EXPERIMENT 2

Parallel Plates and Circular Electrodes
(Electric Field Lines and Equipotential Surfaces)

Purpose:

- To examine the electric fields generated by the uniform charge distributions.
- To observe the relationship between equipotential lines and electric field.
- To identify electric field and equipotential lines/surfaces for parallel plates and circular electrodes.

Experimental Instruments:

- DC Power Supply
- Parallel Plates
- Circular Electrodes
- Connection Cables

Theoretical Information:

<u>Coulomb's Law:</u>

The magnitude of the electrostatic force of attraction or repulsion between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance (**$\mathbf{r}_{21}$**) between them.

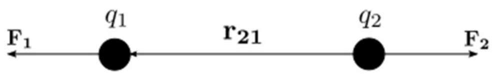

Figure 2.1

Scalar and vector forms of the Coulomb's Law are given below, respectively:

$$|\boldsymbol{F}| = k_e \frac{|q_1 q_2|}{r^2} \tag{2.1}$$

$$\boldsymbol{F}_1 = k_e \frac{q_1 q_2}{|\boldsymbol{r}_{21}|^2} \widehat{\boldsymbol{r}_{21}} \tag{2.2}$$

where k_e is Coulomb's constant ($k_e = 8.99 \times 10^9$ N·m^2·C^{-2})

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Electric Field:

Electric field is a vector field surrounding an electric charge that exerts force on other charges, attracting or repelling them. Electric field is defined by below:

$$\mathbf{E} = k_e \frac{q}{r^2} \hat{r} \qquad (2.3)$$

Electric field lines are directed away from positively charged source charges toward negatively charged source charges. These field lines do not intersect with each other. A number of electric field lines are directly proportional to the electric charge, so, the greater the electrical charge, the more lines around it. Electric field lines around point charges are shown in **Figure 2.2**.

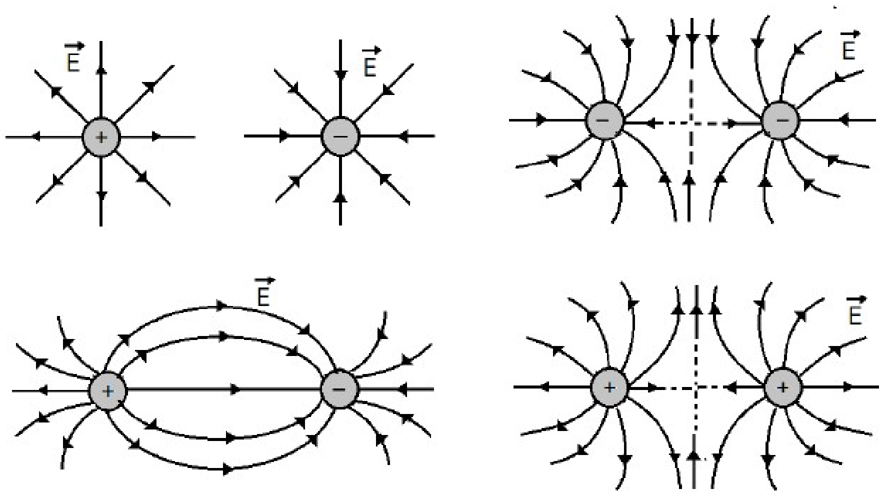

Figure 2.2 Electric field lines around point charges.

Gauss Law:

The total electric flux out of a closed surface is equal to the charge enclosed divided by the permittivity of free space. The total electrical flux is shown in **Figure 2.3**.

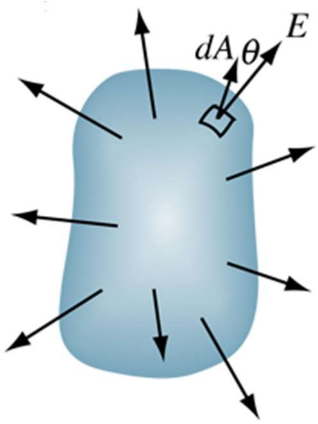

Figure 2.3 Total electric flux of a surface that encloses charges.

The Gauss Law, which is also called as the first Maxwell equation, is defined by Eq.(2.4).

$$\oint_S \mathbf{E}.\boldsymbol{dA} = \frac{q_{total}}{\varepsilon_0} \quad (2.4)$$

The electric field E and the electric potential V are related to each other. Electric potential is a scalar characteristic of an electric field. The potential difference dV between two points a distance ds apart is given by Eq. (2.5)

$$\mathrm{dV} = -\mathbf{E}.\boldsymbol{ds} \quad (2.5)$$

Equipotential Lines:

There are points with the same electrostatic potential in the electric field formed by any charge distribution. The surfaces formed by combining these points are called equipotential surfaces.

Electric field lines and equipotential surfaces are always perpendicular to each other.

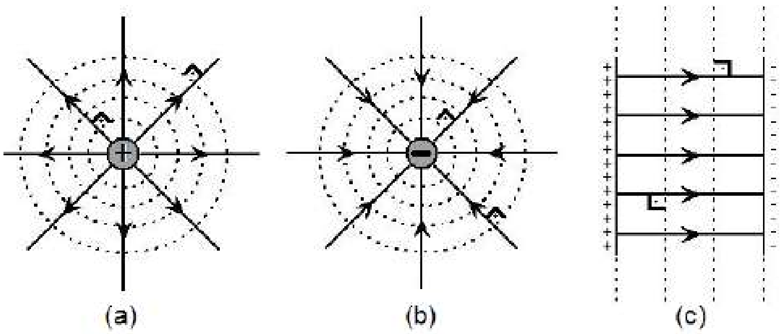

Figure 2.4

(a) Electrical field lines and equipotential surfaces formed by a positively charged particle.

(b) Electrical field lines and equipotential surfaces formed by a negatively charged particle.

(c) Electric field lines and equipotential surfaces formed between two oppositely charged parallel plates

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Experimental Procedure:

<u>Section 1 (Parallel Plates):</u>

1. Draw the electrodes on the paper by placing a millimeter paper on the teledeltos paper, and then drill the corners of each cm^2 square on the millimeter paper to measure with the voltmeter.
2. Apply a potential difference (voltage) of 9V between the conductor lines drawn on the teledeltos paper as in Figure 2.5 and Figure 2.7 (a).
3. To determine the equipotential lines, measure the voltages at the points you drilled on the millimeter paper.
4. Obtain the equipotential surfaces by combining values close to each other from the voltages you have measured. Draw the electric field lines between the plates.

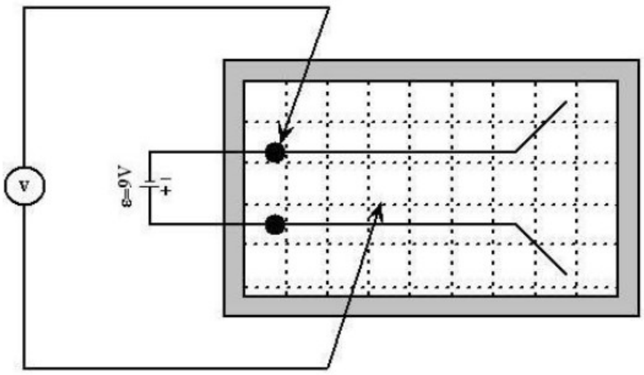


Figure 2.5 Parallel plates experiment scheme.

<u>Section 2 (Circular Electrodes):</u>

1. Set up the experiment as shown in Figure 2.6 and Figure 2.7 (b) and apply a potential difference of 9V between the circular electrodes drawn on the teledeltos paper.
2. Measure the voltage between two electrodes at 6 different points at equal distance from the center. After, measure the voltage at 6 different points for different distance.
3. From the center, measure the voltage values in 0.5cm intervals along a radius direction and record them in Table 2.1.

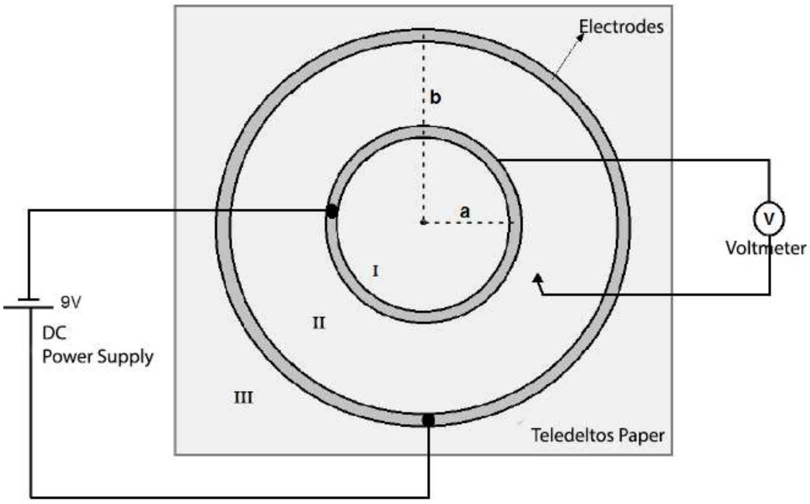
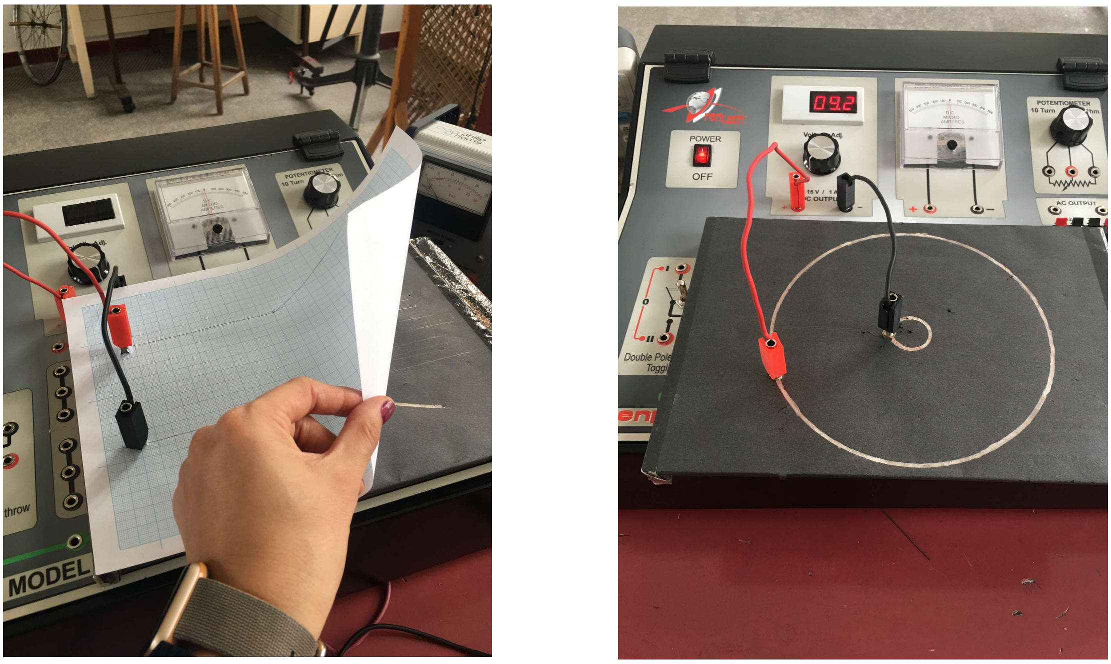


Figure 2.6 Circular electrodes experiment scheme.



(a) (b)

Figure 2.7 (a) Parallel plates experimental set-up, **(b)** Circular electrodes experimental set-up.

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EXPERIMENT 2

Parallel Plates and Circular Electrodes

DATE :

GROUP ID :

Student ID	Name Surname	Signature

Experiment Expectation	

CALCULATIONS AND RESULTS:

Section 2 (Circular Electrodes):

Consider two coaxial cylindrical shells with uniform surface charge densities as shown in Figure 2.8. Each shell has length L.

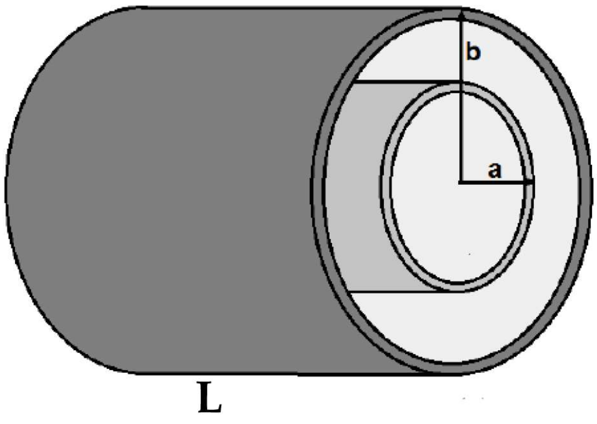

Figure 2.8 Two coaxial cylindrical shell

Find the electric field between two cylinders with Gauss's law and imagine a gauss surface that has the radius r between the two shells.

From Equation (2.4) we get;

$$\boldsymbol{Q_{enc}} = \sigma . \boldsymbol{A} = \sigma\, 2\pi a L$$

$$\mathbf{E}\, 2\pi r L = \frac{\sigma\, 2\pi a L}{\varepsilon_0}$$

$$\mathbf{E} = \frac{\sigma a}{\varepsilon_0}\frac{1}{r}\,\hat{\mathbf{r}} \quad (2.6)$$

Electric potential is calculated from Eq. (2.5) as,

$$V = -\int \mathbf{E}.d\mathbf{r} \quad (2.7)$$

This is the potential at any point between the Gaussian surface with radius s and cylindrical shell with radius a.

$$V(r) - V(a) = -\frac{\sigma a}{\varepsilon_0}\int_a^s \frac{1}{r}\,\hat{\mathbf{r}}\,.\,\hat{\mathbf{r}}\,dr = -\frac{\sigma a}{\varepsilon_0}\cdot \ln\left(\frac{r}{a}\right) \tag{2.8}$$

If we choose r = b and if we say, $k = \frac{\sigma a}{\varepsilon_0}$ then

$$V_b - V_a = -k\,\ln\left(\frac{b}{a}\right) \tag{2.9}$$

Since we assume that the values a, b, V_a and V_b in the equation (2.9) are known, we can obtain the constant k by Eq. (2.10).

$$k = -\frac{V_b - V_a}{\ln\left(\frac{b}{a}\right)} \tag{2.10}$$

Using equation (2.8) we can find a general equation for the potential of an electrode pair consisting of two coaxial cylinders with radius a and b, s away from the center in the radius direction.

$$V_s = \frac{V_b \ln\left(\frac{r}{a}\right) - V_a \ln\left(\frac{r}{b}\right)}{\ln\left(\frac{b}{a}\right)} \tag{2.11}$$

Assume $V_a = 0$, $V_b = V_0$ then,

$$\mathrm{V_r} = \frac{\mathrm{V_0}\ln\left(\frac{\mathrm{r}}{\mathrm{a}}\right)}{\ln\left(\frac{\mathrm{b}}{\mathrm{a}}\right)} \tag{2.12}$$

Table 2.1. Experimental values

r (cm)	$\ln r$	V (Volt)	ΔV (Volt)	r_{ave}	$1/r_{ave}$	$E=-\frac{\Delta V}{\Delta r}(\frac{V}{cm})$
0						
0.5						
1.0						
1.5						
2.0						
2.5						
3.0						
3.5						
4.0						
4.5						
5.0						
5.5						
6.0						
6.5						
7.0						
7.5						
8.0						
8.5						
9.0						
9.5						
10						

- Plot the V- ln$r$ graph.
- Plot and evaluate the E - $1/r_{ave}$ graph.

DISCUSSION AND COMMENTS:

1) Confirm the Equation (2.12) by using V- ln$r$ graph.
2) Explain how electric field lines seem in comparison to equipotential lines.