of the values:

3.131 g + 3.121 g = 6.252 g

Next, find the largest possible value:

3.139 g + 3.125 g = 6.264 g

The uncertainty is the difference between the two:

6.264 g – 6.252 g = 0.012 g

Answer: 6.252 ± 0.012 g.

Note: This uncertainty can be found by simply adding the individual uncertainties:

0.004 g + 0.008 g = 0.012 g

</td>
<td>

Multiplication:

(3.131 ± 0.013 g) x (6.1 ± 0.2 cm) = ?

First, find the product of the values:

3.131 g x 6.1 cm = 19.1 g-cm

Next, find the largest possible value:

3.144 g x 6.3 cm = 19.8 g-cm

The uncertainty is the difference between the two:

19.8 g-cm - 19.1 g-cm = 0.7 g-cm

Answer: 19.1 ± 0.7g-cm.

Note: The percentage uncertainty in the answer is the sum of the individual percentage uncertainties:

$$\frac{0.013}{3.131} \times 100\% + \frac{0.2}{6.1} \times 100\% = \frac{0.7}{19.1} \times 100\%$$

</td>
</tr>
<tr>
<td>

Subtraction:

(3.131 ± 0.008 g) – (3.121 ± 0.004 g) = ?

First, find the difference of the values:

3.131 g - 3.121 g = 0.010 g

Next, find the largest possible difference:

3.139 g – 3.117 g = 0.022 g

The uncertainty is the difference between the two:

0.022 g – 0.010 g = 0.012 g

Answer: 0.010±0.012 g.

Note: This uncertainty can be found by simply adding the individual uncertainties:

0.004 g + 0.008 g = 0.012 g

Notice also, that zero is included in this range, so it is possible that there is no difference in the masses of the pennies, as we saw before.

</td>
<td>

Division:

(3.131 ± 0.008 g) ÷ (3.121 ± 0.004 g) = ?

First, divide the values:

3.131 g ÷ 3.121 g = 1.0032

Next, find the largest possible value:

3.139 g ÷ 3.117 g = 1.0071

The uncertainty is the difference between the two:

1.0071 - 1.0032 = 0.0039

Answer: 1.003 ± 0.004

Note: The percentage uncertainty in the answer is the sum of the individual percentage uncertainties:

$$\frac{0.008}{3.131} \times 100\% + \frac{0.004}{3.121} \times 100\% = \frac{0.0039}{1.0032} \times 100\%$$

Notice also, the largest possible value for the numerator and the smallest possible value for the denominator gives the largest result.

</td>
</tr>
</table>

The same ideas can be carried out with more complicated calculations. Remember this will always give you an overestimate of your uncertainty. There are other calculation techniques, which give better estimates for uncertainties. If you wish to use them, please discuss it with your instructor to see if they are appropriate.

These techniques help you estimate the random uncertainty that always occurs in measurements. They will not help account for mistakes or poor measurement procedures. There is no substitute for taking data with the utmost of care. A little forethought about the possible sources of uncertainty can go a long way in ensuring precise and accurate data.

PRACTICE EXERCISES:

B-1. Consider the following results for different experiments. Determine if they agree with the accepted result listed to the right. Also calculate the precision for each result.

a) $g = 10.4 \pm 1.1$ m/s^2 — $g = 9.8$ m/s^2

b) $T = 1.5 \pm 0.1$ sec — $T = 1.1$ sec

c) $k = 1368 \pm 45$ N/m — $k = 1300 \pm 50$ N/m

Answers: a) Yes, 11%; b) No, 7%; c) Yes, 3.3%

B-2. The area of a rectangular metal plate was found by measuring its length and its width. The length was found to be 5.37 ± 0.05 cm. The width was found to be 3.42 ± 0.02 cm. What is the area and the average deviation?

Answer: 18.4 ± 0.3 cm^2

B-3. Each member of your lab group weighs the cart and two mass sets twice. The following table shows this data. Calculate the total mass of the cart with each set of masses and for the two sets of masses combined.

Cart (grams)	**Mass set 1** (grams)	**Mass set 2** (grams)
201.3	98.7	95.6
201.5	98.8	95.3
202.3	96.9	96.4
202.1	97.1	96.2
199.8	98.4	95.8
200.0	98.6	95.6

Answers:

Cart and set 1: 299.3±1.6 g.
Cart and set 2: 297.0±1.2 g.
Cart and both sets: 395.1±1.9 g.

Appendix C: Graphing

One of the most powerful tools used for data presentation and analysis is the graph. Used properly, graphs are an important guide to understanding the results of an experiment. They are an easy way to make sense out of your data. Therefore, it is important to graph your data as you take it.

LabVIEW™ will often provide you with a graph, but on occasion you will have to make your own. Good graphing practice, as outlined below, is a way to save time and effort while solving a problem in the laboratory.

How do I make a graph?

1. Accurate graphs are drawn on graph paper. Even if you are just making a quick sketch for yourself, it will save you time and effort to use graph paper. That is why every page of your lab journal is a piece of graph paper. Make sure to graph your data as you take it. Never put off drawing a graph until the end.

2. Every graph should have a title to indicate the data it represents. In a large collection of graphs, it is difficult to keep one graph distinct from another without clear, concise titles.

3. The axes of the graph should take up at least half a page. Give yourself plenty of space so that you can see the pattern of the data as it is developing. Both axes should be labeled to show the values being graphed and their appropriate units.

4. The scales on the graphs should be chosen so that the data occupies most of the space of your graph. You do not need to include zero on your scales unless it is important to the interpretation of the graph.

5. If you have more than one set of data on a set of axes, be sure to label each set to avoid confusion later.

How do I plot data and uncertainties?

Another technique that makes data analysis easier is to record all your data in a table.

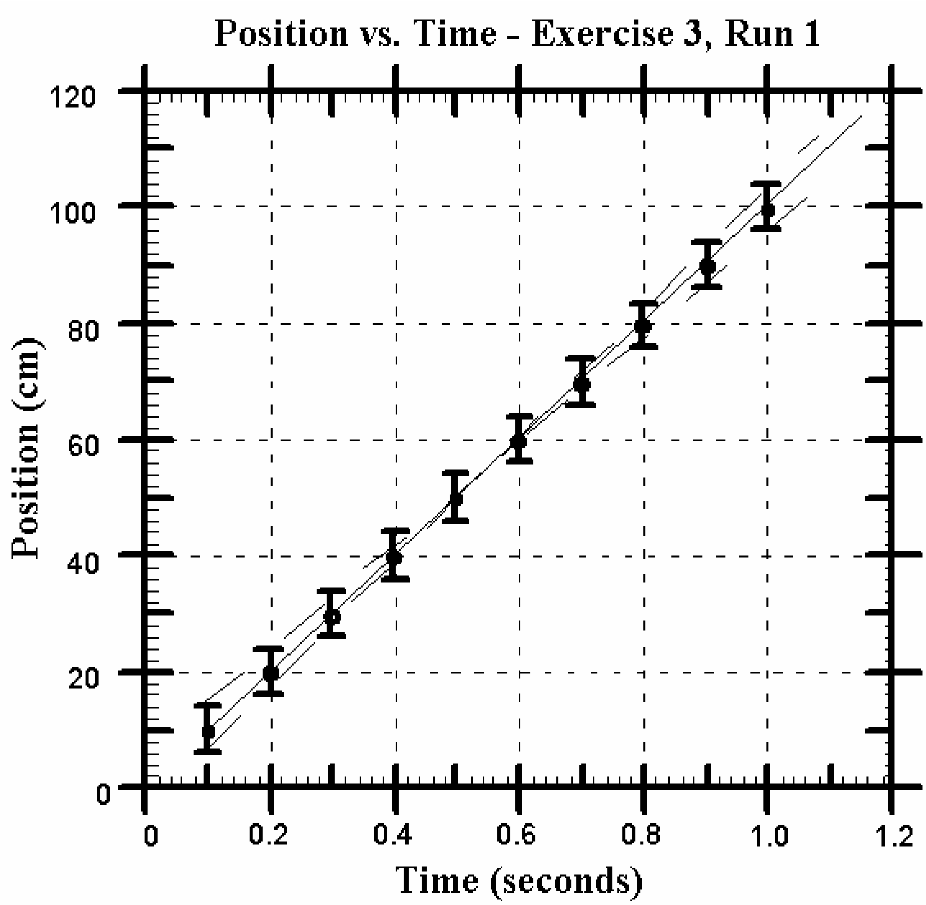
A useful data table will always include a title and column headings, so that you will not forget what all the numbers mean. The column headings should include the units of the quantities listed, and usually serve as the labels for the axes of your graph. For example, look at Table C-1 and Graph C-1 on the next page. This is a position-versus-time graph drawn for a hypothetical situation.

The uncertainty for each data point is shown on the graph as a line representing a range of possible values with the principal value at the center. The lines are called **error bars**, and they are useful in determining if your data agrees with your prediction. Any curve (function) that represents your data should pass through your error bars.

Table C-1: Position vs. Time: Exercise 3, Run 1

Time/sec	Position/cm
0.1	10 ± 5
0.2	20 ± 5
0.3	30 ± 5
0.4	39 ± 5
0.5	49 ± 5
0.6	59 ± 5
0.7	69 ± 5
0.8	79 ± 5
0.9	89 ± 5
1.0	98 ± 5

Graph C-1:



What is a best fit straight line?

If your data points appear to lie on a straight line, then use a clear straight edge and draw a line through all the error bars, making sure the line has as many principal values beneath it as above it. The line does not need to touch any of the principle values. **Do not connect the dots.** When done correctly, this straight line represents the function that best fits your data. You can read the slope and intercept from your graph. These quantities usually have important physical interpretations. Some computer programs, such as Excel or Mathematica, will determine the best straight line for your data and compute its slope, intercept, and their uncertainties. As an example, look at Graph C-1. The dashed lines are possible linear fits, but the solid line is the best fit. Once you have found the best-fit line, you should determine the slope from the graph and record its value.

How do I find the slope of a line?

The slope of a line is defined as the ratio of the change in a line's ordinate (vertical axis) to the change in the abscissa (horizontal axis), or the "rise" divided by "run." Your text explains slope. For Graph C-1, the slope of the best-fit line will be the change in the position of the object divided by the time interval for that change in position.

To find the value of the slope, look carefully at your best-fit line to find points along the line that have coordinates that you can identify. It is usually not a good idea to use your data points for these values, since your line might not pass through them exactly. For example, the best-fit line on Graph C-1 passes through the points

(0.15 sec, 15 cm) and (1.10 sec, 110 cm). This means the slope of the line is:

$$\text{Slope} = \frac{110\,\text{cm} - 15\,\text{cm}}{1.10\,\text{sec} - 0.15\,\text{sec}}$$

$$= \frac{95\ \text{cm}}{0.95\ \text{sec}}$$

$$= 100\,\frac{\text{cm}}{\text{sec}}$$

Note that the slope of a position-versus-time graph has the units of velocity.

How do I find the uncertainty in the slope of a line?

Look at the dashed lines in Graph C-1. These lines are the largest and smallest values of the slopes that can realistically fit the data. The lines run through the extremes in the uncertainties and they represent the largest and smallest *possible* slopes for lines that fit the data. You can extend these lines and compute their slopes. These are your uncertainties in the determination of the slope. In this case, it would be the uncertainty in the velocity.

How do I get the slope of a curve that is not a straight line?

The tangent to a point on a smooth curve is just the slope of the curve at that point. If the curve is not a straight line, the slope will change from point to point along the curve.

To draw a tangent line at any point on a smooth curve, draw a straight line that only touches the curve at the point of interest, without going inside the curve. Try to get an equal amount of space between the curve and the tangent line on both sides of the point of interest.

The tangent line that you draw needs to be long enough to allow you to easily determine its slope. You will also need to determine the uncertainty in the slope of the tangent line by considering all other possible tangent lines and selecting the ones with the largest and smallest slopes. The slopes of these lines will give the uncertainty in the slope of the tangent line. Notice that this is exactly like finding the uncertainty of the slope of a straight line.

How do I "linearize" my data?

A straight-line graph is the easiest graph to interpret. By seeing if the slope is positive, negative, or zero you can quickly determine the relationship between two measurements. But not all the relationships in nature produce straight-line graphs. However, if we have a theory that predicts how one measured quantity (e.g., position) depends on another (e.g., time) for the experiment, we can make the graph be a straight line. To do this, you make a graph with the appropriate function of one quantity on one axis (e.g., time squared) and the other quantity (e.g., position) on the other axis. This is called "linearizing" the data.

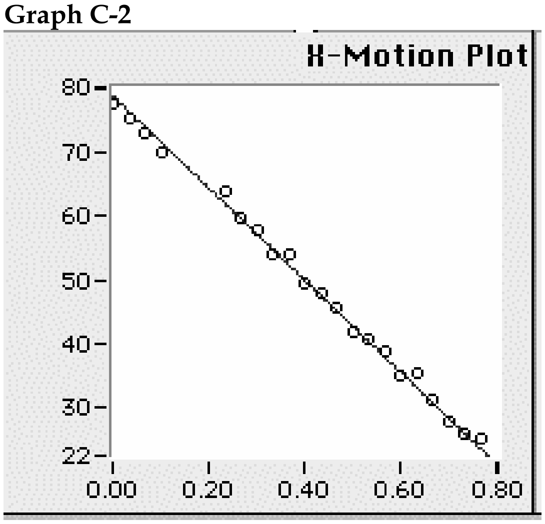
For example, if a rolling cart undergoes constant acceleration, the position-versus-time graph is curved. In fact, our theory tells us that the curve should be a parabola. To be concrete we will assume that your data starts at a time when the initial velocity of the cart was zero. The theory predicts that the motion is described by $x = (½)at^2$. To linearize this data, you square the time and plot position versus time *squared*. This graph should be a straight line with a slope of a/2. Notice that you can only linearize data if you know, or can guess, the relationship between the measured quantities involved. Professional physicists will sometimes try multiple linearizations if they see results in their data for which theoretical predictions explaining the phenomenon are unavailable. While this may seem more like prospecting than science, these guesses at linearization, if successful and repeatable (ie taking the data again), often inform and lead to new theories.

How do I interpret graphs from LabVIEW™?

Graphs C-2 through C-4 were produced with LabVIEW™. They give the horizontal position as a function of time. Even though LabVIEW™ draws the graphs for you, it usually does not label the axes and never puts in the uncertainty. You must add these to the graphs yourself.

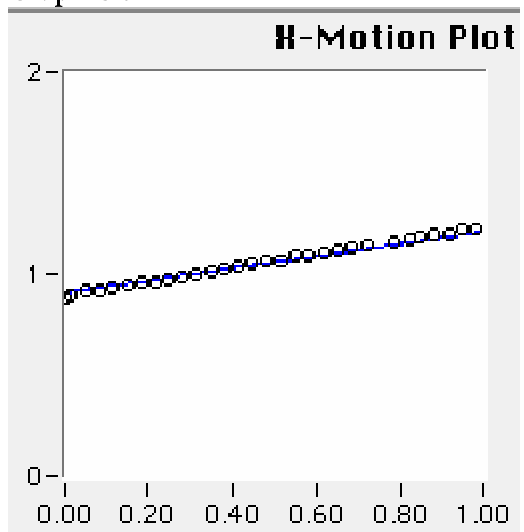
One way to estimate the uncertainty is to observe how much the data points are scattered from a smooth behavior. By estimating the average scatter, you have a fair estimate of the data's uncertainty. Graph C-2 shows position versus time for a moving cart. The vertical axis is position in cm and the horizontal axis is time in seconds. See if you can label the axes appropriately and estimate the uncertainty for the data.

Graph C-2

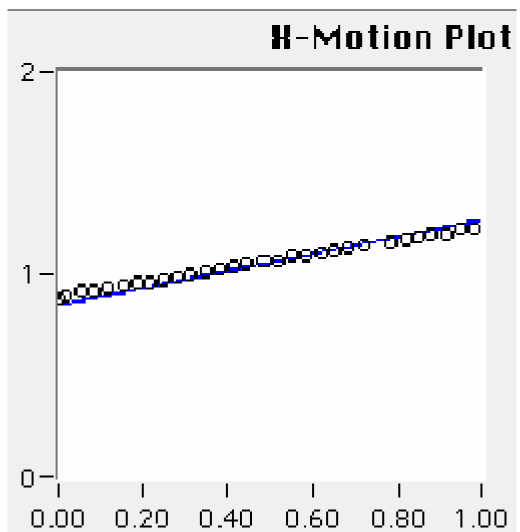


Finding the slope of any given curve with LabVIEW™ should be easy after you have chosen the mathematical equation of the best-fit curve. Graphs C-3 and C-4 each show one possible line to describe the same data. From looking at these graphs, the estimate of the data's uncertainty is less than the diameter of the circles representing that data.

Graph C-3



Graph C-4

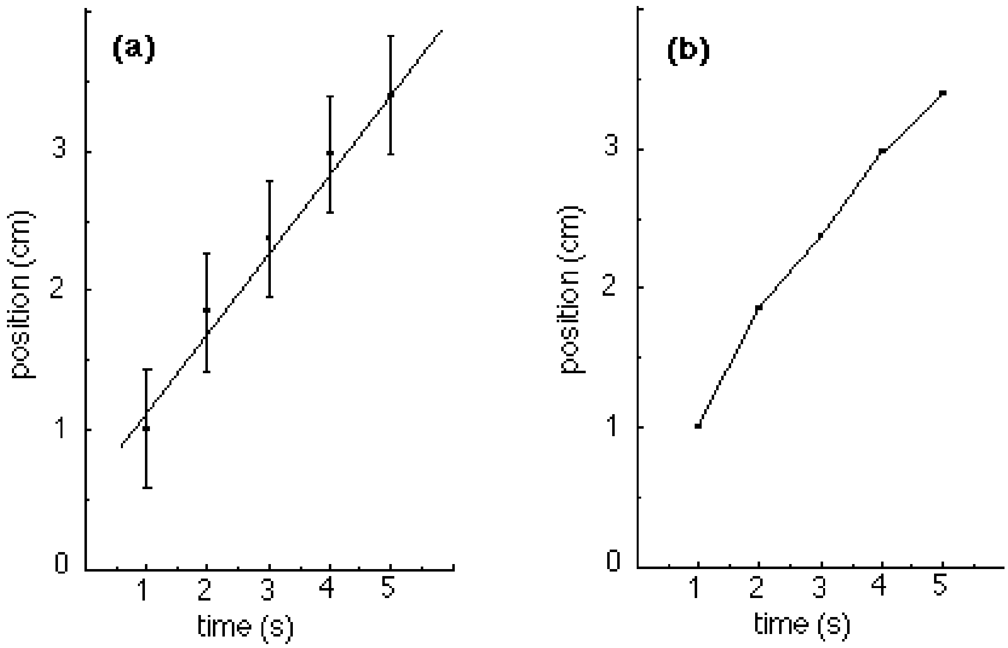


The line touching the data points in Graph C-3 has a slope of 0.38 m/sec. This is the **minimum** possible slope for a line that fits the given data. The line touching the data points in Graph C-4 shows a slope of 0.44 m/sec. This is the **maximum** possible slope for a line that fits the given data.

You can estimate the uncertainty by calculating the average difference of these two slopes from that of the best-fit line. Therefore the uncertainty determined by graphs C-3 and C-4 is $\pm$ 0.03 m/sec.

PRACTICE EXERCISES:

Explain what is wrong with each of the graphs below:



Appendix D: Equipment

ELECTROSTATIC PAPER AND ACCESSORIES:

To investigate electric fields with the electrostatic paper, you need to do the following:

- Lay the electrostatic paper flat. .
- Distribute the pieces of metal (called "electrodes") on the paper, in the configuration whose field you wish to examine. The tips of the long brass rods may also be used as electrodes, to create point-like charges.
- Connect the electrodes to a source of charge. This is done by connecting a wire from the positive ("+") side of the battery or power supply to one electrode and the wire from the negative ("–") side to the other as shown in Figure 1.
- You may wish to place a wooden block on top of the brass rods to increase contact pressure with the paper. This can increase the magnitude of the electric field created on the paper. It also helps to place an extra sheet of paper under the electrostatic paper.

Figure 1: Electrostatic paper Setup

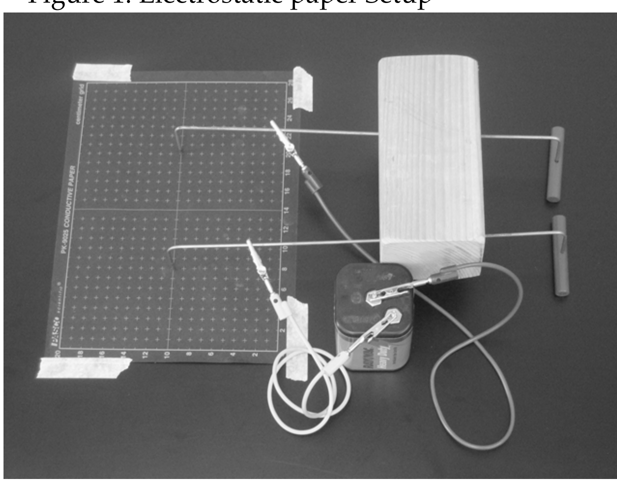
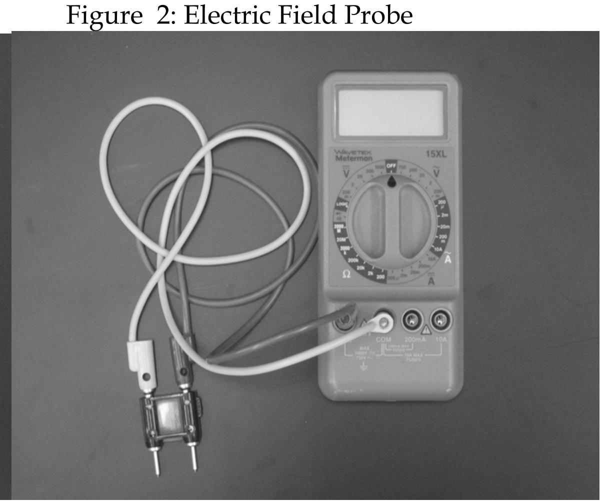


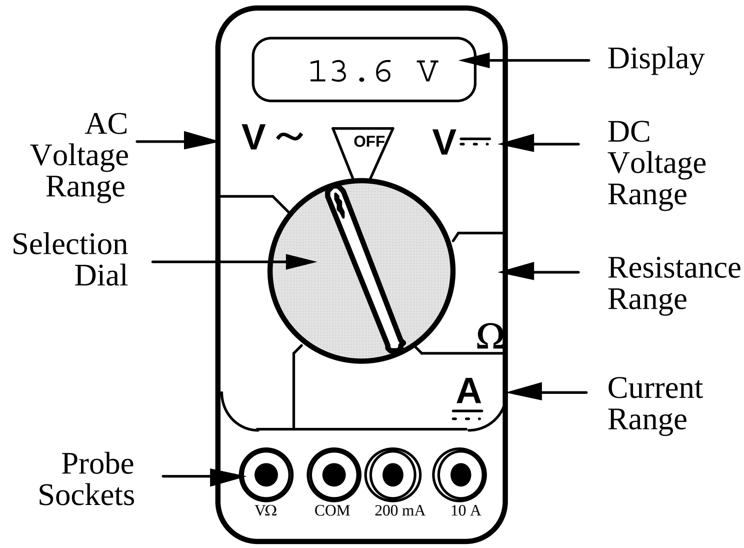
Figure 2: Electric Field Probe



To measure the electric field from the charged electrodes, you will use a probe connected to a digital Multimeter set to measure volts (see Figure 2). For best results, turn the DMM to measure in the two-volt DC range, as indicated in Figure 2.

THE DIGITAL MULTIMETER (DMM)

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

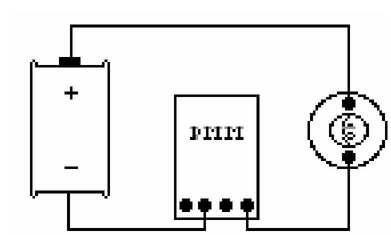


> The DMM can measure currents anywhere from 10 amps to a microamp (10^{-6} amps). This versatility makes the DMM fragile, since measuring a large current while the DMM is prepared to measure a small one will certainly harm the DMM. For example, measuring a 1 ampere current while the DMM is on the 2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

Measuring Current:

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

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



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

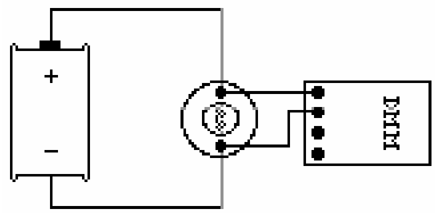
3. If no number appears while the DMM is at the 10A setting, move the wire from the 10A socket to the 200mA socket and then turn the selection dial to the 200 milliamp (200m) setting. If there is still no reading, change the dial to the 20 milliamp setting, etc.

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

Measuring Voltage:

1. Set the DMM selection dial to read DC volts (V⎓). Insert one wire into the socket labeled 'V?' and a second wire into the socket labeled 'COM'.

2. Set the selection dial of the DMM to the **highest** voltage measurement setting. Connect the two wires from the DMM to the two points between which you want to measure the voltage, as shown below.



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

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

Measuring Resistance:

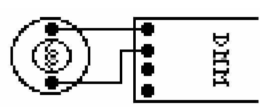
The element whose resistance you are measuring ***must*** *be free from all other currents (due to other batteries, power supplies, etc.) for the DMM to work*. That means you must **remove** it from a circuit.

To measure resistance:

1. Set the DMM selection dial to measure ohms (Ω). Insert one wire into the socket labeled 'VΩ' and a second wire into the socket labeled 'COM'.

2. *Make sure that the circuit element whose resistance you wish to measure is free of any currents.*

3. Attach the wires across the circuit element, as shown in the example below.



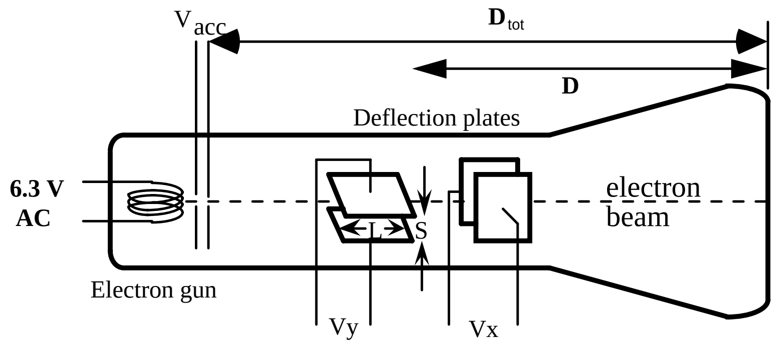
4. If no number appears, try a different measurement scale. Use a logical method that covers all scales, such as beginning at the largest scale (20 MΩ) and working your way down.

CATHODE RAY TUBE (CRT) AND ACCESSORIES:

Use of the cathode-ray tube and its relatives is widespread. It is the heart of many familiar devices, from your computer monitor to your television. The following is a sketch of the tube you will be using and its connections.

Figure 3:
Cathode Ray Tube.

D = 7.4 cm
L = 2.0 cm
S = 0.30 cm
D_{tot} = 9.6 cm



<u>How the CRT works:</u>
Within the electron gun:

- A thin filament (represented above as a coil of wire), similar to a light-bulb filament, is heated by a current. When the CRT is operating, this filament can be seen as an orange, glowing wire. This hot filament ejects slow-moving electrons.
- Some slow electrons drift toward the high-voltage “acceleration plates.” These plates are labeled as Vacc in Figure 3. The electric field between the charged plates accelerates the electrons to high velocities in the direction of the fluorescent screen. The final velocity of an accelerated electron is much greater than its initial “drift” velocity, so the initial electron velocity can be ignored in calculations.

After the electron gun:

- Before hitting the screen, the high-velocity electrons may be deflected by charged plates along the length of the CRT. These charged plates are usually called the “x-deflection” and “y-deflection” plates.
- When the electrons reach the end of the tube, their energy causes the material that coats the end of the tube to glow. This material is similar to the material inside fluorescent light bulbs. The end of the CRT is called the fluorescent screen.

To supply the necessary electric potentials to the CRT you will use a power supply. The power supply provided has the proper potential differences to heat the CRT filament and to accelerate the electrons. The power supplies we use also have built-in circuit breakers. Should you attempt to draw too much current from your power supply, it will shut itself off with an audible “click.” If this happens, check to make sure all of your wires are connected properly, then press in the small white button on the side of the power supply.

Note that the CRT and power supply come as a set, and many of the connections are color-coordinated to avoid potentially damaging misconnections. You will also have an assortment of batteries, which will be used to control the electric field between the CRT x- and y-deflection plates.

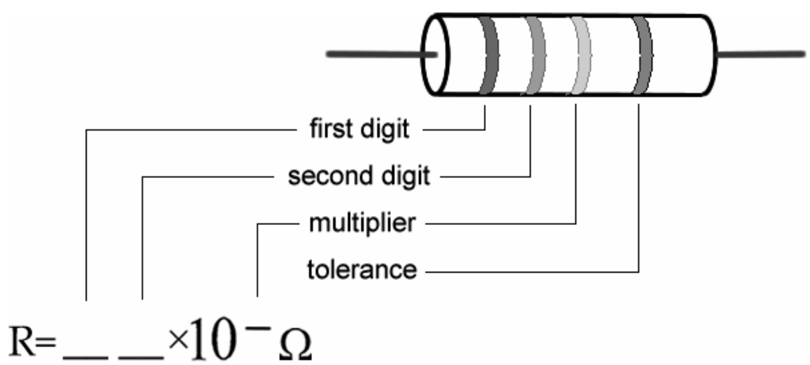
WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. To avoid danger, the power should be turned OFF and you should WAIT at least one minute before any wires are disconnected from or connected to the power supply.

To properly connect the CRT to the power supply:

1. Turn the power supply off.
2. Connect the power supply ports marked "AC 6.3V" (they are green; the voltage differs slightly from one supply to another, but should be clearly marked) to the ports marked "HEATER" or "FILAMENT" on the CRT (these are also green).
3. Connect the appropriate accelerating potential across the cathode and anode. For instance, if your experiment calls for a 500 volt accelerating potential, connect the cathode to the port marked "–250 V" (which may be black or white) and the anode to the port marked "+ 250 V" (which is red). This gives a total potential difference of 500 volts.
4. Turn the power supply on.

RESISTOR CODES

A resistor is a circuit element manufactured to have a constant resistance. The resistance is coded onto the side of the resistor in colored bands, where the color and position of the bands tell you what the resistance is.



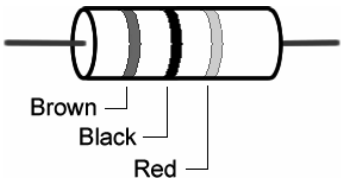
To read the color bands on the resistor, begin by finding the gold or silver band on one end of the resistor; this is the back of the resistor. You begin reading from the other end. Most resistors (including those you will use in lab) are coded to two significant digits. The first two color bands correspond to these two significant digits.

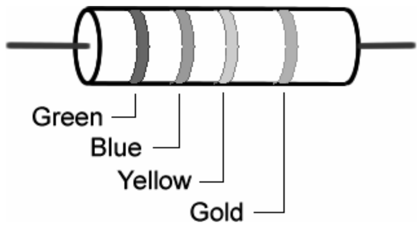
The third color band is called the multiplier. The number coded by this band represents a power of ten which you multiply by the number from the first two bands to get the total resistance.

The fourth color band tells you the tolerance, or error bounds for the coded resistance: gold means ±5% tolerance, silver means ±10% tolerance and no fourth band means ±20%.

Some resistors have a fifth color band, which represents the reliability of the resistor, and can just be ignored for the purposes of these labs.

Examples:





$R = 10 \times 10^2 \Omega \pm 20\%$ $\qquad$ $R = 56 \times 10^4 \Omega \pm 5\%$

Color	Number
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

SORENSEN POWER SUPPLIES

The Sorensen power supply is an all-purpose power supply for the production of constant currents and voltages.

At the top is the main display that reads either current in Amperes or voltage in Volts. There is a switch there that allows you to switch between them.

The current and voltage controls are located in the middle. In between the constant current and constant voltage knobs is a switch that allows you to toggle from high currents to low currents. **It is highly recommended that you use only the low current mode.**

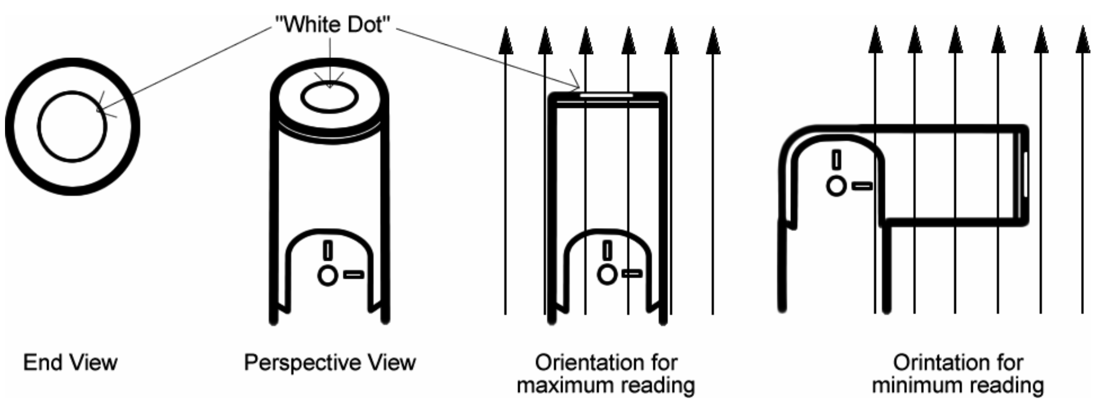
This power supply normally operates in the constant voltage mode. As such, you can only change the voltages by using the constant voltage knobs. **In the event that too much is being pulled from the power supply (as in a short), it will automatically switch to the constant current mode, where the amount of current flowing is greatly reduced.** This is a signal that something is amiss with your circuit.

There is a *mater-slave* switch on the back of the power supply. This should always be set to master for the DMM to function properly. If you experience any problems, this is the first place to check.

THE MAGNETIC FIELD SENSOR (HALL PROBE)

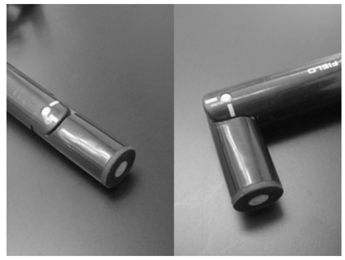
To measure magnetic field strength, you will need a measurement probe (the magnetic field sensor) that connects to a computer through the Vernier *LabPro* lab interface..

The tip of the measurement probe is embedded with a Hall Effect transducer chip (shown above as the white dot on the end of the probe). The chip produces a voltage that is linear with the magnetic field. The maximum output of the chip occurs when the plane of the white dot on the sensor is perpendicular to the direction of the magnetic field, as shown below:



The ***LabPro*** allows the computer to communicate with the probe. In order to measure magnetic fields, the wire leading out of the probe must be plugged into the LabPro port labeled "CH 1". The *LabPro* itself should be plugged into the modem port of the computer. The *LabPro* turns on automatically when its power supply is plugged in. A green light on the top of the *LabPro* indicates that it is on.

The Range switch on the side of the probe is to allow you to measure a greater range of magnetic field strengths. Each setting represents the maximum field strength that the probe can measure: either ±6.4mT or ±0.3mT. When measuring stronger magnetic fields, you should use the 6.4mT setting, but for fields weaker than 0.3mT the lower setting will give you a more accurate reading.



The measurement probes have swiveling tips to allow for more convenient data collection. Note: **that these tips are only meant to swivel in one direction. They will break of they are bent in the other direction, and they are very fragile, so it does not take much to do this.** Please be very careful as these are costly to replace.

MEASURING RADIATION
(Geiger Counter)

To measure radiation you will need a ***Geiger Counter***. The tube detects incoming radiation (alpha, beta, or gamma decay) and produces a voltage spike which the counter unit records. To use the Geiger Counter in conjunction with the computer plug the connecting cord into the round hole on the right side of the counter, and plug the other end of the connecting cord into the LabPro Interface port labeled “DIG/SONIC 1”. The computer uses the software LoggerPro in conjunction with the Geiger Counter to measure radiation. For a description of the LoggerPro software see *Appendix E*.

To begin measuring radiation amounts the power switch on the Geiger Counter must be moved to the “ON” position, or the “AUDIO” position. The Geiger Counter’s red light will flash whenever it makes a radiation count. When in the “AUDIO” position the counter will also make a beep noise whenever it makes a radiation count.

There is a switch on the Geiger Counter that controls its detection sensitivity. The switch has positions labeled 1X, 10X, etc. For the lab problems in this manual the 1X position will most likely be the best setting.

Counts recorded by the detector are the result of radioactive decay, which is a randomly occurring event. Events that are the result of random processes have inherent uncertainty. This means that if the count rate for a certain sample is recorded several times, the number of counts recorded will fluctuate around an average. In a set of N counts, if N is small the uncertainty in N will follow Poisson Statistics. If N is large the uncertainty will follow Gaussian Statistics. (These terms are explained in any math reference book, for example see http://mathworld.wri.com). Keep uncertainty in mind when deciding how many counts are "enough" to allow comparisons among count rates under different conditions.

Appendix E: Software

MEASURING CONSTANT MAGNETIC FIELD
(THE HALL PROBE APPLICATION)

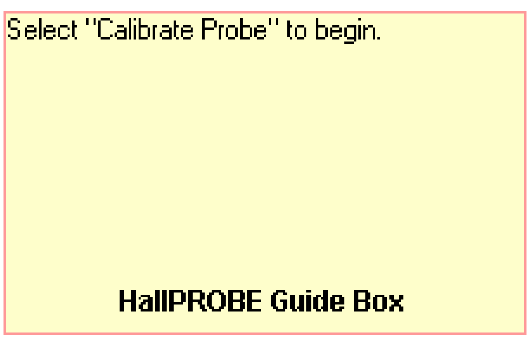
Basics

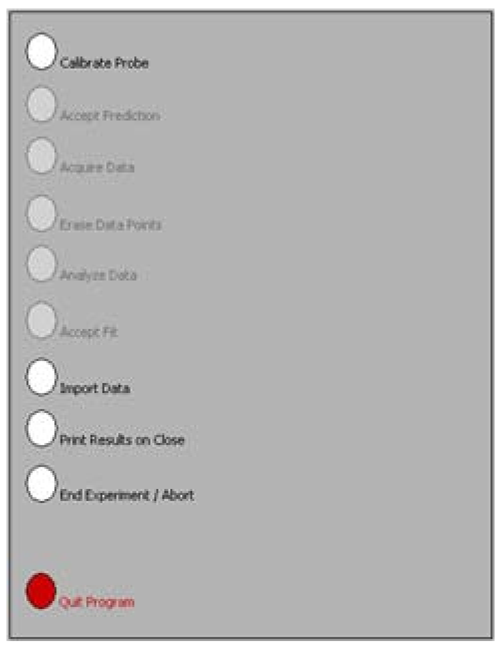
Before you begin, you should ensure that you have read the relevant sections of *Appendix D* to familiarize yourself with the equipment.

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

After logging into the computer, execute the application by double clicking the "HallPROBE" icon on the desktop.

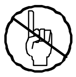
Before you start using the program, you should take a moment to identify several key elements. The two most important of these are the Command Panel, shown to the right, and the Guide Box, shown below.





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

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



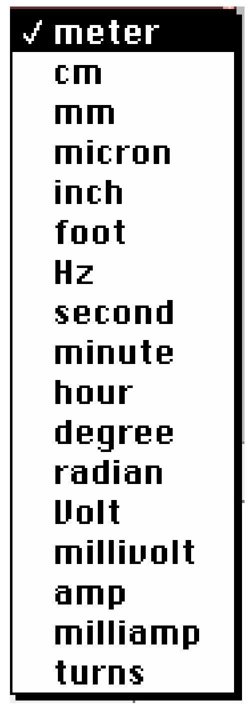
The primary data output you get is by printing your results, so be careful not to quit without printing or exporting your data.

Choosing your sensor range

The application detects the sensor setting when the program is first started. If you find that your initial setting is too big, or the magnetic field sensor is maxed out, you need to restart the software with the new setting.

Calibration

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



You should get a list of choices as shown to the right. By selecting any of these units, you will be making a choice about what you wish to measure. For example, if you choose to use "cm” , you will make a graph of magnetic field strength as a function of distance (B vs. x). Selecting "degree" will make a plot of magnetic field strength as a function of angle (B vs. θ). Click "OK" when you are ready to proceed.

Secondly, you will need to eliminate the effect of the background magnetic fields. This process is called "zeroing the Hall probe" in the Guide Box. **Place the magnetic field sensor wand in the position you would like to take your measurement, but be sure that there are no magnets nearby.** Note that power supplies and computers generate magnetic fields, so it is a good idea to keep away from them! When you are ready, select the "First Calibration Value" as shown below. Now rotate the wand 180 degree around its long axis (similar to rolling a pencil) and select "Second Calibration Value." If you have trouble holding the want in one place you might have good luck rolling it across your lab table.

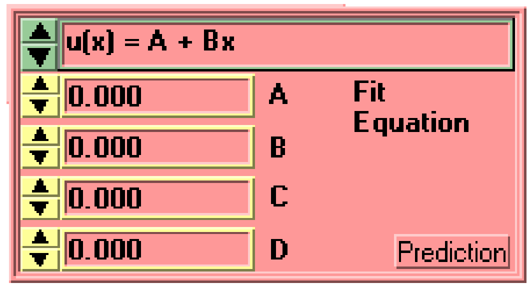
The calibration process is now complete.

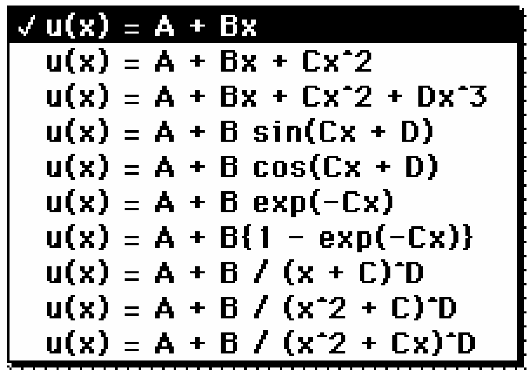
Predictions

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

The first task is to enter your prediction of the mathematical function you expect to represent your data. Making a prediction before taking data is the best way to determine if anything is going wrong (remember Murphy's Law).

It's also a good way to make sure you have learned something, but only if you stop to think about the discrepancies or similarities between your prediction and the results.





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

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

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

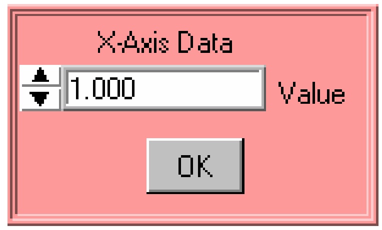
Once you are satisfied that the equation you selected and the values of the constants are correct, select the *Prediction* button in the Fit Equation command box. Your prediction equation will then show up on the graph on the computer screen. If you do not see the curve representing your prediction, change the scale of the graph axes or use the *AutoScale* feature (see Finding Data below). If you wish to change your prediction, simply repeat the above procedure. When you are satisfied, select the *Accept Prediction* option from the Command Panel. Once you have done this you cannot change your prediction except by starting over.

Exploration

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

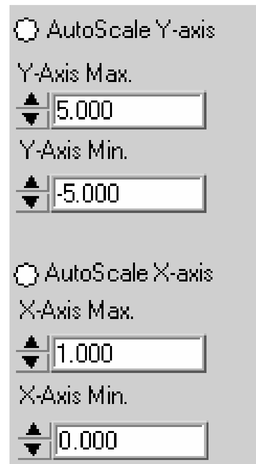
Data Acquisition

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



Finding Data on the Graph

You can find your data on the graph by adjusting the scales of your X-axis and Y-axis plots. This scaling is accomplished by entering the appropriate values into the "Y-Axis Max." and "Y-Axis Min." fields (as shown to the right) as well as adjusting the "X-Axis Max." and "X-Axis Min." fields (also shown to the right). If you cannot locate your data, you can select both "AutoScale Y-axis" and "AutoScale X-Axis" to let the program find the data for you. You can then adjust your axis scales to give you a convenient graph for analysis. Be careful, the AutoScale option will often set the scales in such a way that small fluctuations in the data are magnified into huge fluctuations.



Data Fits

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

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

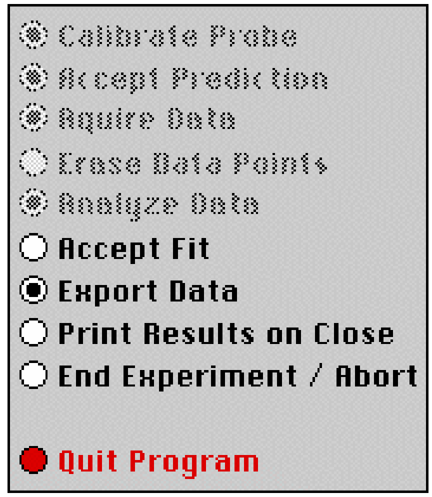
Now you need to estimate the uncertainty in your fit by deciding the range of other lines that *could* also fit your data. This method of estimating your uncertainty is described in Appendix D. Slightly changing the values for each constant in turn will allow you to do this quickly.

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

Importing / Exporting Data

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

To save your data, simply select *Export Data* (as shown to the right) and follow the instructions in the windows. Your file will be saved to your section's lab folder. To retrieve this file, restart *HallPROBE* from the desktop and select *Import Data.*

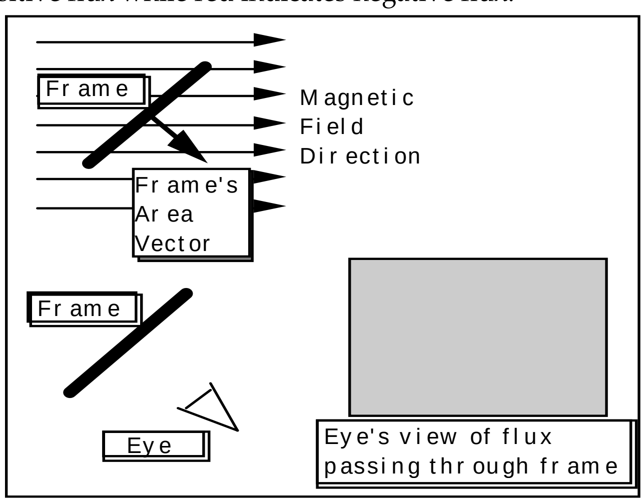


Last Words

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

FLUX SIMULATOR

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



Picture of <u>FluxSimulator</u> Screen

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

Slider

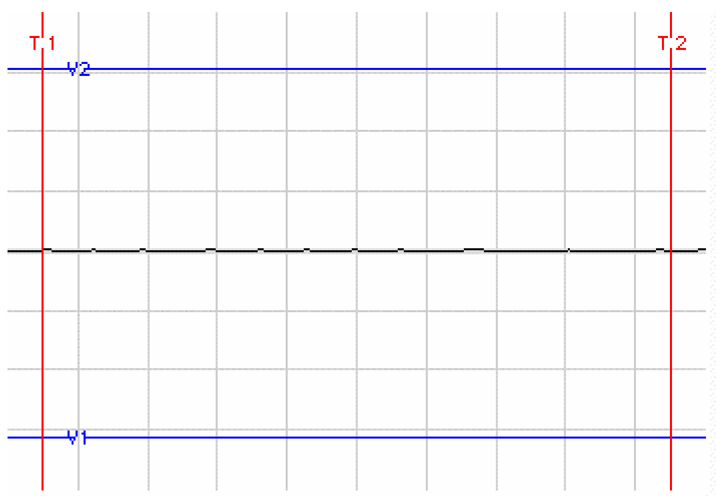
As you rotate the frame, observe both the angle the frame's area vector makes with the magnetic field and the color seen by the eye.

MEASURING TIME-VARYING VOLTAGES
(FaradayPROBE)

The Display:

This software package, written in LabVIEW™, allows you to measure and record potential differences as a function of time. Since the application to measure time-varying voltage is a slight modification of the application to measure magnetic field, you are already familiar with how to use much of it. These instructions assume a working familiarity with the HallPROBE application.

The basic difference between the FaradayPROBE and the HallPROBE applications is an additional display. The potential difference versus period display is described in these paragraphs. The display itself is shown below.



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

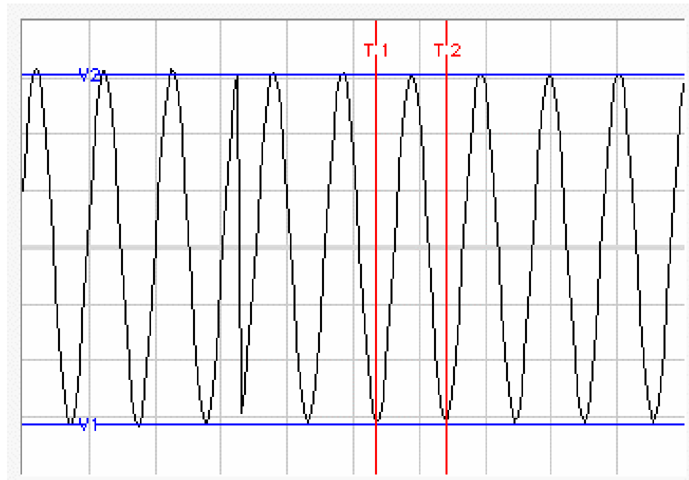
NOTE: Be patient! It takes up to 5 seconds for the display to register a signal.

Measurements:

The FaradayPROBE has two modes for acquiring data. The continuous mode acquires data constantly and updates at specified time intervals. There also exists a one shot mode in which one time interval worth of data will be measured after which the program will pause. Talk to your TA for specifics on which mode might work best in the lab problems you are solving.

Voltage and Time cursors

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



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

MEASURING RADIATION
(Geiger Counter with LoggerPro software)

The software used with the Geiger Counter to measure radiation is called LoggerPro, and a link to it should be located on the desktop.

Depending on which lab you are doing you may wish to measure radiation counts vs. time, radiation counts vs. distance, or radiation counts vs. shielding thickness. Software modules exist for each of these situations. To open the appropriate software module:
- start running LoggerPro 3.4.1
- go to the File menu and choose Open
- from the list of folders select Probes & Sensors
- from the next list of folders select Radiation Monitor
- choose the appropriate module from the list of modules; the list should include counts vs. time, counts vs. distance, and counts vs. shielding

There may be a box that you have to click "ok" in after selecting your module.

You can collect data using the collect button on screen. Depending on what module you've chosen there may be information about how the module works and the default sample time on screen.

Appendix F: A Brief Introduction to RMS Measurements

A problem arises when one wishes to measure an alternating current or potential. All measuring instruments sample a signal over some period of time. A device that samples over a time longer than one period of the signal (such as the DMM) essentially measures the average signal. For sine or cosine functions, the average is zero, which doesn't tell you much about the signal strength.

The solution to this difficulty is to use root-mean-square (RMS) averaging. To eliminate the cancellation of the positive and negative parts of the sine function, it is squared, then the average is taken[1], and the square root of this average yields the RMS value.

For example, to find the RMS value of an AC current that has a maximum value of I_O:

$$I(t) = I_0 \sin(\omega t)$$
$$I^2(t) = I_0^2 \sin^2(\omega t)$$

$$\langle I^2 \rangle = \frac{1}{2\pi} \int_0^{2\pi} I_0^2 \sin^2(\omega t)\, d(\omega t)$$
$$= \frac{I_0^2}{2\pi} \int_0^{2\pi} \sin^2(\omega t)\, d(\omega t) = \frac{1}{2} I_0^2$$

$$I_{RMS} = \sqrt{\langle I^2 \rangle} = \frac{1}{\sqrt{2}} I_0$$

When in AC mode, your DMM displays the RMS values of current and voltage.

1 When a quantity that varies with time is averaged, as in this case, the average value is often designated by putting angle brackets around the quantity. For example, the time average of a sinusoidally varying current is:

$$\langle I \rangle = \frac{I_0}{2\pi} \int_0^{2\pi} \sin(t)\, dt = 0$$

Appendix G: Sample Laboratory Report

There is no set length for a problem report but experience shows that good reports are typically three pages long. Graphs and photocopies of your lab journal make up additional pages. Complete reports will include the terminology and the mathematics relevant to the problem at hand. Your report should be a clear, concise, logical, and honest interpretation of your experience. You will be graded based on how well you demonstrate your understanding of the physics. Because technical communication is so important, neatness, and correct grammar and spelling are required and will be reflected on your grade.

Note: The double vertical bars indicate an explanation of that part of the report. These comments are not part of the actual report.

Statement of the problem

In a complete sentence or two, state the problem you are trying to solve. List the equipment you will use and the reasons for selecting such equipment.

The problem was to determine the distance the deflection plates (x and y) in the Cathode Ray Tube (CRT) using the deflections recorded on the screen at various potential differences. We connected the CRT as shown in Appendix D and recorded the x-deflection and y-deflection resulting from several different voltages applied to the deflection plates.

Prediction

Next comes your prediction. Notice that the physical reason for choosing the prediction is given. This was an exploratory problem asking for a quantitative prediction, but many predictions ask you to find mathematical relationships between two variables.

Note that the prediction is wrong. The prediction does not need to be correct, it needs to be what you really thought before doing the lab; that is why it is called a prediction. The prediction is supposed to be a <u>complete</u> and <u>reasonable</u> attempt by your group to determine the outcome of the problem.

Our group predicted that the distance between the deflection plates can be calculated based on the resultant x and y deflections on the screen at different voltages. The distances D_x and D_y can be easily calculated, which lead us to conclude that the distance that we were interested in for this lab is simply the difference in these two distances.

$$qV_{acc} = \frac{1}{2} m_e \upsilon_{II}^2 \longrightarrow \upsilon_{II} = \sqrt{\frac{2qV_{acc}}{m_e}}$$ (υ_{II} is the horizontal velocity of the electrons)

Time in and vertical velocity due to the deflection plates:

$$t_{in} = \frac{L}{\upsilon_{II}} \qquad \upsilon_{\perp} = a_{\perp} t_{in} = \frac{qE}{m_e} t_{in} = \frac{q\Delta V_{\perp}}{sm_e} t_{in}$$

(s is the separation distance between the 2 parallel deflection plates)

$$\begin{aligned} Deflection &= \frac{1}{2} a_{\perp} t_{in}^2 + \upsilon_{\perp} t_{out} \\ &= \frac{1}{2} a_{\perp} t_{in}^2 + \upsilon_{\perp} \frac{D}{v_{II}} \\ &= \frac{1}{2} \frac{q\Delta V_{\perp}}{sm_e} \left(\frac{L}{v_{II}}\right)^2 + \frac{q\Delta V_{\perp}}{sm_e} \frac{L}{v_{II}} \frac{D}{v_{II}} \\ &= \frac{q\Delta V_{\perp}}{sm_e} \frac{L}{(v_{II})^2} \left[\frac{1}{2} L + D\right] \end{aligned}$$

(L is the length of the length of the plates; ΔV is the potential difference; D is the distance between the deflection plates and the screen of the CRT)

Slopes of x and y deflections vs. potential differences:

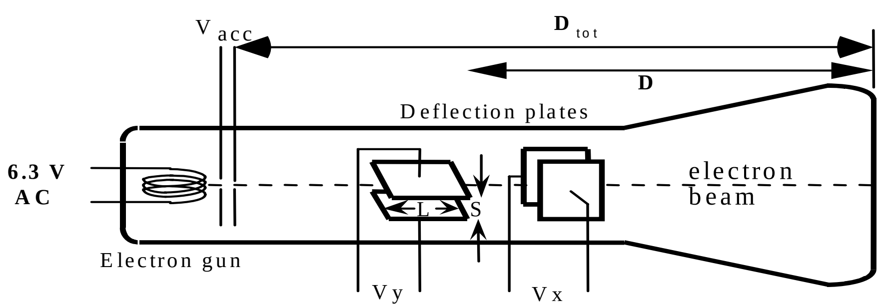
$$m_x = \frac{L}{2sV_{acc}} \left[\frac{1}{2} L + D_x\right] \longrightarrow D_x = \frac{2sV_{acc}}{L} \left[m_x - \frac{L^2}{4sV_{acc}}\right]$$

$$m_y = \frac{L}{2sV_{acc}} \left[\frac{1}{2} L + D_y\right] \longrightarrow D_y = \frac{2sV_{acc}}{L} \left[m_y - \frac{L^2}{4sV_{acc}}\right]$$

Distance between x and y deflection plates:

$$\begin{aligned} D_y - D_x &= \frac{2sV_{acc}}{L} \left[m_y - \frac{L^2}{4sV_{acc}}\right] - \frac{2sV_{acc}}{L} \left[m_x - \frac{L^2}{4sV_{acc}}\right] \\ &= \frac{2sV_{acc}}{L} (m_y - m_x) \end{aligned}$$

With some of the variables given in the laboratory manual, we can calculate this distance after taking our measurements and see whether the result is reasonable.



Experiment and Results

This section describes your experimental method, the data that you collected, any problems in gathering the data, and any crucial decisions you made. Your actual results should show you if your prediction was correct or not.

After hooking up the CRT, we turned it on and arranged the screen so that an x-deflecting voltage would move the beam along the horizontal axis and a y-deflecting voltage would move the beam along the vertical axis. With no deflecting voltage, the electron beam did not hit the screen directly in the center -- we took this point to be our reference point and measured our change in the x- and y-directions from it.

We measured the x-deflection for 6 voltages between 0 and 5 Volts. We then did the same for the y-deflection. (See table 1 from the lab journal)

A discussion of uncertainty should follow all measurements. No measurement is exact. Uncertainty must be included to indicate the reliability of your data.

The largest uncertainty in our measurements came from the deflection of the electron beam from the screen on the CRT. Since the marks on the screen were every 1.0 mm and the electron beam was somewhat distorted, we estimated the uncertainty of our deflection measurements to be 0.5 mm. We verified this uncertainty measurement by having each member of our group measure the x- and y-position of the electron beam at two test points. All measurements were within the stated uncertainty. The uncertainties in our measurement also lead to uncertainties in the slopes of the deflection vs. potential difference graph; the slopes were found to have uncertainties of 0.09 mm/V for x and 0.08 mm/V for y.

Using the values given in the manual, and those found from the experiment, we calculated the distance between the x and y deflection plates to be 36 mm with an uncertainty of 12mm.

Conclusions

This section summarizes your results. In the most concise manner possible, it answers the original question of the lab.

When we graphed the results from our data table, we saw that the y-deflection plates gave us a larger deflection at each deflection voltage used in the experiment. (See Graph A from the lab journal)

A good conclusion will always compare actual results with the predictions. If your prediction was incorrect, then you must discuss where your reasoning went wrong. If your prediction was correct, then you should review your reasoning and discuss how this lab served to confirm your knowledge of the basic physical concepts.

The result of our experiment is consistent with the dimensions of the CRT. The total length from the accelerating voltage plates to the screen is 96mm, and our result showed that the distance between the x and y deflecting plates is somewhere in the range of 24mm to 48mm. The upper bound value may be unlikely, since it wonít leave much room for anything else to fit in the CRT. However, this doesnít mean that the range is unreasonable; any value in the range can still be made to fit inside the CRT. After discussing this as a group we realized that we had over estimated the x- and y-position measurements, and the upper bound value is the result of this.

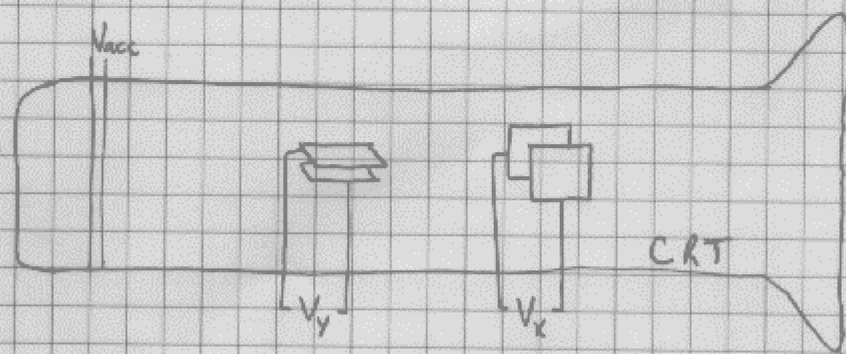
When we thought about the situation more carefully, we realized that we were correct in thinking that an electron is always traveling with the same velocity parallel to the CRT and that the time it is inside each deflection plate will be the same. Thus, at the far edge of each deflecting plate the electron beam has the same perpendicular velocity. Recalling our kinematics from last semester, we realized that this perpendicular velocity will be independent of the parallel velocity. Since the electron beam takes longer to travel from the far edge of the y-deflecting plates (the y-plates are further from the screen) than from the x-deflecting plates, the electron beam under y-deflection will have more time during which it has a y-velocity, and thus it will be deflected more. This allowed us to make the right assumptions and thus yielded a reasonable result.

After you have compared your predictions to your measured results, it is helpful to look at the data from an alternative perspective. This should be a short exercise demonstrating to yourself and to your TA that you understand the basic physics behind the problem.

The situation in this problem is similar to the situation in which a moving soccer ball is moving past two people (See diagram 1 from the lab journal). Either of these two people can kick it perpendicularly to its direction of motion. The diagram shows the resulting position when it reaches the edge of the field when person A kicks it (solid line) versus when person B kicks it (dashed line). Person A is further away from the edge of the field and, thus, her kick results in a greater deflection of the ball. This difference in deflection can be used to determine how far apart the two kickers are.

Sample Lab Journal

July 20, 1999



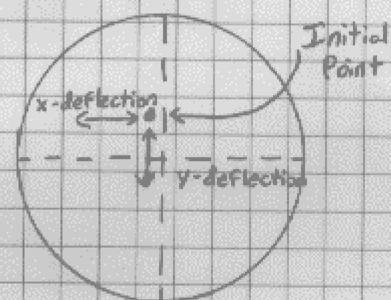
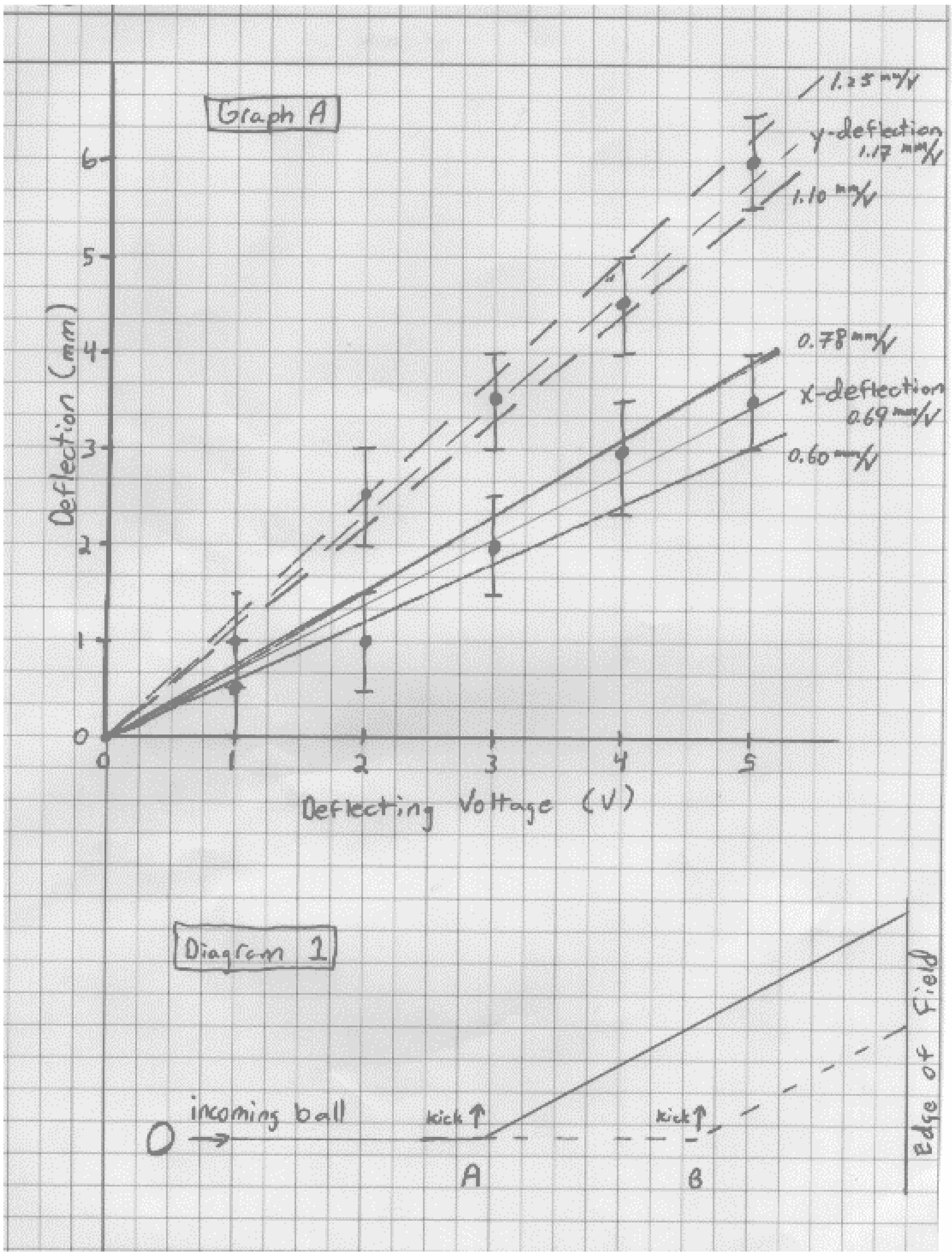


Table 1

X-deflection				Y-deflection			
V_x	X	Y	ΔX	V_y	X	Y	ΔY
0.0V	-1.0mm	4.5mm	0.0mm	0.0V	-1.0mm	4.5mm	0.0mm
1.0	-1.5mm		0.5mm	1.0V		3.5mm	1.0mm
2.0	-2.0mm		1.0mm	2.0V		2.0mm	2.5mm
3.0	-3.0mm		2.0mm	3.0V		1.0mm	3.5mm
4.0	-4.0mm		3.0mm	4.0V		0.0mm	4.5mm
5.0	-4.5mm		3.5mm	5.0V		-1.5mm	6.0mm

Uncertainty is 0.5mm


Graph A
1.25 mm/V
y-deflection
1.17 mm/V
1.10 mm/V
0.78 mm/V
x-deflection
0.69 mm/V
0.60 mm/V
Deflection (mm)
0
1
2
3
4
5
6
Deflecting Voltage (V)
Diagram 1
incoming ball
kick
kick
A
B
Edge of Field