Electric Potential, Electric Field

APPARATUS

1. Plotting Board with Teledeltos Paper
2. Electronic Voltmeter
3. D.C. Power Cord
4. Ruler

INTRODUCTION

When an electric potential difference is established between two conductors there will be an electric field between them. There will also be an electric potential difference $V(x, y, z)$ between any point in space and one of the conductors. In general, it is difficult to calculate V. However, in situations having a high degree of symmetry, Gauss's Law allows a simple calculation of the electric field, from which V can be easily calculated by integration.

This experiment mimics the case of cylindrical symmetry by using a sheet of high resistance conducting paper on which concentric circular conductors are placed. A very small current will flow through the paper guided by the electric field at each point. An electronic voltmeter is used to measure the electric potential difference between points on the paper and one of the electrodes. The voltmeter itself has such a high resistance that it does not disturb the field. Once the potential has been determined at different positions, the electric field can be determined by finding the gradient of the potential.

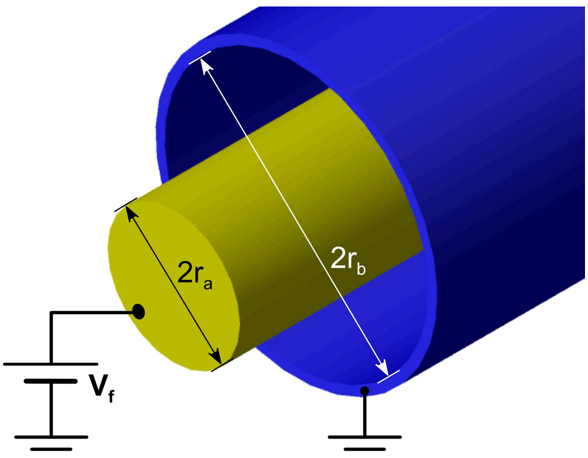

Figure 1: Coaxial arrangement of two conductors.

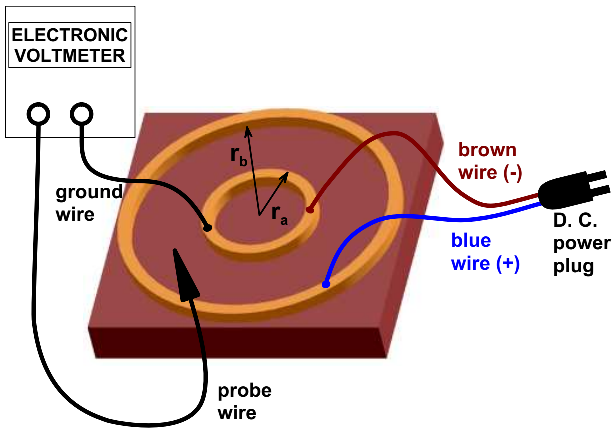

Figure 2: Wiring diagram.

EXPERIMENTAL ARRANGEMENT

The arrangement of concentric cylindrical conductors which we are considering is shown in Fig. 1. Our laboratory arrangement is illustrated in Fig. 2. The electrodes rest on a sheet of uniform conducting paper (trade name TELEDELTOS) so that it is equivalent to a plane section through Fig. 1, perpendicular to the axis of symmetry. Thus, when the terminals of a DC supply are connected to the electrodes, as shown in Fig. 2, the variation in potential between the electrodes will be the same as between the two cylinders of Fig. 1. Potential differences will be measured between points on the paper and the inner electrode.

MEASUREMENT PROCEDURE

A. Determine the radii

r_a is the outer radius of the inner ring. r_b is the inner radius of the outer ring. Measure the diameters to the nearest mm and divide by 2.

B. Wiring

Be sure that the DC power plug is NOT connected to the outlet. It is to be plugged in only after your wiring has been approved by your instructor.

Examine the wiring under the plotting board to see which binding post is connected to the inner electrode. Connect the brown wire (ground) of the DC power cord to this binding post. Connect the blue wire (+) to the outer electrode via the other binding post. Check that the black lead from the voltmeter is plugged into COMMON and that the probe end has an alligator clip on it. Clip it to the screw projecting from the inner electrode. The red lead should he plugged into V-Q-A. This lead will be used to probe the field. HAVE YOUR INSTRUCTOR CHECK YOUR WIRING. If it is approved, you may plug the DC power cord into the special outlet.

C. Set up the Voltmeter

Turn the voltmeter dial to 10 Volts on the DC side. Set the polarity switch to +. Touch the probe to the inner ring. If the meter does NOT read zero, call your instructor.

D. Read the potential difference at various values of r

Positions may be measured from the edge of the inner electrode. The radius may then be calculated by adding the radius of the inner electrode as measured in A. Set up a data table with columns for: distance, radius, V_1, V_2, V_3, and V_{avg}. V_1, V_2, and V_3, are to be measured along three different radii and averaged in the last column.

Gently touch the voltmeter probe to the paper at a point about 5 mm from the edge of the inner electrode. **Do not press hard enough to damage the paper.** Record this data point in your table. Continue along the same radial direction, taking readings every 5 mm.

Repeat for two other radii at about equal angles.

ANALYSIS

A. Linear Plot

Plot the average potential difference against radial distance. Draw a smooth curve that approximates the data points. The theoretical relationship between V and r for the geometry of Fig. 1 is given by

$$V(r) - V(r_a) = constant \times ln\left(\frac{r}{r_a}\right) \tag{1}$$

where the constant is proportional to the potential difference between the electrodes. Given the dimensions of the apparatus and small irregularities in the paper, it may be difficult to see that the data follow equation (1).

B. Semi-Log Plot

If V is plotted against $log_e(r)$, a linear plot should be obtained. Semi-log graph paper has markings along one axis whose distance is proportional to the $log_{10}(x)$, where values of x between 1 and 10 appear on that axis. This means that you do **not** have to calculate logarithms. V is plotted along the linear axis. Plot your data for V vs. r.

Do the data confirm the form of equation (1)? Draw the best straight line that fits the data.

You may notice that the straight line does not intersect the lines for r_a and r_b at the appropriate values of V. This is due to oxidation and poor contact at the copper-paper interface.

C. Cylindrical symmetry

Choose one value of the radius, about 2 cm from the inner ring, and examine the potential difference at several angles different from the data taken earlier. Recognizing that small variations are possible, do your data indicate cylindrical symmetry? Explain your answer

D. Electric Field

The electric field E, at any point may he found from

$$E_r = -\frac{dV(r)}{dr} \tag{2}$$

Choose about six points on the linear plot of part IV.A and use the tangents to your curve at these points to determine E_r.

Applying equation (2) to $V(r)$ from equation (1) yields

$$E_r = constant \times \frac{1}{r} \tag{3}$$

Prepare a table of your values of E (in Volts per cm), r (in cm) and $\frac{1}{r}$. Plot E_r vs. $\frac{1}{r}$ on linear graph paper. Do your data fit a straight line as indicated by equation 3?

E. Other Regions

According to Gauss's Law applied to the situation of figure 1, there should be no electric field outside the outer ring or inside the inner ring. Explore the value of the electric potential in these two regions. (The values may not be zero because of the imperfections mentioned previously.) What do your values for the potential indicate about the electric field outside the outer ring? Inside the inner ring? Explain your reasoning. QUESTION: If your data for V(r) corresponded to the geometry of figure 1, would the charge on the inner conductor be positive or negative? Explain your reasoning.