Name ______________________ Section __________ Date ________________

Laboratory 26. Equipotentials and Electric Fields

Pre-Laboratory Assignment

Read carefully the entire description of the laboratory and answer the following questions based upon the material contained in the reading assignment. Turn in the completed pre-laboratory assignment at the beginning of the laboratory period prior to the performance of the laboratory.

1. Electric field lines are drawn (a) from positive charges to negative charges (b) from negative charges to positive charges (c) from the largest charge to the smallest charge (d) from the smallest charge to the largest charge.

2. The points where the potential is the same (in three dimensional space) have the same voltage. (a) True (b) False

3. The points where the potential is the same (in three dimensional space) lie on a surface. (a) True (b) False

4. The relationship between the direction of the electric field lines and the equipotential surfaces is (a) field lines are everywhere parallel to surfaces (b) field lines always intersect each other (c) field lines are everywhere perpendicular to surfaces (d) field lines always make angles between 0° and 90° with surfaces.

5. For this laboratory why are the measured equipotentials lines instead of surfaces?

6. If two electrodes have a source of potential difference of 100 volts connected to them, how many equipotential surfaces exist in the space between them?

7. How much work is done in moving a charge of 10 microcoulombs 1 meter along an equipotential of 10 volts?

8. For this laboratory why is it important to center the electrodes on the resistance paper?

9. In the performance of this laboratory, what is the recommended maximum allowed potential difference from one end of an electrode to the other end?

10. How are you supposed to decide how many points to measure for each equipotential for a given electrode configuration?

Laboratory 26. Equipotentials and Electric Fields

Objectives

In this experiment the relationship between the equipotential surfaces and electric field lines in the region around several different electrode configurations will be investigated. Electrodes, drawn on carbon impregnated paper with conducting paint and connected to a direct current power supply, will simulate statically charged electrodes to accomplish the following objectives:

1. Determination of the location of equipotential surfaces in the region around oppositely charged electrodes by measurements made with a voltmeter
2. Investigation of the shape of the equipotential surfaces for several specific electrode arrangements
3. Construction of electric field lines from the measured equipotentials by drawing lines perpendicular to the equipotentials
4. Comparison of the experimentally determined shapes of electric field lines with several familiar electrode arrangements (line charge, two line charges of opposite sign, and parallel plates)
5. Determination of the dependence of the magnitude of E on the distance, r, from a line of charge

Equipment List

1. Corkboard and push pins to attach power supply and voltmeter to electrodes
2. Carbon impregnated gridded resistance paper
3. Conducting paint or conducting pen (either silver or carbon based)
4. Direct current power supply (20 volt, low current)
5. High impedance voltmeter (preferably digital)

Theory

Consider two electrodes of arbitrary shape some distance apart carrying equal and opposite charges. There will then exist a fixed potential difference or voltage between the electrodes. Suppose that this potential difference is 20 volts. If the electrode with the negative charge is arbitrarily assumed to be at zero potential, then the electrode with the positive charge is at a potential of +20 volts. Given these assumptions, in the space surrounding these electrodes there will exist points which are at the same potential. For example, for the case described above, there will exist some points for which the potential is +10 volts. There will exist other points for which the potential is +15 volts, and still other points for which the potential is +5 volts. In a three dimensional space all points at the same potential will form a surface, and there will be a different surface for each value of the potential between 0 volts and 20 volts. In fact, there will exist an infinite number of such surfaces because one could divide the 20 volt total potential difference into an infinite number of steps. Each of these surfaces with the same value of potential is called an equipotential surface. In this laboratory the equipotentials for a few simple, but often used, electrode configurations will be determined.

In addition to the equipotential surfaces that exist in the region around charged electrodes, there is also present an electric field. By definition the electric field is a vector field which can be represented by lines drawn from the positively charged electrode to the negatively charged electrode. The direction of the electric field lines at every point in space is the direction of the force that would be exerted on a positive test charge placed at that point in space. To assure the test charge does not disturb the other charges, the test charge must be small. In fact, in the exact definition, the limit must be taken as the test charge approaches zero. The magnitude of the electric field is the force per unit charge on the positive test charge as the magnitude of the test charge approaches zero. The units of electric field are Newton/Coulomb. The number of field lines per unit area at a given point is a measure of the magnitude of the electric field. Thus a region where there are a large number of lines per unit area is a region of large electric field.

The electric field lines must always exist in a fixed geometrical relationship with the equipotential surfaces for any electrode configuration. Simply stated, the relationship is that the electric field lines are everywhere perpendicular to the equipotential surfaces. Since the electrodes themselves are equipotential surfaces, the electric field lines must also intersect the electrodes perpendicularly. This is usually a very helpful guide when attempting to determine the shape of electric fields around an electrode arrangement.

If the change in potential, ΔV, is measured between two points separated by a displacement, Δx, then it can be shown that the following equation is true:

$$E = -\frac{\Delta V}{\Delta x} \qquad (1)$$

where E stands for the electric field. To be exact, the limit of equation (1) must be taken as $\Delta x \rightarrow 0$, but equation (1) can be useful as an approximation if Δx is small. According to equation (1) if $\Delta V > 0$ for a Δx in a given direction, then E is in the opposite direction of the displacement, Δx, but if $\Delta V < 0$ then the field is in the direction of Δx. Equation (1) also shows that another proper unit for the electric field is volt/meter. Another important fact that can be seen from equation (1) is that it takes no work to move an electric charge on an equipotential surface because along the equipotential $\Delta V = 0$ and thus $E=0$ along the equipotential surface.

Since the electrodes that can be drawn on the carbon paper are limited to two dimensions, they represent a slice taken through a real three dimensional electrode configuration. As a result, the equipotentials mapped by this laboratory will be equipotential lines rather than surfaces. Any two dimensional electrode arrangement can be produced by drawing the desired electrode shape on the carbon paper with conducting paint or a conducting pen and then attaching a source of potential difference to the electrodes. A direct current power supply will provide the source of potential difference and will serve to keep the voltage between the two electrodes fixed at whatever value is chosen from the power supply. The electrode to which the negative terminal of the power supply is attached will arbitrarily be chosen to be the zero of potential, and all measurements will be made relative to that electrode. A voltmeter will then be used to find the points on the paper in the region of the electrodes that are at some given value of potential. Once enough points at that potential have been located to establish the shape of the equipotential, the equipotential line can be constructed by joining the points with a smooth curve. The number of data points needed to establish the shape must be decided by the student.

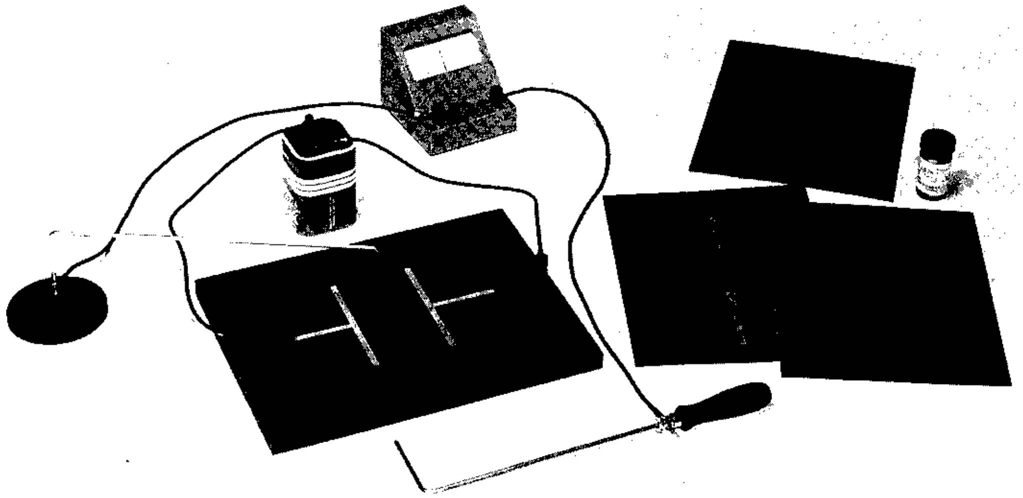
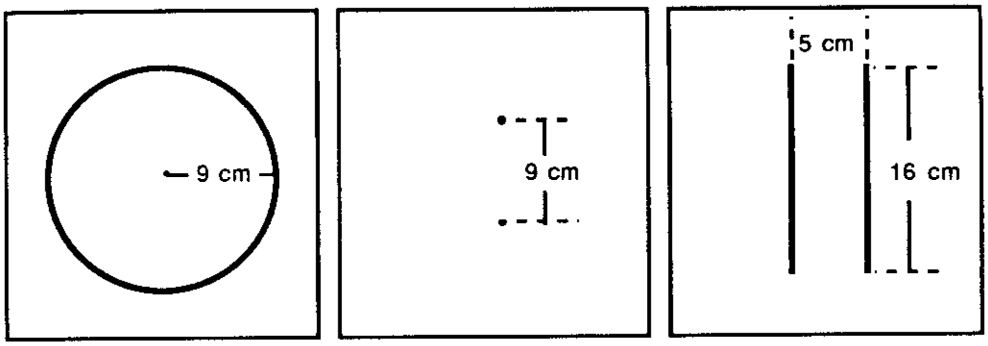


Figure 26-1. Equipotential mapping apparatus shown here using a battery rather than a power supply.(Photo courtesy of Sargent-Welch Scientific Company)



(a) (b) (c)

Figure 26-2. Electrode configurations to be mapped.

Experimental Procedure

1. Use a paint brush or conductive ink pen to draw the three electrode configurations shown in Figure 26-2. Note carefully the following important cautions: (a) Place the conductive paper on a hard surface to draw the electrodes. Do not draw while the paper is on the corkboard. (b) Make sure that the conductive paint or ink flows smoothly and evenly when drawing electrodes, and that a solid line is obtained.

2. Draw the three electrode configurations pictured in Figure 26-2 and described below. For each configuration use one clean sheet of carbon paper and arrange the electrodes as nearly centered on the paper as possible because edge effects can be important in some cases. (a) Line of charge perpendicular to the paper and guard cylinder of radius 9 cm--draw a small dot at the center of the paper and then draw a circle of radius 9 cm centered on the dot. Be sure that the dot is centered on one of the grid markings. (b) Two lines of opposite charge perpendicular to the paper--draw two small dots 9 cm apart symmetrically located on the paper. (c) Parallel plate capacitor--draw two straight lines 16 cm long and 5 cm apart symmetrically located on the paper.

3. For each electrode configuration in turn, place the metal push pins in the electrodes and connect the two leads from the power supply to the pins. For the parallel plate and two line charge configuration there is symmetry, and the assignment of which electrode is negative and which is positive is arbitrary. For the line charge and guard ring choose the line charge as positive and the guard ring as negative. 2 – 60 volt Batteries

4. In each case set the potential difference between the electrodes to be ~~20.0~~ volts. 12 ✓ To set this value connect the voltmeter between the electrodes with the negative voltmeter lead connected to the negative power supply output, and the positive voltmeter lead connected to the positive power supply output. Once this value is set it should remain fixed.

5. For each electrode configuration make sure that all connections are secure and that the push pins are pressed firmly into the corkboard which will assure good contact with the electrodes. In order to check that the electrodes themselves have the proper conductivity, connect one lead of the voltmeter to one of the electrode push pins, and then using the other lead of the voltmeter as a probe, touch it to various parts of the same electrode. For a properly conductive electrode the maximum voltage between any two points on the same electrode should be less than 0.2 volts. Repeat this test for the other electrode.

6. Determine the equipotentials by connecting the negative voltmeter lead to the electrode push pin which is connected to the negative output of the power supply (which is to be considered the zero of potential). As illustrated in Figure 26-3, the other voltmeter lead then serves as a probe, and it is used to measure the potential at any point on the paper by touching the probe to the paper at that point. Be sure that the probe used has a sharp point, and that the probe is held perpendicularly to the paper so that only the point of the probe touches the paper. A given equipotential line (for example the 10.0 volt equipotential) is mapped by moving the probe around to find the points at which the voltmeter reading is 10.0 volts, and then connecting these points to produce a smooth curve or line. For each equipotential obtain enough points to clearly define the shape of that equipotential line.

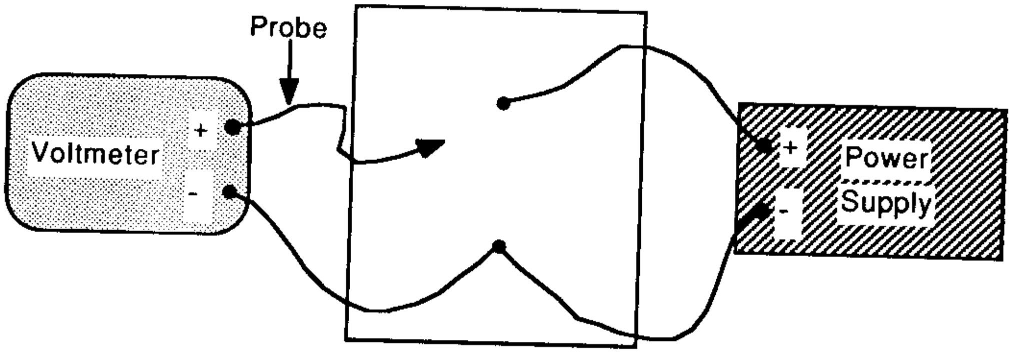


Figure 26-3. Power supply and voltmeter connections for mapping equipotentials.

7. Using the procedure described above in step 6, map in pencil the following equipotential lines for each electrode configuration:

6V → 0V
8 MEASUREMENTS

(a) Line charge -- 15.0, 10.0, 6.50, 4.50, 3.50, 2.50, 1.50, and 0.75 volts.
(b) Two line charges -- 16.0, 13.0, 11.5, 10.0, 8.50, 7.00, and 4.00 volts.
(c) Parallel plates -- 4.00, 8.00, 12.0, and 16.0 volts.

8. In general, electric field lines were stated to be everywhere perpendicular to equipotential surfaces. Because our electrodes are confined to the plane of the paper, the equipotentials are lines, but it is still true that the electric field lines are everywhere perpendicular to these equipotential lines. For each set of electrodes draw a set of lines

that are perpendicular to your measured equipotential lines. These are the electric field lines. Place arrows on them to indicate their direction from positive charge to negative charge. Distinguish them in some way from the equipotential lines, either by dotting the lines or drawing them in a different color.

9. Make the following measurements for the electrode configuration of the line of charge. Measure the value of the change in potential at the distances from the line of charge listed in the Data Table. Tape the two voltmeter probes together with a small piece of insulating material holding the points of the probes apart at a fixed distance, Δx, of about 0.003 m. Place the probes symmetrically about the grid positions on the paper at the values listed in the Data Table in such a manner that the gap between the probes is centered on each grid position in turn. It is extremely critical that the gap be as precisely centered on each position as possible. Record the values of ΔV and the value of Δx in the Data Table.

Calculations

1. For the measurements made in step 9 above, calculate the approximate value of E at each point as $\Delta V/\Delta x$. Record these values of E in the Calculations Table.

2. Perform a linear least squares fit to this data of E versus 1/r. Note that the ordinate is to be E, and the abscissa is to be 1/r. Determine the slope, intercept, and the correlation coefficient for the fit and record them in the Calculations Table.

Graphs

1. Construct accurate drawings on 1 cm by 1 cm graph paper showing the electrodes and your measured equipotentials and electric field lines for each electrode configuration.

2. Make a graph of the data for E versus 1/r for the line charge data. Also show on the graph the straight line obtained in the least squares fit.

Name ______________________ Section __________ Date __________

Laboratory 26

Equipotentials and Electric Fields

LABORATORY REPORT

Data Table

r (m)	ΔV (volt)
0.0150	
0.0200	
0.0300	
0.0400	
0.0500	
0.0600	
0.0700	
0.0800	

Δx = __________ m

Calculations Table

$E = \frac{\Delta V}{\Delta x} \left(\frac{\text{volt}}{\text{m}}\right)$	$^1/_r$ (m^{-1})

Slope = ______________

Intercept = ______________

Regress. coeff. = ______________

SAMPLE CALCULATIONS

QUESTIONS

1. Although the magnitudes of the equipotentials and electric fields for electrode configurations (a) and (b) are consistent with interpretation of those arrangements as line charges, the shapes of the equipotentials and electric field lines are the same as those for a point charge and a dipole charge. Compare your graphs with those in your textbook for a point charge and a dipole. Comment on their similarities and differences, if any.

2. Point A in Figure 26.4 represents a point halfway between the (+) electrode and the 16.00 equipotential on the plot of your data. Calculate the electric field E_A at the point A using equation 1. Note that the value of ΔV is given by the difference in potential between the (+) electrode and 16.00 V. In other words, if the (+) electrode has a potential of 20.00 V then $\Delta V = 4.00$ V. The value of Δx to be used is the distance from the center of the (+) electrode to the 16.00-V equipotential measured in the direction from the (+) electrode toward the (−) electrode. In a similar manner, calculate the field E_C at point C, which is halfway between the (−) electrode and the 4.00-V equipotential. Point B is at the center of the electrodes. Calculate E_B using ΔV between the 8.50-V equipotential and the 11.50-V equipotential, and using for Δx the distance between those equipotentials measured along the line between the electrodes. Record the values of E_A, E_B, and E_C.

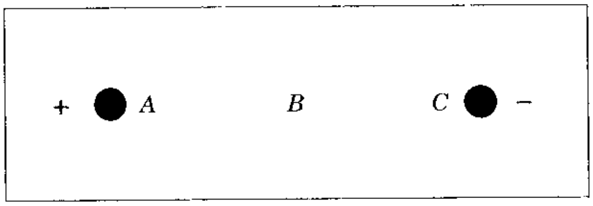


Figure 26.4 Point *A* near positive electrode, *C* near negative electrode, and *B* at center.

E_A = ________ V/m E_B = ________ V/m E_C = ________ V/m

3. Are the results for the E field at points A, B, and C in the preceding question consistent with what you would expect for the relative values at these points? State your reasoning.

4. According to theory, the E field in the region between the plates in electrode configuration (c) should be constant. Calculate the E field from equation 1 at points A, B, and C defined by Figure 26.5 below using the same process as in question 2.

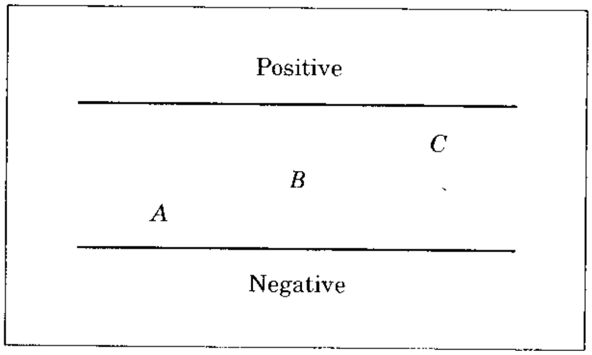


Figure 26.5 Point *A* near negative electrode displaced slightly from the center, *C* near the positive electrode displaced same amount in the other direction, and *B* at center in the middle.

E_A = ________ V/m E_B = ________ V/m E_C = ________ V/m

5. Are the values for the E field at the points in question 4 approximately constant within the experimental uncertainty?

6. According to theory, the electric field E for a line of charge should be proportional to $1/r$, where r is the distance from the line of charge. Considering the graph of the data and the value of the correlation coefficient, comment on whether or not your data for the line of charge confirms this dependence.