

EXPERIMENT 4 ELECTRIC FIELD PLOTTING

I. THEORY

The electric field vector at a point in space is defined as the force acting on a small test charge located at the point, divided by the test charge.

An electric field line is a line having the property that a straight line tangent to it at any point is parallel to the electric field vector at the point.

The potential at a point P relative to a reference point R may be defined as the work which must be done by an external force in moving a small test charge from R to P, divided by the test charge. By definition, the potential at R is zero. In systems containing only electrostatic charges, the reference point R is commonly taken as infinitely far from any of the charges. In DC circuits containing a battery or power supply, as in this experiment, it is more convenient to define the point of zero potential as the negative terminal of the battery or power supply.

An equipotential surface is a surface of constant potential. Such a surface has the property that a small test charge can be moved freely about the surface without doing work. It may be shown that electric field lines and equipotential surfaces must be perpendicular to each other wherever they intersect.

It will be shown later in this course that when a source of potential difference V , such as a power supply, is connected to a series combination of n equal electrical resistors, the difference in potential across each resistor is V/n . In this experiment we will connect a 4.0 V power supply to eight equal resistors connected in series. The difference in potential across each resistor is then 0.5 V. Choosing the negative terminal of the power supply as the point of zero potential, we find that the circuit has nine junctions with potentials of 0, 0.5, 1.0, ..., 4.0 V.

In this experiment the body to be studied consists of a layer of graphite deposited on a plate of masonite. Certain regions are also painted with conducting silver paint. Such regions have essentially constant potential, due to the fact that the silver paint has much lower electrical resistance than the graphite. The 4.0 V power supply mentioned in the previous paragraph is connected to two of the painted regions. This causes a very small flow of charges, that is, a very small electric current, along electric field lines joining the two regions. For the two-dimensional surface we will use, we will find equipotential lines at which the equipotential surfaces intersect the plane. The electric field lines in the plane will be perpendicular to these equipotential lines.

The purpose of this experiment is to trace out equipotential lines with the help of a sensitive detector of potential difference. Then a second family of lines will be drawn freehand in such a way as to intersect the first family at right angles. The second family will be a set of electric field lines.

A galvanometer is a sensitive instrument whose needle deflects when its two terminals are not at the same potential. Suppose we connect one terminal of the galvanometer to the junction between the first and second resistors mentioned above, that is to a point

whose potential is 0.5 V. Suppose a lead wire running to the other terminal of the galvanometer is touched to various points on the graphite layer. All points producing no deflection of the needle will be points lying on the 0.5 V equipotential line. In a similar way we may locate points lying on the lines of potential 1.0, 1.5, ..., 3.5 V.

If the scalar potential function V is known as an analytic function of position in a region of space, then the vector field function E may be found by taking the negative gradient of V . The scalar component of E parallel to a path s may be found from the simpler equation

$$E_s = -dV/ds \quad (1)$$

If V is known only as a series of numerical values at a limited number of points, as in this experiment, we may approximate the magnitude of E by using the approximate equation

$$E = \Delta V/\Delta s \quad (2)$$

in which Δs is the length of the path connecting two points on the same electric field line, and ΔV is the magnitude of the potential difference between the two points. The negative sign has been dropped, since we are concerned only with the magnitude of the electric field vector.

II. LABORATORY PROCEDURE

1. Select one of the graphite-coated masonite plates. Fasten the plate to the underside of the plotting board, making certain that the graphite layer faces outward. Tighten the thumbscrews securely so that good electrical conduction will occur.
2. Use masking tape to fasten a sheet of paper (the data sheet) to the upper side of the plotting board.
3. Find the plastic template which matches the pattern of silver paint on the masonite plate. (Each of the two plastic templates can be matched to two or three different masonite plates, but each masonite plate can be matched to only one template.) Place two of the holes of the template over the pegs of the plotting board in such a way that the patterns match, point for point. Trace out the pattern on the data sheet. Remove the template.
4. Check that none of the three buttons of the galvanometer is in the depressed position; if any is, rotate it to release it. Use a banana plug lead wire to connect one terminal of the galvanometer to the junction between the fourth and fifth resistors of the plotting board (2.0 V). Connect the other lead wire of the galvanometer to the U-shaped probe. Slide the probe over the plotting board so that the metal button of the probe makes contact with the graphite layer on the underside of the masonite plate. Connect the binding posts of the plotting board to the binding posts of the triple-output power supply. **Do not plug in the power supply yet.** Rotate the VOLTAGE and CURRENT knobs counter-clockwise to their full extent. Have the instructor check your electrical connections before plugging in the power supply and proceeding.
5. Plug in and turn on the power supply. Both digital displays should read zero. Rotate the CURRENT knob to its full clockwise position. NOTE: Both digital displays will still

read zero. Slowly rotate the VOLTAGE knob of the power supply clockwise until the voltage display reads 4.0 V. Mark the appropriate conductor on the data sheet zero, and the other conductor +4.0 V. (The red terminal of the power supply is at a higher potential than the black terminal.) Depress the left (least sensitive) button of the galvanometer and move the probe until the galvanometer shows no deflection. In order to locate a point on the 2.0 V equipotential line more precisely, switch to the middle button of the galvanometer, and again move the probe until there is no deflection. Repeat with the right (most sensitive) button. Mark the point on the data sheet. When checking a point with the galvanometer, gently squeeze the U-shaped probe to improve the electrical contact. **Do not squeeze the U-shaped probe while moving it, as this will scratch the surface of the plate and alter its conduction properties.**

6. If the null point of step #5 is less than 2 cm from either of the painted regions where the potential difference is applied to the graphite surface, then the graphite surface is badly worn; the masonite plate should be taken to the instructor, and another plate chosen.
7. Find and mark another null point no more than one cm from the first. Continue this process until the points making up the 2.0 V equipotential line extend nearly across the data sheet. Do not include as null points those points at the edge of the masonite plate where graphite has worn off.
8. Move the banana plug to a different junction and trace out the next equipotential line in the same way. Repeat this process for all of the remaining junctions, obtaining seven equipotential lines in all. It is perfectly all right if some of these null points are less than 2 cm from the regions of silver paint. In fact some null points may be so close to the thumbscrews that the probe cannot reach them; such null points may be omitted.
9. Rotate both knobs of the power supply to their full counter-clockwise position. *Then*, turn the power supply off and unplug it.
10. Remove the masonite plate from the back of the plotting board.
11. Repeat steps 1-10 for a second plate, if required by the instructor.
12. Dismantle your circuit and return the masonite plate(s) and plastic templates to their respective envelopes.
13. One copy of each data sheet should be prepared for each student in your group by one of the following methods:
 - (a) Have everyone in your group sign both data sheets. Obtain the instructor's initials. Make photocopies later.
 - (b) Use carbon paper to trace out enough copies for everyone. Sign only your own copies. Obtain the instructor's initials.

III. CALCULATIONS

1. Draw a smooth curve through the points of each equipotential line on the original data sheet(s). Label the seven lines and the two terminals with the numerical values of their potential, from zero to + 4.0 V.
2. Draw freehand 10 well-spaced smooth curves representing electric field lines. Each line must begin and end on a conductor. Each line must intersect both conductors at right angles. Each line must also intersect each equipotential line at right angles.
3. Choose at random three points that lie on electric field lines and are halfway between two equipotential lines. For each of the three points measure the length of the segment of the electric field line which lies between the two nearest equipotential lines. Use equation (2) approximate the magnitude of the electric field vector at each of the three points.
4. At each of the three points of step #3, draw a line tangent to the electric field line. Along each of the tangent lines draw an arrow representing the electric field vector. The direction of each arrow must be from high potential to low. The length of each arrow should be approximately proportional to the magnitude of the electric field vector as calculated in step #3.

IV. DIAGRAM

