Electric Field
PHYS 296

Your name__________________ **Lab section____________________**

PRE-LAB QUIZZES

1. What will we investigate in this lab?

2. In a uniform electric field between two parallel plates, a potential probe records the electric potential changing from *2.0* to *2.8 V* when it moves *1.0 cm* along the direction perpendicular to the plates. Calculate the electric field between the plates.

3. In Figures 1a and 1b, the electric potential difference between the electrodes is *5.0* V. Draw four equipotential lines with *1 V*-difference between two neighboring lines and label each line with the corresponding voltage. Also draw two electric field lines in each figure.

Figure 1a Two parallel copper plates with uniform charge distribution on each plate

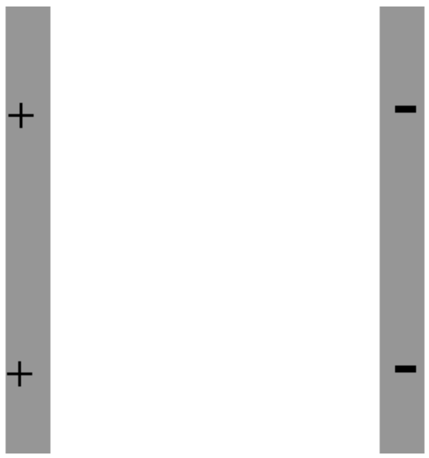
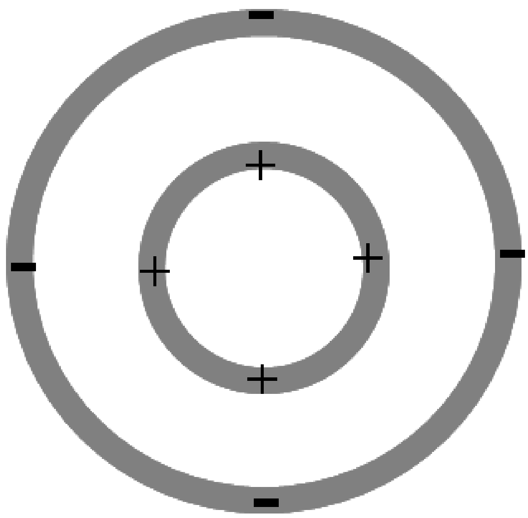


Figure 1b Two concentric copper rings with uniform charge distribution on each ring



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PHYS 296

Name____________________________________   Lab section________________________

Lab partner's name(s)____

Objective

In this lab, we learn how to determine electric field through measuring the distribution of electric potential. We will study several common but important examples of equipotential surfaces and the corresponding distributions of electric field.

Background

Electric field is a vector field with magnitude and direction. The electric field (***E***) at a point is defined in terms of the force acting on a test charge (*q*) placed at the point following Equation (1):

$$\boldsymbol{E}=\boldsymbol{F}/q. \tag{1}$$

The direction of the field at the point is the same as the direction of the force acting on a positive test charge at that point. The unit of electric field is *Newton-per-coulomb* (*N/C*), or equivalently, *volt-per-meter* (*V/m*). Electric field lines are often drawn to represent the direction and magnitude of the electric field in space. The ***E***-field line always points from a positive charge to a negative charge. The direction of the electric field is indicated by arrows drawn on the ***E***-field lines and the magnitude of the field at any point by the line density near that point.

On an equipotential surface, the electric potential is the same at every point of the surface. At each point of the equipotential surface, the ***E***-field line is normal to the surface. If the potential difference between two equipotential surfaces is ΔV and the distance between a point **A** on one equipotential surface and another point **B** on the second equipotential surface is Δd, the component of the electric field in the direction pointing from **A** to **B** is given by

$$E=-\Delta V/\Delta d, \tag{2}$$

where ΔV is the potential difference (in *volts*) between the two points and Δd is the distance (in *meters*) between the two points.

PART I The Electric Field Between Two Parallel Rectangular Plate Electrodes

As shown in Figure 2, the two parallel thin rectangular copper plates are used as two electrodes. One plate is grounded and a bias voltage (V_0) is applied on the other plate. The electric field is approximately uniform in the center area between the two parallel plates. The magnitude of the electric field (E) equals the electric potential (V_0) across the plates divided by the distance between the two plates (d): $E = -V_0/d$. We denote the y-axis parallel to the plates and the x-axis perpendicular to the plates. The y-coordinates can read on the plastic rulers which is parallel to the copper plates.

To measure the electric potential between the plates, a rheostat is set across the two copper plates. We use the sliding probe on the rheostat to measure the electric potential at the position of the sliding probe which is connected to a potential sensor. The position of the sliding probe, relative to the left end of the rheostat, can be simultaneously measured by a position sensor which is also connected to the sliding probe. The rheostat works like a potentiometer containing a rectangular-shaped thin film resistor (length $L=10\ cm$ with the total resistance at $10\ k\Omega$), as shown in Figure 3. The sliding probe is connected to the resistor. When the sliding probe moves, the resistance between the probe and the left end of the resistor is proportional to the distance between them. Therefore, when a constant electric potential different (V_0, which in this lab is set as the same as the potential drop between the two plates) is applied across the resistor, the potential different between the movable probe and the left end is $V(x) = V_0 \cdot x/L$. In practice, it is more precise to determine the potential difference $V(x_1) - V(x_2)$ between any two positions, x_1 and x_2. It is obtained by measuring the potential when the sliding probe is moved to x_1 and the potential when it is moved to x_2.

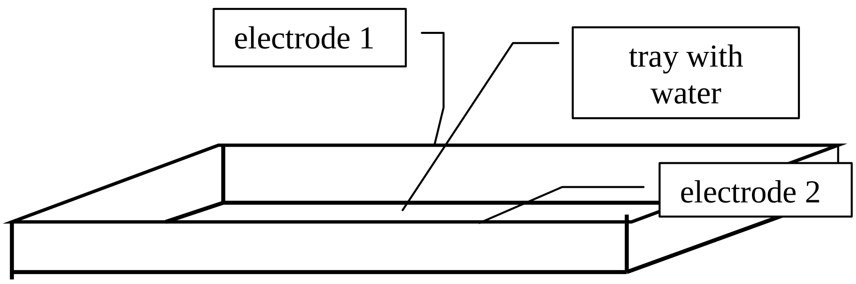


Figure 2

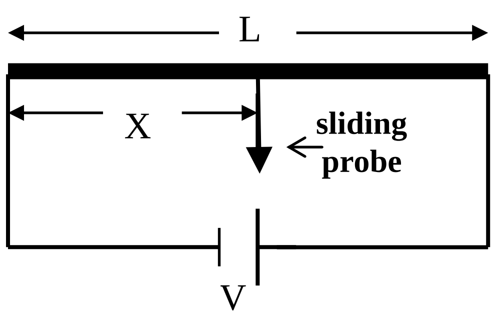


Figure 3. The sliding probe measures two potentials. As shown, it measures the potential drop on the thin film between its end and the position at the connecting point with the sliding probe. It is measured by the red wire soldered on the screw. This potential drop measures the distance. The other potential is measured by the tip of the sliding probe which gives the potential at the tip.

QUESTIONS

1. The resistor in this experiment is *10 cm* long. If a voltage of *5.0 V* is applied between the ends of the resistor and the potential drop measured between the left end of the resistor and the sliding probe is *1.5 V*, calculate the distance of *x* between the left end of the resistor and the sliding probe.

PROCEDURES

1. Connect the output on ***750 Interface*** to the "V-input" plug-ins on the Electric-Field-Mapping tray. Connect one voltage sensor to the "Potential Sensor" plug-ins on the Electric-Field-Mapping tray, and connect this voltage sensor to input channel A on ***750 Interface***. Connect another voltage sensor to the "Position Sensor" plug-ins on the Electric-Field-Mapping tray, and connect this voltage sensor to input channel B on ***750 Interface***. Make sure that each connection correctly matches the colors of the connectors and plugs.
2. Open ***Data Studio***, click on the icons of analog input channels A and B, select voltage sensors for both channels. Click on the icon of output channel. In the opened window, set the output signal to **DC at *5.0 V***.
3. Set the rheostat on top of the parallel plates. Fill the tray with water (provided) and cover the plates with water. The copper tip of the probe of the rheostat is also immersed in water to break the surface tension of the water. NOTE: the rheostat is sensitive to water. DO NOT drop it into water or pour water over it.
4. The voltage reading of Channel B (connecting to the position sensor) is used to determine the position of the probe of the rheostat. To convert the voltage into the position, double click the "Calculate" button on the tool bar of ***Data Studio***. The *Calculator* window pops up. Type in *x(cm) = (10/V0)*VB*. To define the variables, click on the drop down menu arrow in the *Variables* box for "*V0*". Select "Data Measurement" from this menu and then choose "Output Voltage". It sets the "*V0*" variable as the output voltage from ***750 Interface***. Similarly, to define the "*VB*" variable, select "Voltage, ChB" and set it as the reading (voltage) from channel B. Note: the full length of the resistor of the rheostat is *10 cm* and the output voltage is chosen in step *2*. Click "Accept" and close the *Calculator* window.
5. Open Graph Display to display channel A, which is the potential measured by the potential sensor. Because you need to measure the curve of potential versus distance, find in the Data menu the new variable you defined in step 4, "x(cm)". Drag the icon of "x(cm)" into the graph and on top of the x-axis. This should replace the x-axis coordinate from "time" to "x(cm)".
6. Set the sampling rate and the sensitivity of the voltage sensors at the default values of *100 Hz* and Low Sensitivity, respectively.
7. Place the rheostat at the center position between the two ends of the plates (using the ruler: it should read 7.5 cm). During the measurement, move the probe along the x-axis which is perpendicular to the plates. Now, set the probe of the rheostat all the way to the left end of the rheostat and click "Start" to begin taking data. Slowly and smoothly move the probe from one plate to the other plate, while you make sure you do not move the rheostat parallel to the plates (i.e. along the y-axis). Data should now be recorded and displayed in the graph. Practice until you become familiar with the procedure.
8. Delete all old test runs from the *Data* window by clicking on them to highlight and then pressing "delete" on the keyboard and then pressing "enter". Now, it is ready to take data. You should take 5 data sets, each at a different y-axis position (see Table 1). Avoid the end positions of

the plates because the electric field may not be uniform because of the edge effect. Use the ruler to determine the position. For each run, move the probe as described in step 7. To obtain the slope for each data set, select "Linear Fit" from the Fit menu. For good fitting, select only the center portion of the curve by dragging a box around the region you want to make a fitting. The data corresponding to these x-axis coordinates near both plates cannot be described by a uniform field and should be discarded. Record the fitted slopes in Table 1. Meanwhile, for each data set, choose four appropriate potential values, *2, 2.5, 3, 3.5 V*. For each potential value, you need to find the data point in each data set that match this potential value. Using the *smart cursor* tool to determine the x-coordinate of the data point and record it in Table 2.

TABLE 1

RUN #	Y-POSITION	SLOPE
1	5.5 cm	
2	6.5 cm	
3	7.5 cm	
5	8.5 cm	
6	9.5 cm	

TABLE 2

Potential	*2.0 V*	*2.5 V*	*3.0 V*	*3.5 V*
Run #1__(y =5.5 cm), x=				
Run #2__(y =6.5 cm), x=				
Run #3__(y =7.5 cm), x=				
Run #4__(y =8.5 cm), x=				
Run #5__(y =9.5 cm), x=				

DATA ANALYSIS

1. Plot the data points of Table 2 in the rectangular graph paper shown on the next page and connect every five points in Table 2 with the same potentials to draw the equipotential lines.

For each potential value, find the x and y coordinates of the corresponding five data points (shown in Table 2) and draw these five points in the graph paper. Draw a line connecting these five data points in graph paper.

Repeat for all the four potential values. You should obtain four equipotential lines.

2. Calculate the electric field between the plates at y = *7.5* cm using the equation, $E = -\Delta V/\Delta x$, where Δx is the distance between any two adjacent equipotential lines. Enter the calculated values for each row in the Table 3.

TABLE 3

Equipotential Lines	Potential Difference	Distance	E – Field Strength
using equipotential lines 2.0V & 2.5V			
using equipotential lines 2.5V & 3.0V			
using equipotential lines 3.0 V & 3.5V			

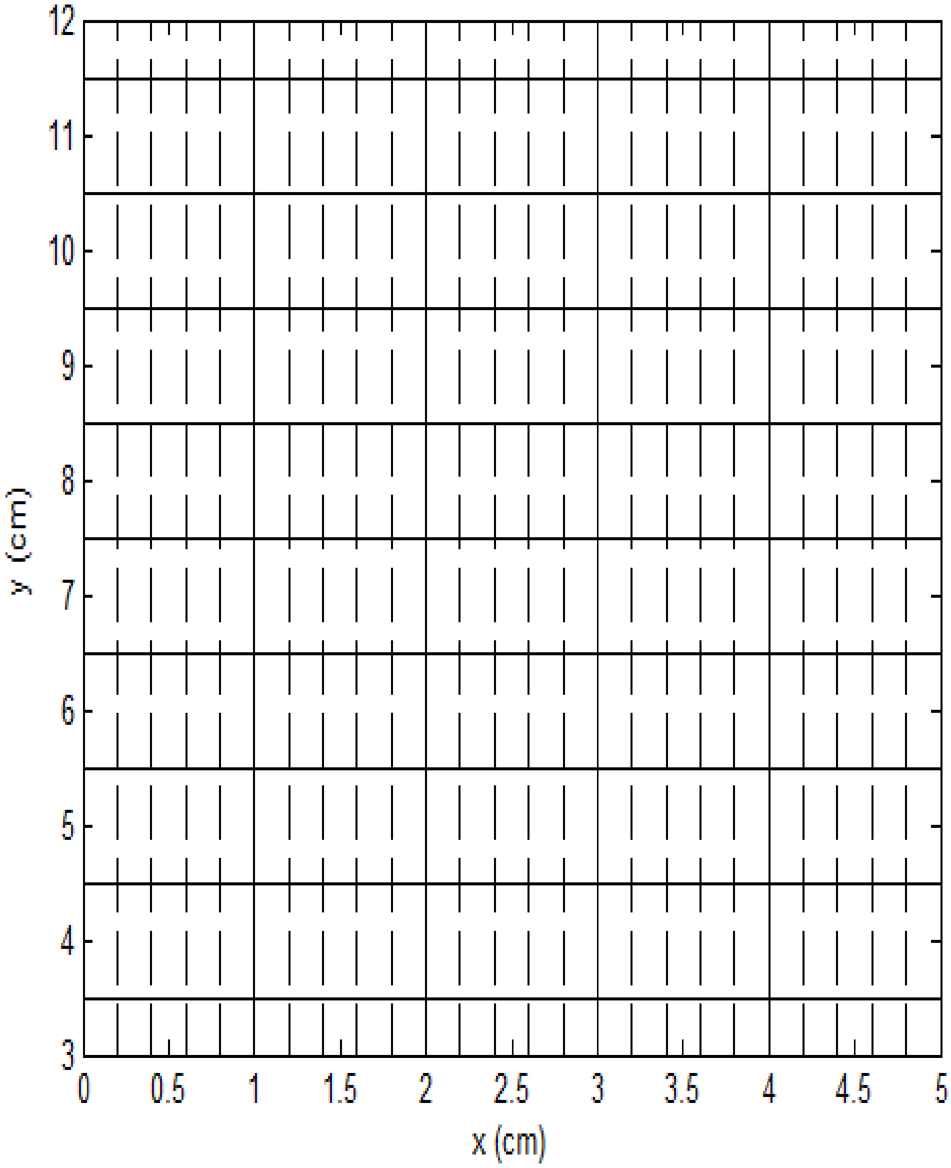
QUESTIONS

1. By comparing the slopes of the data sets with the derived electric fields, discuss how you can measure electric field.

2. There is a common feature among the electric fields at different x-coordinates between the parallel plates. What is it?

3. Calculate the average value of the electric field between the parallel plates.

4. Explain why the equipotential lines are parallel to each other and to the plates.



12
11
10
9
8
7
6
5
4
3
y (cm)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
x (cm)

PART II Electric Field Between Two Concentric Rings

In this experiment, we study the electric field between two concentric ring electrodes.

PROCEDURES

1. The connections of the potential sensor, the position sensor, and the V-input sensor are kept the same as in Part I. Move the rheostat from the parallel plates to the ring electrodes. One end of the rheostat has a metal peg. Insert the peg into the center ring. Slide the white Teflon stand onto the other end of the rheostat and use it as a support. Be careful! Do not break any wires.
2. Use the same "calculator" settings. **Set the DC output again to *5.0 V***. Select four different radial positions. For each, measure the potential as you slowly and smoothly move the sliding probe from the center to the outer ring. Repeat the measurement until you are satisfied with the data.

DATA ANALYSIS

1. To determine the equipotential lines, select four potential values that fall within the measured potential range of the four data sets. They are given in Table 4.
2. For each selected potential value, find the data point from each data set that corresponds to this potential value. Write the corresponding radial coordinates (r, θ) appropriately in Table 4.
3. Draw the equipotential lines on the polar graph paper shown on the next page. Connect the four data points with the same potential.

TABLE 4

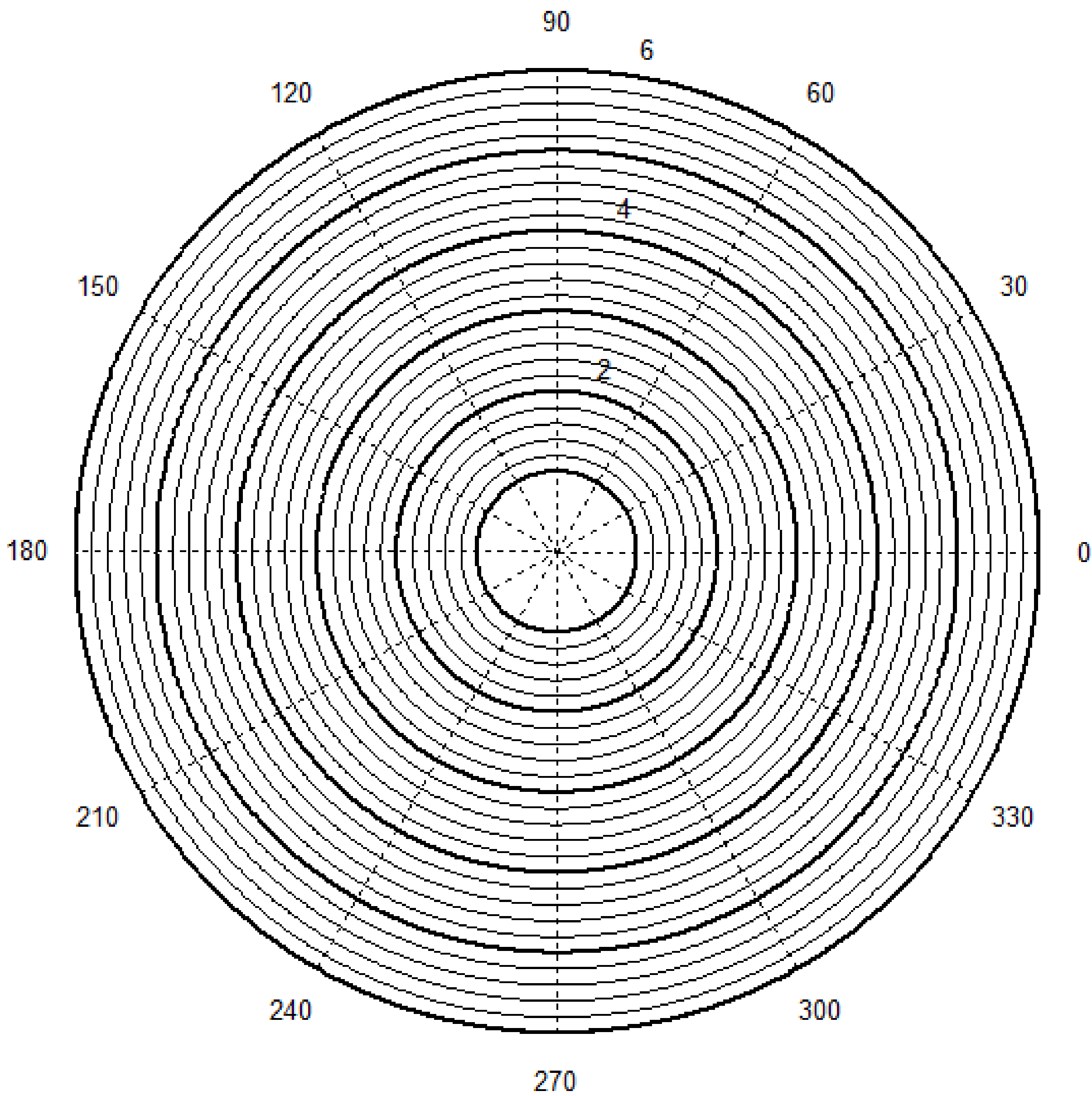
Potential	*2.0 V*	*2.5 V*	*3.0 V*	*3.5 V*
Run #1__(θ=0°), *r*=				
Run #2__(θ=90°), *r*=				
Run #3__(θ=180°), *r*=				
Run #4__(θ=270°), *r*=				

QUESTIONS

1. What kind of curve describes the equipotential lines?

2. For the same potential change, does the distance between the equipotential lines stay the same?

3. Examine the curve of the potential versus the radial distance. Which function describes the curve? $V(r) \propto r^{-1}$, or $V(r) \propto r^{-2}$, or $V(r) \propto r^{-3}$, …?


90
6
120
60
4
150
30
2
180
0
210
330
240
300
270

DATA ANALYSIS

As you have observed that the curve of *r* versus *V(r)* is not a straight line but a curve with a decreasing slope. The best fit for the curve is a logarithmic function. Obtain the best fit using the ***Data Studio*** curve-fitting program. The formula of fitting is a natural log fit,

$$V(r) = a \ln r + b$$

1. Write down the fitting formula corresponding to the best data set you took:

2. The electric field as a function of *r* can be derived by calculating $-dV(r)/dr$. Use this formula to find *E(r)*.
3. Use the derived *E(r)* to calculate the electric fields for six different *r* values at increment of *0.5 cm*. Record them in Table 5.

TABLE 5

Radial Coordinate, r	Electric Field
2.5 cm	
3.0 cm	
3.5 cm	
4.0 cm	
4.5 cm	
5.0 cm	

QUESTIONS

1. Give an example of electric field symmetry which produces uniform electric field?

2. Give an example of electric field symmetry which produces electric field $E \propto 1/r$?

3. Give an example of electric field symmetry which produces electric field $E \propto 1/r^2$?