Mapping Electric Fields

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**Objective**: In this lab, we will map the magnitude and distribution of an electric field by mapping equipotential lines and potential differences found by passing electrical current between two electrodes, connected via a semi-conductive paper, and mapping the potential differences through the use of a voltmeter.

**Theory**

Charged objects emanate fields that exert forces on other charged objects. This force is defined as

[1]

where force is measured in Newtons, k is the Coulomb constant 8.99 E9 N\*m2/C2, q0 is the charge of the reference object and q1 is the charge of the nearby charged object, or “test” charge being acted on, both measured in Coulombs, r is the distance between q0 and q1 along with its direction measured in meters.

The electric field is defined as the vector field that exerts electrical force exerted on a test charge as the product of the magnitude of that charge. This field is defined in the following manner:

[2]

where the field magnitude is measured in Newtons per Coulomb, k is Coulomb’s constant, q1 is the magnitude of the test charge in Coulombs, and r is the distance and direction between the source charge and the test charge in meters. It is important to note that these formulas apply when the test charge is small, such that the electric field is not appreciably disturbed.

Much like a gravitational fields, electric fields also require work to navigate, objects placed varying distances from the field source will have varying potential energies relative to the field source. Often of interest is the work required to traverse the distance between two points in the field. This work difference, or potential difference (which is scalar, and not a vector), is defined, in several ways, by:

[3]

where ΔV is measured in volts, ΔW is measured in Joules, q1 is measured in Coulombs, E is measured in Newtons per Coulomb, and Δr is measured in meters. The negative sign is present because potential difference is measured in a frame of reference where a position nearer to the field source is considered a higher potential. In vector notation, we can describe an electric field as the negative of the gradient of the potential difference:

[4]

again, measured in the units previously mentioned. It should be noted that one volt is equivalent to one Joule per Coulomb. For informational purposes, the gradient of a quantity is a vector that points in the direction of greatest increase, thus, in this case, the decrease in potential difference will point towards the source of the electric field.

When a charge conductor has not charge flowing through it, it does not produce an electric field. This is because the charges inside are all distributed evenly, and therefore, no charge difference is apparent. When an electrical current is moved through a conductor though, a charge difference becomes apparent in the conductor, and the conductor can be considered charged. This causes the conductor to emit an electric field. When this occurs, a “surface” outside that of the surface of the conductive material is produced, such that the potential difference between the conductive material and this new “surface” is the same at all points along the “surface.” This phenomenon is known as an equipotential surface, the term surface being used in the sense of describing a three-dimensional shape, rather than the boundary of a solid object. It should be noted first, that there are infinitely many such surfaces, one for each level of potential difference, and second, that the equipotential surfaces do not necessarily take the same shape as that of the conductor.

In this lab, we will be measuring an electric field with the probes of a voltmeter. This presents a concern, as voltmeters do draw some current when taking their readings. By drawing a current, the conductive probes will produce their own field, which would disrupt any static electric field we might be trying to measure. However, in the case of a dynamic field, this would make charge continuously available, making the field more difficult to disrupt. By measuring the electric field produced by a dynamic, or continuously powered, system we can measure a field that will be negligibly disrupted by the minor field produced by the voltmeter probes. The dynamic system to be used will be created by passing current between two electrodes, separated by a semi-conductive paper. Because the paper is much less conductive than the electrodes, this will ensure that the current will still pass from electrode to electrode, but the charge will not disperse much as it follows the path of least resistance through the circuit. It is also important that the paper is less conductive than the electrodes because if it weren’t, the charge would rapidly flow through the entire sheet of paper, rather than flowing to the electrode, thus disrupting our experiment. Using this method will allow us to map the electric field in two dimensions.

**Procedure**

This experiment will require a DC power supply, a voltmeter, two conductive test probes, a sheet of conductive paper, a sheet of carbon paper, a sheet of paper for traces to be drawn onto, and an apparatus that includes two electrodes and the capability to secure the sheets of paper together for the duration of the experiment.

First, the papers will layered on the apparatus and secured in the following order: the plain paper on bottom, next, the carbon paper with the marking side down, and finally the conductive paper on top. Then the electrodes will be placed on opposite ends of the paper, secured, and connected to the DC power supply. Lightly trace the electrodes onto the bottom sheet of paper and label their voltage for reference. The apparatus is now ready for the experiment.

The experiment will be carried out in two parts: first, five equipotential surfaces will be mapped, then various potential differences over 1 cm will be mapped to determine the strength of the electric field.

In the first part, one probe of the voltmeter will be held on the ground (negative) electrode, and the other probe of the voltmeter will be placed on the paper and moved until the meter displays a reading of a predetermined potential difference. The paper will be lightly pressed upon at this point to make a mark on the bottom sheet of plain paper. This point should also be marked with the potential difference read at this point. This will be repeated several times until an approximation of the equipotential surface can be drawn on the bottom sheet of paper, using the previously marked dots for reference. This process will be repeated to draw five equipotential surface approximations.

In the second part, gradient lines of the electric field will be mapped. To do this, the probes of the voltmeter will be held 1 cm apart, and placed on the paper, and the potential difference measured. Once the negative electrode is placed, the pair should be rotated until the positive probe is placed such that the maximum voltage reading is achieved. This should be done five times near each electrode, and five times somewhere in between, and the points labeled with the measured potential difference. The marks should also be supplemented with an arrow indicating the direction of the potential difference.

Finally, a few field lines should be drawn using the lines in the second part, and these should be compared to the equipotential surfaces to see if the gradient matches the “general flow” of the equipotential surfaces.