PHYS 102 EXPERIMENT 2. EQUIPOTENTIALS AND RADIAL ELECTRIC FIELD LINES

Objective:

The purpose of this experiment is to study the electric field concept by mapping electric field lines and equipotential lines on two oppositely charged concentric rings and two oppositely charged dot configurations.

Introduction:

The field concept is very useful in describing interactions between charged particles and objects. The electrostatic interaction of two charges can be described in terms of forces, but often it is easier to speak of electric fields. By definition, the electric field $\vec{\boldsymbol{E}}$ is the electrostatic force $\vec{\boldsymbol{F}}$ per unit positive charge Q:

$$\vec{\boldsymbol{E}} = \frac{\vec{\boldsymbol{F}}}{Q}\,. \qquad (1)$$

Any charged object is said to establish an electrostatic field in the entire space surrounding it and any second charge present in this field experiences a force proportional to the field. If the field is produced by a single positive point charge, or positively charged spherically symmetric object, it is directed radially outward from its center, decreasing as $1/r^2$. If the field source is more complex, the field configuration is correspondingly more complex. With the interaction a potential energy can be associated, and also a potential energy per unit charge, called the electric the potential. Thus, interactions between charges at rest are described in terms of electric field and electric potential. When dielectric media or conductors are present, the charge configurations in the materials must also be taken into consideration. The strength of the electric field depends on the source charge(s). The electric field may be thought of as the force per unit positive test charge that would be exerted before the field is disturbed by the presence of the test charge. The direction of the force exerted on a negative charge is opposite to that exerted on a positive charge. Because an electric field has both magnitude and direction, the direction of the force on a positive charge is chosen arbitrarily as the direction of the electric field. Because positive charges repel each other, the electric field around an isolated positive charge is oriented radially outward. When represented by lines of force, or field lines, electric fields are depicted as starting on positive charges and terminating on negative charges. These lines are artificially introduced to visualize the electric field. The lines also indicate the path that a small positive test charge would take if placed in their field. A line tangent to a field line indicates the direction of the electric field at that point. When the electric field lines are close together, the electric field is stronger than when they are farther apart. In other words, the density of the lines is proportional to the intensity of the electric field at that region of space. The lines or surfaces drawn perpendicular to the electric field lines are called equipotential lines or surfaces, or simply equipotentials. An equipotential surface is therefore defined to be the one on which the potential is everywhere constant.

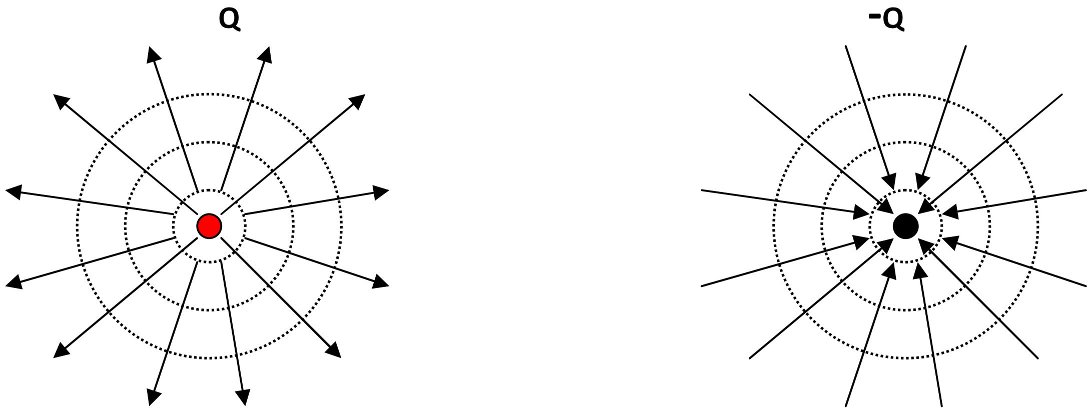

Figure 1: The electric field lines and corresponnding equipotential lines of positive and negative charges

The surface of a sphere having a point charge at its center is an example. In this experiment, we study field and potential patterns in the vicinity of electrodes. Each conducting electrode forms an equipotential surface and, if a potential difference is imposed on two electrodes, an electric field pattern is established in the region between them. Ideally, we would like to be able to measure fields in vacuum in the vicinity of deflecting electrodes. Such measurements are possible, but they are difficult and not very illuminating to someone who studies electrostatics for the first time. Instead, we shall study a much simpler problem, the potential pattern on a high-resistance conductive sheet for various electrode configurations. The relation between the potential and field configurations on a two dimensional conductive sheet will be further developed in the course of this experiment.

Questions to Think About:

1. For an arrangement of two point charges:
    a) Is it possible to find two points (neither at infinity) where $\vec{\boldsymbol{E}} = 0$?
    b) Is it possible to find an off-axis point (not at infinity) where $\vec{\boldsymbol{E}} = 0$? What conditions are required? Explain.

2. Is it possible for two or more different equipotential surfaces to intersect?

Equipment:

The following equipment will be supplied;

- A multimeter;
- A 30 V DC power supply;
- Conductive carbon sheet;
- Cable sets.

The following items must be brought by you and will not be supplied.

- A ruler;
- A scientific calculator;
- A pair of compasses.

Procedure:

PART A:

1. Using metal pushpins mount the given conductive carbon paper onto the corkboard.
2. Set up the circuit given in Fig. 2 where the negative terminal of the power supply is connected to the inner ring and positive terminal to the outer ring. Apply 20 V between the inner and outer rings. Then, connect one of the probes of the voltmeter to a terminal of the power supply. The remaining free probe will serve for tracing and recording the electric potential in the region between the rings.
3. Divide the 4.5 cm separation between the inner and outer ring into 0.5 cm intervals.
4. Measure and record the potential values as a function of radius at equal intervals of 0.5 cm starting from the inner circle. Tabulate your data in Table 1.
5. Since you measured the potential at discrete points compute the average field over successive intervals and for that use the Lagrange's formula for numerical differentiation. Hence, calculate the electric field as a derivative of V (E=dV/dr) numerically, using Eq. 2 and fill in Table 1.
6. Plot the graph of the electric field as a function of 1/r and calculate its slope.
7. Place the free probe of the voltmeter at some radius between the rings (say, 4 cm from the center); read the potential and record this value in Table 2. Repeat the above step for a few more different radii; e.g., try r = 5 and 6 cm, for instance.
8. Calculate the theoretical values of the equipotentials you have obtained in the previous step using the formula given in remark 2. Compare them to the experimental equipotentials readings. All the data and results must be recorded in Table 2.

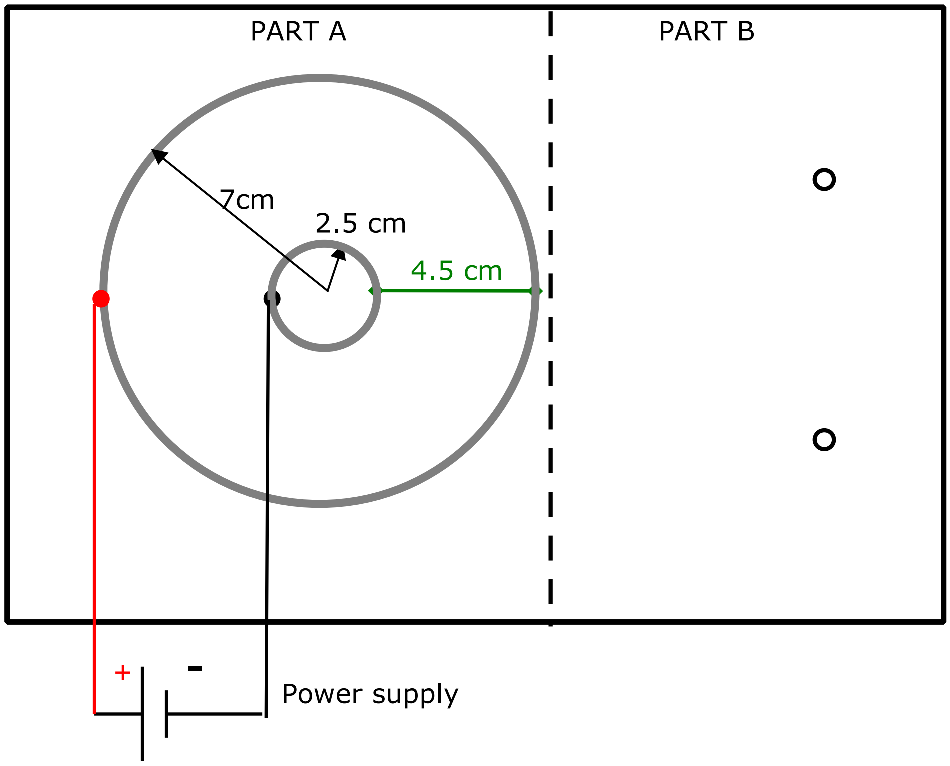

Figure 2: Schematic apperance of the experimental setup

$$\frac{dV}{dr} = \frac{1/3}{\Delta r}\left[\frac{1}{4}V_{-2} - 2V_{-1} + 2V_1 - \frac{1}{4}V_2\right]. \qquad (2)$$

PART B:

1. Connect the terminals of the power supply to the two silver dots that are apart from each other by 7 cm, on the second half of the carbon sheet away from the rings as shown in Fig. 2, and repeat the above procedure. Use Table 3 to record all of your data.

Remark 1: Potentials will be measured by a digital voltmeter. One possible concern is that we may alter the potential by placing the voltmeter probe in contact with the conductive paper. This is a problem with typical meter movements, which require substantial currents in order to obtain a deflection. With high-impedance digital voltmeters, however, the current drawn from the conductive paper is extremely small so that for most applications the change in the potential will be negligible. Clearly, the voltmeter reading which you record on the conductive paper will give you the value of the electric potential relative to the selected ring whose potential is arbitrary. In particular, if the potential on the inner is selected as the reference potential and is assigned the value zero (as in our case), then the potential on the outer ring will merely be the voltage of the power supply.

Remark 2: It should be noted that in this experiment, the electric field has not been generated by static charges, but instead, created by passing current from one ring to the other via the conductive graphite paper. In order to provide a satisfying explanation for such a situation and see the connection with a similar configuration with static charges in empty space, we need to discuss the behavior of the system which we have been investigating. In fact, in this experiment we examine the flow of current in the configuration consisting of two concentric circular silver rings with the space in between filled with graphite. If the resistance of the silver rings to circumferential current flow is very small compared to the resistance of the graphite to radial current flow, it should not make much difference where the current enters and leaves the silver (that is, where the probes are located). In that case, we may assume each silver ring is an equipotential. Indeed, comparing the respective electrical conductivities, we see that silver is at least a factor of 10^3 more conductive than graphite, around room temperature. So the assumption is valid provided that the silver painted rings are not extremely thin. Proceeding with this assumption, we can derive an expression for the electric potential in the region between the rings given that the potential difference between them is fixed at V_0. If one has a radially symmetric geometry for the conductors such as concentric cylindrical tubes in three-dimensions or concentric rings in two-dimensions, then the electric field is radial and falls off with $1/r$, i.e. $E = K/r$ rather than $1/r^2$, which would be the result for a point charge. The constant K depends on the strength of the charge on the inner conductor and the units; we need not be concerned with this aspect of the problem just now.

It can be shown that if we have an equipotential ring of radius a at zero potential and an equipotential ring at $r = b, (b > a)$, at potential V_0, then the potential at any intermediate radius will be given by the expression

$$V(r) = V_0 \frac{\ln(r/a)}{\ln(b/a)}. \qquad (3)$$

We may, for example, establish the potential V_0 using a battery or a power supply and forget about the charges and their flow altogether.

Name & Surname :	**ID#:**	**Section:**

Data & Results: [20]

r (cm)	**V ( )**	**E ( )**	**1/r ( )**
2.5			
3.0			
3.5			
4.0			
4.5			
5.0			
5.5			
6.0			
6.5			
7.0			

Table 1: Electric potential and field of two concentric rings as a function of r

r (*cm*)	**V [measured] ( )**	**V [calculated] ( )**	**% Error**

Table 2: Equipotentials

r (*cm*)	**V ( )**	**E ( )**	**1/r ( )**
2.5			
3.0			
3.5			
4.0			
4.5			
5.0			
5.5			
6.0			
6.5			
7.0			

Table 3: Electric potential and field of dots as a function of r

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Name & Surname :	**ID#:**	**Section:**

Questions:

1) [5] What would you expect for the variation of potential V with radius r for a different radial direction? Measure a few points to check out your prediction.

2) [5] Based on your measurements of electrical potential, what must be the direction of the electric field? What do the equipotentials look like?

3) [5] If the power supply voltage in the experiment were doubled, how would the field pattern change? How about the potentials?

4) [5] Why does not current flow along equipotential lines?

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Conclusion: [15]

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Plot [15]