PHYS 0040 Electrical Field Measurements

ELECTRIC FIELD MEASUREMENTS

Introduction

Charged electrical conductors (electrodes) give rise to electric fields in the space around them. In this experiment, we explore the electric fields generated by metal electrodes using a special graphite-impregnated paper.

We use conducting silver paint to create electrodes of various shapes. The electrodes are painted on the graphite-impregnated paper with a paintbrush dipped in conductive silver paint. The conductors are then charged by connecting them to the terminals of a power supply, thus producing electric fields in the plane of the paper. Since a small electric current flows within the paper, the potential difference (voltage) between any two points on the paper can be measured by touching them with the two metal probes which are connected to a high-impedance voltmeter. The voltmeter probes can also be used to measure the direction and magnitude of the electric field vector \( \mathbf{E} \) at a point on the paper. By these means you are to investigate the equipotential curves, electric field vectors, and their relationships, for the fields produced by charged conductors of different shapes.

Experimental Techniques

The following are general instructions to be used in carrying out the experiments listed in the next section.

**Charging the conductors:** The power supply must remain connected to the conductors to maintain them in charged condition while you carry out the procedures; once the power supply is disconnected, the charge leaks off through the paper. The paper is fastened to a corkboard backing and a mental threaded hook should be screwed firmly through the conductor into the cork. Best results are achieved if hook is screwed all the way into the corkboard so that the base of the hook is firmly pressing against the conductor. The power supply wires are connected to these hooks, which are in contact with the appropriate conductors. The power supply wires should never be connected to each other.

**Testing the quality of the conductors:** There is no measurable potential difference between any two parts of a good conductor. Each time a new conductor is charged (power supply connected) it should be tested by measuring the potential difference between the two most widely separated points on it, using the voltmeter. If the potential difference is more than 1 Volt, the conductor is of poor quality and should be changed.

**Tracing equipotential curves:** The set of all points around the conductor at which the potential is the same forms a 2-dimensional curve on the paper. To map out such an "equipotential curve" around a conductor, one of the voltmeter probes is attached to the conductor and the other touched to the bare paper. The voltage is read (this is the potential difference between the conductor and the point on the paper) and then the free probe is moved on the paper to nearby points until the measured voltage returns to the initial value. The new point is marked and the process is continued until enough points (all being at the same potential relative to the conductor) have been located and marked to draw the full curve on which they lie. This curve is the equipotential curve for that particular value of potential.

**HINT:** to avoid tracing curves that run off the paper, the first point chosen in tracing any one equipotential curve should be as far away from the conductor as you want to go (i.e., start near the edge and work inward).

**Measuring the electric field**

\( \mathbf{E} \) : For this measurement, the two voltmeter probes are fastened together with a rubber band to maintain a fixed, small distance between the probe points. One of them is held on the paper point at which you want to find the electric field vector; the other probe is rotated around the first one, maintaining contact with the paper and tracing a small circle about the first, as with a drawing compass. The direction of maximum potential difference (voltage reading) is noted, as well as the value of that reading. Then, the direction of \( \mathbf{E} \) is the direction in which the maximum reading is found; the magnitude of \( \mathbf{E} \) is the value of the maximum potential difference divided by the separation between the probe points. Note the direction of \( \mathbf{E} \) always points from the probe of higher potential \( + \) to the one of lower potential \( - \). These facts all follow from the relation:

\[
\mathbf{E} = -\Delta V / \Delta x,
\]

where \( V \) is the potential and \( \Delta x \) is along the direction with the largest change in \( V \) per unit distance.

**Recording your results on the graphite-impregnated paper:** Colored pencils are provided for this purpose. Since both equipotential curves and field vectors are to be drawn, it makes sense to color-code them. Plan ahead before you start drawing curves and vectors so that the identification of your results will be both clear (uncluttered) and complete (with everything identified).
Experiments to be done

Relation between equipotential curves and electric field vectors: The conductors to be used are a point and a line segment. Put the point (a circle of small radius, made of metal or cut out of conducting tape) roughly in the center of the paper. Put the line about 9 centimeters from it and parallel to the edge of the paper. (The length of the line does not matter as long as it’s longer than 10 cm or so.) Mount the paper and connect the poser supply to the two conductors, connecting to the line near one end (Fig. 1)

(a) Trace three well-spaced equipotential curves which completely surround the point conductor, forming closed curves (Fig. 2). Label each with its potential relative to the point. (For neatness and clarity it’s best to label each curve with a number or letter, and record the potential values in your notebook as well as on the graphite paper.)

(b) Measure and record the electric field vectors at four widely spaced points on each of the equipotential curves (12 field points). Indicate the magnitudes and directions by appropriately drawn vectors, as well as recording the magnitudes in your notebook and on the graphite paper.

Electric field of a point charge: Using a fresh sheet of graphite-impregnated paper, construct a “frame” near the edge of the paper with a point conductor in the center (Fig. 3). Connect the power supply between the frame and the point conductor. Measure the potential relative to the frame, the electric field, and the distance from the center of the point conductor for at least four points.

Calculation and Discussion

Fasten the sheets of graphite paper containing your work into your notebook as part of your data. (Since you have probably worked with a partner, each should keep one of the sheets and make a sketch of the other sheet.) In making each of the following comparisons, tell what you expect to be the case and why; how your result compares with your expectation; and, if there is significant discrepancy, what may be the cause. Be sure to take into account the experimental uncertainties in your measurements.

Part 1

(i) Compare the direction of the $\mathbf{E}$ vectors with equipotential curves on which they were taken.

(ii) Compare measured $\mathbf{E}$ magnitudes with the values computed from the equipotential curves $E = (V_2 - V_1)/D$, where $V_1$ and $V_2$ are the potentials of two adjacent equipotential curves and D is the distance between them.

Part 2

(i) We expect the potential to be proportional to $\ln r$, where $r$ is the distance from the location where the potential is measured to the center of the point charge. Test this by graphing the potential versus $\ln r$.

(ii) We expect the magnitude of $\mathbf{E}$ to be proportional to $1/r$. Test this by checking whether the product $r$ and $E$ is the same for all points.

Reference

Young and Freedman, University Physics Extended Version with Modern Physics, Chapters 22-24