Experiment 1
Electric field and electric potential

Purpose
Map electric equipotential lines and electric field lines for two-dimensional charge configurations.

Equipment
Three sheets of conductive papers with conductive-ink electrodes, push pins and wires, a comfort grip voltage probe with silicone insulated, marker pen, ruler, (15 cm), corkboard, digital multimeters (DMM), DC power supply (HY152A).

Theory
The magnitude of electrostatic force between two point charges Q and q is given by Coulomb's law:

$$F = k\frac{|Qq|}{r^2} \tag{1}$$

where r is the distance between the charges, k is the Coulomb constant ($k = 9.0\times10^9\ Nm^2/C^2$). The directions of the forces the two charges exert each other are always along the line joining the two point charges and like charges repel, unlike charges attract.

The magnitude of the electric field is defined as the electrical force per unit charge, i.e., $E = F/q$ (N/C), here q is a test point charge. In the case of the electric field associated with a single-source charge Q, the magnitude of the electric field a distance r away from the source charge is

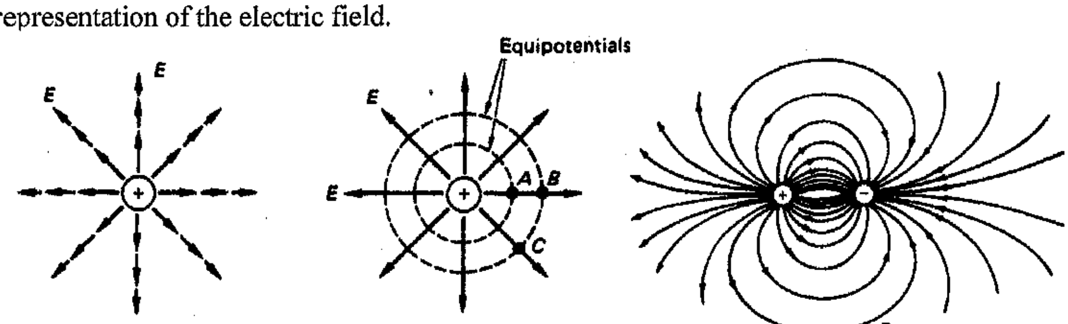
$$E = \frac{F}{q} = k\frac{|Q|}{r^2} \tag{2}$$

Electric field is a vector quantity which is specified by both its magnitude and direction. Using the unit vector $\hat{r} = \frac{\vec{r}}{r}$, we can write a vector equation that gives both the magnitude and direction of the electric field $\vec{E}$ due to a point charge Q:

$$\vec{E} = k\frac{Q}{r^2}\hat{r} \tag{3}$$

The electric field of a point charge always points away from a positive charge but towards a negative charge.

Figure 1 (a) shows the electric field vectors from a positive source charge. By drawing lines through the points in the direction of the field vectors, we form the electric field lines (Fig. 1 b & c), which give a graphical representation of the electric field.



(a) Electric Field Vectors (b) Electric Field Lines (c) Dipole Electric Field

Figure 1

It can be shown (see your textbook) that the electric potential at a distance r from the source charge Q is:

$$V = k\frac{Q}{r}. \tag{4}$$

Electric potential is a scalar quantity which is specified by its magnitude only. Electric potential can be either positive or negative depends on the sign of the source charge Q.

The electric potential of two or more point charges is simply the algebraic sum of the potentials due to each point charge separately:

$$V = k\sum_{i=1}^{N}\frac{Q_i}{r_i}, \text{ where N is the total number of point charges.} \tag{5}$$

Since a free charge moves in an electric field by the action of the electric force, we say that work (W_{AB}) is done by the field on moving a charge from one point to another (e.g. from A to B in Fig. 1 b). To move a positive charge from B to A would require work supplied by an external force to move the charge against the electric field. The work done by an electric field in moving a unit charge from point A to point B is called the potential difference between these two points:

$$\Delta V_{AB} = V_A - V_B = \frac{W_{AB}}{q} \tag{6}$$

If a charge is moved along a path perpendicular to the field lines, no work is done, i.e., W = 0, since there is no force component along the path. Then along such a path (Fig. 1b between B and C) $\Delta V_{BC} = V_B - V_C = \frac{W_{BC}}{q} = 0$ and $V_B = V_C$. Hence the potential has a constant value along a path perpendicular to the field lines. Such a path is called an equipotential line which is always perpendicular to the field lines. Different equipotential lines have different potential values, therefore, equipotential lines can never intercept.

An electric field may be mapped experimentally by determining either the field lines or the equipotential lines. Equipotential line can be determined by measuring the potential difference ΔV between two points. If $\Delta V = 0$, the two points are on an equipotential line.

Caution: Make sure that the "+" and "−" leads from the DC power do not touch each other before you turn on the power supply in all the measurements.

Measurement 1: Map equipotential lines for parallel-plates capacitor.

1. Mount the conductive paper #1 (with printed side up) on the corkboard using two metallic pushpins at the two electrodes which are drawn with conductive ink on the conductive paper #1.
2. Connect the two electrodes on the conductive paper #1 to the DC power supply (HY152A).
3. Connect the black banana jack (ground) on DMM to the ground (black banana jack) on the DC power supply (HY152A). Connect the red banana jack on DMM to a comfort grip voltage probe with silicone insulated. Select voltage scale of 20 V on DMM.
4. Turn on the DC power to 10 V.
5. To measure the voltage at a point, say 1A, on the conductive paper #1 in Fig. 2, just let the tip of the voltage probe touch point 1A.

   Attention: To reduce measurement error, the tip of the voltage probe should be perpendicular to the conductive paper at the touch point (+ in Fig. 2).

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Note: In Fig. 2 draw a vertical line through label 1 and a horizontal line through label A, the cross point of these two lines is the point 1A, similarly for points 1B, ... 5E.

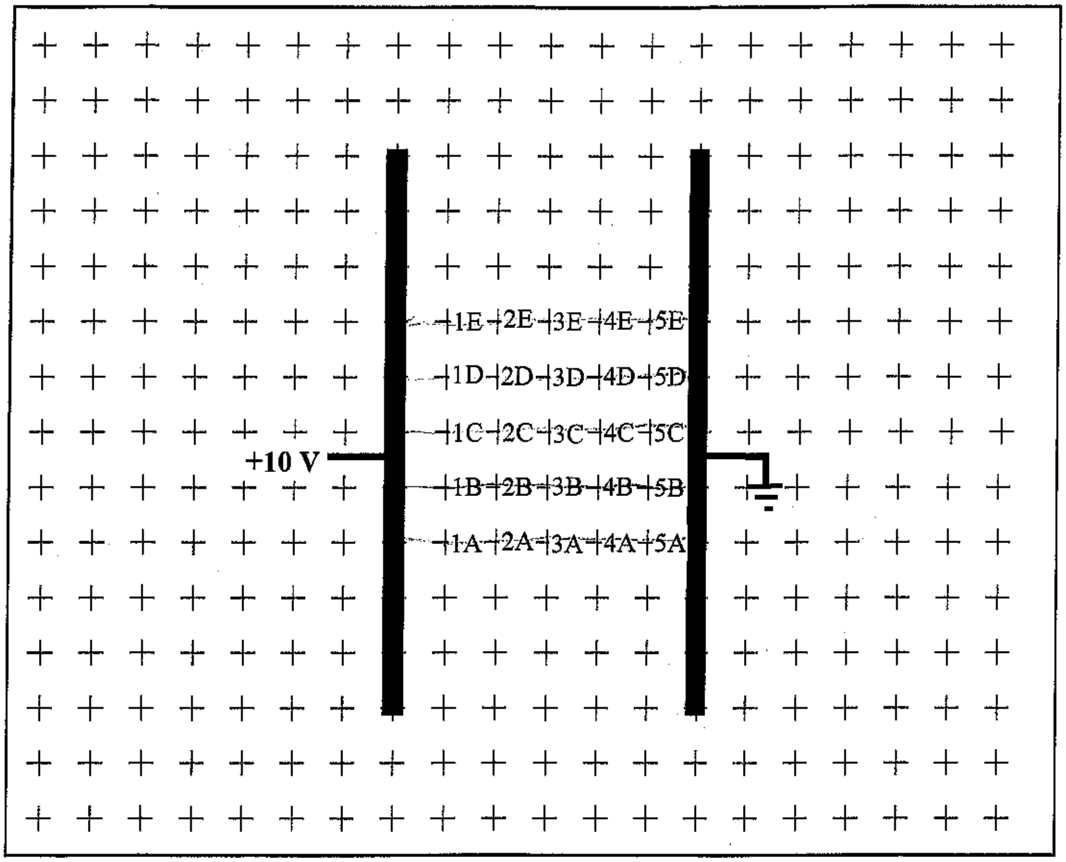

Figure 2 Conductive paper #1

6. Measure voltages at all the points labeled in Fig. 2. Record the data in Table 1.
7. Turn the voltage to 0V before shut down the DC power (HY152A).

Table 1 Measured voltages at all the points labeled in Fig. 2 (conducting paper #1).

	Voltage (V)				
1	8.50	7.90	7.92	8.46	7.91
2	6.83	6.70	6.65	6.43	6.63
3	4.61	5.10	4.46	4.61	4.80
4	3.25	3.31	3.29	3.07	3.12
5	1.63	1.85	1.79	1.60	1.28
	A	B	C	D	E

Data Analysis 1

1. Draw equipotential lines on Fig. 2 using a red pen. Draw field lines (from high to low voltage) using a blue pen.

2. Are the field lines perpendicular to the equipotential lines?

   Yes, they are perpendicular to the equipotential lines.

3. Use a ruler to measure Δx on the conductive paper. Record Δx value in Table 2.

4. Calculate the magnitude of the electric field E for the parallel plate configuration using formula $E = \Delta V / \Delta x$. Record the data in Table 2.

Table 2 Potential difference between two vertical lines with indices 1, 2, ….5 labeled in Fig. 2.

ΔV	$\Delta V_{12} = V_1 - V_2$	$\Delta V_{23} = V_2 - V_3$	$\Delta V_{34} = V_3 - V_4$	$\Delta V_{45} = V_4 - V_5$
$\Delta x =$				
$E = \Delta V / \Delta x$				

5. Are the E values close each other?

6. Is it true that $\vec{E}_{1A} = \vec{E}_{1B} = ... = \vec{E}_{5E}$? Why?

Measurement #2: Map equipotential lines for a point charge with guard rings.

1. Mount the conductive paper #2 (with printed side up) on the corkboard using two metallic pushpins at the two electrodes which are drawn with conductive ink on the conductive paper #2.
2. Connect the two electrodes on the conductive paper #2 to the DC power supply (HY152A).
3. Connect the black banana jack (ground) on DMM to the ground (black banana jack) on the DC power supply (HY152A). Connect the red banana jack on DMM to a comfort grip voltage probe with silicone insulated. Select voltage scale of 20 V on DMM.

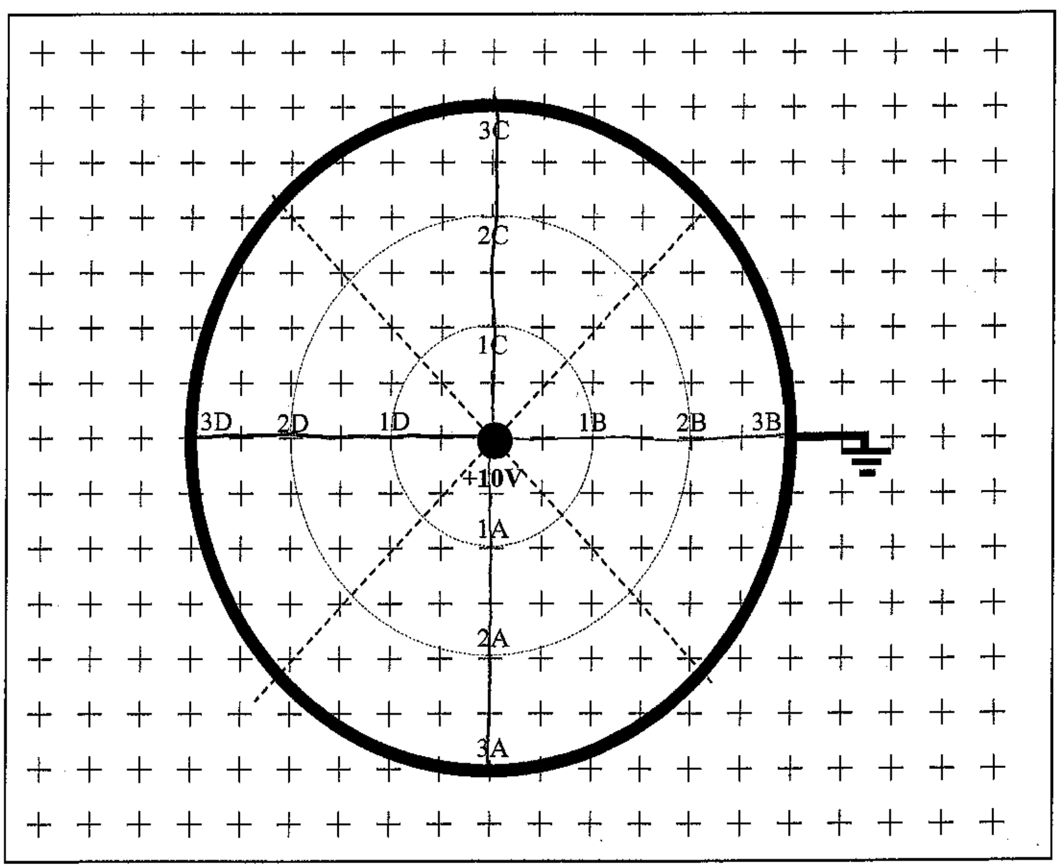

Figure 3 Conductive paper #2

4. Turn on the DC power to 10 V.
5. **Attention:** To reduce measurement error, the tip of the voltage probe should be perpendicular to the conductive paper at the touch point.
6. Measure voltages at all the points labeled in Fig. 2. Record the data in Table 3.
7. Turn the voltage to 0V before shut down the DC power (HY152A).

Table 3 Measured voltages at all the points labeled in Fig. 3 (conductive paper #2).

	Voltage (V)			
1	2.75	2.24	2.62	2.33
2	1.00	0.38	0.87	0.77
3	0	0	0	0
	A	B	C	D

Data Analysis 2

1. Based on the data in Table 3 draw equipotential lines on Fig. 3 using a red pen. Draw field lines (from high to low voltage) using a blue pen. Are the field lines perpendicular to the equipotential lines?

2. Theoretically, should the points 1A to 1D be on an equipotential line? Are the measured voltage values at points 1A to 1D very close each other? If not, what is the main source of error?

Measurement #3: Map equipotential lines for two-point-charge configuration: one is at +10V, the other at 0 V.

1. Mount the conductive paper #3 (with printed side up) on the corkboard using two metallic pushpins at the two electrodes which are drawn with conductive ink on the conductive paper #3.
2. Connect the two electrodes on the conductive paper #3 to the DC power supply (HY152A).
3. Connect the black banana jack (ground) on DMM to the ground (black banana jack) on the DC power supply (HY152A). Connect the red banana jack on DMM to a comfort grip voltage probe with silicone insulated. Select voltage scale of 20 V on DMM.
4. Turn on the DC power to 10 V.
5. Attention: To reduce measurement error, the tip of the voltage probe should be perpendicular to the conductive paper at the touch point.
6. Measure voltages at all the points labeled in Fig. 4. Record the data in Table 4.
7. Turn the voltage to 0V before shut down the DC power (HY152A).

Table 4 Measured voltages at all the points labeled in Fig. 4.

	Voltage (V)				
1	7.66	7.54	7.69	8.05	-------
2	7.00	6.01	6.79	7.57	-------
3	5.03	5.00	4.94	4.95	4.95
4	2.99	2.24	2.96	3.22	-------
5	2.19	1.65	1.98	2.38	-------
	A	B	C	D	E

Data Analysis 3

1. Based on the data in Table 4 draw equipotential lines on Fig. 4 using a red pen.

2. What is the main cause for the difference in shape of the equipotential lines between Fig. 3 and Fig. 4?

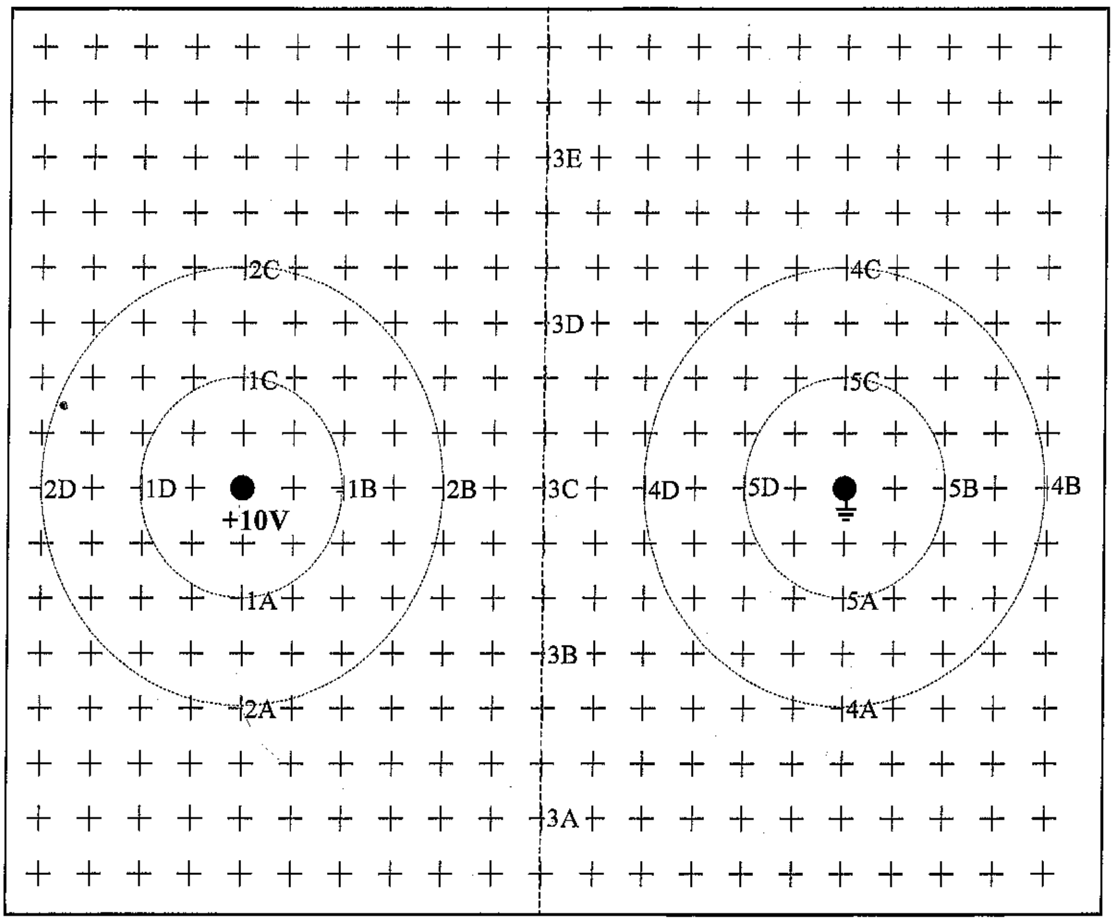

Figure 4 Conductive paper #3

Work to be done:

1. Check that the DC power (HY152A) is off. If not, turn voltage to 0V then shut it down.
2. Let your TA check your data pages. If they are OK, your TA will sign them.
3. Clean up your bench.

Lab report on Experiments 1

1. Your lab report should be in the required format described in the "Introduction" of the lab manual.
2. Figures 2, 3 and 4 with recorded data should be included in your lab report.

3. Tables 1 to 4 should be included in your lab report.
4. It is required that the answers to the questions listed in each data analysis and in "Questions and Exercises" should be included in your lab report.
5. You may tear the pages out of the lab manual, which contain your data Tables and your answers to the listed questions. Use these pages as a part of your lab report.

Questions and Exercises

The following three electrostatic charge configurations are in three separated spaces.

1. Use ruler to draw vector arrows with label $\vec{E}_a, \vec{E}_b, \vec{E}_c$ on each diagram to indicate the electric field lines through points a, b, c respectively in each of the three charge configurations.

2. Let E_a, E_b, E_c be the magnitudes of $\vec{E}_a, \vec{E}_b, \vec{E}_c$ respectively. Use smaller (<) , greater (>) and equal (=) signs to describe the relationships among E_a, E_b, E_c in the configurations:

   configuration (1): ________________________________.

   configuration (2): ________________________________.

   configuration (3): ________________________________.

3. The electric potentials at points a, b, c are denoted V_a, V_b and V_c respectively. Use smaller (<) , greater (>) and equal (=) signs to describe the relationships among V_a, V_b and V_c in:

   configuration (1): ________________________________.

   configuration (2): ________________________________.

   configuration (3): ________________________________.

4. Now a negative point charge $-q$ $(|-q| \ll Q)$ is placed at point a.

   Use ruler to draw a vector arrow (with a label $\vec{F}_a$) on each diagram to indicate the direction of the motion of q in each of the three charge configurations.