Experiment

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Electric Field Mapping

1. Introduction

For macroscopic objects with electrical charges distributed throughout the volume, the calculations of the electrostatic forces from the 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.

$$F = qE \qquad (1)$$

As seen from the above equation, the knowledge of the electric field enables calculations of the electrostatic forces. An electric field can be found by analyzing the 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 E; the vector E is always tangential to the lines of forces. 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 electric field is given by the formula

$$E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2} \qquad (2)$$

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

The electric field lines can be found by plotting the equipotential lines of the electric field. If the large number of points of the same potential needs is found, they may be connected together with a smooth line or surface, which is called an equipotential line or surface. The electric field lines must always be perpendicular to the equipotential lines or surfaces.

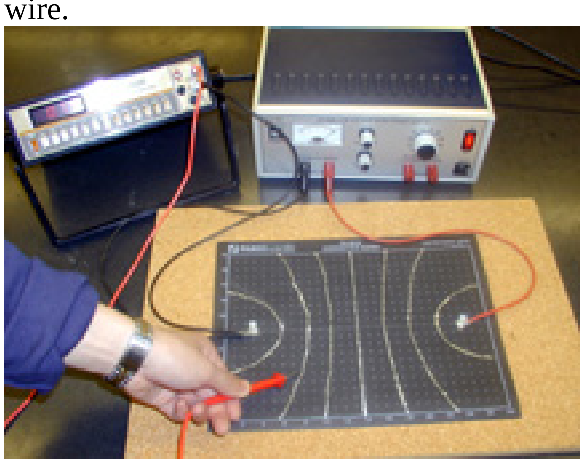
2. Procedure

The experiment will be performed using the electric field mapping board, high resistance paper, a conductive ink, a power supply (or a battery) and a voltmeter.

The conductive ink is produced from copper or nickel flakes in a suspension. When the ink dries, the metal particles settle on the top of each other, forming a conductive path. The resistance of the ink is about 2 to 5 ohm/cm and can be neglected in comparison with the resistance of the paper, which is 20,000 ohm/cm. Therefore, the potential drop across the electrodes can be considered negligible.

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. When the line you made is spotty, shake the can again and draw over the line. A smooth solid line is essential for good measurements. Let the ink dry for about 20 minutes before making measurements. Therefore, plan your experiments and draw the electrodes as soon as possible.

Mount the conductive paper on the corkboard using push pins in the corners and connect the electrodes to a power supply (or a lantern battery) and to the voltmeter. Make sure that there is a good contact between the line, a wire, and the pin. If the electrode has been properly drawn, and a 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.



A photograph of the experimental setup.

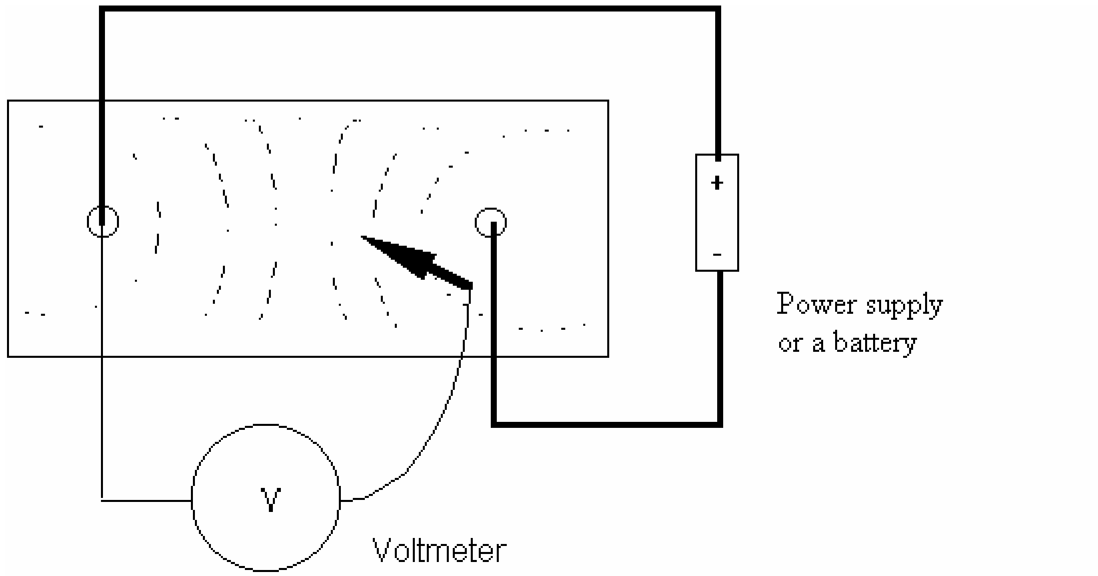


Fig. 1. A schematics of the experimental setup.

The equipotential surfaces are plotted by connecting one lead of the voltmeter to one of the electrode push-pins. This electrode becomes the reference. 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. Figure 1 schematically indicates the method of mapping equipotentials. 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 in order to find a series of points at the same potential across the paper. Connect the points with a smooth line and write the potential difference. This is the equipotential line.

Repeat the measurements for different potentials between the probe and the reference electrode. Find at least 10 equipotential lines for voltages of 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, and 22V.

From the symmetry, you can guess the 1, 3, 5 Volts surfaces and so need not measure them.

Do not try to mark the electric field lines; it takes too much time. Do it later at home.

If the system has an axial symmetry, you may limit your measurement to one side of the symmetry axis. The equipotentials in the other half can be determined by reflecting the found lines about the axis.

2.1. Equipotentials between parallel lines

Find the equipotentials outside and inside the parallel lines which symbolizes a parallel plate capacitor. Next, sketch in lines of electric field force. Remember that lines of force are always perpendicular to equipotential surfaces; and, since conductors are equipotential surface, field lines must be perpendicular to the surface of both conductors. Sketch lines of forces first lightly, and when you have them right, draw them darkly. It is useful to choose a different color for the field lines than that used for the equipotential lines. Keep the same distance between the electric field lines close to the silver lines representing the capacitor. Remember that the electric field lines are perpendicular to the equipotential lines and to the metal surfaces.

In the report, answer the following questions:

1. What is the electric field inside the capacitor?
2. What is the electric field outside the capacitor? Is it constant?
3. How do the edges of the plates affect the electric field?

(PHYS 20481 and PHYS 20484 only)

From the measurements, calculate the components of the electric field at the center of the capacitor and at a point at the edge. Since the potential has been measured in large steps of voltage, you can only estimate the components E_x and E_y from:

$$(E_x; E_y) = -(\delta V/\delta x; \delta V/\delta y) = -(\Delta V/\Delta x; \Delta V/\Delta y)$$

2.2 Equipotentials between two parallel lines with a floating circular electrode.

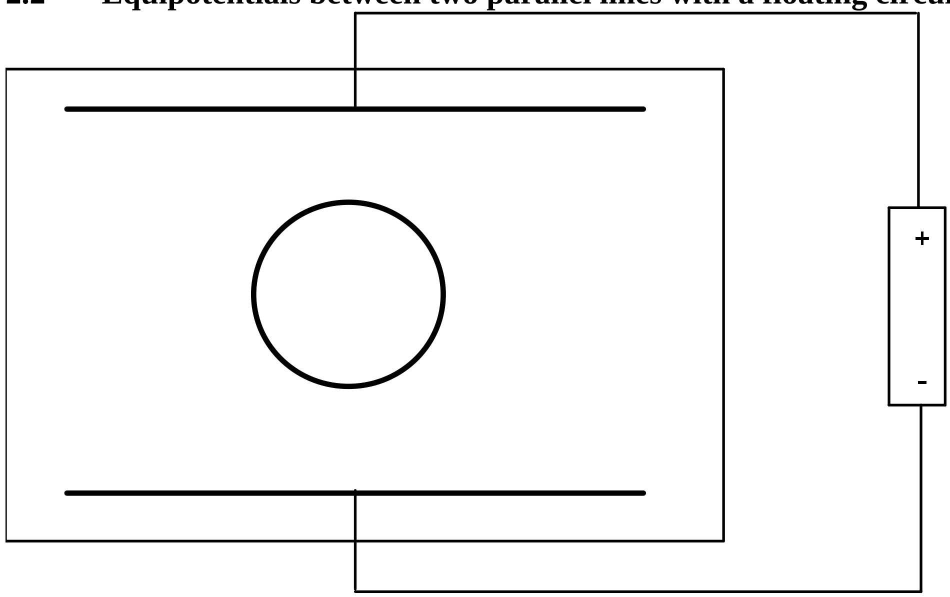


Fig. 2. Capacitor with a hollow metal sphere between the plates.

Draw a circular electrode between two parallel lines (Fig. 2) and map the equipotentials. The circular electrode symbolizes a hollow metal sphere between the capacitor plates. In the report, answer the following questions:

1. How does the circular electrode distort the field? Compare the result with those obtained for two parallel lines.
2. What is the electric field inside the circular electrode? What is the field on the electrode surface?
3. What is the potential of the circular electrode? What is the potential inside the electrode?

2.3 Clouds and a house during a thunderstorm.

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. During a thunderstorm, the clouds 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. Map the equipotential lines and mark the electric field lines. In your report, discuss the distribution of the electric field lines, especially in the close proximity of the roof. Where will the lightning strike, outside the house or on the tip of the roof?

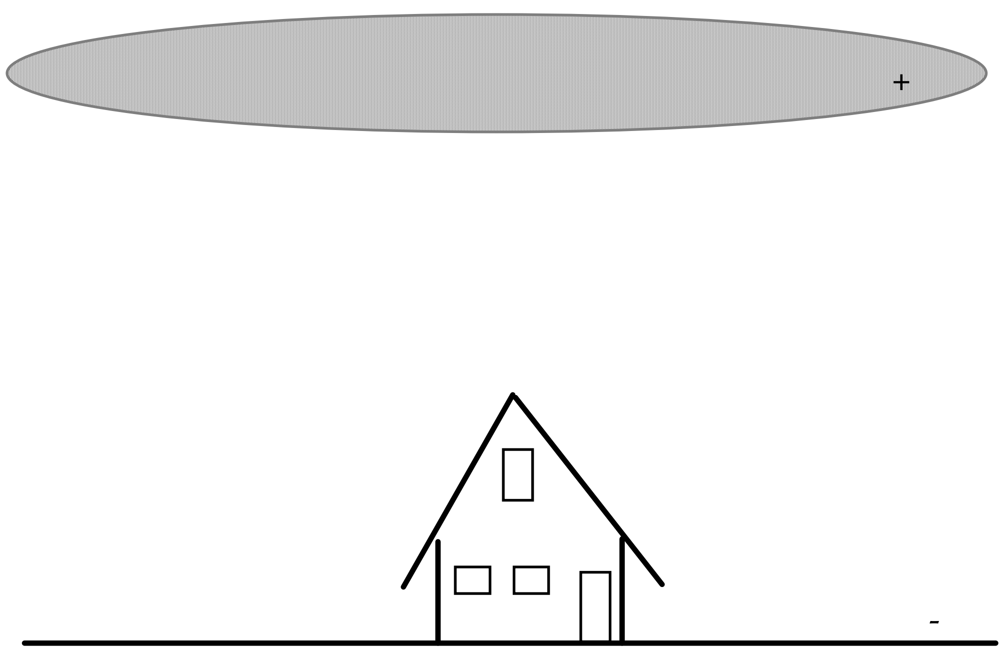


Fig. 3. Simulation of an electric field during a thunderstorm.

2.4 Quadruple moment (20481 and 20484 only)

Draw the electrodes as in Figure 4. Find the equipotentials and electric field lines. Determine the electric field components, E_x and E_y for two points on the xy plane.

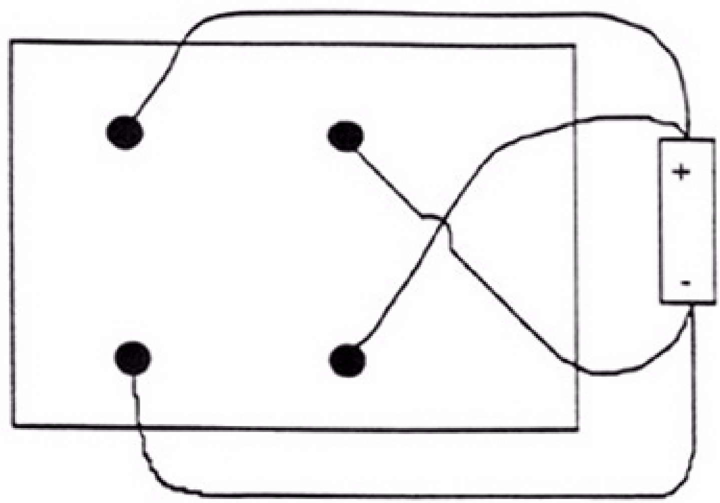


Fig. 4. Electric field measurements for a quadrupole moment.