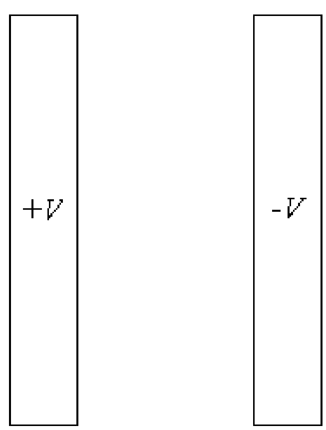
Lab 1: Electric Potential and Electric Field

- **I.** Before you come to lab...
  - **A.** Read the following chapters from the text (Giancoli):
    - **1.** Chapter 21, sections 3, 6, 8, 9
    - **2.** Chapter 23, sections 1, 2, 5, 7
  - **B.** Read through the entire lab.
  - **C.** Answer the following questions on a separate sheet of paper. Be sure to write your name and lab section on the page. You will hand it in to a lab TF at the start of the lab period.
    - **1.** Sketch a prediction of what you think the equipotential contours and electric field lines would look like for the given arrangement of electrodes.

    - **2.** Do the same for the arrangement below.



II. Introduction

A. Electric potential and electric field

1. Any arrangement of static charges produces an electric field in its vicinity. In lecture you have learned about Coulomb's Law and the principle of superposition, which make it possible to (theoretically) calculate the field produced by a set of charges. But in practice it is mathematically very difficult to do so for all but the simplest charge configurations. And even in the simple configurations, the task is difficult because of the vector nature of the electric field.
2. Electric potential, on the other hand, is a scalar, which makes it much easier to work with. And the best part is, the electric potential contains all the same information as the electric field--if you know the potential, you can calculate the field, and vice versa.
   - **a.** If you know V(x, y), then **E** is the vector whose components are (-dV/dx, -dV/dy).
   - **b.** If you know **E**, then you can calculate V anywhere by taking minus the integral of **E** · d**s**.
3. In this lab, you will determine the electric potential produced by a set of electrodes held at fixed voltages. The working surface of the experiment will be a two-dimensional sheet of paper. Rather than measure the potential at every single point, you will use equipotential contour lines to visualize the potential. You can also use these lines to draw the corresponding electric field lines.
4. The relationships between field lines and contour lines are outlined below. You don't need to know any calculus to use these rules, but they are all derived from the mathematical relationship between **E** and V.

B. Electric field lines:

1. Begin on + and end on - charges
2. Do not begin and end except on charges/electrodes
3. Always point from high potential to low potential
4. Always point in the direction the potential is decreasing most rapidly ("downhill")
5. Never form closed loops
6. Never cross other field lines
7. Always cross equipotential contours at right angles
8. Are closer together in areas where the field is stronger

C. Equipotential contours:

1. Always form closed loops (except at the boundary of the paper)
2. Always cross field lines at right angles
3. Never cross other equipotential contours
4. Never pass through electrodes
5. Are closer together in areas where the field is stronger
6. Any good conductor is its own equipotential

III. Materials

A. Potential plotting board

1. This is just a board with two rows of screw holes which are electrically connected to the terminals at the edge of the board.
2. Screwing an electrode tightly into one of the holes will create an electrical contact that will maintain the electrode at the terminal voltage.
3. Another way of attaching an electrode is by placing a piece of conducting tape on the sheet and connecting it to an external power supply using alligator clip leads.

B. Conductive paper

1. This is a sheet of carbon paper which is slightly conducting. Unlike a metal, the sheet itself is

not such a good conductor that it is at the same voltage everywhere. Rather, the presence of electrodes held at fixed potentials on the sheet will cause a distribution of voltages and fields all over the sheet, which can then be probed using a digital voltmeter.

2. The two sides of the sheet are not identical. To make sure you are working on the correct side, place the sheet on the equipotential board so that the edges of the paper curl upwards. The side you will be working on is the less glossy, more matte black side.

3. Try to handle the sheet as little as possible, and only around the edges. While you are making a voltage measurement, you can touch the paper lightly but do not rest your weight on it, as that could distort the electric fields in the paper.

C. Digital multimeter

1. The multimeter is the tool you will be using to measure voltages. There are several settings on the dial; the one you will be using is the setting that says V with a pair of straight lines (not V with a wavy line, which is used to measure oscillating voltages).

2. Depending on the model of multimeter, you may also have to set the range of the instrument. For the purposes of this lab, you should use the 20-volt setting.

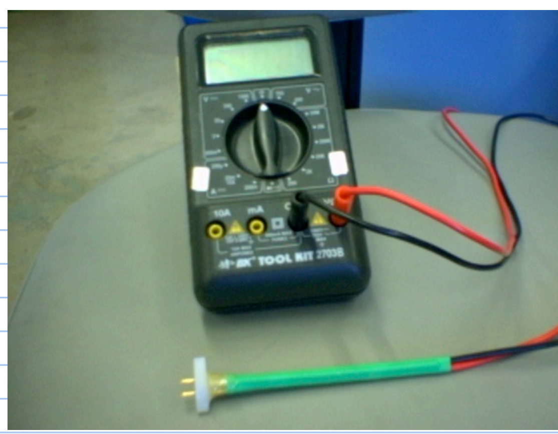
3. The multimeter probes must both be in contact with something in order to get a reading. The digital readout will indicate *the voltage of the red probe minus the voltage of the black probe*.

4. This is a general convention for electric components: red terminals and leads are considered "positive" and black ones "negative." For a meter, nothing bad will happen if you reverse the two--you will just get a negative reading if you put the red probe at a lower voltage than the black probe.

5. If your probes are disconnected or you are switching probes, make sure to plug the red probe into the jack labeled "VΩ" and the black probe into the jack labeled "COM."

D. Electric field probe

1. This two-pronged probe connects to your digital multimeter in place of the red and black single-pronged probes. It consists of two prongs 0.5 cm apart.



2. This simple device converts your digital multimeter into an electric field meter. Simply press it down onto the conducting sheet (making sure both prongs are in contact with the paper), and read off the voltage from the multimeter. Double that value and you have the electric field at that location (or at least, in that vicinity), in units of volts per cm.

3. Note the polarity of the device. The red (positive) probe of the multimeter is connected to the probe at the head of the arrow, and the black probe is at the tail of the arrow. So the probe will give a positive reading when the arrow points in the direction of increasing voltage. Which direction does the electric field point?

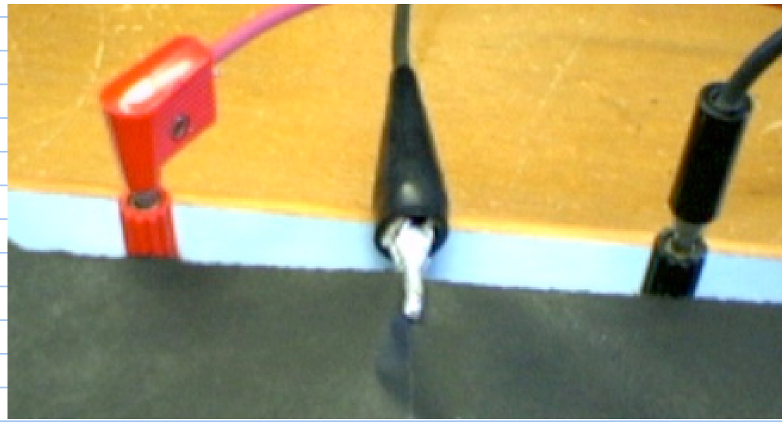
4. Recall that electric field is a *vector*; the probe only measures the projection of the field in the direction of the probe's orientation. If you orient the probe perpendicular to the actual direction of the field, you will get a reading of zero. If you orient it parallel to the field, you will get (plus or minus) the magnitude of the field. If you don't know the direction of the field, you can use the probe to determine its components (E_x, E_y) by measuring the field strength in the horizontal and vertical directions. Then you can use your knowledge of vectors to determine the magnitude and direction of the vector **E**.

- **E.** DC power supply
  - **1.** This supply will maintain a constant voltage between its terminals. The red terminal is held at a higher voltage than the black terminal, in accordance with the usual color convention.
  - **2.** You can adjust the voltage of the power supply using the knob. The push-button switch toggles between the 0 to 12 volt and 12 to 24 volt settings.
- **F.** Selection of electrodes
  - **1.** These are metal conducting blocks with screw holes.
  - **2.** To achieve the best electrical contact with the paper, place the side with raised edges facing down. Also, you may want to rub that side down with steel wool to make sure it is clean.
- **G.** One white pencil and one red pencil
  - **1.** These pencils will make non-conductive marks on the paper, unlike a regular lead pencil.
- **H.** Conductive tape
  - **1.** This is specialized adhesive tape which is conducting on both sides.
  - **2.** This will be used in place of electrodes for the third part of the lab.

IV. Procedure

- **A.** Before you begin...
  - **1.** Take a picture of your lab group using Photo Booth and drag it into the space below:
  - **2.** Tell us your names:
  - **3.** Make sure you go over the descriptions of the materials you will be using, so that you will know how to use everything properly.
- **B.** Drawing equipotential contours

  In this part of the lab, you will use a multimeter probe to map out equipotential contours around a pair of electrodes on a sheet of conducting paper.
  - **1.** Set up your potential plotting board and carbon conductive paper as described in the materials section. (Remember to place the correct side of the sheet facing up.)
  - **2.** Place two electrodes on your paper and bolt them into the board tightly. Use either two small circles, or two long bars, so that you get one of the configurations you made predictions for in the pre-lab exercise. (Your TFs should tell you which configuration to use.) If you are using the long bars, each bar should be attached with two bolts, one at either end of the bar.
  - **3.** Connect the red and black terminals of the board to the DC power supply. Turn on the power supply and use the knob to adjust the output to about 20 volts.
  - **4.** Using an alligator clip lead, connect the black terminal of the multimeter to the edge of the conducting paper, halfway between the terminals of the board, as in the picture below:



5. Using the red probe of the multimeter, measure the voltage of the positive and negative terminals of the board relative to the point halfway in between them where you clipped the alligator lead in the previous part. You should get approximately equal and opposite numbers. If you don't, adjust the position of the alligator clip a little bit to one side or the other to balance them. When you are satisfied with your results, record the voltages here:
   Voltage of + terminal:
   Voltage of - terminal:
6. Move the red probe around the sheet of paper to explore the electric potential on the sheet. Make sure the probe is in contact with the sheet, but you do not need to press it very hard (the weight of the probe itself is usually sufficient), and be sure not to drag the probe across the surface. Above all, do not poke a hole through the paper or tear it. (Be especially careful around the places in the board where there is a screw hole beneath the paper surface.) By exploring the sheet with the multimeter probe, you can "map out" the potential in the two-dimensional space you are working in.
7. Move the red probe around the sheet until you find a point which gives a reading of half of the voltage of the positive supply. When you find such a point, mark it with the white pencil.
8. Move the probe several centimeters away from your previous point and try to find another point at the same voltage. Mark it with the pencil. These two points are the beginning of your plot of an equipotential contour at this voltage.
9. Continue in this fashion until your contour either closes in on itself or reaches the edge of the paper. At the places where the contour is highly curved, it will be necessary to take more measurements closer together than in the areas where the contour is fairly straight. Far from the electrodes, you probably only need a point every few inches. The idea is to plot just enough points that you can be fairly sure of the shape of the equipotential contour. If you reach the edge of the sheet before the contour closes in on itself, go back to your original starting point and trace the contour in the opposite direction.
10. Using the white pencil, connect the points you have plotted with a smooth curve, and then label the curve with its voltage.
11. Repeat steps 7-9 for contours at 0 volts and half of the negative supply. You should switch tasks among the members of your lab group for the different curves.

C. Exploring the electric field

1. Using the red pencil, draw in the electric field lines. Be sure to indicate the direction of the field. Refer to the rules for field and contour lines in the introduction if you do not know how to do this. If you don't have enough contour lines to make an accurate drawing of the field lines, plot some more. A good way to choose which voltage to look for is by simply selecting a point about halfway between two existing contours and measuring the voltage there; then

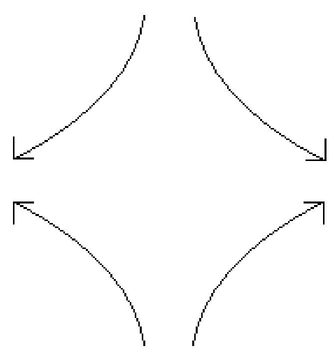
plot out the entire contour which passes through that point.

2. How does your paper look compared with the prediction you made in the pre-lab exercise?
3. When you reach this point, talk to a TF. Your TF will indicate four points on your sheet where you are to measure the electric field, using the electric field probe.
4. Remember, the electric field probe only measures one component of the field. To determine the direction, you can either measure the x- and y-components and then use the equations for vector components, or you can just turn the probe until you get a reading of zero, which occurs when the probe is perpendicular to the field.
5. Does your sketch of field and contour lines correctly indicate the direction of the electric field at the four points?
6. Does your sketch correctly indicate the relative electric field strength at the different points?
7. Unscrew your electrodes and remove the sheet of conducting paper. Write your names and your lab section time on it. and turn it in to a TF.

D. Challenge puzzles

In this part of the lab, you will be given a diagram of an electric field and asked to determine a configuration of conductors that will produce such a field.

1. Get a fresh sheet of conducting paper and place it on your board. Again make sure that the edges curl upwards.
2. Using Scotch tape, tape the corners of the sheet down to the board.
3. Your goal is to produce the electric field shown below:
   - **a.**



4. Instead of using electrodes bolted into the board, this time you will use pieces of conductive tape. This gives you more flexibility, as you are not limited by the locations of the screw holes in the board.
5. You can use as many or as few pieces of tape as you like (although you must have at least two). For each piece of tape, leave the edge of it curled up instead of stuck to the paper. Attach an alligator clip lead to the edge of the tape to provide an electrical connection to the power supply.
6. Before you start slapping tape down all over the place, consult with your lab partners and try to draw the arrangement you think will produce the desired field. Once you all agree, then put it into practice.
7. When you have arranged your conducting tape in the desired configuration, attach the power supply. Using the electric field probe, determine the electric field direction in key places to see if your configuration actually produces the electric field in the diagram. If not, think about why it didn't work and try again. Talk to a TF if you get stuck.
8. If you successfully finish, get another sheet and try to produce the following configuration:

a.

b. You only need to have the field at those two locations point in the indicated directions; anywhere else, it can look however you want. Be warned, though, that this is not as easy as it might sound.

V. Conclusion

- **A.** Congratulations--that's it for this first lab!
- **B.** Your TFs will instruct you on how to submit your lab report for grading.