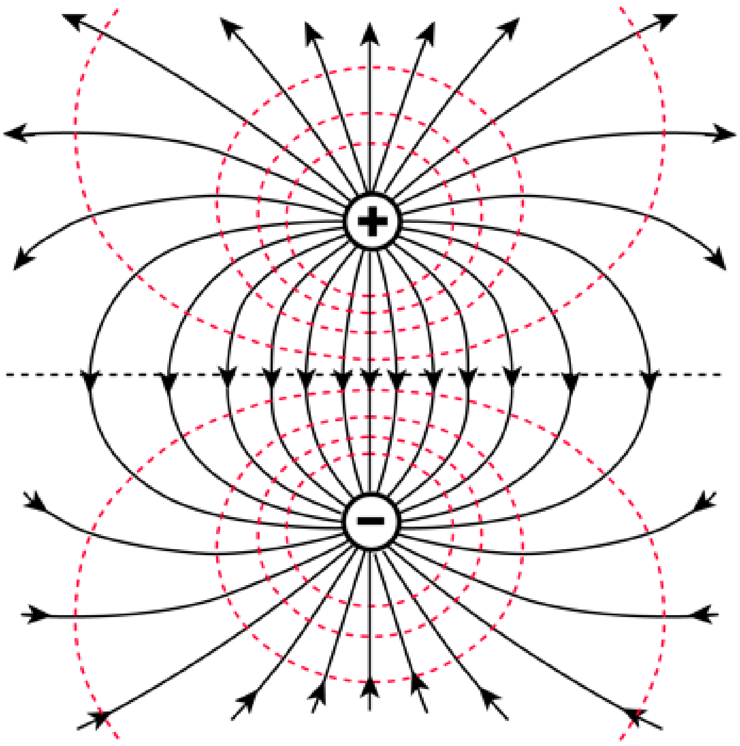
Experiment 5:
Equipotential Lines



3rd Year of the Degree in Physics
Experimental Project
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1 Introduction

In this experiment, we aim to find the dependence of an electrostatic potential with the distribution of charges and the geometry of them. Another objective of the experiment is to visualize and find the form of the equipotential lines. To achieve these objectives we will use electrodes with different kind shapes.

In this document we will explain the theoretical principles of the experiment followed by the experimental process. Finally we will analyse the results of the experiment, answer some questions related with the practice and give some final conclusions.

2 Theoretical Fundaments

When a collection of charges are arranged in space in a concrete and static distribution the surrounding space is filled with the resulting electric field of the contributions of all the charges in the system. The electric field is a vectorial field, that means that to any point in space we can associate an arrow with a direction, every path that appears when you follow the direction of these arrows is what we call the field lines.

$$\vec{E} = \frac{KQ}{r^2}\vec{u_r} \tag{1}$$

To get the electric field between two parallel plates we apply the Gauss Law choosing as our initial conditions an infinite and homogeneously charged plane of which we will enclose some fraction of the surface into some prism-like shape:

$$\oint_{\partial V} \vec{E} \cdot d\vec{S} = \frac{Q_{\text{enc}}}{\varepsilon_0} \tag{2}$$

As the lateral surface don't have any contributions, the other faces are equal and perpendicular to the field and the field is constant in these surfaces:

$$\oint_{S_1} \vec{E} \cdot d\vec{S} + \oint_{S_2} \vec{E} \cdot d\vec{S} = \frac{Q_{\text{enc}}}{\varepsilon_0} \tag{3}$$

$$E \oint_{S_1} dS + E \oint_{S_2} dS = \frac{Q_{\text{enc}}}{\varepsilon_0} \tag{4}$$

$$ES + ES = \frac{Q_{\text{enc}}}{\varepsilon_0} \tag{5}$$

$$E = \frac{Q_{\text{enc}}}{2S\varepsilon_0} = \frac{\sigma}{2\varepsilon_0} \tag{6}$$

Along with the electric field, it also appears the so called potential field, which is a scalar field. The interesting characteristic that relates this two apparently different fields is that the electric field lines are always perpendicular to the equipotential lines on the potential field, that is the points of the space that have the same potential and joined together form a line/surface that we call equipotential.

$$U = \frac{KQ}{r} \tag{7}$$

3 Experimental Procedure

In order to perform the experiment, several materials are needed. We will set the electrodes in a plastic trough filled with $400cm^3$ of distilled water so it covers them fully.

A sheet of graph paper is placed below the trough, marking the position of the electrodes. These electrodes will be connected to a power supply that has to be set between 3 and 5 V AC to prevent deposits from being formed on the electrodes.

To measure the potential difference, the measuring electrode , which will be mounted on a stand, will be connected to a multimeter. The experiment will be performed with electrodes of different shapes.

Finally, to plot the equipotential lines we will measure the points with similar potential difference and trace them on a separate graph paper. Once you have found all the points, they can be joined together by drawing a line. For each electrode' shape, the graph of the equipotential lines will have a different geometry.

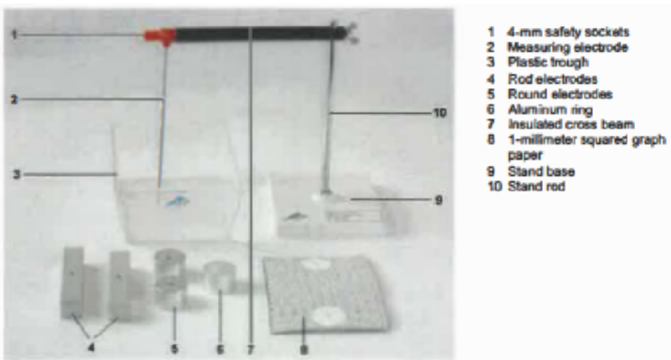

Figure 1: Experimental Set-up for the experiment

4 Experiment Data and Final Results

We can see in the figures below that the electric field generated by two parallel plates causes equipotential lines that are also parallel to the plates and go higher the closer they get to the positively charged plate.

We can also see that the electric field generated by two points with opposite charge causes equipotential lines that are perpendicular to the line that links both charges only in the middle of the distance between them and the rest of the lines become increasingly curved as they get closed to each charge. Also the potential increases as the lines approach the positive pole.

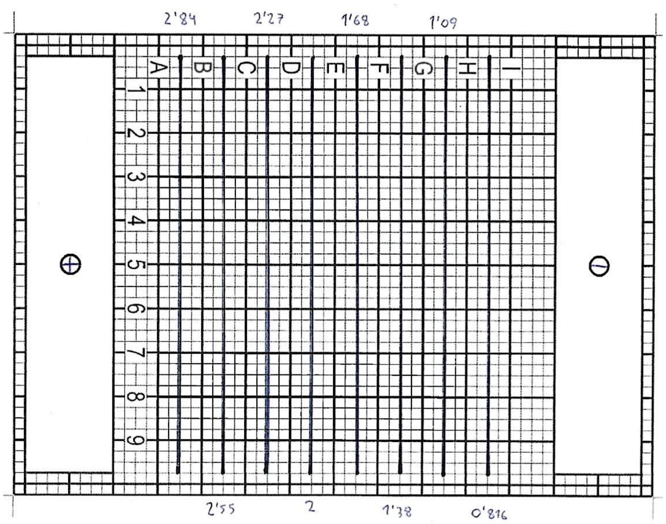

Figure 2: Parallel Plates configuration

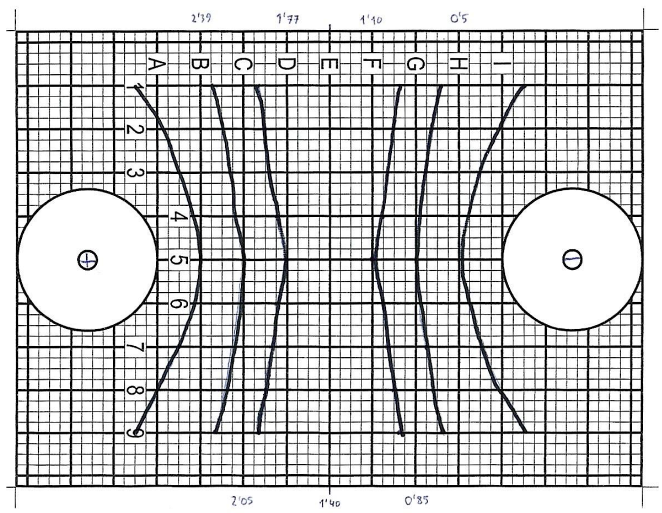

Figure 3: Point Charge bar configuration

5 Discussion and Evaluation

Is it possible to determine the shape of the electric field for each electrode configuration based on the collected data?

The shape of the electric field can be determined with the graph paper. As appears in the results of the experiment, the different values of the potential enable us to draw the shape of the equipotential lines on the paper.

Since the electric field is defined as the gradient of the potential, the intensity of the electric field has only a dependence on the distance to the electrode.

- For the parallel plates configuration, the electric field will form uniform parallel lines orthogonal to the equipotential lines.
- For the circular electrodes, the field depends only on its radial component. So it will form radial lines around the electrode. However, near the centre of the plastic trough it will become more uniform and similar to the field of the parallel plates.

Can the experimental method used determine equipotential lines in empty space?

The dielectric constant ε varies with the medium in which the experiment is performed. Its relationship with the potential is:

$$U = \frac{Q}{4\pi\varepsilon r} \tag{8}$$

This constant is defined in terms of the vacuum permittivity ε_o as $\varepsilon = \varepsilon_r \varepsilon_o$, where ε_r is the relative permittivity that measures how much the permittivity of the material differs from ε_o.

According to this definition, the dielectric constant of distilled water is $\varepsilon = 80\varepsilon_o$, meaning that it is 80 times greater than the vacuum permittivity. Since this constant appears in the denominator of the potential law, by replacing it with the vacuum permittivity, the potential would be 80 times higher than in water. As the experiment operates in voltages between 3 to 5 V this would cause an overflow in the multimeter, preventing it from measuring the values of the potential lines.

In the configuration of parallel plates, in what direction with respect to the equipotential lines was the greatest potential difference measured, and in which direction does the electric field go?

The potential in the parallel plates configuration increased as it get closer to the positively charged side. This means that the the greatest potential difference measured would be exactly the one between both plates.

On the other side, the electric field, as proven in the "Theoretical Fundaments", is constant, perpendicular to the plates and points to the positive side in every point of space.

What type of shape do the equipotential lines have when the point-charge-bar configuration was used?

With this type of configuration we observe that the equipotential lines, at first sight, draw concentric circles around each of the electrodes, but as we get closer to the middle of both charges these lines begin to get more straight being at the limit a perfect straight line, perpendicular to the intersection between the charges, at the exact middle.

Were equipotential lines or surfaces detected in this experiment?

The equipotential lines were detected in the experiment. As shown in the results section.

- In the parallel plates distribution the equipotential lines appeared in the plastic trough as parallel lines between both plates.
- In the circular electrodes configuration the shape of the equipotential lines formed concentric circles around the electrode.

How does the mineral concentration affect the experiment?

Not only the distilled water is important for the experiment but also the composition of the metal that is being electrically charged. This is due to the dielectric properties of the metal bar, notice that as the electric permittivity rises up the electric field generated by the material shrinks as the Gauss equation says:

$$E = \frac{\sigma}{\epsilon} \tag{9}$$