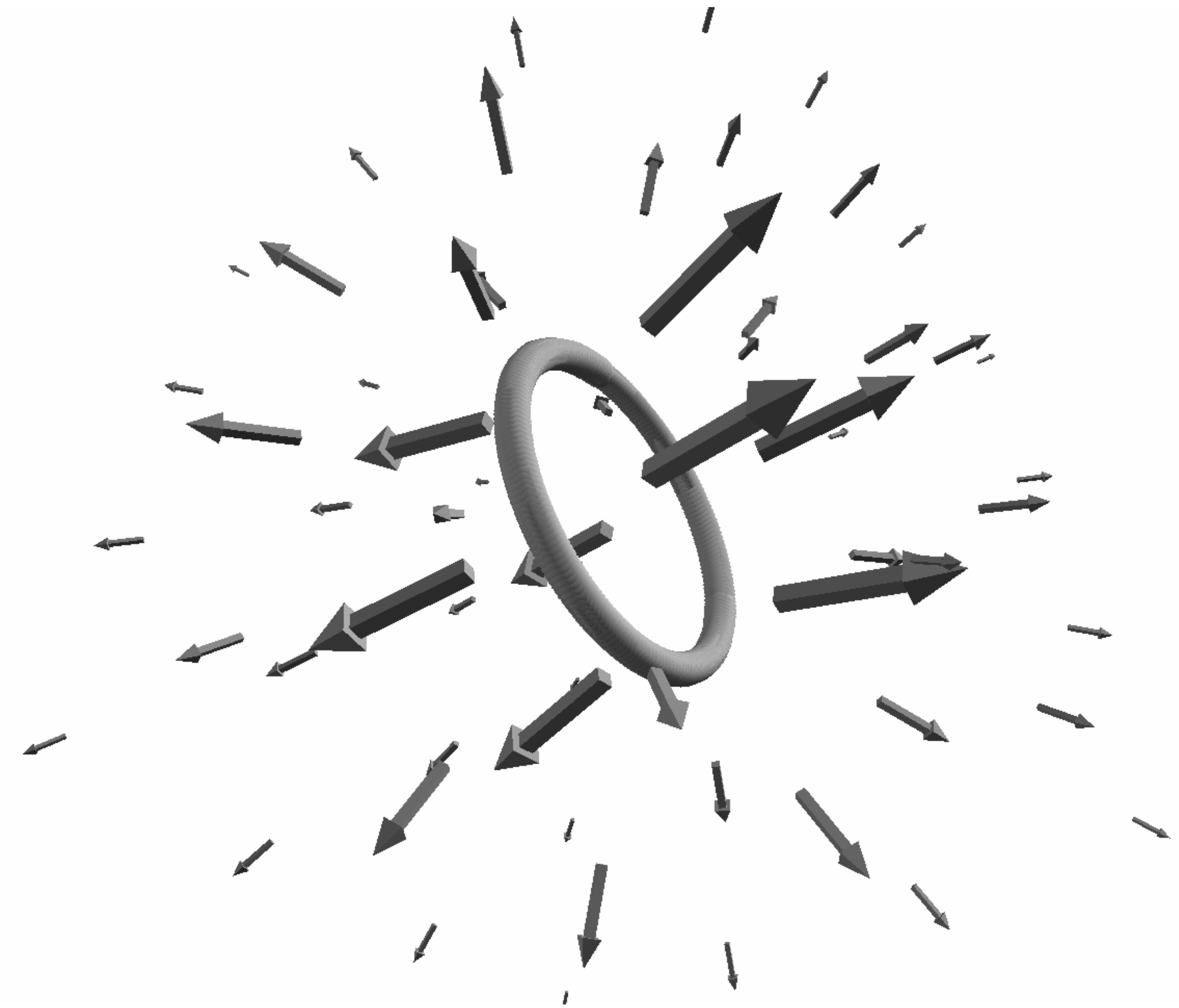
Laboratory Manual for Physics 272/272H

Summer 2008



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The cover shows the electric field of the uniformly charged ring. It was drawn using VPython.

Table of Contents

Lab Policies and Crucial Information

You will need a lab notebook (a standard spiral notebook is fine; you do not need a special lab notebook).

<u>What happens in the lab?</u>

The laboratory offers short experiments, computer modeling, and problem solving sessions. These are tightly integrated to the lecture material and the problems on the exams.

The labs are overseen by a graduate teaching assistant (GTA). He or she is responsible for the grading and administration of your lab section. An undergraduate teaching assistant (UTA) who is familiar with the experiments will be assisting the GTA

GTA's Name & email____

<u>I missed a lab or will miss a lab. What do I do?</u>

For an excused absence, there is no penalty. As soon as possible (preferably within 24 hours of your scheduled session), contact your laboratory GTA via email (please "cc" the laboratory coordinator on your email jyeazell@purdue.edu). Your laboratory GTA will tell you when to make up the experiment and set a due date for the associated laboratory work. Be prepared to show your laboratory GTA proof of your illness (e.g., doctor's note, hospital receipt) or documentation of a formal excuse (e.g., absence for sporting event).

For unexcused absences (e.g., overslept, car didn't start, etc.) there will be no make-ups. We strongly recommend reading and doing the lab on your own since understanding the material is crucial to passing the course. WebAssign exercises associated with an unexcused absence may be done for credit provided you complete them within the specified due date of the missed lab and you email your GTA and the lab coordinator (jyeazell@purdue.edu).

<u>I have a missing lab score. What should I do?</u>

Contact your laboratory GTA so that the error can be corrected. This must be done before the final exam.

<u>Help, I don't know what to do!</u>

If you have a question or a problem regarding the lab that cannot be answered satisfactorily by your GTA please contact John Yeazell at jyeazell@purdue.edu

Lab 1: Electric Fields, Vectors, and VPython

This is NOT an in laboratory classroom exercise. It is highly recommended for those students who did not take Physics 172 and should be done on your own. This review or refresher exercise has no point value.

In this lab we will explore the concept of electric fields and review the use of VPython. From last semester recall that VPython is a simple, 3D programming language and it will be used here to display vectors representing electric fields and the effect the electric fields have on a charged particle.

- VPython is on the hard disks of the lab computers.
- VPython is available on all ITAP computers. It is found under the Start button. Follow the All Programs tree (All Programs/Course Software ... Science/Physics/Vpython 2.4. Install the most recent version of VPython. Once installed, you can find the executable VPython in the main All Programs menu list. Open the Idle for Visual Python.

1. A charged particle in an electric field

When a charged particle encounters another charged particle it experiences a force (Coulomb's force law). If the same particle encounters many other charged particles it experiences a net force that is the vector sum of the individual forces due to each particle. If the test charge has a charge of q and the other charges have charge q_j and have relative position vectors pointing from the jth particle to the test charge of $\vec{r}_{qj}$, then the net force on the particle is

$$\vec{F}_{net}(x,y,z) = \sum_j \vec{F}_{qj} = \frac{1}{4\pi\varepsilon_o} \sum_j \frac{q q_j}{\left|\vec{r}_{qj}\right|^2} \hat{r}_{qj} = q\left[\frac{1}{4\pi\varepsilon_o} \sum_j \frac{q_j}{\left|\vec{r}_{qj}\right|^2} \hat{r}_{qj}\right]$$

Let's assume that all the other charged particles are fixed so that 'test' charged particle you introduce does not affect their positions. Then it is convenient to define an electric field that is associated with all these other charges so that you can quickly calculate the force on any test charge you place at the position (*x, y, z*) no matter what its charge. The net electric field is simply everything in the square bracket above or

$$\vec{E}_{net}(x,y,z) = \left[\frac{1}{4\pi\varepsilon_o} \sum_j \frac{q_j}{\left|\vec{r}_{qj}\right|^2} \hat{r}_{qj}\right] = \sum_j \vec{E}_{qj}$$

The simple concept of a field has proven surprisingly useful in broad areas of physics including quantum field theory.

Let's say you arrange a set of fixed charges so that in a region of space the electric field is the same at all the locations in that region or uniform. This means that the force experienced by a test charge will not vary by position within that region.

The force on a charged particle (of charge *q*) in such a region is $\vec{F}_{region} = q\vec{E}_{region}$ and the field is called a uniform electric field.

A Charged Particle in a Uniform Electric Field

In the program **ChargeinEfield.py** you will observe the motion of a charged particle in the presence of a uniform electric field.

This program and all the others used in the lab are found on lab software website (below). You may wish to save it as favorite or bookmark. Open this URL.

http://web.ics.purdue.edu/~jyeazell/Phys272Lab.htm

Right click the program link on that page, **ChargeinEfield.py,** and save it to your desktop. Open the Idle for Visual Python and open the file you saved on the desktop.

The electric field in this program is defined so that the electric field points in the positive x direction in the region where $x < 0$ and the same magnitude electric field points in the positive y direction in the region where $x > 0$.

You will need to:

- Set the electric fields as indicated in the program.
- Draw the force and momentum vectors as arrows with their tails on the particles.
- Complete the momentum and position update equations.

2. Electric field maze

On the homepage find the program **efieldmaze.py.** Save, open, and run the program. Your goal is to make the charged particle travel around the barrier and exit through the door on the lower right. The ball should not touch or go through any of the walls.

- Change only the directions of the Electric fields in each of the four regions (**E1, ..., E4**) to accomplish this. These directions are called theta1, theta2, theta3, and theta4.

3. Superposition Principle

Electric fields add vectorially. The net electric field at a given point is the sum of all the electric fields present at this point. Consider an additional electric field which points in the positive *y*-direction and effects all four regions. This vector **Eadd** in your program is initially set to zero ...

- Set **Eadd** so that it points in the +*y*-direction and has a magnitude of 0.3. Run the program. Your solution from part 2 will, most likely, no longer work.
    - In your lab notebook, indicate how you could change the individual magnitudes of each electric field vectors (**E1, ..., E4**) so that this solution will again work.

- Change only the directions of the Electric fields in each of the four regions to again solve the maze (do not change the magnitudes of the electric fields).

4. Creating Objects and Arrows in VPython

1) Start a new program by pulling down the File menu in IDLE and choosing New Window. The first two lines of the program should be these (you can copy and paste these into the idle window):

from visual import *
from __future__ import division

(Note that the second line is typed: `"from space underscore underscore division underscore underscore space import space division"`. This line instructs Python to treat numbers as real numbers rather than integers when dividing, so 1/2 = 0.50, and not zero.)

Save your program to your desktop, making sure to give it a name ending in '.py'.

Spheres at the corners of a cube

2) **Create 8 spheres**, of any color, located at the corners of a cube. Make the spheres small enough, or the cube large enough, that the spheres are separated by a distance at least 10 times as large as the radius of a single sphere (that is, the spheres should not be too close together). For example:

ball1=sphere(pos=(.5,.5,.5), radius=.1,color=color.red)
ball2=sphere(pos=(.5,.5,-.5), radius=.1,color=color.red)

Run the program.

3) **Create 4 arrows**, placed tip to tail in such a way that they form a rectangle, with each vertex being the center of one of the spheres at the corners of the cube. For example, the arrows could go around one face of the cube, or they could form a rectangle that cuts diagonally through the cube. For example the arrow from **ball1** to **ball2** is

arrow1=arrow(pos=ball1.pos, axis=ball2.pos-ball1.pos, color=color.blue)

Run the program.

Using a loop to create a circle of spheres

4) At the end of your program, write a loop to place 12 spheres in a circle surrounding the cube. To do this, you will need a loop that changes the value of the angle in 12 steps to make a complete circle. For example,

```
theta=0.0
deltatheta=2*pi/12
while theta<2*pi:
    ball=sphere(pos=(?,?,?), radius=.1,color=color.red)
    theta=theta+deltatheta
```

- You need to define the ball's position in terms of theta and the desired radius of the circle.

It is easiest to place the spheres in either the *xy* plane, the *yz* plane, or the *xz* plane. In this case only two of the coordinates vary. Also remember that the radius of the circle and the sine or cosine of the angle are needed to determine the coordinates of each sphere.

In VPython, *sin* is written `sin(theta)`, and *cos* is written `cos(theta)`. Angles are in radians.

Run the program.

- Add 12 arrows with their tails on the spheres and their tips pointing radially outwards from the center of the cube.

Run the program.

Using VPython outside of class

You can download VPython from http://vpython.org and install it on your own computer. VPython is also available in all ITAP computer labs.

Programming help

There is an on-line reference manual for VPython. In the text editor (IDLE), on the Help menu choose "Visual". The first link, "Reference manual", gives detailed information on spheres, arrows, etc. In the text editor (IDLE), on the Help menu choose "Python Docs" to obtain detailed information on the Python programming language upon which VPython is based. We will use only a small subset of Python's extensive capabilities.

Lab 2: Calculating and displaying the electric field of a single charged particle.

Group Problems

Do the following problems as a group in your lab notebooks:

- 13.P.36 and 13.RQ.31

CHECKPOINT 1: Ask an instructor to check your work for credit. You may proceed on while you wait to be checked off.

Computer Aided Calculation and Display

You have calculated the electric field produced by a single charged particle. The somewhat tedious process of calculating electric field vectors can be automated by programming a computer to do this. In addition, doing the calculations in VPython will allow us to display the electric field in multiple locations, so we can examine the 3D pattern of field created by a charged particle.

I. A VPython program to calculate the electric field due to a single charged particle.

- Load VPython as usual from the START Menu.
- On the lab software site (http://web.ics.purdue.edu/~jyeazell/Phys272Lab.htm), right click on **EfieldCharge.py** and save it to your desktop, then open it in VPython.

The first two lines access the Visual library and deal with integer division.

Constants
Constants should be defined at the beginning of your program. In the template two constants are defined.

```
## constants
oofpez = 9e9
qproton = 1.6e-19
```

The first line gives the name "**oofpez**" (which stands for One Over Four Pi Epsilon-Zero), to the number 9e9.

The second line gives the name "**qproton**" to the charge of a proton.

Creating the charged particle

Set the characteristics of the sphere in the program to represent a charged particle.

- The name of the sphere is "**particle**"
- The sphere should be located at the origin.
- The radius of the sphere should be 1e-11 m. (This is much larger than the radius of a proton, which is about 1e-15 meters, but we will exaggerate the size of the particle in order to make it easily visible in our display.)
- Run the program. You should see a sphere in the center of your display window. If you don't see anything, first check the Python Shell window for error messages, then try again.

II Calculating and displaying the electric field

Now we assign a symbolic name to the observation location. We need a symbolic name for this location, because we will eventually want to instruct VPython to calculate the electric field at many different observation locations. Since there is no object at the observation location, we must create a vector variable to represent the observation location. We call it "**obslocation**".

obslocation = vector(1.41e-10, 1.41e-10,0)

This defines a vector named "**obslocation**" to represent the location where we want to find the electric field.

Later we will have the program calculate the electric field at other locations, too. (A *vector* is not a displayable graphical object, so it doesn't have a position, and we can't use "**.pos**" to refer to it.)

Instructing VPython to calculate and display the relative position vector $\vec{r}$

When calculating the electric field at an observation location, the relative position vector always points from the source particle (the initial location) to the observation location (the final location).

- In your program, complete the code that correctly calculates the relative position vector $\vec{r}$. In the program, remove the comment symbol from this vector is called "**r**". Also remove the comment from the print statement for **r.**

- Uncomment and Complete the code for the green arrow named **"ra".** The tail should at the center of the source charge, and whose axis is $\vec{r}$, the relative position vector you just calculated.

- Run the program. In the display window you should see a green arrow from the source charge to the observation location, and in the Python Shell window you should see the printed value of $\vec{r}$.

Telling VPython how to calculate the magnitude of $\vec{r}$

We need to translate the equation $|\vec{r}| = \sqrt{r_x^2 + r_y^2 + r_z^2}$ into VPython.

The components of a vector are attributes of the vector, so they can be referred to with "." syntax. The components of a vector named "**r**" are **r.x, r.y,** and **r.z.** In VPython, the operator ** raises a quantity to a power; b^3 is written **b**3. sqrt()** is used to compute a square root, e.g. $\sqrt{3}$ should be written **sqrt(3)**

- In your program, complete the line of code to calculate **rmag**.

rhat is the unit vector in the direction of $\vec{r}$.

.

You have now calculated **r**, **rmag**, and **rhat**. Finally, we need to use all of these pieces to calculate the electric field, as a vector, at the observation location.

- Write down the symbolic algebraic equation used to calculate the electric field vector then convert it to VPython. Use the name "**E**" for the electric field vector you will calculate.

- To find out if your expression is correct, type it into your VPython program, and uncomment the print statement after the calculation:

print 'Electric field vector is', E

Run your program.

CHECKPOINT 2: Ask an instructor to check your work for credit. You may proceed on while you wait to be checked off

Drawing an arrow to represent the electric field vector

We want to represent the electric field vector with the arrow named "**ea**".

- Remember that the tail of the arrow must be placed at the observation location!
- Think about what the axis of the arrow should be, and write the appropriate code.

Run the program.

You should see an arrow pointing in the appropriate direction. However, you can't see the sphere representing the positively charged particle, or the arrow representing the position vector! The arrow is so big that when VPython positions the "camera" so we can see the arrow, the sphere is too small to see.

Scaling the arrow to a reasonable size
At the moment, the axis of the arrow is a vector equal to the electric field at the observation location. We need to "scale down" the arrow so it is not gigantic compared to the sphere representing the charged particle. To do this, we need to multiply that vector by a scalar, thus changing the magnitude of the vector without changing its direction.

In the axis variable of the arrow **ea**, we need to multiply E by a scalar factor to decrease its magnitude, while keeping its direction the same. We can estimate a scale factor "**scalefactor**" by noting that the distance between the source charge and the observation location is 2e-10 m, so a reasonable length for the arrow in this case would be something like 2e-10. So the scalefactor should be something like 2e-10 divided by the magnitude of E. Calculate this by hand and put it into your program in the constants section.

Your program should now include the following:

scalefactor = (*your value*) # in the constants section of the program

ea = arrow(pos = (*appropriate location)*, axis=scalefactor*E, color=color.orange)

Run the program, and make sure you can see the sphere, the arrow representing the position vector, and the arrow representing the electric field vector. You may want to change the scalefactor so the display looks better to you.

Check your own work:

- **Does the orange arrow point in the correct direction?**
- **Is the tail of the orange arrow at the observation location?**

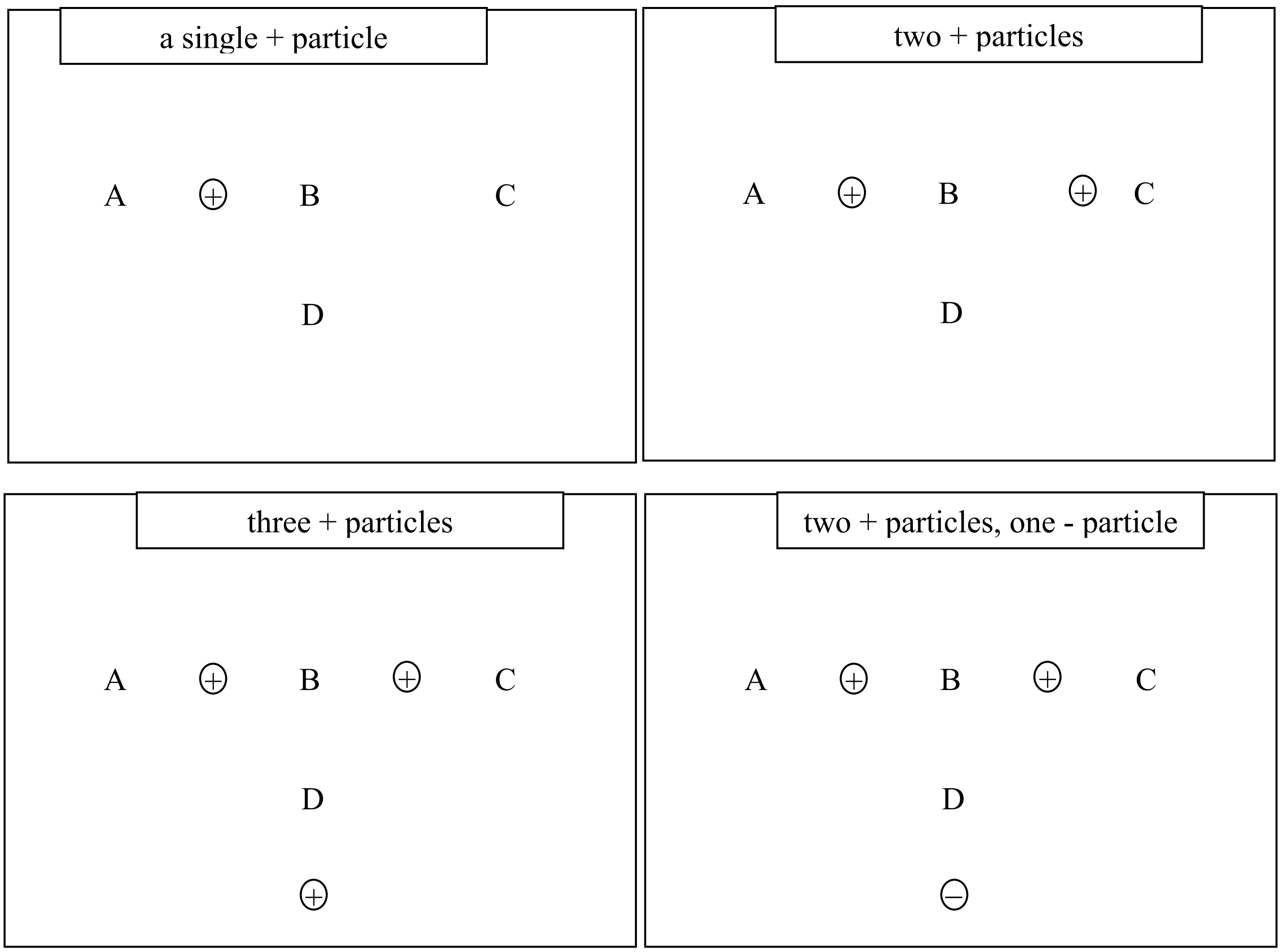
III. Add more observation locations
To see the pattern of electric field around a charged particle, you will extend your program to calculate the electric field at many locations, all the same distance from the source charge. One way to do this is to copy the code you have written to calculate and display the electric field, and paste it in multiple times, typing new values for the observation location each time.

- In your program, add code to calculate and display the electric field at 6 more locations on the positive and negative *x, y, z* axes. .
    - Each location should be 2e-10 m from the origin, and should be located on one of the axes. For example, you should have one located at < 2e-10, 0, 0> m and another at < -2e-10, 0, 0> m, and so on.

Your program should now display 7 orange arrows, representing the electric field at 7 locations. 6 of these observation locations should be on the positive and negative *x, y, z* axes. Make sure the arrows point in the correct directions!

IV. Sketching electric fields for some simple charge distributions

In the following boxes you will see several different sets of charged particles and the same observation points (A, B, C, and D). Sketch the electric field vector due to the superposition of the fields of all the charged particles at each of the observation points.



CHECKPOINT 3: Ask an instructor to check your work for credit. If you have time you may work on your WebAssign lab exercise or complete it after class (the due date is two days after your lab session at 5PM).

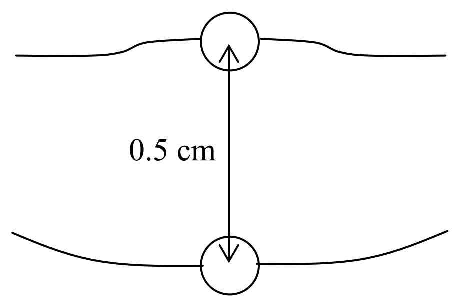
Lab 3: Charge on tape

With your partners, work these problems in your lab notebooks. You should finish these problems in about 35 minutes, to leave time to do the experiment.

1. At location A there is an electric field of $\vec{E}$=<5x10^4, 0, 0> N/C . A tiny plastic ball, which has been rubbed all over with wool and has acquired a charge distributed uniformly over its surface, is placed at location A.

The ball experiences an electric force of $\vec{F}$ = <-2x10^{-6}, 0, 0>N. **What is the amount of charge on the ball?**

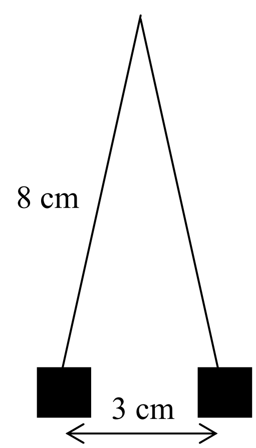
2. Two small plastic balls, each of mass 2 g, are rubbed all over with wool, and both acquire the same amount of charge. Attached to each ball are four insulating nylon strings arranged so that the balls may only move in the vertical direction. When one ball is held above the other as shown, the top ball "floats" about half a centimeter above the other ball, and the strings attached to it become slack (i.e., they exert no upward force on the ball.)



What is the approximate amount of charge on each ball?

Can you determine the sign of the charge, or only the absolute value?

3. Two small hollow glass cubes, of mass 1.4 g, are each rubbed with silk, and acquire a positive charge. The cubes hang motionless from strings, as shown in the diagram. The lengths of the strings are 8cm.



What is the approximate amount of charge on each cube?

What simplifying approximations did you have to make to get this answer?

CHECKPOINT 1: Have an instructor check your work, for credit. Proceed to the next section while you wait.

Design and carry out an experiment to determine, approximately, how much charge is on a piece of charged invisible tape. In designing your experiment, think about problems you have worked which may give you some hints. Available equipment: invisible tape, meter stick. We have also measured the mass of 1m of tape (0.00125 kg per meter).

EXPERIMENT DESIGN: In your lab notebook, make a clear and understandable diagram of your experimental setup.

In this diagram, show and label all objects. Show and label any quantities that you will need to measure. Do not show forces; they will be shown later in a physics diagram. From your diagram it must be clear exactly what you will measure. Another person should be able to repeat your experiment from looking at your diagram.

CHECKPOINT 2: You must have your experimental design approved by an instructor before going on.

MEASUREMENTS: Clearly record all measurements you make in your lab notebook. Make sure you measure all relevant distances.

PHYSICS DIAGRAM: Draw a clear physics diagram, in your lab notebook, showing all vector quantities (such as forces) with labeled arrows.

CALCULATIONS: Calculate the following, in your lab notebook:

1) What is the amount of charge on one of your tapes, in Coulombs. Show every step in your work, starting from fundamental physics principles (e.g., the momentum principle).

2) How many excess electrons produce this charge? Show your work.

3) What approximations did you make in your analysis? State these clearly. (This is important!)

4) Lower bound on reasonable answers: What is the smallest amount of charge that could possibly be on a charged tape? Explain briefly. Is your answer larger than this number?

5) If you assume the tape is made entirely of carbon atoms (atomic mass 12), estimate the largest amount of charge that could possibly be on a charged tape. Show all steps in your work (make your reasoning clear). Is your answer smaller than this number?

6) Calculate the fraction of the molecules on the surface of the tape which gained or lost one electronic charge. (see p. 477 for a discussion of how to estimate the number of molecules on the surface of the tape). Show all your work clearly.

CHECKPOINT 3 Have an instructor check your work for credit. You may begin your Lab Webassign exercise while you wait.

Lab 4: Calculating and displaying the electric field of a dipole

Write a VPython program which does an exact calculation of the electric field of a dipole, and displays the field at 22 locations.

The dipole consists of:

- a particle of charge +*e* located at <-0.5e-10, 0, 0>, represented by a red sphere, and
- a particle of charge –*e* located at <+0.5e-10, 0, 0>, represented by a blue sphere.

The observation locations should be:

- 12 locations evenly spaced on a circle of radius 2e-10 in the xy plane, centered on the dipole
- 12 locations evenly spaced on a circle of radius 2e-10 in the xz plane, centered on the dipole

At each location you will display an arrow representing the net electric field at that location, due to both of the charges in the dipole.

2. Diagram

On paper, make a careful 2D diagram of the system, in the *x*y plane. ***Each particle and vector should be labeled with the name you will use for it in your program.*** Your diagram should include:

- both charged particles
- a single observation location (not on an axis)
- all relative position vectors you will need (think about what the "source" charges are)
- the individual electric field vectors you will calculate (just estimate their directions, and draw arrows)
- the net electric field vector at the observation location (estimate this and draw an arrow)

CHECKPOINT 1. Ask an instructor to check your work, for credit.

3. Writing the program

On the lab software site (http://web.ics.purdue.edu/~jyeazell/Phys272Lab.htm), right click and save the template program, **EfieldDipole.py**.

<u>*Constants*</u>
Some values of the physical constants you will need are present. A scale factor is also present with the temporary value of 1.0 (you will change this later). If you need other constants later, please define them in this section of the program.

Objects
You will use two spheres to represent the two charged particles. Each has a radius of 1E-11 m and the correct positions. The negative charge is cyan and the positive charge is red.

Initial values
To get started, you will calculate the net electric field at one observation location. Later you will modify this, and write a loop to calculate and display the electric field at many observation locations. You will need to have a variable that contains the value of the observation location, so we have created this vector with an initial value of < 2E-10, 0, 0> m

obslocation = vector(2e-10, 0,0)

Calculations
You can't use the approximate formula for a dipole in these VPython calculations, because you are going to calculate the field at many locations where that formula doesn't apply. You must go back to the superposition principle. At each observation location, you must calculate the electric field due to the positive charge, the electric field due to the negative charge, and the net electric field, which is the sum of these two.

- Calculate the net electric field at location < 2E-10, 0, 0> m. This value is printed to the shell window.
- To check that your calculation is correct within an order of magnitude, compare your answer to the answer you get using the approximate formula for the electric field of a dipole (on your calculator).

Arrow representing electric field
Figure out approximately what value you will need for a scalefactor to make an arrow representing the electric field at the observation location an appropriate size for your display.

- How did you estimate the value of your scale factor? Your instructor will ask you to explain this.

- Create an arrow representing the electric field at the observation location, and scale it appropriately, so both of the charges and the field vector are clearly visible.

4 Adding more observation locations

To see the pattern of electric field around a charged particle, you will extend your program to calculate the electric field at 12 locations, all lying on a circle of radius 2e-10 m, centered on the dipole in the *xy* plane.

Instead of copying and pasting code 12 times, you will put your calculation in a loop. In an earlier program, you wrote a loop to create a circle of spheres. You may want to refer to this earlier program.

Calculating electric field at multiple locations on a circle surrounding the dipole

In your initial values section set the angle to zero.
##initial values
theta = 0

In your calculations section set up the theta loop as follows.
##calculations
while theta < 2*pi: #Note that pi is defined for you in Vpython
calculate new vector value for obslocation, using this angle
[your code here]
use superposition principle to calculate Enet at obslocation
[your code here]
print values of obslocation, and Enet vector
create an arrow to display Enet at obslocation, and scale it
[your code here]
calculate new value of theta

- Run your program. It should calculate and display the electric field as arrows at 12 locations on a circle surrounding the particle. Do not display the relative position vectors – there are too many of them, and they will clutter up the display.
- Your program should print the value of each observation location, and **Enet** at that location.
- LOOK at your display. Does it make sense? Do the magnitudes and directions of the 12 orange arrows make sense.

5 Adding more locations in a different plane

- Finally, add code to compute and display the electric field at 12 evenly spaced locations lying on a circle in the *xz* plane. There are several ways to achieve this; work with a partner to figure out one that works.

- Note that two of the locations (on the *x* axis) will be the same as two of the previous locations. This is okay. The electric field arrows at these two locations should overlap completely -- it should look as if there is only one arrow there.

CHECKPOINT 2. Ask an instructor to check your work, for credit. You may proceed to the group problems while you wait.

Group Problems

Do the following problems in your lab notebooks:

- 15.P.35 and 15.P.39

CHECKPOINT 3. Ask an instructor to check your work, for credit. You may proceed to your Lab Webassign exercise while you wait.

Lab 5: Electric field of a uniformly charged rod

The goal of this VPython problem is to write a program to calculate and display the electric field of a uniformly charged rod at locations not in the plane bisecting the rod (in other words, at locations where the analytical formula DOES NOT apply).

The rod has a length 2m, and a total charge of 3e-8 C. You will divide the rod into a number (N) of pieces, which you will approximate by point charges; then apply the superposition principle to get the net field at the observation location.

In your program, you will write a loop to "step" through the rod piece by piece, starting at the left end and moving to the right. For each piece, you will find $\Delta\vec{E}$, the contribution of that piece to the net field at the observation location.

The following questions will help you create algebraic expressions for important quantities to use in the program.

Planning: Do sections 1-5 in your lab notebook.

1) Diagram. Consider a rod of length 2 m, oriented along the x-axis, with the center of the rod at the origin. The rod is positively charged. Initially you will divide it into 6 equal length segments. Initially the observation location will be <0.3, 0.4, 0>m. Draw axes, the rod, the segments, the observation location, and what you expect the net electric field to look like at this observation location.

2) You will start by approximating the rod as 6 point charges. What is the length of each "point-like" segment of the rod?

Now write a general symbolic expression for the calculation you just did: If the length of the rod is L, and the number of pieces is N, what is a symbolic expression for Δx, the length of one piece, in terms of L and N?

3) What is the amount of charge on each of the 6 pieces?

Now write a general symbolic expression for the calculation you just did: If the total charge of the rod is Q, and the number of pieces is N, what is a symbolic expression for ΔQ, the amount of charge on one piece, in terms of Q and N?

4) What is the position vector of the *center* of the leftmost piece of the rod (relative to the origin)?

Now write a general symbolic expression for the calculation you just did: If the length of the rod is L, and the length of one piece is Δx, what is the position of the center of the leftmost piece of the rod? Your answer should be a vector (relative to the origin.) (Hint: what is the x-coordinate of the left end of the rod?)

5) What is the position vector of the center of piece #2?

What quantity did you have to add to the x-coordinate of piece #1 to get the x- coordinate of piece #2?

What quantity, expressed symbolically, will you add to the x-coordinate of the current source location to get the x-coordinate of the next piece?

CHECKPOINT 1: Have an instructor check your diagram and your plan, for credit.

6) Program organization. Your program will have 5 sections:

#constants

#initial values

#first loop to create objects (spheres) representing the pieces of the rod

#second loop to calculate net electric field at observation location,
#due to all the point-like pieces of the rod

#finally, create an appropriately scaled arrow to visualize the net electric field
at the observation location; and print the value of net field

(Note: This is a simple way to organize the program; if you are a skilled programmer you are free to use more advanced features of Python to do this more elegantly.)

6.1) #constants

Start your program with the usual two lines (remember that the second line has 4 underscores)

```
from visual import *
from __future__ import division

#constants
L = ??? ## see problem statement
N = 6 ## to begin with; you will change it later
Q = ??? ## see problem statement
oofpez = 9e9
scalefactor = 1.0 ## not the correct value; you will change it later
deltax = ??? ## use your symbolic expression from above
deltaQ = ??? ## use your symbolic expression from above
```

6.2)#initial values

Give the variable *x* the initial value of the *x*-coordinate of the center of piece 1, using your symbolic expression from above. This is the *x*-component of the position vector for the location of the center of piece 1.

x = ???

6.3)#first loop to create spheres representing the pieces of the rod

Now write a loop to create a red sphere, with radius deltax/2, at the center of each piece of the rod. You should end up with N red spheres in a line on the x-axis.

```
while x < ???:
        sphere(pos = ??? #remember that .pos is a vector
        # now add the appropriate constant to x to get the position of the next sphere
```

RUN THE PROGRAM. Does it display 6 spheres in a line on the x-axis?
SELF CHECK: Change the value of N to 15. Does your program display 15 spheres?

6.4) #second loop to calculate the net electric field at a single observation location

In the #constants section, change N back to 6.

After the first loop that creates and displays the spheres, ***un-indent your code***.

- Give an initial value of < 0.3, 0.4, 0> to "obslocation".
  obslocation = ???

- Create a vector named Enet that starts off with zero values for each component:
  Enet = vector(0,0,0)

- Set "x" back to the value it had initially before you created the spheres (just copy the line you used before).

- Now write a second loop to do the following:
  1. loop through the locations of the source charges (the "point charges" represented by the spheres)
  2. for each point charge, calculate deltaE ($\Delta\vec{E}$) at the observation location due only to that "point charge"

(Note: because the spheres don't have names, you can't use sphere.pos ***here; to calculate $\vec{r}$ you must first create a vector that is the position of the center of the piece of interest. You might call the vector*** **sourcelocation*)***

3. add this contribution of deltaE to the net field Enet:

Enet = Enet + deltaE

6.5) #displaying an arrow

After the second loop, un-indent your code.

• Print the value of Enet. Also print the magnitude of Enet.
• Create an orange (color.orange) arrow at the observation location to represent Enet. Note, you will need to figure out a scale factor. Look at the printed value of Enet to figure this out.

SELF CHECK: What is the value of Enet when N = 6? When N=10? When N=25? When N=50? Do your results make sense?

CHECKPOINT 2. Ask an instructor to check your work, for credit.

7) Make sure you understand the organization and functioning of your program, because:

When you do your WebAssign, you will be asked to change some or all of the following quantities, and report on the results:

- Number of pieces into which the rod is divided
- Observation location
- Amount of charge on the rod
- Length of the rod

Lab 6: Measuring Potential Differences

1 Setting up the voltmeter

You will use a digital multimeter to measure potential differences. Since the meter can measure different things, you need to set it to measure DC voltages.

Plug the red probe lead into the leftmost socket, labelled VΩ.
Plug the black lead into the socket labelled COM.

Set the dial to the Volts DC function (⎓ V).

Don't use other functions than Volts DC at this time (you could blow a fuse in the meter).

You may have expectations about the outcomes of the following measurements. However, **Record your actual measurements, not your expectations!**

2 Measuring ΔV

Record all your measurement from the voltmeter and answer all the questions in your lab notebook:

a) Touch the black and red leads together and record the reading on the voltmeter:

b) Get a connecting wire (with alligator clips on the ends) from the electricity experiment kit. Clip one end of the wire to the red lead, and the other end to the black lead. What is the reading on the voltmeter?

c) Take a single battery (no battery holder). Touch the red lead to the end of the battery marked +, and the black lead to the other end. What is the reading on the voltmeter?

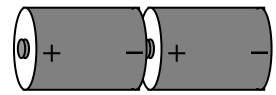
If the symbol "OL" (overload) appears on the display you may have to press and hold the range button to turn on the autoranging of the meter.

d) Reverse the leads of the voltmeter, so the black lead now touches the positive end of the battery and the red lead the negative end of the battery. What is the new reading

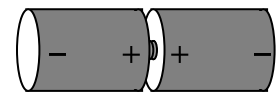
e) To get a positive reading, which voltmeter lead should touch the negative end of the battery?

f) Use a ruler to measure the length of the battery. What is the magnitude of the average electric field inside the battery? Show your calculations.

g) Take a second battery. Put the batteries end to end, so the negative end of one touches the positive end of the other. Measure the potential difference across the two batteries:



h) Turn one of the batteries around and repeat the measurement. What is the potential difference?

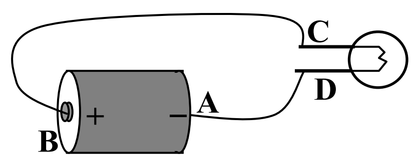


CHECKPOINT 1: Have an instructor check your work, for credit.

i) In the kit are two kinds of light bulbs: short round light bulbs, and long light bulbs.

Use only ONE battery, ONE ROUND light bulb, and ONE connecting wire from the kit. (Do not use a socket or a battery holder). Make the light bulb light. Draw a diagram showing your circuit:

Now put the battery into the battery holder. Using two connecting wires (with alligator clips), one battery, one socket, and a ROUND light bulb, connect the circuit shown at right, so that the bulb is lights when you make the last connection.



Measure and record the following potential differences and the between the points indicated below, and calculate the magnitude of the electric field between these points.

Be careful about signs. Keep the leads in the same relative position for all measurements. That is always place the black on the first point indicated, e.g. for (1) below the black lead is connected to A and the red lead is connected to B.

Some values should be positive, others negative. **Make sure the bulb is lit for each of the following measurements (j thru m):**

j) From A to B across the battery

V_{AB}= L_{AB}= $\left|\vec{E}_{AB}\right|$=

k) From B to C across a connecting wire (make sure the voltmeter is on the most sensitive scale)

V_{BC}= L_{BC}= $\left|\vec{E}_{BC}\right|$=

l) From C to D (the length of the actual filament, uncoiled, is 1 cm)

V_{CD}= L_{CD}=0.01m (uncoiled) $\left|\vec{E}_{CD}\right|$=

Is the filament in static equilibrium? How do you know?

m) From D to A the other connecting wire (use the most sensitive scale on the voltmeter)

V_{DA}= L_{DA}= $\left|\vec{E}_{DA}\right|$=

Disconnect the one of the connections so the bulb is no longer lit.

p) What is the round trip potential difference from A to B to C to D back to A? Show your calculation:

q) Take the bulb and socket out of the circuit. Measure the potential difference across the bulb.

V_{bulb}= Is it in static equilibrium?

CHECKPOINT 2: Have an instructor check your work, for credit. You may proceed to the group problems while you wait.

Group Problems

Do the following problems in your lab notebook:

- 16.P.43.,16.P.52, 16.P.66

CHECKPOINT 3: Have an instructor check your work, for credit.

There is no Webassign exercise this week!

Lab 7: Magnetic field of current-carrying wires.

1. Observing a compass deflection due to a magnetic field

Make a two-battery circuit with a **ROUND** bulb in a socket, using a battery holder, as shown in Figure 1. **Leave the last connection undone (bulb not lit)**.

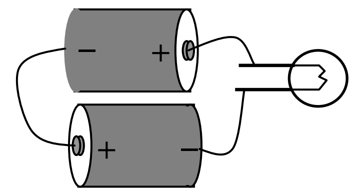


Figure 1. two battery, round bulb circuit

Place your magnetic compass on a flat surface under one of the wires (Figure 2). Keep the compass away from steel objects, such as the steel-jacketed batteries, and the alligator clips on the ends of your wires. (For flexibility in placement, you may find it useful to make a long wire by connecting two of your wires together.)

Align the compass so the arrow on the plastic case is aligned with the needle, which is pointing North.

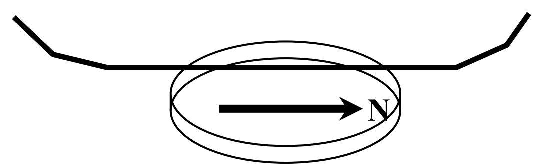


Figure 2. Wire parallel to North.

Make the last connection so that the bulb glows (the bulb must glow!), and do the following:

- Lift the wire up above the compass.
- Orient a section of the wire to be horizontal and lined up with the compass needle. (Using a long wire may make it easier to do this.)
- Bring the aligned wire down onto the compass (Figure 2)

(a) What is the effect on the compass needle as you bring the wire down on top of the compass?

(b) Turn the wire, so the current flows in the opposite direction over the compass. What do you observe?

(c) What happens when the wire is initially aligned perpendicular instead of parallel to the needle (Figure 3)?

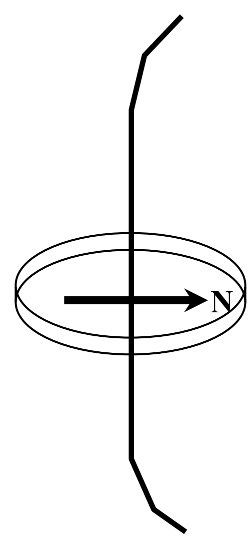


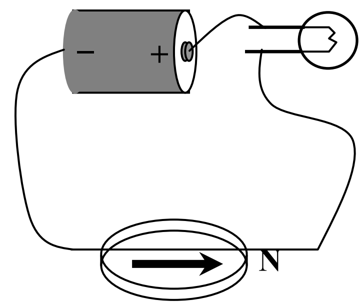
Figure 3. Wire aligned perpendicular to North.

(d) Undo the last connection (bulb not glowing), and repeat the measurement. What happens?

2. Measurement of magnetic field made by moving electrons in a wire

As discussed in the textbook (Sec. 17.2, pp. 588-589), a compass points in the direction of the net magnetic field at the location of the compass. When a current flows through a wire the moving electrons create a magnetic field everywhere in space. A compass placed under a wire is affected by magnetic fields from two sources: (1) the Earth, and (2) the current in the wire. See figure 17.5 on page 589 of the textbook.

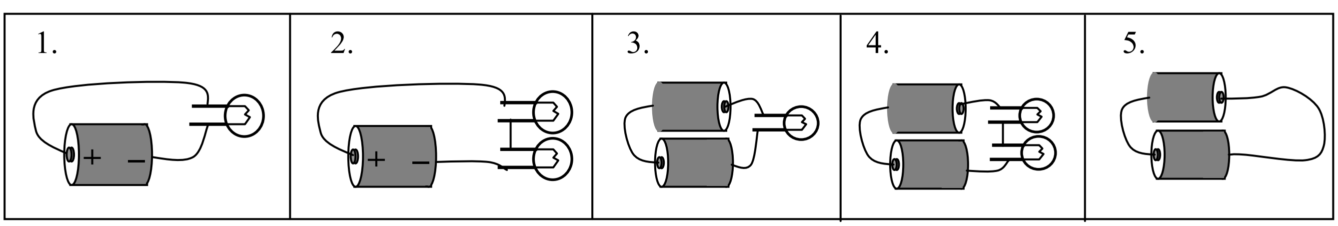
- Move all wires and batteries far from the compass, so the compass points North. Assemble a circuit consisting of one battery and one round bulb. You should use a socket and a battery holder. Make sure the bulb lights, then undo a connection. Align one wire carefully with the compass needle then make the connection. Don't move the compass! Carefully measure the compass deflection (to the nearest 2 degrees) when current is flowing through the circuit.



Show in detail your calculation of the magnetic field made by the current in the circuit. **Include a clear vector diagram**. At this latitude, the horizontal component of the Earth's magnetic field is approximately 2 x 10^{-5}T.

CHECKPOINT 1: Have an instructor check your work, for credit.

- In the following circuits, you will use sockets and battery holders. For each of the following circuits, use a compass to measure the magnetic field made by the moving electrons in the current.



  - Make and break the connection to the battery or batteries, to be sure you are observing a genuine deflection each time.
  - For each circuit make 2 measurements, and use the average value to calculate the magnitude of the magnetic field at the location of the compass.
  - Record your observed values in the table below.

Circuit	brightness (Hi, Med, Lo)	deflection (degrees)	deflection (degrees)	average $\left\|\vec{B}\right\|$, in units of Tesla
1. One battery, one round bulb				
2. One battery, two round bulbs				
3. Two batteries, one round bulb				
4. Two batteries, two round bulbs				
5. Two batteries, wire, no bulbs	Not applicable			

- Rank order the circuits above in terms of the magnitude of the magnetic field due to each circuit (e.g. one possible but not necessarily correct ranking is $\left|\vec{B}_3\right| > \left|\vec{B}_2\right| > \left|\vec{B}_5\right| = \left|\vec{B}_1\right| > \left|\vec{B}_4\right|$).

    - If your values of magnetic field do not agree with your observations of bulb brightness, you need to repeat your experiments!

CHECKPOINT 2: Have an instructor check your work, for credit.

3. Distance dependence of the magnetic field of a long, straight current-carrying wire

You will need *one battery, two clip leads, a compass, a meter stick, and a long wire (~ 1 m)*.

- As accurately as you can, measure the distance dependence of the magnetic field due to a current in a long straight wire. Make sure that the straight segment of the long wire is **at least 60 cm long**.

    - ***Using one battery and no bulb, first find a distance from the compass that produces a 40 degree deflection.*** We will call this distance r_{40}. Make and break a connection each time to be sure you are observing a genuine deflection each time. Make and record 3 measurements of the distance in the table on the following page.

- Next change the distance of the wire to the compass so that it is 1.5 times the average value of r_{40}, and make three more measurements of the deflection.

- Do the same for 1.75 times the average value of r_{40}, and for 2 times the average value of r_{40}. At each distance, compute an average value for the magnetic field.

Distance from wire (m)	compass deflection (degrees)	calculated $\|\vec{B}\|$, (T)	average $\|\vec{B}\|$, (T)
r_{40}=	40		XXXXXXXXXX
r_{40}=	40		XXXXXXXXXX
r_{40}=	40		XXXXXXXXXX
$r_{40,average}$=	40		
1.5 x ($r_{40,average}$)=			XXXXXXXXXX
1.5 x ($r_{40,average}$)=			XXXXXXXXXX
1.5 x ($r_{40,average}$)=			
1.75 x ($r_{40,average}$)=			XXXXXXXXXX
1.75 x ($r_{40,average}$)=			XXXXXXXXXX
1.75 x ($r_{40,average}$)=			
2.0 x ($r_{40,average}$)=			XXXXXXXXXX
2.0 x ($r_{40,average}$)=			XXXXXXXXXX
2.0 x ($r_{40,average}$)=			

A simple and useful approach to extracting the distance-dependence from your experimental data involves making a logarithmic plot of your observations. Here is why:

- Assume that the magnitude of the magnetic field due to the current in the wire is proportional to some constant times some power of the distance. We can write this dependence as: $|\vec{B}| = Kr^n$. We expect the magnitude of the magnetic field to decrease with distance, so *n* should be a negative number. For example, if $|\vec{B}| = Kr^{-2}$, then *n*=-2 , and so on.

- From a plot of $|\vec{B}|$ vs. *r*, it is difficult to tell exactly what your experimental value of *n* is, unless you use curve-fitting software.

- However, if we take the logarithm of both sides of the initial equation, we get:
  $$\ln|\vec{B}| = \ln(Kr^n) = \ln(K) + n\ln(r) .$$

- Since $\ln\left|\vec{B}\right|$ and $\ln(r)$ vary, but *n* is a constant (and *K* is also constant), a plot of $\ln\left|\vec{B}\right|$ vs. $\ln(r)$ will give a straight line with slope *n* (and $\ln(K)$ intercept). Use Excel to make this plot and find *n*. Record it in your notebook.

You may already know what the theoretical prediction for *n* is for a long straight wire. Do your experiments agree?

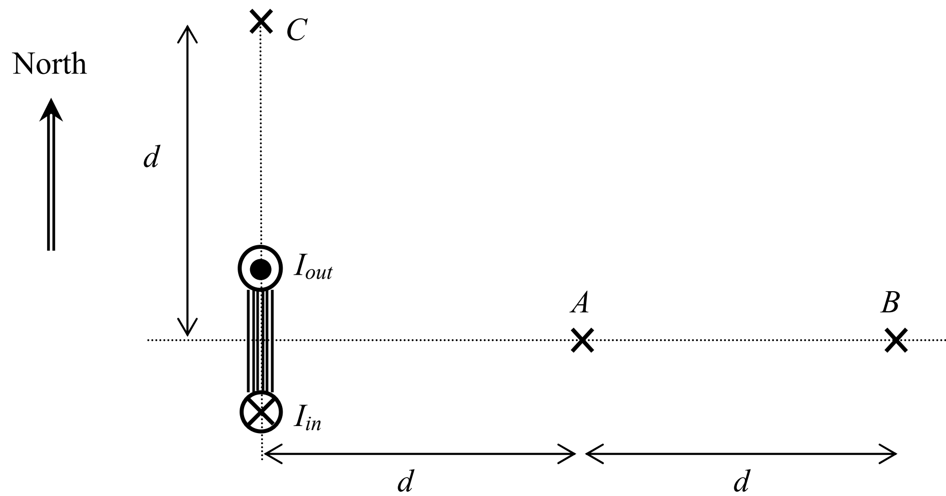
CHECKPOINT 3: Have an instructor check your work, for credit.

There is no webassign exercise for Lab 7.

Lab 8: Magnetic Dipoles

Part I: Predict the magnetic field near a coil of wire carrying a current *I*:

The coil is oriented with the symmetry axis pointing East-West, as shown in the diagram. The coil is shown as a cross-section so that the current flows "out of the paper" at the top and "into the paper at the bottom of the coil .



- **Draw on the diagram your prediction for the magnetic field from this magnetic dipole at the three points A, B, and C.**

Part I: Measuring the magnetic field near a coil of wire:

Take an insulated wire 1 or 2 meters long and wrap a coil of about 20 turns loosely around two fingers. Twist the ends around the coil to hold it together, and remove the coil from your fingers. Attach clip leads so you can connect the coil to **one** battery but do not make the last connection yet.

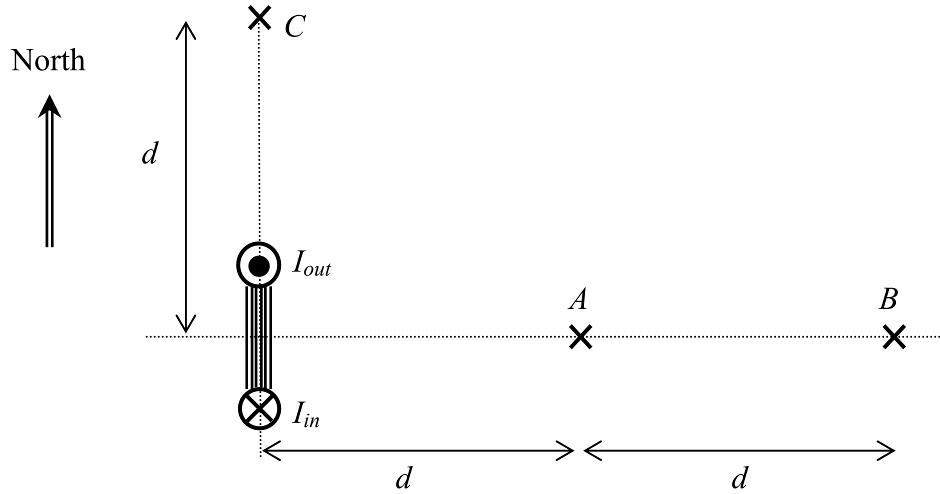
Orient the coil perpendicular to the table, with its axis pointing East-West, as shown in the diagram. Make sure the current will flow as indicated. Note that electrons leave the negative pole of the battery, so "conventional current" leaves the positive pole of the battery.

- Make the last connection and find the location *A* along the axis of the coil, so that the needle of a compass is deflected by 50°. Measure this distance *d* carefully and record the result below in the table.

- Using this value of *d* to set the locations of points *B* and *C* measure the compass deflections at *B* and *C*. Note it is easier and the measurements are more accurate if you move the coil rather than moving the compass!

(I.a) At each location (A, B, C), draw and label two arrows:

- *Direction of compass needle* (draw accurate deflections)
- *Direction and relative magnitude* of the magnetic field due to the coil



(I.b) Record these values:

number of turns in coil	
coil radius	
distance *d* (50° deflection)	
compass deflection at *A*	
compass deflection at *B*	
compass deflection at *C*	

DISCONNECT THE BATTERY FROM THE CIRCUIT AFTER THESE MEASUREMENTS!

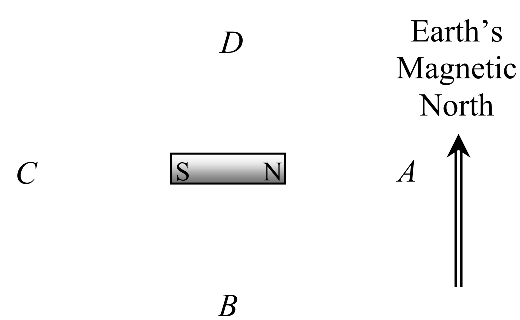
(I.c) How well does your measured values of the magnetic field match your earlier predicted values? Is the pattern of magnetic field you observe characteristic of a dipole? Why or why not?

(I.d) Calculate the magnitude of the conventional current running in the coil. Show your work.

CHECKPOINT 1: Have an instructor check your work, for credit

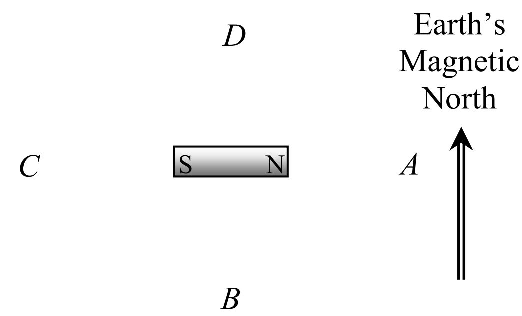
Part II: Predicting and measuring the magnetic field near a bar magnet:

Predict the direction and relative magnitude of the magnetic field at each of the points A, B, C, and D (on the diagram at right). Draw arrows representing the magnetic fields at each location.



Now use a compass to measure the magnetic field at each of these points and draw arrows representing:

- The direction the compass needle points
- The direction and relative magnitude of the magnetic field due to the bar magnet.



Look at the pattern of magnetic field you have recorded. Does it make sense?

(II.b) Distance dependence of magnetic field:

Carefully align the magnet and compass as in position A in the diagram above. Move the magnet toward or away from the compass until the deflection is 70°, and record this distance (d_{70}) below. Measure the deflection for twice d_{70}.

Calculate the magnetic field at these two locations and find the distance dependence. Record these quantities listed in the table and show your calculations in your notebook.

II.b.1) center-to-center distance for 70° deflection (d_{70})	
II.b.2) calculated magnetic field of magnet at d_{70}	
II.b.3) deflection at 2 times d_{70}	
II.b.4) calculated magnetic field of magnet at 2 d_{70}	
II.b.5) distance dependence; n = ?	

Remember that if $\left|\vec{B}\right| = Kr^n$, then $\left|\frac{\vec{B}_{2d}}{\vec{B}_d}\right| = \frac{K(2d)^n}{K(d)^n} = 2^n$, and $\ln\left|\frac{\vec{B}_{2d}}{\vec{B}_d}\right| = \ln(2^n) = n\ln(2)$

(II.c) Magnetic dipole moment of bar magnet

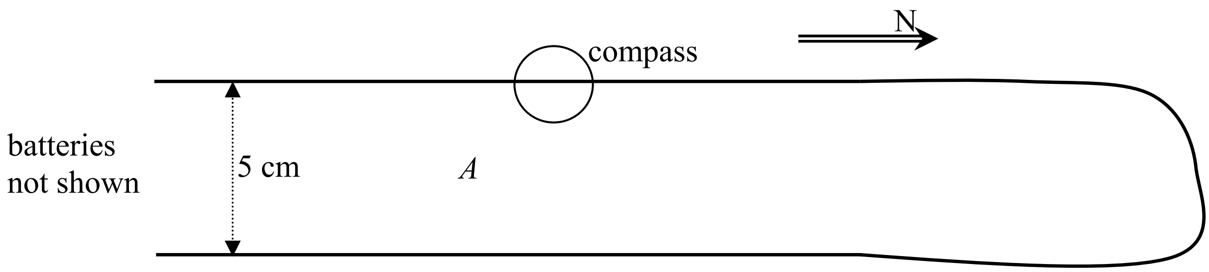
Using data from measurement **(II.b.1)** (70° deflection) above, calculate the approximate magnetic dipole moment of your bar magnet. Show your calculations, which should be organized clearly and legibly.

CHECKPOINT 2: Have an instructor check your work, for credit

Group Problems (do in lab notebook)

Problem 1: Magnetic fields near a wire

A wire is connected to batteries not shown in the diagram and a current runs through the wire. The wire lies flat on a table, except where it passes over a compass at a height of 0.004m above the compass needle. The diagram is a top view looking down at the table. The compass needle is deflected 12 degrees East of North (East is down on the page).

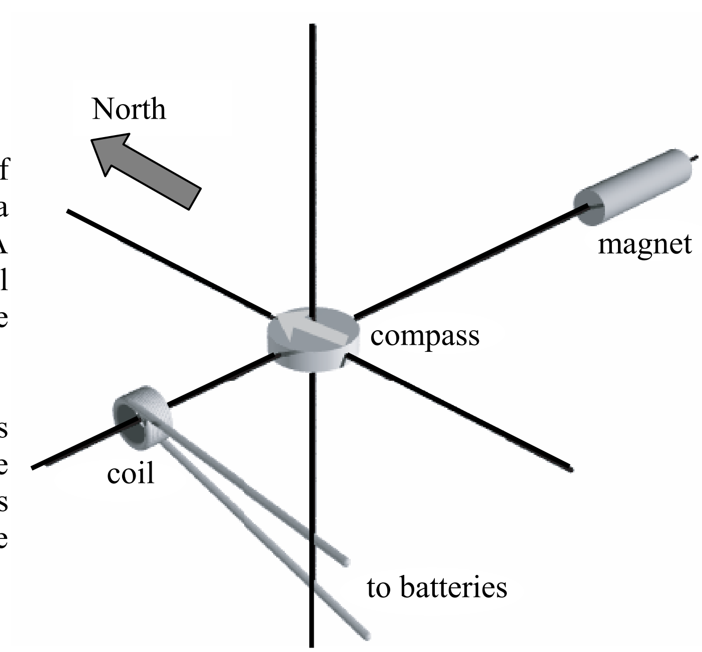


Find the magnetic field at location *A* due only to the current in the wire. This point is midway between the two straight sections of wire (0.025m from each). If you make any assumptions or approximations, state them.

Problem 2: Magnetic Dipole Moment

You make a coil of wire with 12 turns of radius 0.01m. You connect the coil to a battery and a conventional current of 6A runs through the coil. You place the coil 0.11 m away from a compass (see diagram).

A bar magnet lies along the opposite axis with its center 0.25m away from the compass. The compass needle points North. What is the magnetic dipole moment of the bar magnet?



CHECKPOINT 3: Have an instructor check your work, for credit.
There is no webassign exercise for Lab 8.

Lab 9: Energy conservation in circuits; charge on a capacitor

1 Using an ammeter

Set up the digital multimeter to be an ammeter. Since you will be measuring currents larger than 200 mA, it is important to set up the meter correctly, so you do not blow a fuse and render the meter useless.

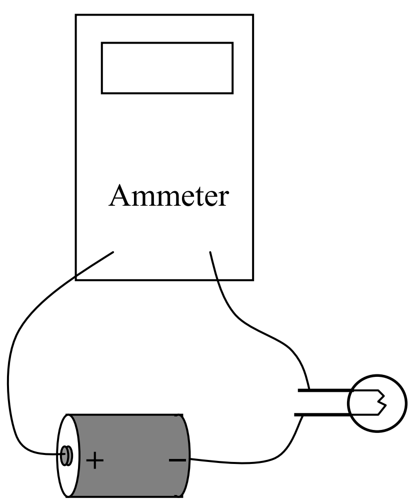
- Connect the black wire to COM, as shown at right.
- Connect the red wire to the leftmost connector, labeled **10A**.
- Set the dial to **10A** .

Don't use other functions than 10A at this time (you could blow a fuse in the meter).

You may have expectations about the outcomes of the following measurements. **Record your actual measurements, not your expectations!**

2 Measuring Current

Unlike a voltmeter, an ammeter must be inserted into a circuit. Set up the following circuit, using one battery and one round bulb, BUT DO NOT MAKE THE FINAL CONNECTION UNTIL AN INSTRUCTOR HAS CHECKED YOUR SETUP. You may want to use clip leads to connect the ammeter probe wires to the circuit.



CHECKPOINT 1: Do not make final connection until checked by instructor!

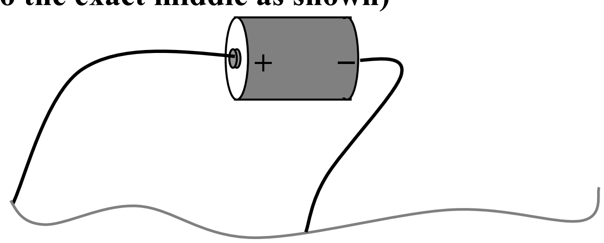
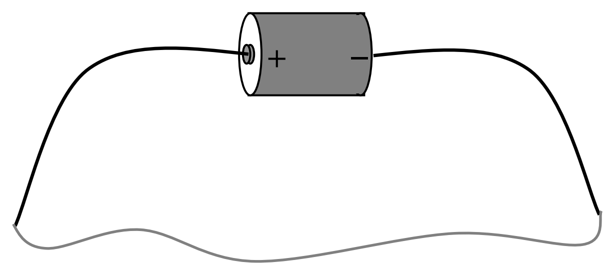
What is the current in this circuit? ___________________

Predictions (based on fundamental principles) and Experiments

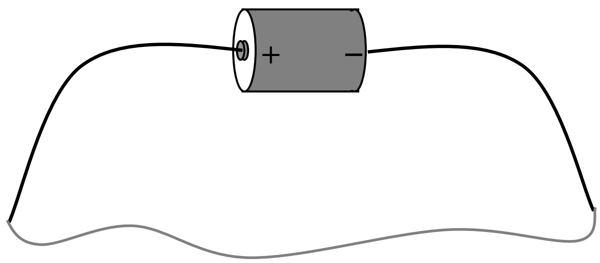
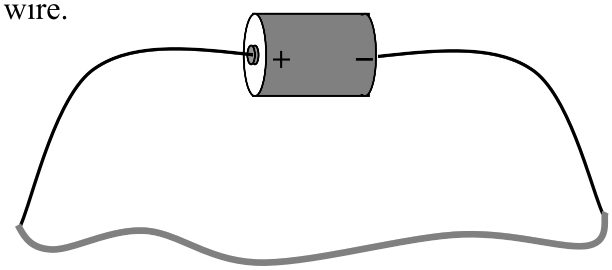
For each circuit depicted below,
(1) write an energy conservation (round-trip) equation
(2) solve symbolically for E in terms of the length of the wire ($L/2$ or L) and the **emf** of the battery.
(3) using basic equations relating current and electric field, predict how the current in the circuit on the left should compare to the current in the circuit on the right.
(4) insert an ammeter into the circuit, and measure and record the current in each circuit.

- Find the two nichrome wires in your experiment kit. Make sure that you have one thick and one thin wire. It is easier to compare the wires by touching them than by looking at them. The ratio of their cross-sectional areas is approximately 2:1.

I. Length Dependence

<table>
<tr><td>Circuit 1: Thin Nichrome wire of length L/2
(Do not cut the wire! Connect the clip lead to the exact middle as shown)

</td><td>Circuit 2: Thin nichrome wire of length L.

</td></tr>
<tr><td>1.1 Write Energy Conservation Equation.</td><td>2.1 Write Energy Conservation Equation.</td></tr>
<tr><td>1.2 What is E_1=?</td><td>2.2 What is E_2=?</td></tr>
<tr><td colspan="2">3. Predict how will i_2 and i_1 be related, i.e. current i_2= _______ x i_1 ? Why?</td></tr>
<tr><td>1.4 What is the observed current i_1?</td><td>2.4 What is the observed current i_2?</td></tr>
</table>

II. Cross-sectional area dependence

Circuit 3: Entire length of thin Nichrome wire 	Circuit 4: Same length of Thick Nichrome wire. 
3.1 Write Energy Conservation Equation.	4.1 Write Energy Conservation Equation.
3.2 What is E_3=?	4.2 What is E_4=?
3. Predict how will i_4 and i_3 be related, i.e. current i_4= _______ x i_3 ? Why?	
3.4 What is the observed current i_3?	4.4 What is the observed current i_4?

III. Doubling the EMF

Circuit 5: The Entire length of thin Nichrome wire across one battery	Circuit 6: The Entire length of thin Nichrome wire across Two batteries
5.1 Write Energy Conservation Equation.	6.1 Write Energy Conservation Equation.
5.2 What is E_5=?	6.2 What is E_6=?
3. Predict how will i_6 and i_5 be related, i.e. current i_6= _______ x i_5 ? Why?	
5.4 What is the observed current i_5?	6.4 What is the observed current i_6?

Checkpoint 2 Have an instructor check your work for credit.

IV: Charging and discharging capacitors

You will need two batteries, connecting wires, round bulb, long bulb, socket, capacitor, stopwatch.

- In each case, record your observations in your notebook, then repeat them and time the phenomenon. Record these times in your notebook.

1) To make sure the capacitor is discharged, connect a wire across it for several seconds.

2) Connect the capacitor in series with a ROUND bulb and two batteries (Fig. IV.1). What do you observe? How long until the bulb is again dark?

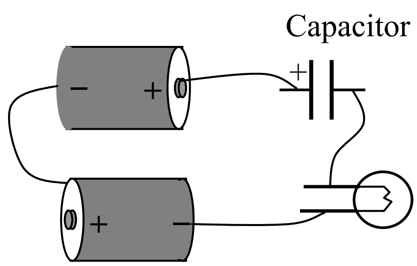


Figure IV.1. Capacitor Charging Circuit

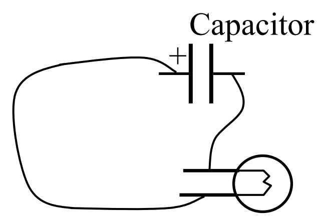


Fig. IV.2 Capacitor Discharging Circuit

3) Remove the batteries and connect the ROUND bulb directly across the capacitor (Fig.IV.2). What do you observe? How long is it till the bulb is dark?

4) Connect the capacitor in series with a LONG bulb and two batteries. What do you observe? How long is it till the bulb is again dark?

5) Remove the batteries and connect the LONG bulb directly across the capacitor. What do you observe? How long is it till the bulb is dark?

V: THE EFFECT OF DIFFERENT BULBS ON FINAL CHARGE OF A CAPACITOR

V.A: HYPOTHESIS: You observed different behavior (time, brightness) when charging a capacitor through a long bulb vs. through a round bulb. In which situation (long bulb vs. round bulb) do you think more charge accumulates on the plates of the capacitor? Formulate a hypothesis about this, and state it clearly. (It is ok if your hypothesis turns out to be incorrect - that's what experiments are for! However, it must be clearly stated, and you must give at least one reason you think it may be correct).

Record HYPOTHESIS and reason in your notebook.

V.B: EXPERIMENT: You will perform the following experiment to test your hypothesis. (If you have a different or better idea for an experiment, check with your instructor before proceeding):

1) Charge the capacitor through the ROUND bulb and then ... Discharge the capacitor through ROUND bulb. Time how long the bulb remains lit.

2) Charge the capacitor through the LONG bulb and then ... Discharge the capacitor through ROUND bulb. Time how long the bulb remains lit.

Think about how this experiment will allow you to determine if your hypothesis is correct or not: **If your hypothesis is correct, what should you observe. Record your prediction in your notebook?**

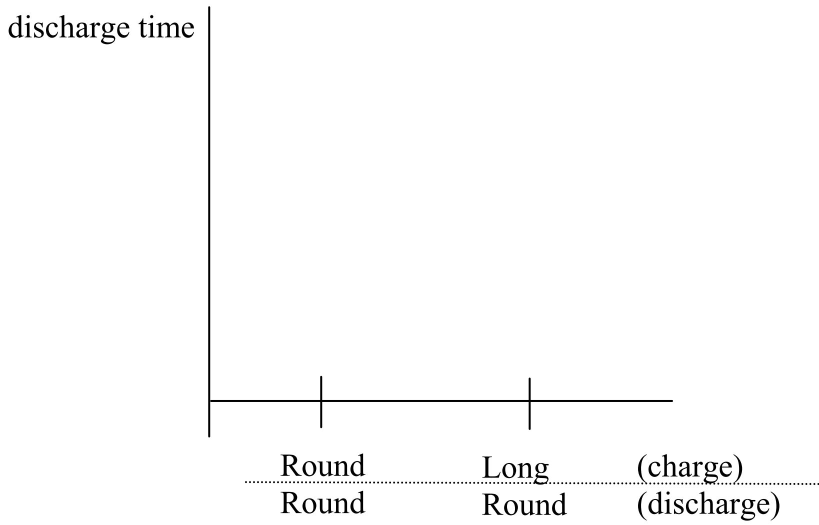
If your hypothesis is incorrect, what should you observe?

V.C: EXPERIMENTAL DATA: Make a table in your notebook like the one shown below. Measure four discharge times each of the two cases. Calculate the average discharge time and either the maximum deviation or the standard deviation for each case.

<u>An explanation of deviation and error bars is on the software webpage</u>

1) Charge with Round Discharge with Round	Discharge time 1	Discharge time 2	Discharge time 3	Discharge time 4	Average Discharge time	Max. or Standard deviation
2) Charge with Long Discharge with Round	Discharge time 1	Discharge time 2	Discharge time 3	Discharge time 4	Average Discharge time	Max. or Standard deviation

V.D: ANALYSIS AND CONCLUSIONS: Record your data on plot like the one shown below. ***For each case, show the average value and the error bars for the discharge time***, based on your data from part V.C above.



Explain clearly and rigorously (do not leave out steps in reasoning) whether your results confirm or contradict your hypothesis.

CHECKPOINT 3: Have an instructor check your work, for credit.

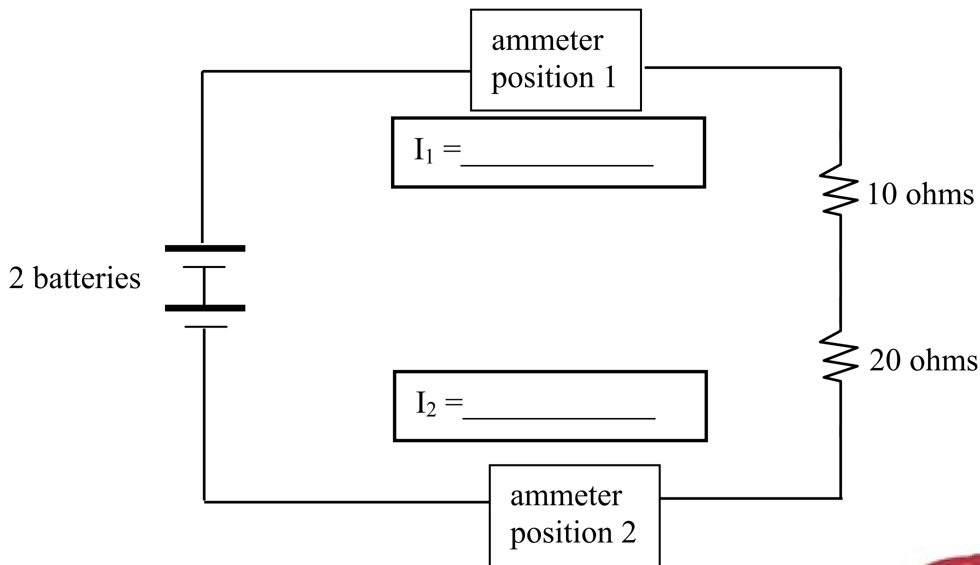
There is no Webassign exercise this week!

Lab 10: Macroscopic View of DC and RC Circuits

You are provided with two different resistors that have approximately 10 and 20 Ohms, respectively.

1. CHARGE CONSERVATION AND ENERGY CONSERVATION IN SERIES CIRCUITS

Predict and record in your notebook the currents I_1 and I_2 that would be measured by the two ammeters in the circuit below:



Next set up a digital multimeter to be an ammeter, i.e.

• Connect the black wire to COM, as shown at right.
• Connect the red wire to the leftmost connector, labeled **10A**.
• Set the dial to **10A** .

Don't use other functions than 10A at this time (you could blow a fuse in the meter).

Assemble the above circuit with the resistors, the ammeter in position 1, and use a clip lead in position 2 (no ammeter). Double check your connections and settings. A wrong connection can blow a fuse or even damage the ammeter! Connect the ammeter in such a way that the ammeter will read positive values. An ammeter will read a positive value if conventional current flows *into* the terminal marked "10A".

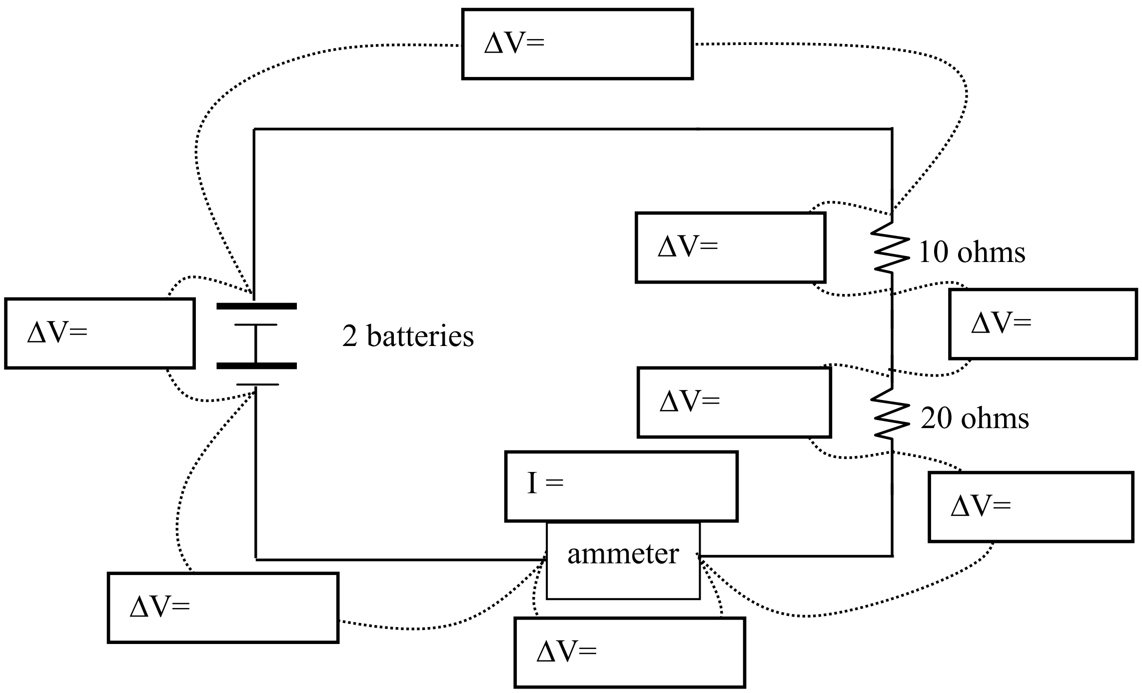
A) After your instructor has checked your circuit, connect the two batteries and **record the ammeter reading for first position 1 and then position 2.** Were your predictions for I_1 and I_2 about right?

B) Reverse the connections to the ammeter to see what the ammeter reads when inserted "backwards."

C) Next, setup your PASCO voltage probe to be a voltmeter. On the lab software page you'll find the file **Voltmeter.ds**. Right click and download it to your desktop (**using the .ds extension**). Double click the file on your desktop and it should open. Click START and touch the red lead to the + side of a battery and the black lead to the – side of that battery. If it is correctly setup the digital display on your computer screen should show ~ 1.5V.

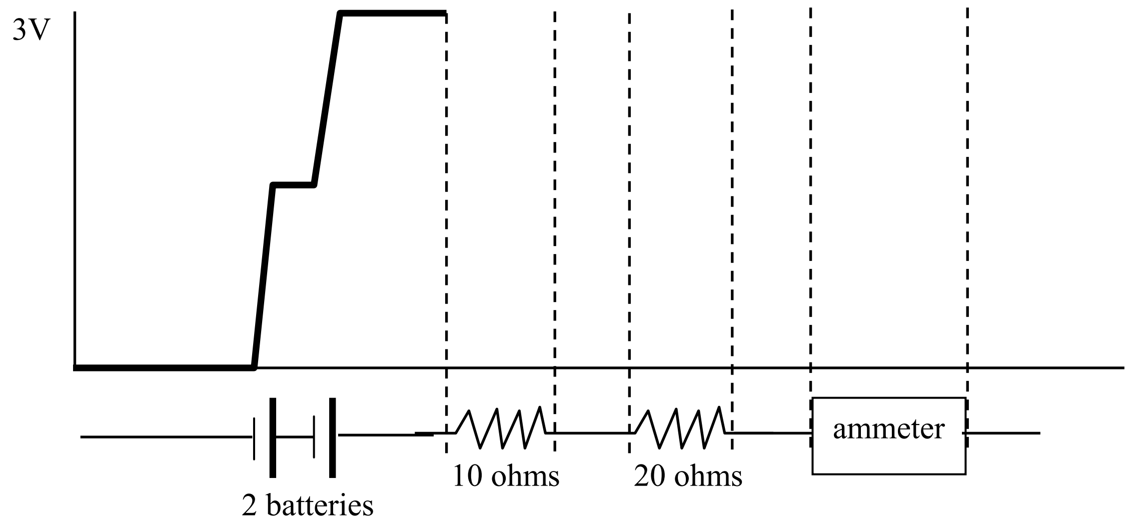
D) Put the ammeter in position 1 in the circuit. Use the red and black leads of the PASCO voltage probe to connect it into the circuit at position 2 as a voltmeter. *Describe* and *explain* the new readings on both of the meters.

D) Remove the voltmeter (PASCO voltage probe) from the circuit and reassemble the circuit below. Use the volt meter to measure the potential difference for each part of the path around the circuit. Record the potential differences on the diagram. Include the sign of each potential difference. To measure a potential difference, simply touch the two leads of the voltmeter to the two points between which you want to measure ΔV. Keep the order of the leads the same (e.g. red first) as you move them around the circuit. Also record the current I.



The individual potential differences should add up to zero for a round trip around the circuit. What do they add up to?

- Complete this approximate graph of potential (relative to the negative end of the battery) vs. position around the circuit, showing and labeling the various measured potential differences. Part of the graph is drawn for you (see below). Electric field is the (negative) gradient of the potential, so the slope of this graph should be steep where the electric field is large.



CHECKPOINT 1: Ask your instructor to check your graph before continuing.

E) When you attach the voltmeter, you alter the circuit. Why doesn't the ammeter reading change?

F) Connect the voltmeter across the 20-ohm resistor again, and note the ammeter reading.

G) From your measurements recorded on the diagram, calculate and record the resistance of each of the following circuit elements:

- R "10 ohm" resistor = $\Delta V/I$
- R "20 ohm" resistor
- R_{wire}
- $R_{ammeter}$

Trust your own measurement of the resistance, not the approximate values stated in this manual for the resistances.

2. OHMIC AND NON-OHMIC RESISTORS

A) Take the circuit completely apart. Choose an OHM setting on the multimeter, and connect the ohmmeter to a resistor with nothing else connected to the resistor. Use the ohmmeter to measure the resistances of the "10-ohm" resistor, of the "20-ohm" resistor, and of a long bulb (in a socket for convenience). Record these measurements,

- *R* "10-ohm" resistor by ohmmeter
- *R* "20-ohm" resistor by ohmmeter
- $R_{\text{long bulb}}$

Note how these ohmmeter readings for the resistors compare with your own resistance measurements recorded earlier.

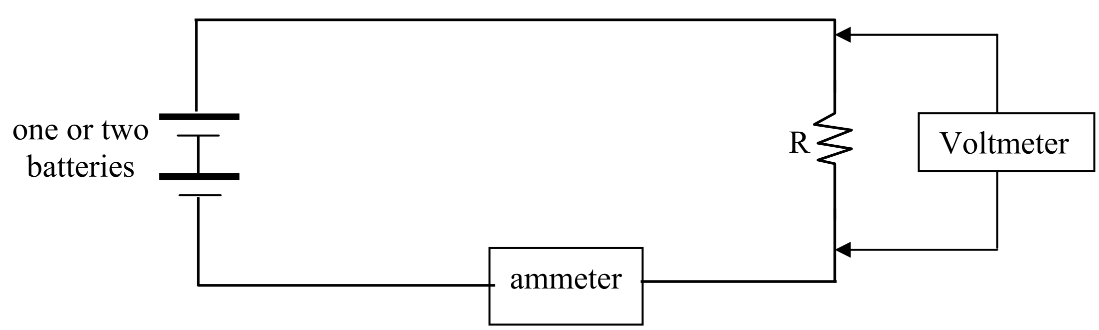
B) The reason you must remove a resistor from a circuit has to do with the way the ohmmeter works: a non-digital ohmmeter applies a small potential difference to a resistor and measures the current that flows, just as you did in part A, so the ohmmeter is an active element. (A digital ohmmeter drives a small current through the resistor and measures the potential difference.)

- With the ohmmeter measuring a resistor, use another group's meter to measure the potential difference across the ohmmeter, $\Delta V_{\text{ohmmeter}}$.

(It may take a sensitive scale to observe this potential difference, which is small but not zero.)

C) A resistor is said to be "ohmic" if the current *I* through the resistor is related to the potential difference ΔV across the resistor by the equation $I = \Delta V/R$, where the resistance *R* is a constant and does not vary with the voltage difference ΔV. Other resistors whose resistance is not constant as a function of potential difference are called "non-ohmic resistors." We will investigate both kinds of resistors.

The approach is to place an ammeter (handheld multimeter) in series with a resistor, and to place a voltmeter (Pasco probe) across the resistor. By using different numbers of batteries in series, you get pairs of values for *I* and ΔV which can be used to test whether the resistor is ohmic or not. Here is a schematic diagram of the circuit:



Place a 10-ohm resistor in the circuit shown above. Measure the potential difference ΔV across the 10-ohm resistor and the resulting current *I* through the resistor with one battery and then with two batteries in series, and calculate the resistance. Include your earlier ohmmeter measurements from page 3. Organize your results in a table like the one below in your notebook:

***ΔV*, volts**	***I*, amperes or mA**	***R* of "10-ohm" resistor**
from part B above: *ΔV* of ohmmeter =	(*I* not needed)	from part A above, *R* =
1 battery: *ΔV* =	*I* =	*R* = *ΔV/I* =
2 batteries: *ΔV* =	*I* =	*R* = *ΔV/I* =

Why do we say that this 10-ohm resistor is an ohmic resistor?

Replace the 10-ohm resistor with a long bulb in a socket, and repeat the measurements:

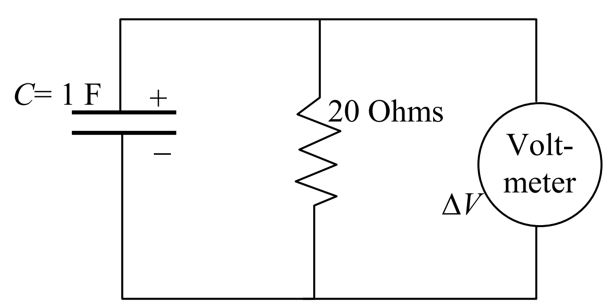
***ΔV*, volts**	***I*, amperes or mA**	***R* of long bulb**
from part B above: *ΔV* of ohmmeter =	(*I* not needed)	from part A above, *R* =
1 battery: *ΔV* =	*I* =	*R* = *ΔV/I* =
2 batteries: *ΔV* =	*I* =	*R* = *ΔV/I* =

Evidently the long bulb is not an ohmic resistor. Explain why as ΔV increases the resistance increases. (what microscopic property of the metal changes? Why?)

CHECKPOINT 2: Ask your instructor to check your explanations.

3. TIME-DEPENDENT VOLTAGE ACROSS A DISCHARGING CAPACITOR: RC CIRCUITS

You have seen that when a capacitor discharges through a light bulb the bulb starts out bright and then gets dimmer and dimmer. We will analyze this process in terms of potential.



Consider this circuit containing only a charged capacitor and a resistor.

The energy conservation equation for this circuit is (assuming the electric field in the connecting wires is negligible):

$$\Delta V_{capacitor} + \Delta V_{resistor} = 0$$

Since $\Delta V_{capacitor} = Q/C$ and $\Delta V_{resistor} = -IR$, we can write this as $Q/C-IR=0$. We also know that $I = -dQ/dt$ (the amount of charge dQ flowing off of the capacitor in a time dt is Idt). **Write the conservation equation as a differential equation in your notebook (in terms of *Q* and *dQ/dt*).**

- This is the differential equation describing the decrease in charge on the capacitor as a function of time.

Show that $Q(t)=Q_0\exp[-t/RC]$ is a solution to your differential equation, where Q_0 is the initial charge on the capacitor.

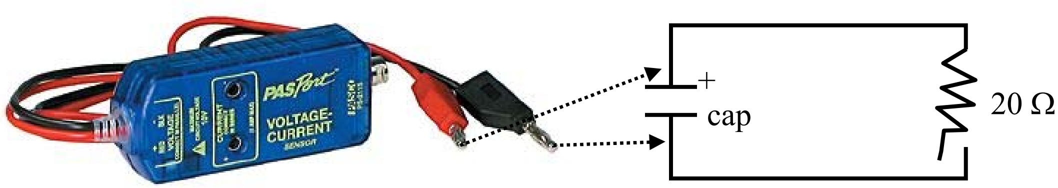
Given this solution for the charge on the capacitor, the voltage across the capacitor must have the similar form

$V(t)=V_0\exp[-t/RC]$

As the charge on the capacitor decreases, the voltage across the capacitor also decreases. *RC* is called the "time constant" of the circuit. This is the time at which the voltage difference has dropped to $1/e$ of its original value, V_0.

Measurements

Charge the 1 farad capacitor to ~3V by connecting it to your batteries. Make sure you connect the positive side of the batteries to the positive side of the capacitor. Then remove the batteries and assemble the following circuit, but don't make the final connection to the resistor until you are ready to start taking data. As soon as that connection is made the capacitor will start to discharge.



Use PASPort voltage probe to measure the voltage across the capacitor as it discharges.

1. On the lab software site, right click and save the data acquisition program **DischargeCapacitor.ds** to your desktop with the **.ds extension**. Double click it and it should automatically start software known as Datastudio.

2. Connect the red lead of the PasPort voltage probe to the "+" side of the capacitor and the black lead to the other side.

3. Complete the connection between the resistor and the circuit and then immediately Click the START button.

4. Stop the data collection when the voltage drops roughly to zero (it will take a long time).

5. Use your mouse to highlight all the data.

6. Go to the fit menu and choose Natural Exponent Fit. This fits an exponential to your data (the fit equation has the form $A\exp(-Ct)+B$; note this C is not capacitance).

    - **In the dialog box, use the constants of the fit to find the initial voltage on the capacitor and the *RC* time constant. Make sure your answer make sense with what you see on the plot. Record the values of V_0 and *RC* in your notebook.**

    - **Use your own measured value for the resistance *R* of the "20-ohm" resistor, and determine *C*.**

The manufacturing tolerances on these 1F capacitors are not strict. The actual value may range from 0.8F to 1.8F. **Does your result fall in this range?**

These capacitors may also have an internal resistance (the datasheet for the capacitor suggests perhaps as high as 10 ohms!).

- **Suggest an additional measurement that will allow you to find the actual capacitance (*C*) and the internal resistance (R_c) of your capacitor. Write down the equations that will allow you to solve for these two unknowns.**

CHECKPOINT 3: Ask your instructor to check your data, graph, calculation, and suggested measurement. There is no Webassign exercise this week!

Lab 11: Motion of a Charged Particle in a Magnetic Field

On the software homepage, right click and save the template program **MagneticForce.py** for this lab.

The template draws a "floor" and displays the uniform magnetic field, which is initially set to < 0, 0.5, 0> T.

A: First, get a proton moving across the screen (with no magnetic field)

We've created a sphere representing a proton, at location <-0.25, 0.1, 0.25>m. **Give it an initial velocity 1e7 m/s in the –z direction, by defining an appropriate vector quantity**:

proton.v = vector (## you fill this in)
proton.p=proton.m*proton.v

Write a loop to move the proton in the direction of its velocity, by following the instructions below. (If this is a very familiar task to you, you can do it now, without reading the rest of section A.)

We include a variable to represent the force of the magnetic field on the proton (**Fmag**), but since there is no magnetic filed in this section of the problem **Fmag** is zero.

You will use the relation between velocity (a vector) and position (a vector) to calculate the position of a moving particle at successive times, separated by a short time step.

In VPython, this translates to a statement like:

proton.pos = proton.pos + proton.p/proton.m*deltat # the position update equation

What is the value of deltat set in the program shell?

Inside the loop, we advance the position of the proton by using the position update equation.

Leaving a trail. After creating the proton, we added the following line of code before the loop:

trail = curve(color=proton.color) ## set up trail using the color of the proton

Inside the loop, we added this line after updating the position:

trail.append(pos=proton.pos) ## extend the trail as the proton moves

Run the program and make sure the proton moves in a straight line (no magnetic force).

B: Now you are ready to add a magnetic force, and observe its effect

- Calculate the magnetic force on the proton $\vec{F}_{magnetic} = q(\vec{v} \times \vec{B})$.

  You can calculate the cross product by the standard procedure of multiplying and subtracting the appropriate components of these two vectors. The following code will do this for the arbitrary vectors **D** and **G**!

C = vector((D.y*G.z-D.z*G.y), (D.z*G.x-D.x*G.z), (D.x*G.y-D.y*G.x))

1) **Since the initial velocity is in the –*z* direction and the magnetic field is in the positive *y* direction, what is the initial direction of the force on the proton?**
2) **Will the proton ever experience a force in the *y* direction?**
3) **Predict the path of the proton.**

Since VPython can do vector operations, you can also ask VPython to do the cross product, but make sure you can do this also by hand:

C = cross(D,G)

- Use the magnetic force to modify the momentum of the proton, using the momentum principle. Reminder:

$$\vec{p}_f = \vec{p}_i + \vec{F}\Delta t$$

To calculate the new momentum, we add the change in momentum to the old velocity or in Vpython:

proton.p = proton.p + Fmagnetic * deltat ## momentum update equation

Run the program. Is the path what you predicted?

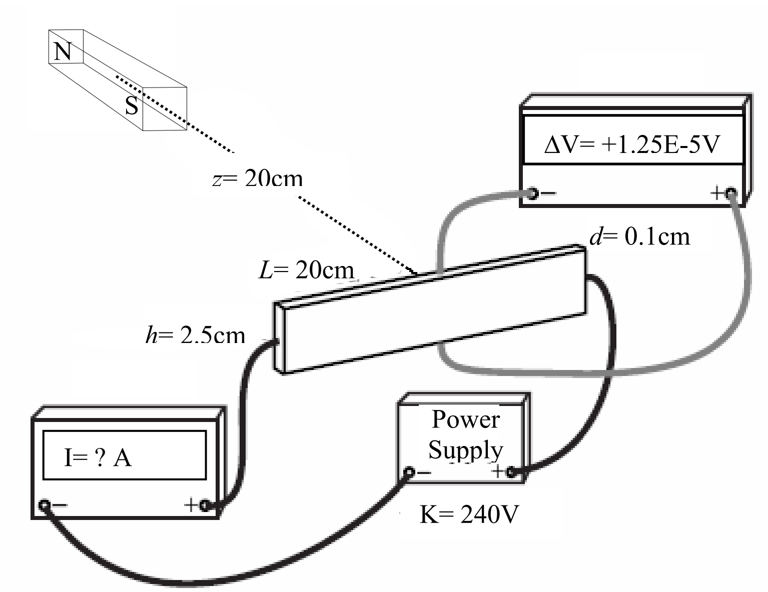
- If you changed the sign of the initial velocity so that it initially moves in the positive *z* direction will the proton move on the same path? Try it and see if your prediction agrees.

4) Calculate by hand the cross product of A = vector(0,1,-3) and B = vector(0,2,0)

- If you add a +y component to the proton's velocity what will be the new path? Try it and see if your prediction agrees.
- Change the proton to an antiproton, a particle with the same mass as the proton, but a charge of -e. What do expect to happen? What do you observe?

CHECKPOINT 1: Have an instructor check your work, for credit. While you are waiting you may proceed on to these group problems.

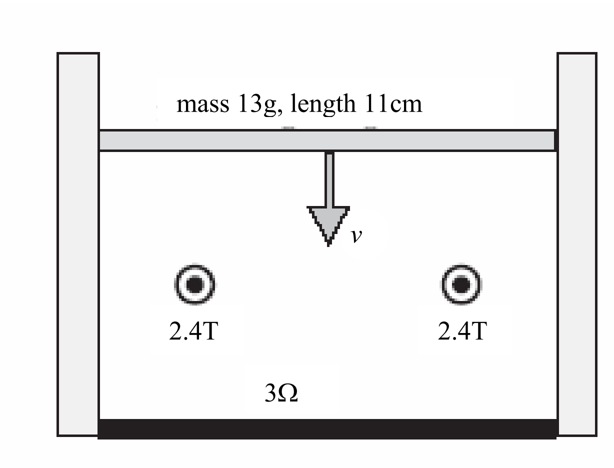
1. Determining a magnetic dipole moment:



The center of a large bar magnet is 20 cm from a thin plate of high-resistance material 12 cm long, 2.5 cm high, and 0.1 cm thick. The plate is connected to a 240V power supply (the internal resistance of the power supply is negligible). The bar magnet is perpendicular to the plate. The mobility of the charge carriers in the thin plate is 3.5×10^{-4} (m/s)/(N/C), and the number density of singly-charged carriers is 4×10^{23} m^{-3}. A voltmeter is connected precisely vertically across the thin plate and reads $+1.25 \times 10^{-5}$ volts. A low resistance ammeter is in series with the rest of the circuit.

(a) Are the charge carriers electrons or holes? Explain including a physics diagram.
(b) What is the magnetic dipole moment of the bar magnet? Include units.
(c) What does the ammeter read, including the sign?

2. A falling metal rod:



A metal rod of mass 13 g and length 11 cm slides with negligible friction but with good electrical contact down between two vertical metal posts (see above). The bar falls at a constant speed. The falling bar and the vertical metal posts have negligible electrical resistance, but the bottom rod is a resistor with resistance 3Ω. Throughout the entire region there is a uniform magnetic field of magnitude 2.4 T coming straight out of the page. Show every step in your work clearly and in detail.

(a) Calculate the amount of current I running through the resistor.
(b) On a diagram, clearly show the surface-charge distribution all the way around the circuit, and the direction of the conventional current I. Explain.
(c) Calculate the constant speed v of the falling bar.

CHECKPOINT 2: Have an instructor check your problems, for credit. If you have time, you may proceed to your WebAssign Exercise for this Lab.

Checking your program on WebAssign.

Read the instructions in WebAssign carefully. You may be asked to change some values before answering the questions with your program.

Lab 12: The Magnetic field of a Single Moving Charged Particle.

In this lab, you will compute and display the magnetic field at a single location in space, due to a moving charged particle. As the particle moves, the magnetic field will of course change. The particle is initially located at <$4x10^{-10}$, 0, 0>m and has a velocity <-$4x10^{+4}$, 0, 0>m/s. As it moves across the screen your program will show the magnetic field vectors at four observation locations, changing dynamically as the particle moves.

1. Calculating & displaying the magnetic field of a moving charge at one instant

On the lab software site, right click and save the program **MagneticFieldParticle.py**.

You will need to use the cross product for calculate the field. Recall that you can calculate the cross product by the standard procedure of multiplying and subtracting the appropriate components of these two vectors. The following code will do this.

C = vector((A.y*B.z-A.z*B.y), (A.z*B.x-A.x*B.z), (A.x*B.y-A.y*B.x))

Since VPython can do vector operations, you can also ask VPython to do the cross product:

C = cross(A,B)

Calculating a magnetic field in VPython

1. The necessary constants are defined in your program. Make sure you can identified what they have been named.

2. In your program, the moving particle will be a proton. Define **proton** to be a red sphere representing the particle at the initial location specified above of <$4x10^{-10}$, 0, 0> m. Give the sphere a radius of 1e-11m (this is of course larger than the real radius of a proton; we need to be able to see the sphere.

3. Create a vector quantity **velocity** representing the velocity of the proton, <-$4x10^{+4}$, 0, 0> m/s.

4. Create an arrow at the observation location <-6e-11, 0, 6e-11> m with **axis=vector(0,0,0)**. Name the arrow **barrow1** so you can refer to it later. Note that the tail of the arrow is at the observation location, so you can simply refer to the pos of the arrow (**barrow1.pos**) when you want to refer to the observation location.

5. Run the program.

6. Why don't you see the arrow? (Be prepared to explain this to an instructor.)

7. Using Biot-Savart's law

$$\vec{B} = \frac{\mu_o}{4\pi}\frac{q(\vec{v}\times\hat{\vec{r}})}{|\vec{r}|^2}$$

write symbolic VPython statements to calculate the magnetic field (**Bfield**) at the observation location, due to the "moving" proton. (Think about what quantities you need to know in order to do this calculation, e.g. relative position vector, etc.).

8. Print the value of the magnetic field (which should be a vector). Is the direction of the magnetic field you calculated correct? Check with the right-hand rule.

Displaying the Magnetic Field

The axis of **barrow1** should represent the magnetic field vector (i.e., **barrow1.axis = Bfield * scalefactor**). The scale factor is needed to make it conveniently observable. Suppose you want the arrow to be small but visible when the proton is in its current location. If you set the scale factor equal to the magnitude of the current position of the proton and divide it by the magnitude of the magnetic field that you just printed out, how long will the arrow be?

This is probably too large so divide it by ten to make the arrow smaller. You'll need to adjust the scale factor later. The maximum of the magnetic field will change as the proton moves. Once you know this maximum value you can set a final value,

scalefactor = (max. desired length of the arrow)/(max. magnitude of the field it represents)

9. Since you already created an arrow, you don't need to do it again. All you need to do is change its axis. Set the axis of the arrow to be the magnetic field you calculated, multiplied by an appropriate scale factor to make the size of the arrow appropriate for this display.
barrow1.axis = Bfield * scalefactor

10. Run the program. Do you in fact see a cyan arrow at the observation location, pointing in the appropriate direction?

CHECKPOINT 1: Have an instructor check your work, for credit.

2. Animating the motion of a particle

A computer animation of the motion of an object uses the same principle as a movie or a flip book does. You display the object at successive locations, each at a slightly later time; to your eye, the motion can look continuous. In a program, you calculate the position of the object, and it is displayed in that position. You calculate where the object will be a very short time **deltat** later, and change its position to the new location, so it is displayed in the new location.

- To keep the camera from zooming in and out again, remove the comment from the following line of code:

scene.autoscale = 0

You will use the relation between velocity (a vector) and position (a vector) to calculate the position of a moving particle at successive times, separated by a short time step. Remember that, in vector terms:

$$\vec{r}_f = \vec{r}_i + \vec{v}\Delta t$$

The new position is equal to the old position plus the velocity times the small time Δt.

In VPython, this translates to a statement like:

proton.pos = proton.pos + velocity*deltat

where velocity is the vector quantity which you have initialized earlier in the program.

For this program you will use a time step of 5e-20 seconds:
deltat = 5e-20

Stop the loop when the proton has gone off the screen (i.e. when the *x*-component of the proton's position becomes greater than 5e-10 m). The beginning of the loop is in the code but you will need to uncomment it:

```
while proton.x > -5e-10:
    proton.pos = proton.pos + velocity*deltat
```

11. ***Run your program***. Does the particle move down the screen?

3. Calculating and updating the magnetic field as the particle moves

When the particle moves, the magnetic field due to the particle changes, so you need to recalculate it each time you move the particle.

12. Think about the Biot-Savart law (the equation you use to calculate the magnetic field of a moving charged particle). Which of the quantities in this equation change when the position of the particle changes? Which quantities do not change?

13. Move all the lines of code involving changing quantities so they are inside the loop, after the line of code updating the particle's position.

15. Do NOT move the line of code that creates the arrow! This line should remain before the loop. You do not want to create a new arrow each time through the loop - this would make thousands of arrows, all on top of each other! If your program runs very slowly, you may have made this error.

16. Do NOT put a print statement inside the loop. This makes the program run very slowly.

17. ***Do*** move the line of code that ***changes*** the arrow, so the arrow will continually display the changing magnetic field due to the moving particle.

18. Run the program. You will need to adjust the scalefactor.

4. Adding observation locations

Add three additional observation locations, in locations with the same *x*-coordinate, but different *y* and *z* coordinates, so that the four locations are at the corners of a square surrounding the path of the particle. Your finished program should display the magnetic field vectors simultaneously at all these locations as the particle moves.

You will want to rotate your viewpoint using your right mouse button so that you can see the proton passing through the center of this square.

Set the scalefactor to a value that makes the arrows representing the magnetic field large, but not so large that they extend offscreen.

CHECKPOINT 2: Have an instructor check your work, for credit.

5. Group Problems

Do 21.P.23 in your lab notebooks. There is a example/help sheet for doing Gauss's Law problems on the lab software site.

CHECKPOINT 3: Have an instructor check your work, for credit. If you have time, you may proceed to your WebAssign Exercise for this Lab.

6. Checking your program on WebAssign.

Read the instructions in WebAssign carefully. You may be asked to change some values before answering the questions with your program.

Lab 13: Faraday's Effect and AC circuits

In this lab you will predict and then measure the emf in a coil due to a time-varying magnetic flux.

Part 1: Predicting an emf

a) Magnetic dipole moment of a bar magnet

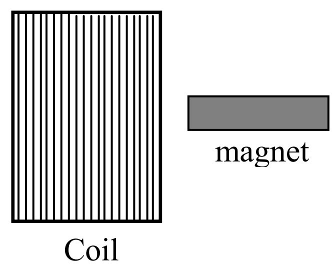
Quickly determine the magnetic dipole moment of the bar magnet in your kit. (Remember that you can do this with a compass and a ruler: find the center-to-center distance at which the magnet deflects the compass 70 degrees from North; treating the magnet as a magnetic dipole, calculate the magnetic dipole moment of the magnet.) The details of this measurement are given in the Lab 8 writeup.

b) Calculating magnetic flux through the coil

Examine the coil, which has 1600 turns of wire, in many layers. Note that the inside and outside diameters of the coil are rather different.

Magnetic flux: Initial position

Hold the bar magnet so the closer end of the magnet is just outside the coil, as shown at right. You need to calculate the approximate magnetic flux through one turn of the coil, due to the magnet. In order to do this, answer the following questions:



c) What value will you use for the area of one turn of the coil? Explain what you needed to measure to determine this.

d) What value will you use for the magnetic field of the bar magnet? Explain what you needed to measure to determine this.

e) What is the approximate magnetic flux through one turn of the coil in this initial situation? Explain your calculation.

f) What is the average magnetic flux, Φ_i , through ALL turns of the coil?

Magnetic Flux: Final position

Move the bar magnet away so the center of the magnet is 30 cm from the center of the coil.

g) What value will you use for the magnetic field of the bar magnet? Explain your calculation.

h) What is the approximate magnetic flux through one turn of the coil in this situation? Explain your calculation:

i) What is the approximate magnetic flux, Φ_f, through ALL turns of the coil in this final position?

Predicting emf

You wish to move the magnet rapidly away from the coil so that the change in flux is large. A typical time for moving your hand rapidly away from the coil is ~.05s. There is a motion sensor attached to the TA's computer where you can check how fast you can move your hand if you wish.

j) Use either the typical Δt=0.05s or the time you measured for Δt along with the change in flux from initial to final position, $\Delta\Phi$, to predict the emf you should observe when you quickly move the magnet from near the coil to 30 cm away. SHOW YOUR CALCULATIONS.

CHECKPOINT 1: Have an instructor check your work, for credit

Part 2: Measurement of emf

- Log on to the lab computer, and on the software homepage, right click and save the data acquisition program **faraday.ds** to your desktop (specify the .ds extension). Double click it and it should automatically start software known as Datastudio.
- Connect the Pasport voltage sensor cables to the coil. Click "START" to start recording, and move the magnet back and forth a few times to see what happens. Recording will automatically stop after 5 seconds for each run.

l) Move the magnet slowly. Describe qualitatively what you observe.

m) Move the magnet rapidly. Describe qualitatively what is different in your observations.

n) Now measure the peak emf in the coil when you move the magnet away rapidly several times. What do you observe?

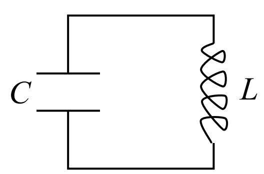
o) How does your experimental value compare to your predicted value? Given the approximations you made in estimating the emf, is this good agreement?

CHECKPOINT 2: Have an instructor check your work, for credit. You may proceed to the following section on modeling the time dependence of a circuit made up of an inductor and a capacitor

Part 3: Oscillating Circuits

We've looked at a circuit where the energy stored in a charged capacitor is dissipated in a resistor (or lightbulb). Energy may also be stored in an inductor in the magnetic field generated by a flowing current. What happens if a circuit consists only of an inductor and a capacitor (see below)?

- Write the energy conservation loop rule for this circuit (see section 22.7.3 of your text). Recall that $\Delta V_{capacitor} = Q/C$ and $\Delta V_{inductor} = -L\, \Delta I/\Delta t$. Q is the charge on the capacitor, C is the capacitance, L is the inductance, and ΔI is the change in the current for a given change in time, Δt.



- Solve this conservation equation for ΔI. This is a current update equation that is exactly analogous to the momentum update equation you used in mechanics.

$\Delta I=$

There is also charge update equation that is analogous to the position update equation. (note the sign ... does the charge increase or decrease on the capacitor as current flows?)

$\Delta Q = -I\Delta t$

- On the lab software site, right click and save the program **LCcircuit.py**. **Put in your equation for updating the current.** The program plots the charge on the capacitor as a function of time. Also assume the capacitor is initially at 3V and put the appropriate charge on the capacitor (Q).
  - o How well does your numerical solution for this LC circuit match the analytical prediction for the period $T = 2\pi\sqrt{LC}$ (printed in shell window)?

- Typical inductors have some resistance (a notable exception is a superconducting coil). Include a resistor in series with the ideal inductor in your circuit. Add the energy term for the resistor ($\Delta V_{resistor} = -IR$) to your energy conservation equation on the previous page and solve for a new current update equation.

$\Delta I=$

- Insert your solution into the program. The coil you used in the earlier part of the experiment has an inductance of 0.052H and a resistance of 35.4Ω. Set the resistance R to 35.4Ω.
  - o Describe what happens when you run the program. Do you see oscillations? If you built this actual LC circuit would you expect to see oscillations?
  - o If your coil had a smaller internal resistance would you see oscillations? Try smaller values of R=1Ω, 0.1Ω, and 0.01Ω and describe what happens.

Group Problems

Do problem 22.P.26 in your notebook.

CHECKPOINT 3: Have an instructor check your work, for credit.

There is no webassign exercise for this experiment.

Lab 14: Interference and Optics

The superposition principle applied to electromagnetic radiation

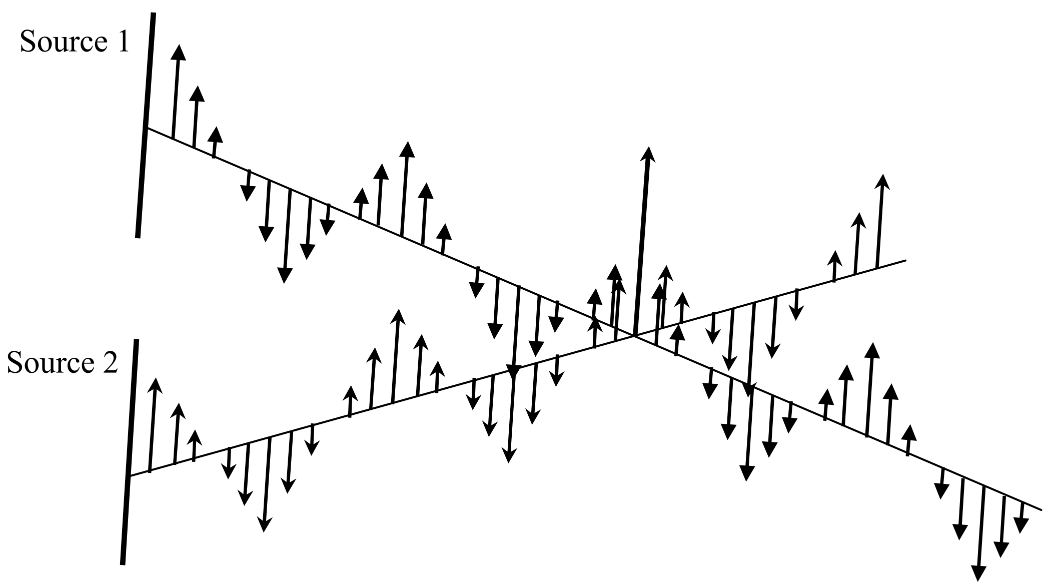
When two sinusoidal electromagnetic waves of the same wavelength reach the same location at the same time, the superposition principle says the net electric field at that location is the vector sum of the electric fields in each wave. (The same is of course true for the magnetic fields; we will talk only about electric fields here, because they are responsible for most of the interaction of electromagnetic radiation and matter.)

I. Constructive interference

If the two electric fields add to make a larger field, this results in a "bright spot". This is called **constructive interference**. In the diagram, note the larger field at the location where the two waves coincide.

Constructive interference occurs when each source is an integer number of wavelengths from the intersection point. The integers can be different.

In the diagram, what is the distance from each source to the crossing point, measured in wavelengths?

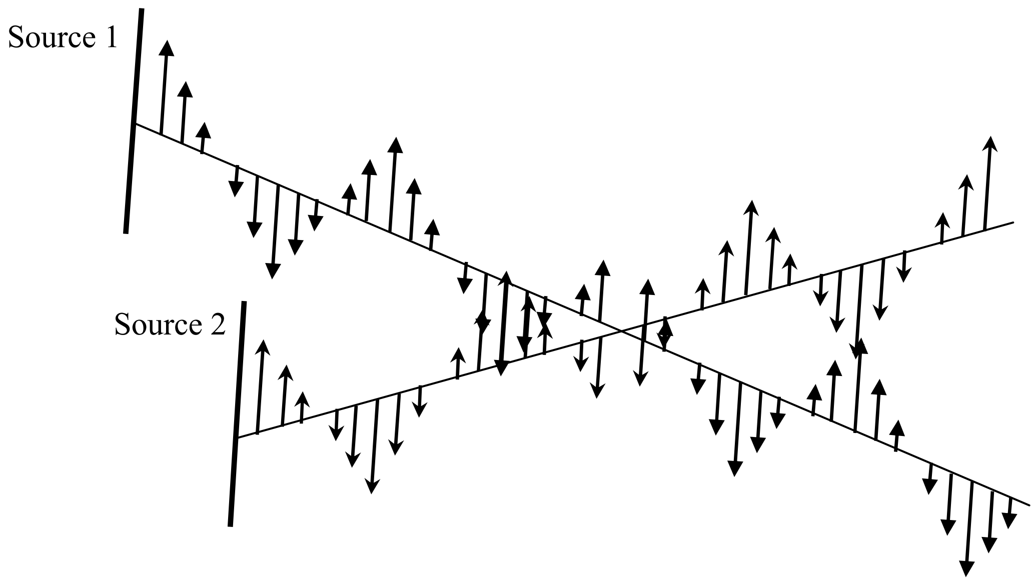


II. Destructive interference

If the two electric fields happen to be in opposite directions, they may add to zero, producing a "dark spot". This is called **destructive interference**.

Destructive interference occurs when the difference in path lengths (distance from source to intersection point) is half a wavelength, or 1.5 wavelengths, or 2.5 wavelengths, etc.

In the diagram, what is the distance from each source to the crossing point, measured in wavelengths?



III. Interference of two point sources at observation plane

When the laser apparatus is available, please take a break from this Vpython exercise and make the measurements indicated in part IV.

On the lab software site, right click and save the program **TwoSource.py. Run it in the usual manner**. What you will see represented is the electric field of an approximate point source. An ideal point source emits a spherical wave. We only show a portion of the spherical wave propagating as a beam in the positive *x*-direction towards the observation plane. The black circular arcs indicate the peaks of the sinusoidal electric field.

When you click with the mouse on the screen a second point source and its electric field appears. Along the direction where the peaks of the two electric fields coincide you have constructive interference, e.g. along the positive *x*-axis. Red lines are drawn using the theoretical formula for the location of interference maxima on the observation plane.

$$m\lambda = d\sin(\theta)$$

where m is the order of the interference maximum (m=0 is on the positive x-axis, m=+1 is above the x-axis, m=-1 is below the x-axis). The separation of the sources is d and λ is the wavelength of the sources, and θ is the angle measured from the x-axis.

1) Modify the program so that there is destructive interference along the positive x-axis. The variable **xoffset** changes the location of the second source. How far do you need to move it to make the interference destructive along the positive x-axis, i.e. what is **xoffset**? Does it appear that the distance between interference maxima is changed?

2) Double the separation (d) between the sources. What do you observe?

IV. Using a laser light source (if the laser is being used go to part V).

When using a laser light source, you must protect your eyes and the eyes of others. Do not look directly into the laser beam. Be careful not to shine the beam directly into the eyes of another person.

Observing constructive and destructive interference

You will make two "sources" of electromagnetic radiation by shining a laser beam into two small slits. Since the two "sources" are made from the same laser light these sources will be coherent and interfere. For example, if the slits are perpendicular to the propagation direction of the laser beam, the electric fields of the two sources are identical. That is, when the electric field is maximum at the location of one slit, it will also be a maximum at the location of the other slit, as shown in the diagrams on the previous page.

(1) The laser is pointing at a white wall a fairly large distance from it. Observe the appearance of the bright spot.

(2) Now position the slide with slits just in front of the laser. Choose a pair of slits that are either 0.25 mm or 0.125 mm apart, and align the beam so it goes through the slits. The small bright spots a few millimeters apart are interference **maxima**, due to constructive interference. The dark spots in between are interference **minima**, due to destructive interference.

- ***Concentrate on the bright spots within the bright central region, not on the larger bright and dark regions (a few cm wide) that you may see***. Draw what you see in your notebook.

- Measure the distance L from the slits to the wall.

- Measure the distance x between central maximum (bright spot) and next nearest maximum.

(3) By carefully measuring the two distances above, you can calculate the wavelength of the laser light. As is explained in the textbook (section 24.1, pp. 844-847), when the length of the paths traveled by light from the two slits differ by one wavelength (symbolized by the Greek lowercase lambda):

$$\lambda = d\sin(\theta) = d\frac{x}{L}$$

where *d* is the distance between the slits (e.g. 0.25mm or whatever slit separation you used).

CHECKPOINT 1: Have an instructor check your work, for credit. You may proceed to the next section of this lab while you wait.

V. Interference of Multiple Sources: Gratings and Lenses

Gratings

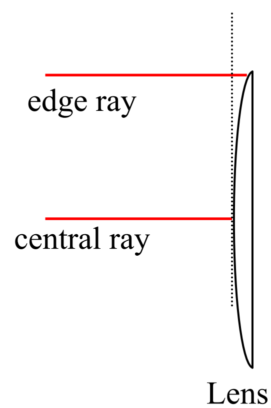
Download the program **ManySourceInterference.py** and run it. It first shows the interference pattern of two sources. Clicking the screen with the mouse increases the number of sources to 6. All these sources are equally spaced and in phase.

- Describe what happens to the contrast of the interference maxima as these additional sources are added. That is, how much darker are the regions between the maximas compared to the brightness of the maxima?

A diffraction grating is made up of many equally spaced slits. The resulting sharpness of the interference maxima allows the grating to separate a multi-color source into its various components (e.g. an atomic spectrum).

Lenses

A lens also uses interference to focus light. If you have a collection of sources, each with a specific relative delay, a single interference maximum can result that is localized to a small spot (or focus) in space. For example, if a beam of light strikes a glass lens the central portion is delayed more than the edges since light travels more slowly through glass -- the speed of light in glass in given by $v=c/n$, where n is the index of refraction of the glass and $n>1$.



From the figure you can see that the central portion (or ray) of light travels through much more glass than the ray at the edge. So if the two rays of light were in phase at the dotted line in the figure, the central ray will be delayed compared to the edge ray as it travels through the extra glass. So the edge ray will be ahead when it leaves the lens.

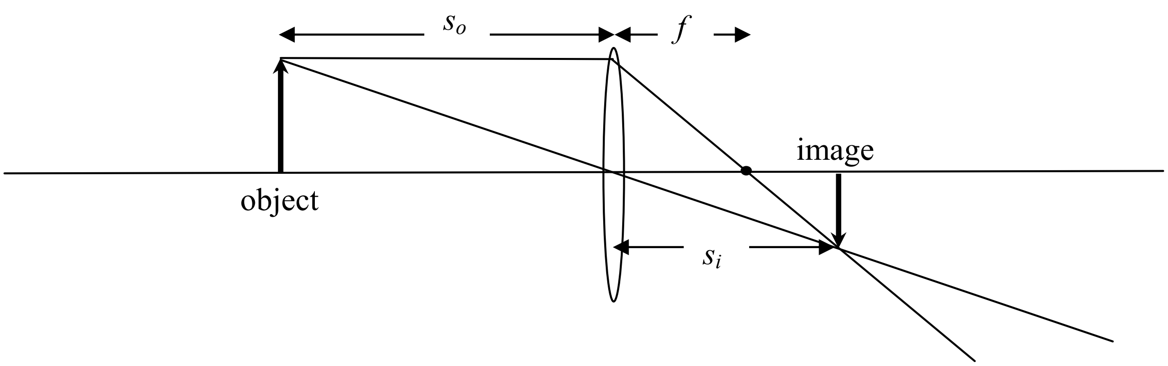
- Download **InterferenceLens.py** and run it. First only two sources appear and you see the familiar pattern for the interference of two sources. Click the screen and many more sources appear. They are arranged on a circular arc whose center lies at the intersection of the two red lines. All the sources are in phase at the positions shown but note that the ones at the edge are substantially further forward than those at the center (just as we described for the lens above).

- Describe the shape of the focal spot (i.e., the white spot). Where is it located? Is it round? Cigar-shaped?

- Try changing the focal position and see what happens.

This interference picture of how a lens works is informative and accurate, but it can be cumbersome for every day use. Fortunately, the behavior of a lens can often be modeled simply.

If the lens is thin there is a simple formula governing the location of the image. A lens is considered thin if the thickness of the lens is much smaller than the distances to the object (s_o) or image (s_i). The thin lens formula is $\frac{1}{f}=\frac{1}{s_o}+\frac{1}{s_i}$ where f is the focal length of the lens. The focal length is determined by the shape and materials properties of the lens. The geometrical picture of thin lens imaging is that a ray of light from the tip of the object, traveling parallel to the axis, is bent by the lens so that it passes through the focal point. A second ray from the tip of the object that goes through the center of the lens continues on its path without deviation (for a thin lens the center is essentially flat so the ray is not bent). The intersection of these two rays defines the location of the tip of the image.



- Download the **ThinLens.py** and run it. The program uses the thin lens approximation to find the position and size of the image. Initially, f= 1.0m and s_o= 2.0m.

- Describe what happens to the image as you change the object distance (**so**) to 4.0m and to 1.5m (e.g., Where is the image located? Is it right side up or upside down? How big is it compared to the object?). Sketch what happens to the two rays of light coming from the tip of the object for these two situations.

- Describe what happens when the object distance is set to 0.7m. (Note that the rays going through the lens never intersect ... can you explain the image shown in the drawing? If you put a card where the image is shown do you think you'd see an image on the card? Imagine the rays of light coming from the lens entering your eye, what would the image look like? What kind of image do you see in a magnifying glass? This type of image is commonly called a virtual image.)

CHECKPOINT 2: Have an instructor check your work, for credit.
There is no webassign exercise for this experiment.