Electric Field Mapping

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Lab 1

Electric Field Mapping

1.1 Introduction

For macroscopic objects with electrical charges distributed throughout the volume, the calculations of the electrostatic forces from Coulomb's formula is difficult. Therefore, it is useful to describe the interaction forces as a product of the charge, q, and the electric field intensity, E.

$$F = qE. \tag{1.1}$$

As seen from the above equation, knowledge of the electric field enables calculations of the electrostatic forces. An electric field can be found by analyzing a map of the electric field lines. The electric field lines, also called the lines of forces, originate on and are directed away from positive charges, and end on and are directed toward negative charges. The electric field lines enable one to find the direction of the vector $\vec{E}$. But to fully characterize the electric field vector, we need also to give its magnitude. The magnitude, or strength of the electric field, can be measured from the density of lines at a given point. For example, for point charges, the magnitude of the electric field is given by the formula

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}, \tag{1.2}$$

which predicts that the field intensity decreases with increasing distance, r, from the charge, q. The density of field lines is largest when close to point charges and quickly decreases with distance. The goal of this experiment is to find the electric field lines for several objects.

Since it is difficult to directly measure the electric field, you will find the electric field lines by first plotting the equipotential (equal potential or equal voltage) lines near charged objects. Equipotential lines connect points that have the same potential (voltage). The electric field lines are always perpendicular to the equipotential lines.

1.2 Equipment

High resistance paper, power supply, voltmeter, conductive ink pen, coloured pencil, corkboard, push pins, wires

1.3 Procedure

You will use the conductive ink pen to draw various conductive objects on the high resistance paper. The conductive ink is produced from silver flakes in a suspension. When the ink dries, the metal particles settle on top of each other, forming a conductive path. The resistance of the ink is about 2 to 5 Ω/cm and can be neglected in comparison with the resistance of the paper, which is $20,000\ \Omega$/cm. Therefore, the potential drop within a continuous curve drawn with the ink is negligible.

1. Place the conductive paper on a smooth surface (**do not place it on the corkboard**) and draw the electrodes with the conductive ink. Shake the conductive ink can vigorously for about one minute. Keep the can perpendicular to the paper while drawing the electrodes. If the line you made is spotty, shake the can again and draw over the line. A smooth solid line is essential for good measurements. The objects you draw with the conductive ink pen will be referred to as electrodes. The ink needs to dry for about 20 minutes before making measurements, so plan your experiments and draw the shapes described below as soon as possible.

2. Mount the conductive paper on the corkboard using push pins in the corners and connect the conductive ink figures to a power supply and to the voltmeter using wires and push pins (see Fig. 1.1, left). Make sure that there is good contact between the conductive ink, the wire, and the pin. Set the power supply provide a constant voltage and set the voltage to 20 V. If the electrode has been properly drawn, and good electric contact has been established, the potential drop across the electrode should be less than 1%. If the voltage across the electrode is greater than 1%, then remove the pins from the corkboard and draw over the electrodes a second time with the conductive ink, or find another place to hook up the wire.

3. The equipotential surfaces are plotted by connecting one lead of the voltmeter to one of the electrode push pins. This electrode becomes the reference (ground). The other voltmeter lead (the probe) is used to measure the potential at any point on the paper simply by touching the probe to the paper at that point (see Fig. 1.1, right). To map an equipotential, move the probe to the point at which the voltmeter is indicating the desired potential. Mark this point with a white pencil. Move the probe to a new position which maintains the voltmeter at the same reading. Mark this point. Continue moving the probe until you have equipotential points across the paper. Connect the points with a smooth line and write the potential difference between this line and the reference electrode. This is one equipotential line.

4. Repeat the measurements for different potentials between the probe and the reference electrode. Find about 10 equipotential lines for each of the systems described below. Do not try to mark the electric field lines until you have finished all your voltage measurements. You can also do it later at home.

1.3.1 Electric field of point charges

The simplest electrical system that can be studied is the point charge.

1. You will study the electric field between two nearby point charges by drawing two dots on opposite ends of the high resistance paper.

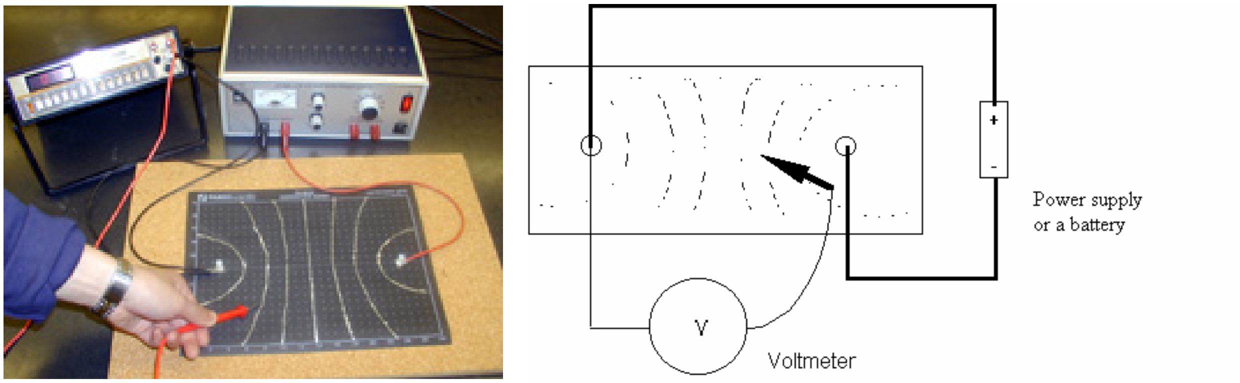

Figure 1.1: **Experimental setup.** A photograph (left) and schematic (right) of the experimental setup.

2. Connect each dot to one terminal of the power supply and map the equipotential lines as described above.

1.3.2 Electric field of a parallel plate capacitor

A parallel plate capacitor is an important electrical device. It consists of two metal plates parallel to each other at some fixed distance. This device can accumulate and store electric charges. You will study the electric field of a parallel plate capacitor by drawing two parallel lines on the high resistance paper.

1. Draw the two lines fairly far apart so you can accurately determine the electric field between the two plates, but leave some room to also examine the electric field outside the two plates.

2. Connect one terminal of the power supply to each of the parallel lines.

3. Find the equipotentials outside and inside the parallel lines and sketch in lines of electric field. Remember that the electric field is always perpendicular to equipotential surfaces and since conductors are equipotential surfaces, field lines must be perpendicular to the surface of both conductors.

1.3.3 Electric field of a hollow conductor

1. Draw a circular electrode between two parallel lines (Fig. 1.2) and map the equipotentials. The circular electrode represents a hollow metal sphere between the capacitor plates.

2. Connect one terminal of the power supply to each of the parallel lines.

3. Draw equipotential lines, remembering to also check the potential *inside* the hollow sphere.

1.3.4 Clouds and a house during a thunderstorm.

1. Draw two electrodes, one in the shape of a cloud, another in the shape of a house. Exaggerate the shape of the roof and make it very sharp (Fig. 1.3). During a thunderstorm, the clouds

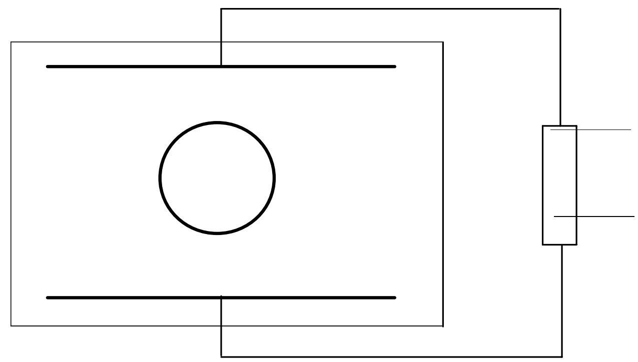

Figure 1.2: **Capacitor with a hollow metal sphere between the plates.**

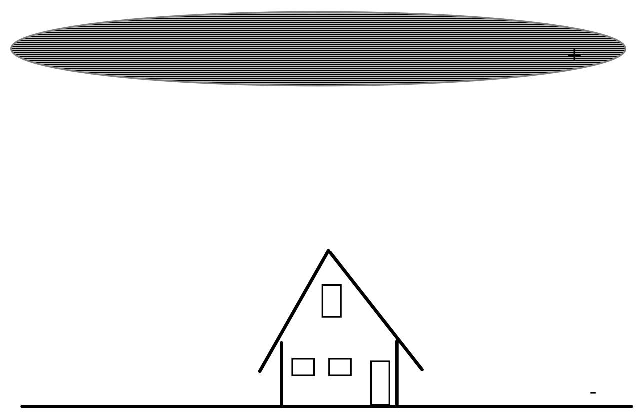

Figure 1.3: **Simulation of an electric field during a thunderstorm.**

carry large charges which create an intense electric field between the clouds and the ground. Your electrodes simulate this charge separation and the generated electrostatic field.

2. Connect the ground terminal of the power supply to the house and the other terminal to the cloud.

3. Map the equipotential lines and mark the electric field lines.

1.4 Report

In the report, answer the following questions:

1. Describe the equipotentials of point charges?

2. What is the electric field inside the capacitor?

3. What is the electric field outside the capacitor? Is it constant?

4. How do the edges of the plates affect the electric field?

5. How does the circular electrode distort the field? Compare the result with those obtained for two parallel lines.

6. What is the potential of the circular electrode? What is the potential inside the electrode?

7. What is the electric field inside the circular electrode? How does this result help explain why cell phones don't work in an elevator?

8. Discuss the distribution of the electric field lines during a thunderstorm, especially in the close proximity of the roof. Can you use your results to explain why lightning is more likely to strike tall buildings?