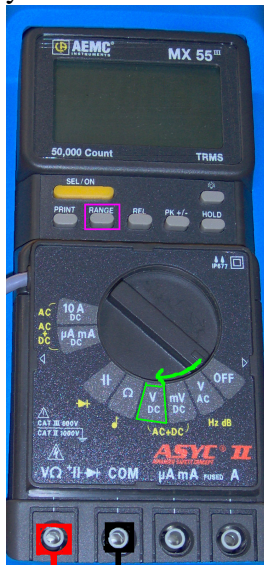


## Electrostatic Field Mapping Revised Spring 2007

**Note: when you switch the mx55 on, you need to select the 1000 M $\Omega$  input impedance. The procedure for doing is on the lab website. After you have completed the lab, make sure that you switch off the mx55.**

In this lab, you will verify many of the qualitative aspects of the electric and potential fields. Your equipment consists of a cork board, a volt meter, a dc power source, several leads, several pieces of wire, plastic push pins, carbon paper, graph paper and conductive paper.

We will use leaded push pins in this lab. Since I have a very limited number of these pins, please be sure to leave your pins on the cork trays when you leave. These will serve as your point charges. Connect the dc + and – leads to each of these pins (don't connect the same leads to the same pin since sparks will result). Attach the other end of the leads to your 9 volt transistor battery



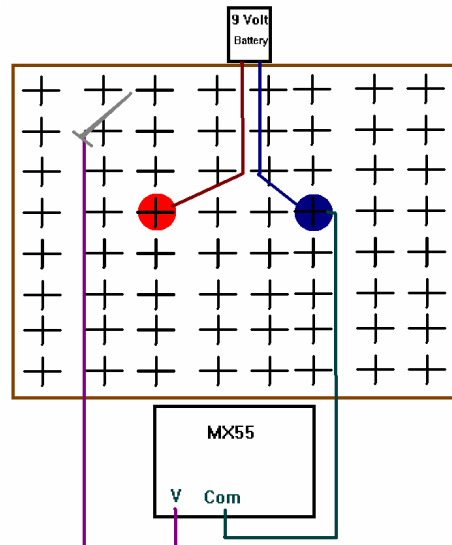
Here is a picture of the MX55 together with important areas indicated. The red and black leads are connected as shown. The purple button is used (when switching on) to toggle the input impedance. The green setting is the correct setting for measurements in today's lab.

Take a length of chart graph paper for the bottom layer. Place on this a piece of carbon paper. Make sure that you have the carbon paper oriented so that marks made on the conducting paper will write onto the chart paper. Over the carbon paper, place a sheet of conducting paper. This is the general setup for each charge configuration which will be studied today.

### Part 1: The field map from the electric dipole.

Place your two pins about 5-9 cm apart on your paper arrangement near the center as indicated. Connect the leads from your power supply. Connect one of your leads from your mx55 to the negative terminal **of the battery**. This terminal will be marked Com. *It is probably easier to connect to the battery directly rather than to the pin as indicated in the sketch.* Your probe will be one of the dissecting pins. Your other lead will connect to one of the charges.

The idea is this: with the dissecting pin attached to the voltmeter, start at the negative the negative lead and map out equipotential surfaces at increments of 1 volt until you reach the positive terminal. Press the point of the dissecting pin to make a mark on the chart paper when the desired positions are obtained. You ought to make a hand



sketch recording voltage values for each surface. You should also make attempts to go behind the pins and also above and below the pins.

Now, remove your push pins and remove the underlying chart. You should have a series of dots representing the equipotential surfaces around the charges. Connect these dots in a smooth curve in order to make the surfaces stand out more. **Label each surface with the voltage reading you obtained earlier.** Now you are ready to sketch in your electric field lines. Apply your rules for the electric field lines and sketch several in from the + charge to the – charge. The particular rules you need to apply are these:

- (1) Lines of E are always perpendicular to the potential surfaces.
- (2) Lines of E do not intersect.
- (3) Density of lines is proportional to E strength

## II: The field map of the parallel plate capacitor

Take two straight pieces of wire and arrange them into the form of a parallel plate capacitor, separated by about 5-7 cm. Use plastic pins to hold it in place and in good contact with the paper as necessary. Use one leaded pin at the center of each plate in order to place charge on the plates. Now, apply the voltage and map out the potential fields and electric fields as before. Try to be particularly careful towards the edges.

I want you to calculate some of the electric fields inside the capacitor near the center. Here is how you can do this. Find two parallel equipotential lines. Measure the shortest distance between these two lines (near the center). The electric field is then given by:

$$\left| \vec{E} \right| = \left| \frac{\Delta V}{\Delta x} \right|$$

I would like for you to calculate this for about 10 different locations near the center of the parallel plate capacitor. (I have not provided a spreadsheet for this calculation). Average your results. In your write-up, report the average showing how you made this calculation, together with correct SI units.

Calculate the value of the electric field towards the center of the capacitor. If we had a true parallel plate capacitor, the plates would have a cross sectional area given by:

$$A = (\text{Length}) \times (\text{width})$$

The electric field between the parallel plates would be given by

$$E = \frac{\sigma}{\epsilon_0}$$

Where  $\sigma$  is the surface charge density.

You need to make lots of measurements of your system to verify that the electric field is uniform near the center of the capacitor. The field will diverge near the edges, however. Try to sketch these “fringing fields” as much as possible.

Be sure on your field map to indicate the equipotential surfaces and the electric field lines. Remember: the electric field points towards the lower potential in the quickest way possible.

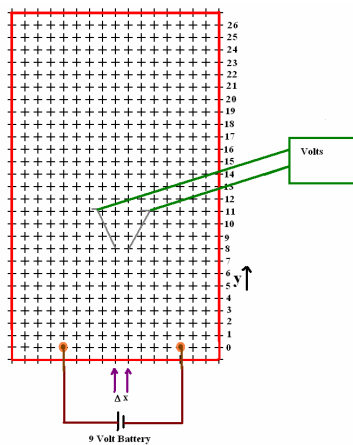
### III: The Faraday cage

Bend one of your pieces of wire into a circle and attach it to the conducting paper with pushpins. Use one push pin to make a connection to the circle. How big should your circle be? It should be about 3-4 cm in diameter.

Take your other push pin and place it about 7 cm away from the circle. Attach your leads and map out the field external to the circle as you have done before. Now, with your lead make measurements inside the circle. You should notice that the potential is about constant inside the circle. This means that the circle acts as a Faraday cage in that it insulates the inside from external electric fields. Now, you want to place a lead (disconnect the circle) of your source at the center of the circle and see if you can measure the electric field both inside and outside the circle. What happens is this: if a metal conductor has a cavity inside and a charge is placed in the cavity, according to Gauss's law, you are enclosing a charge and therefore, you will have an electric field inside the cavity. Mapping out the surfaces outside the circle should show that the system acts as if a point charge is located at the center of the sphere. To show this, next connect your center lead to the circle and map out the potential surfaces external to the circle.

Remember this if you decide to become a spy: putting a Faraday cage around your office won't necessarily shield your signals from the outside world (unless, perhaps, you decide that you want to ground your Faraday cage). Hmm ... wonder why sometimes you see little fine wires running through the windows of certain government buildings?

### IV: Procedure for determining the Electric Dipole Field y-dependence



To the right is shown the layout for measurement of the electric dipole y-dependence. You have two lead push pins connected to the battery terminals. This should be located at row 1 (not along the white edge) of the conducting paper. There should be a total of 8 [+] marks between the two pins. This is very important!

Now notice the column of + marks above the arrows marked  $\Delta x$ . You should take your two dissecting pins which are connected to your voltmeter and make 26 measurements from  $y=0$  to  $y=26$ , recording the voltage and the row number for each. Your voltages will probably vary between about 0.8 V and 0.01 V. You should point the dissecting pins onto the exact center of the white crosses but poking them through the paper is not recommended ... touching them to the white lines will be good enough. In fact, just touching the ends to the white crosses rather than poking them through the paper will give better and more stable results. The actual value of the electric field is related to the potential difference by:

$$|E| = \frac{\Delta V}{\Delta x}$$

**and this is a very important result for not only this lab, but also the class.**

Next record your data in the spreadsheet for this portion of the lab. You will need to also measure the distance between two crosses and the diameter of your lead push pin. On the

spreadsheet, after you have entered your data, you will do a manual fit to your data by varying the digits in the parametrical charge on the push pins. You will see, if you experiment is successful, a very good correspondence between the 3-dimensional behavior of the electric field and this two dimensional behavior. You will probably want to know that the uncertainty in the measurement of the electric field is given by:

$$\pm\delta E = \pm\sqrt{\left(\frac{\partial E}{\partial(\Delta V)}\delta(\Delta V)\right)^2 + \left(\frac{\partial E}{\partial(\Delta x)}\delta(\Delta x)\right)^2} = \pm\sqrt{\left[\frac{\delta(\Delta V)}{\Delta x}\right]^2 + \left[\frac{\Delta V}{(\Delta x)^2}\delta(\Delta x)\right]^2} \text{ with } |E| = \frac{\Delta V}{\Delta x}$$

where  $\delta(\Delta V)$  is your estimated uncertainty in the potential difference measurement and  $\delta(\Delta x)$  is your uncertainty in the measurement of  $\Delta x$  ( $\Delta x$  should be very close to 10 mm if you followed my procedure above) and  $\delta\Delta x$  should be about 1.5 mm at the most. It should not be a surprise that the fit misses in places: this is because of the two-dimensional nature of the problem. Also the internal resistance of the voltmeter becomes more significant when measuring large resistances. The technique that I used to obtain this result is the same one that was used in lab 10 in physics 241.

There are a number of important things you will obtain from this lab. By correctly fitting the function to the data, you will be effectively doing a manual non-linear least squares fit. The spreadsheet algorithm that you follow is useful to remember in all your science courses, not just for this lab.

### Data page for Electric dipole experiment

$\Delta x$  [mm]: \_\_\_\_\_

(this is the separation between the points of the dissecting pins ... it should be also the distance between the centers of two white crosses on the paper)

Distance between any two rows [mm]: \_\_\_\_\_

Pin Base Diameter [mm]: \_\_\_\_\_

Number of '+'s between positive and negative pins (a) [8]: \_\_\_\_\_ rows

Note that the total # is 10 (one additional cross under each pin). However in the spreadsheet, enter 8 in cell g2: I add in the additional 2 which a is calculated.

Row #	$\Delta V$ [V]		Row #	$\Delta V$ [V]
0			14	
1			15	
2			16	
3			17	
4			18	
5			19	
6			20	
7			21	
8			22	
9			23	
10			24	
11			25	
12			26	
13			27	

### Spreadsheet Analysis for the Electric Dipole

The electric field from a three dimensional dipole varies as:

$$\vec{E} = \frac{2akq}{[a^2 + y_p^2]^{3/2}} \hat{y}$$

along the symmetry axis of the dipole. Here, your data can be used to somewhat verify this behavior although it will also show deviations due to other effects. The verification is as follows:

Define a variable  $y$  given by:

$$u \equiv \frac{2ak}{[a^2 + y_p^2]^{3/2}}$$

Then your measurements of  $V$  are converted into  $E$  by dividing by the distance between the two dissecting pins:

$$|\vec{E}| = \frac{\Delta V}{\Delta x}$$

A plot of  $E$  vs.  $u$  should then yield a straight line with a slope equal to the charge  $q$ . In actuality, the departure from the 3-d behavior is most significant at small  $y$  values. I have therefore only provided the linear fit for the  $y$ -values which are further away (after row 6 or so). The  $R^2$  value will provide you with an indication of how close to a linear relationship the curve actually is. If you are careful with taking your data, you may get a nice linear relationship as I have shown from my data on the spreadsheet. With the existence of a nice linear relationship, your confidence in the methods used to calculate potentials arising from various charge configurations is hopefully increased.

I have also provided a second graphical output to show how the measured  $E$  varies with  $y$ . While we could fit this directly, I believe it is more convincing to show the linear relationship which was obtained.

In your write-up of these parts of the lab, each student should turn in individual electrostatic maps, meaning that someone will need to make copies of the maps. Be sure to include copies of your data, calculations, etc., together with a discussion of the results.