# III. ELECTROSTATIC FIELDS (CONTINUATION) — *f03.01*

## INTRODUCTION

This experiment is a continuation of studies on electrostatic fields discussed in the previous experiment.

## PURPOSE

In the previous experiment we traced equipotential lines for various electrostatic fields. The equipotential lines provide useful qualitative description of such fields. In this experiment we will study electrostatic fields in a quantitative way. The measurement process will be computerized.

## PRE-LAB ASSIGNMENTS

### A. Readings:

Electric potential and electric field vector were discussed in the theoretical introduction to the previous experiment. You may need to read it again. Additional formulae are given below.

Electric field $\vec{E}$ between two parallel plates, separated by distance $d$ and kept at the voltage difference $\Delta V$, is uniform (i.e. it has a constant magnitude and direction). It is directed from the positive electrode to the negative one. The value of the electric field strength is given by:

$$E = -\frac{\Delta V}{d}$$

The potential in between the plates is changing linearly as a function of the distance from the negative plate ($x$):

$$V = V_0 + E\,x$$

.

The electric field due to concentric cylinder(s) is

$$E = \frac{\lambda}{2\pi\epsilon_0\,r}$$

where $\lambda$ has to do with the cylinder charge and $r$ is the distance to the center of the cylinders. This formula implies logarithmic dependence of $V$ on $r$:

$$V = V_0 + \alpha\,ln(r)$$

(where $\alpha$ is a constant related to $\lambda$).

### B. Exercises:

Please answer the questions on Report Sheet III–1, which will be collected at the *beginning* of the laboratory session and graded by your instructor.

**REPORT SHEET III–1**

Date____________________________ Name____________________________

Instructor____________________________

PRE-LAB EXERCISES

**Exercise 1.**
How would the electric field strength between the two parallel plates change if you doubled the distance between the plates kept at the constant potential difference?

**Exercise 2.**
What is the direction of the electric field vector in between the two parallel plates with some potential difference.

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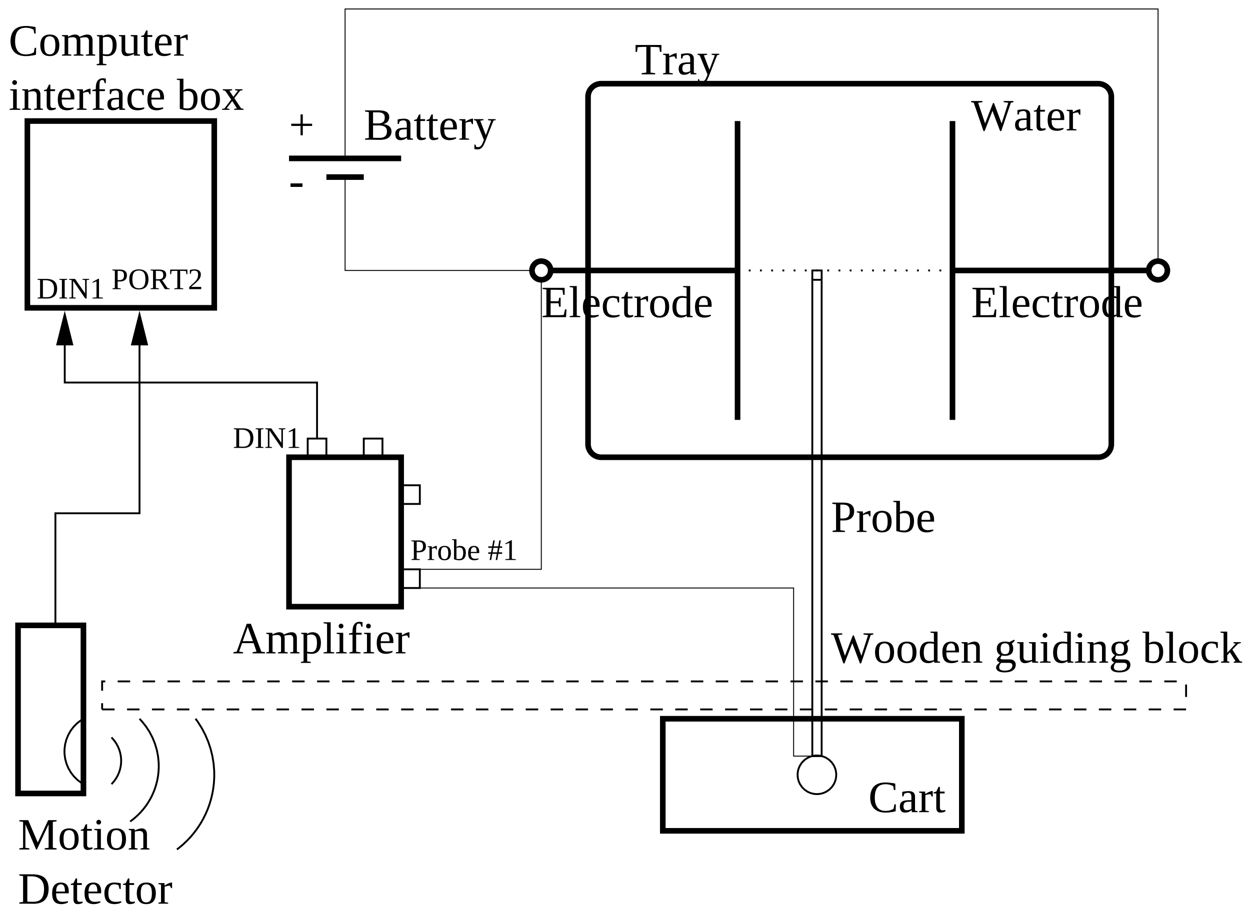



Figure 1. Diagram of the experimental set-up for measuring potential as a function of position in between the electrodes.

## Experiment A–F: *Quantitative Study Of Electrical Fields With The Electrolytic Tank Method*

**Materials Needed:**

- Tray with tap water
- Electrodes:
  **(A-D)** Two flat plates, **(E-F)** 1 inch (or 1/2 inch) and 8 inch cylinders.
- Battery (~4.5 V)
- Probe mounted on a cart
- Wooden guiding block
- Dual Channel Amplifier with voltage probes
- ULI computer interface box
- Voltmeter

- Cables
- **(B-F)** Motion Detector

**The Task:**

To graph potential and electric field strength as a function of the probe position.

**Procedures**

**A-1.** The electrical circuit in this experiment (see Fig. 1) is essentially the same as in the previous one, except that instead of the power supply, we will use a $\sim 4.5$ V battery to generate a potential difference between the electrodes, and instead of the hand-held digital voltmeter, we will use a voltage probe which is readout by a computer.

Voltage probes should be connected to the Dual Channel Amplifier (only the Probe 1 will be used in this experiment). The DIN1 output from the Dual Channel Amplifier should be plugged into the DIN1 input on the ULI computer interface box. Make sure the ULI interface box is on (the ON/OFF switch is on the back panel of the box, there is a green power indicator light on the front panel). Start the computer, and click on the PHY222 icon to start the program which works with the voltage probe. If you happen to exit the program (which you should do at the end of the laboratory session) please **do not** save any settings to a file when the program offers you this option. To load the proper initialization file, choose "Open…" from the "File" menu. Open the file "electricfield" in PHY222 subdirectory. The voltage probe reading is shown near the bottom of the screen, in the small box which says "Potential=".

**A-2.** Check the voltage probe reading. Connect the red and black voltage probe leads to each other. The reading on the computer should be close to zero. Measure voltage supplied by the battery with the hand-held voltmeter (if it is below 1V, the battery is dead and you need a new one). Then connect the computer voltage probe to the battery and see if you get similar reading with the computer. If the voltage probe is off by more than 0.3V at any of these two voltage readings, the probe is not working properly (ask the lab instructor for help).

**A-3.** If the probe passed the test described in the previous step, but its readings disagree with the voltmeter measurements by more than 0.1V, you can improve its accuracy by changing its calibration. To calibrate the voltage probe go to "Calibrate" under the "Experiment" menu. Click on "DIN1" and then on "Perform now" button. With the voltage leads connected to each other, enter "0" in the "Value 1" box and then click on the "Keep" button. Now connect the voltage probe to the battery (the black lead to to the black connector, red to red) and enter in the "Value 2" box whatever value you measured with the hand-held voltmeter. Click on "Keep" and then on the "OK" button. Check how well the probe measures zero volts and the battery voltage again (see the previous step). If you get weird readings, try calibrating again and if it doesn't help, the probe may be broken (ask for help).

**A-4.** Set up the electrical circuit as shown in Fig. 1. The tray should be clean, without residue on the bottom. Use fresh, clean tap water. Use two flat plate electrodes, separated by 14cm (electrodes at the 7cm mark) along the longer dimension of the tray with tap water. The red lead of the voltage probe should be connected to the probe mounted on the cart. The black lead should be connected to the negative pole of the battery also indicated by the black color (you can clamp the lead on the electrode connected to that pole). Use a wooden board to guide the probe along the middle line of the tray. Make sure that at any position of the cart the probe tip is well under water and that it is not getting stuck on the bottom of the tray.

**A-5.** Now we are ready to measure potential as a function of the position in between the electrodes. Record value of the potential readout from the computer for the probe positioned at −6cm, −5cm, −4cm, ..., +6cm in the Report Sheet III–2 (we use the minus sign to indicate positions closer to the negative electrode).

Transfer these measurements onto the "Potential vs. Distance" graph on the same Report Sheet. You will need to set-up a range of the vertical axis by yourself. Make zero the minimal value on the graph. Choose a round number, higher than any of your measurements and easily divisible by 10 for the maximal value (e.g. 2V, 4V, etc.). Label some of the lines dividing the vertical axis to make graphing easier. Represent each measurement as a point on your graph. Draw lines connecting the neighboring points.

**A-6.** The strength of the electric field $E$ along the scanned direction can be calculated from the formula: $E = -\frac{dV}{dx}$. Here $dV$ is a difference between values of the potential when the position of the probe is changed by infinitely small amount $dx$. This formula is still approximately correct when a finite position change is taken. Thus, we will set $dV_i = V_i - V_{i-1}$ where $i$ is the index numbering your voltage measurements. Since we changed the probe position in 1cm steps $dx_i = x_i - x_{i-1} = 0.01$m, and $E_i = -\frac{dV_i}{dx_i} = -dV_i * 100$ V/m.

Calculate the "dV$_i$" column in the Report Sheet III–2 and transfer these results onto the "Electric Field Strength vs. Distance" graph. Again, you will need to set up a range of the vertical axis by yourself. Make zero the maximal (or the minimal) value on the axis.

Answer the question at the bottom of the Report Sheet.

**REPORT SHEET III–2**

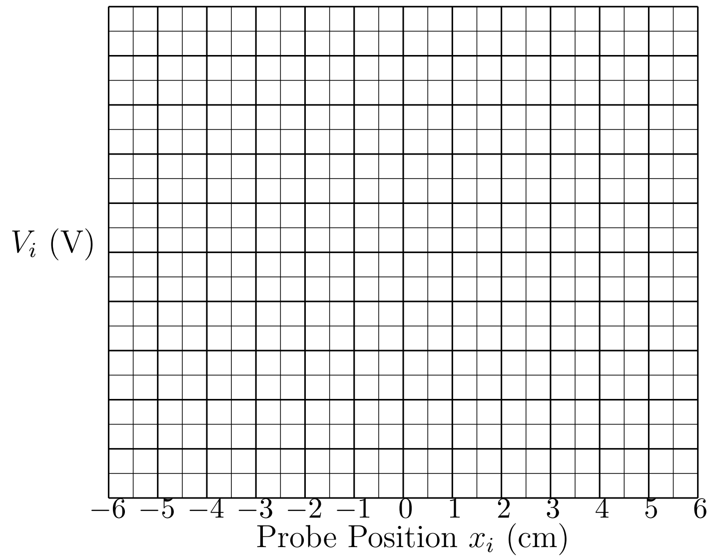
Date____________________ Name____________________

Instructor____________________ Partner(s)____________________

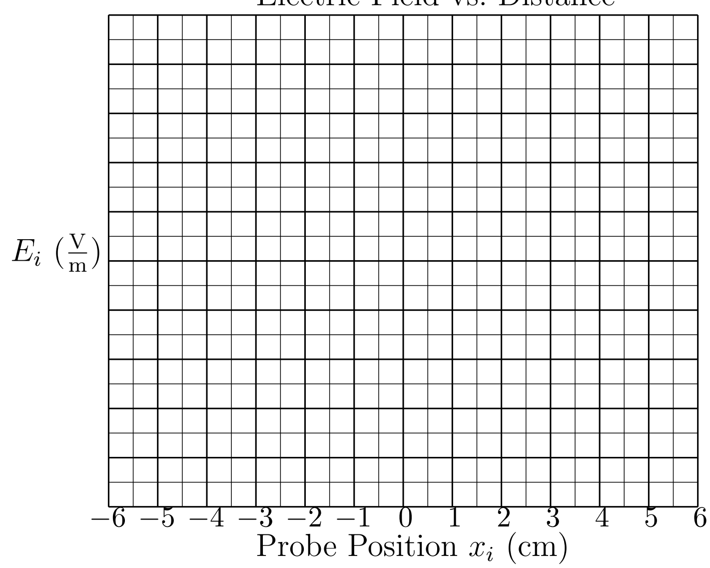
**A.**

| $i$ | $x_i$ | $V_i$ | $V_i - V_{i-1}$ |
|---|---|---|---|
| 1 | −6 | | —— |
| 2 | −5 | | |
| 3 | −4 | | |
| 4 | −3 | | |
| 5 | −2 | | |
| 6 | −1 | | |
| 7 | 0 | | |
| 8 | 1 | | |
| 9 | 2 | | |
| 10 | 3 | | |
| 11 | 4 | | |
| 12 | 5 | | |
| 13 | 6 | | |

Potential vs. Distance




Electric Field vs. Distance




Are your measurements of the potential vs. distance and of the electric field strength vs. distance roughly consistent with the theoretical expectations? Explain.

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**B.** You may wonder why you have been asked to use the computerized voltage readout instead of hand-held voltmeter to perform the experiment A. We will repeat the previous experiment with fully automated voltage and probe position measurements. This will be a good illustration of the benefit of computerized experiments.

The probe position will be located with the Motion Detector connected to PORT2 of the ULI interface box. The red light on the Motion Detector should be on. Position the Motion Detector at the end of the wooden board facing the cart. The closest position of the cart to the Motion Detector should be at least 0.5m (the Motion Detector will fail for smaller distances). Make sure that there are no obstacles between the Motion Detector and the cart (like wires or parts of your body). Do not hold the cart by the end facing the Motion Detector.

To start collecting data click on "Collect" button above the computer graphs. The data will be collected for ten seconds. The two graphs on the left will show how the readout from the Motion Detector (the top graph) and from the voltage probe (the bottom graph) is changing with time. Of course, we are not interested in time dependence but in the dependence of the potential and electric field strength on the probe position which are shown by the two graphs on the right. The electric field strength is calculated by the computer from the voltage measurement by numerical differentiation similarly to the calculation you did manually in the experiment A (except that the $dx_i$ intervals are now much smaller since the computer collects 20 measurements per second). For the electric field measurement it is important that you move the probe from one electrode to the other relatively fast – imagine what happens when the probe is not moving at all: $dx_i$ and $dV_i$ are both zero and our measurement of $E$ is $0/0$ which has an undefined value (for that reason some entries in the computer graph of $E$ should be ignored). Move the probe from one electrode to the other in one stroke and then stop (leaving the rest of the time unused) or move the probe back-and-fourth between the electrodes until the time runs out. Experiment with different probe motions until you are satisfied with the results.

Copy what you see on the screen to the Report Sheet III–3. It is not important that you copy the computer graphs with great precision. Just try to reproduce the most important features. Indicate range of values on the horizontal and vertical axes (e.g. copy to your report the position of the lowest and the highest number describing the axis on the computer graph). Notice that the horizontal and vertical lines on the computer graphs and on the report sheet graphs have a different pattern. Nevertheless they should be helpful in tracing the data curves.

Compare the results you have obtained here with the results obtained in the experiment A. Are they in qualitative agreement?

**C.** In this experiment we will try to verify the theory for the dependence of the electric field strength on the separation of the two flat electrodes. Read out the value of the electric field in the middle point between the two electrodes from the data you collected in point B. You can do it "by eye" from the graph, or you can make the computer help you by clicking on "Examine" in the "Analyze" menu. Now position the pointer at the point of the Distance vs. Time graph which corresponds to the middle point. The computer will display the corresponding value of the other displayed variables for this point. Record this electric field strength at the bottom of the Report Sheet III–3.

Now double the electrode separation (position them at $\pm$14cm). Collect the data for this new configuration and determine the electric field strength in the middle point. Record the measured value in the Report Sheet III–3 and answer the question.

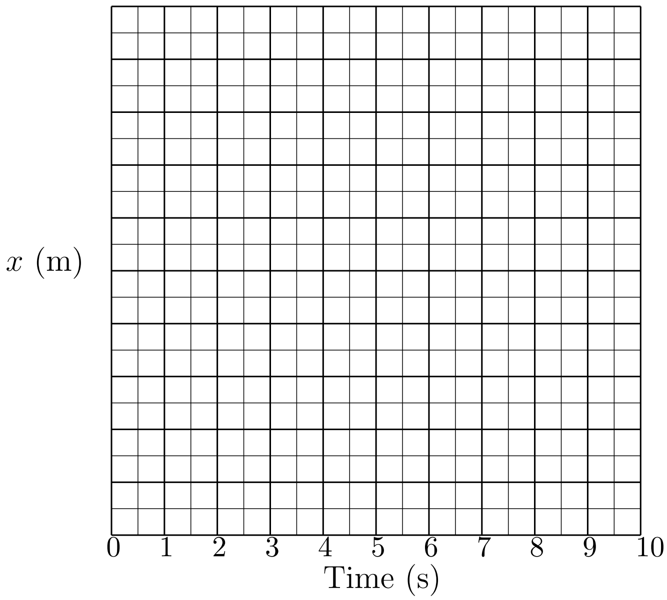
**REPORT SHEET III–3**

Date________________________ Name________________________

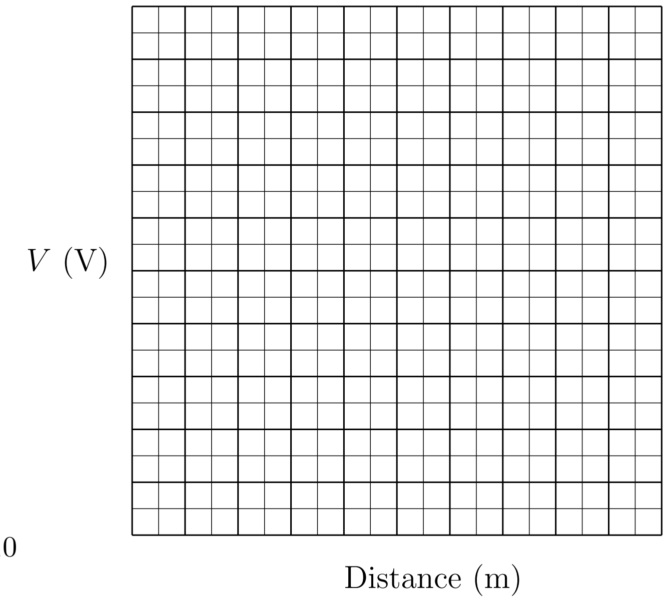
Instructor________________________ Partner(s)________________________

**B.**

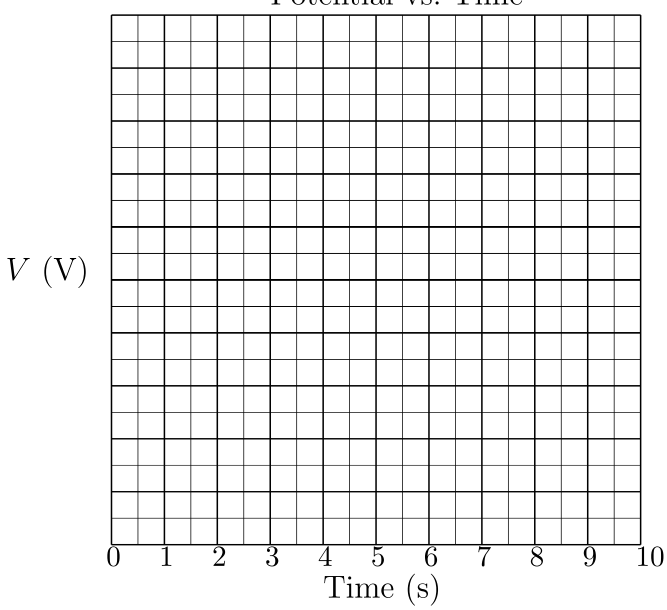
Distance vs. Time



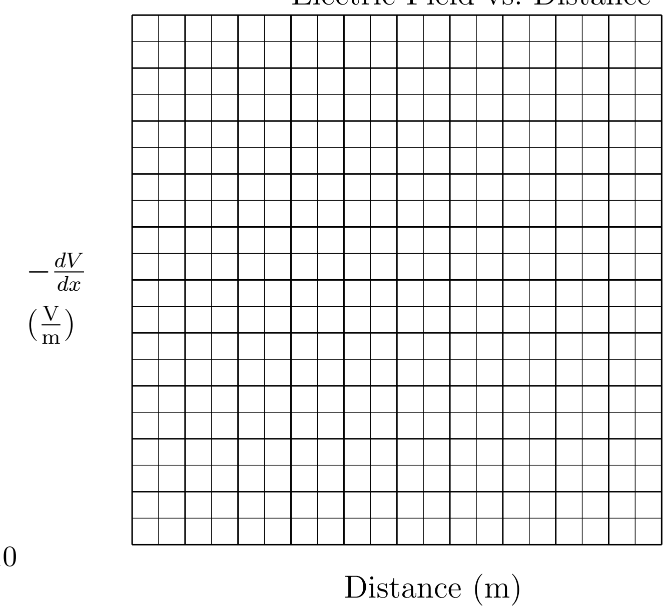

Potential vs. Distance




Potential vs. Time




Electric Field vs. Distance




**C.** Value of the electric field strength in the midpoint between the electrodes

for the data shown above $E =$

for the twice larger plate separation $E =$

Does the change of electric field strength with doubling the plate separation roughly agree with the theoretical expectations? Explain.

**D.** So far we have been moving the probe from one electrode to the other. This determines the value of electric field in the direction perpendicular to the electrodes. The electric field is a vector, thus in principle, it could have some value in the direction parallel to the plates. Reposition the electrodes at $\pm 7$cm points along the short tray direction. The probe is still moving along the long tray dimension, which is now parallel to the electrodes. We will measure component of electric field in this direction 1cm away from the positive or negative electrode (not in the middle between the electrodes!). You may need to reposition the tray with respect to the probe.

Collect the data including the points beyond the extent of the electrodes. Copy what you see on the screen to the Report Sheet III–4. Record the value of the electric field near the center of the electrode at the bottom of the report sheet. Answer the questions.

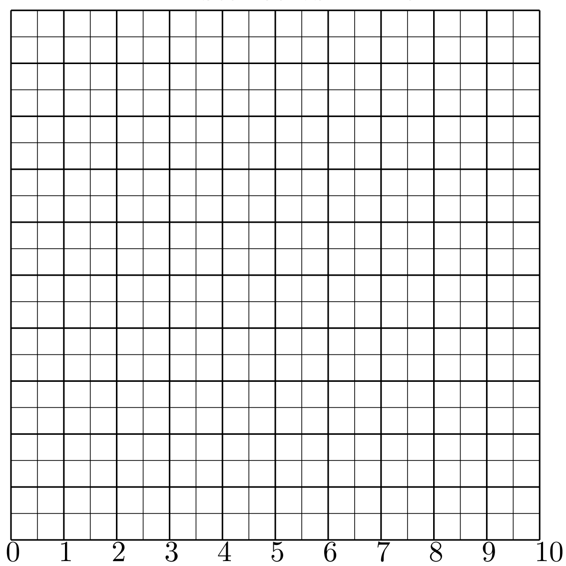
## REPORT SHEET III–4

Date____________________ Name____________________

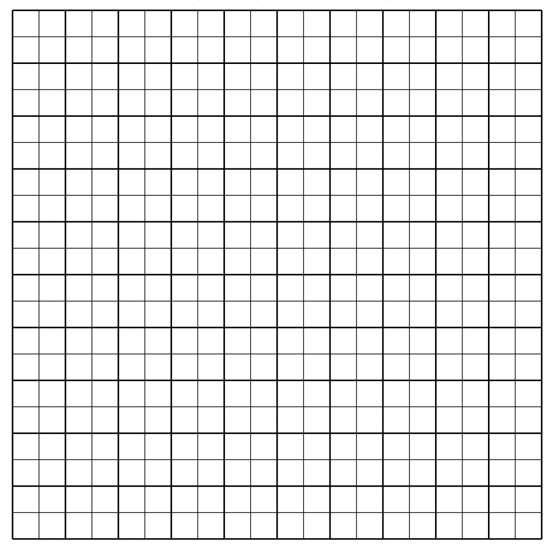
Instructor____________________ Partner(s)____________________

**D.**

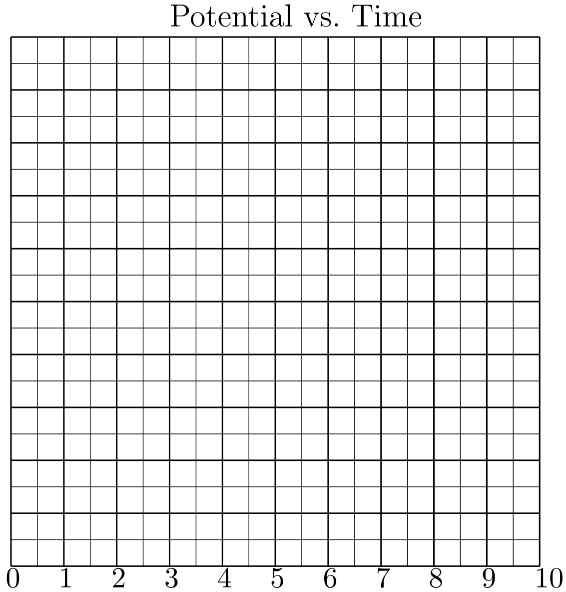
Distance vs. Time



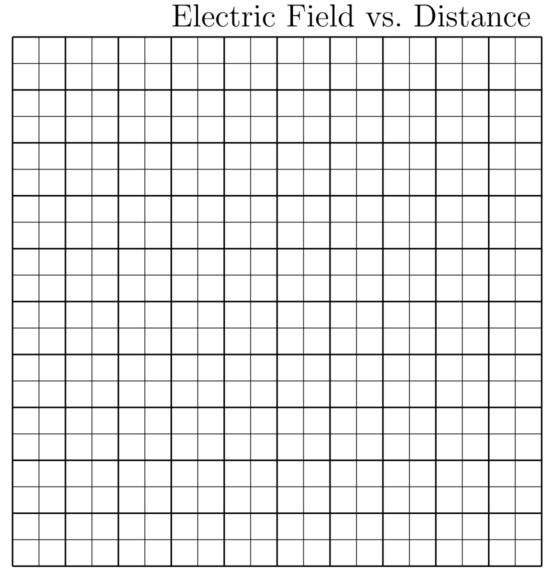

Potential vs. Distance




Potential vs. Time




Electric Field vs. Distance




Value of the electric field strength near the plate center $E =$

The theory says that in between the electrodes the electric field vector should be directed from one electrode to the other. Therefore, the value measured here should be small compared to the electric field in the perpendicular direction measured previously for the same separation of electrodes. Compare the value above with the result in the Report Sheet III–3.

(see also the question on the back of this page)
Try to relate what happens to the value of electric field beyond the extent of the electrodes as compared to the value near the electrode center (observed in this experiment) to the pattern of equipotential lines you traced for this set-up a week ago.

**E.** In this experiment we will measure electric field for the 1 inch (some set-ups use 1/2 inch) and 8 inch concentric cylinders. Put the center small cylinder on the positive potential. Configure the probe to pass near the inner cylinder as close as possible. Collect the data when you move the probe from one side of the outer cylinder to the other, passing near the inner cylinder in the middle (you can move back-and-forth). If the measured values of $E$ go beyond the range displayed at the bottom right graph, you will need to change the graph range. To change the minimal (or maximal) displayed value click on it on the graph, and type in a new value. You can also click at any other point in the area where the numbers describing the vertical axis are and a window should pop-out in which you can change the minimal and the maximal value.

Copy the computer graphs onto the Report Sheet III–5 and answer the question.

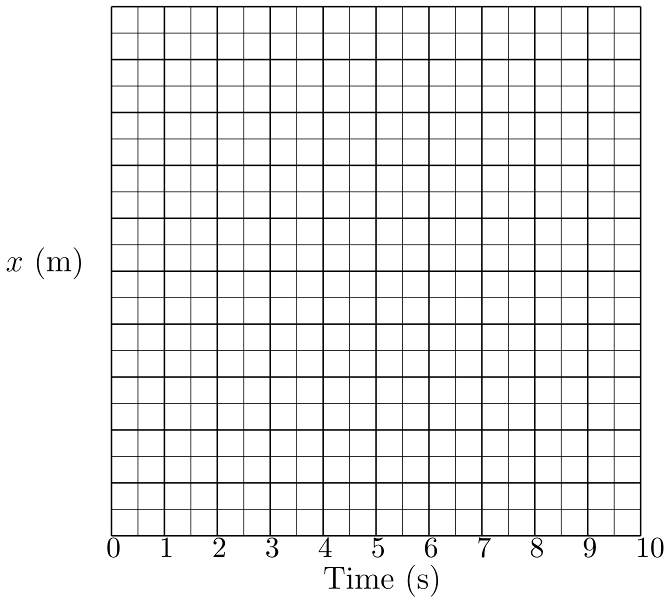
## REPORT SHEET III–5

Date____________________________ Name____________________________

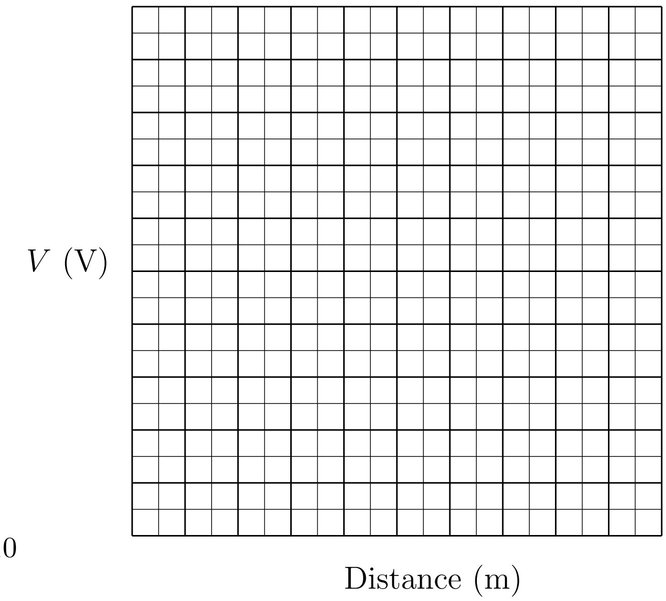
Instructor________________________ Partner(s)________________________

**E.**

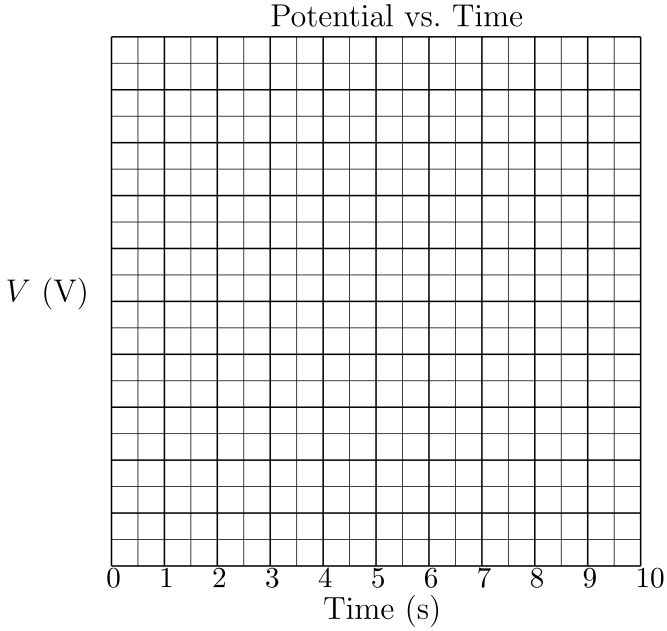
Distance vs. Time



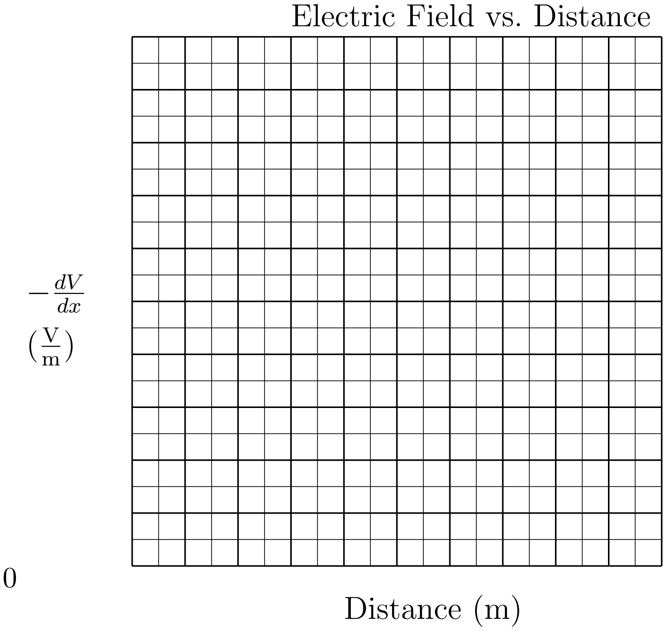

Potential vs. Distance




Potential vs. Time




Electric Field vs. Distance




You should be able to see change of sign of the electric field when passing near the inner electrode. What is the meaning of this change?

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**F-1.** Experiment F is more difficult to perform, therefore it is optional.

In the previous step the probe was moving almost radially, but not quite, which was the most apparent when passing near the inner electrode. Now configure the probe to move exactly in radial direction from the inner to the outer electrode (if your set-up has a plastic strip connecting the cylinders, make it perpendicular to the direction of the probe motion to eliminate the obstruction on the probe motion). Collect the data when you move the probe in between the inner and the outer electrodes. Start from the probe being exactly 1.5cm away from the center of the electrodes. Leave the probe at this position for the first second or two of the data collection, then start moving it.

**F-2.** The theory predicts that the electric potential in between long charged cylinders should be $V = V_0 + \alpha\, ln(r)$ where $\alpha$ is some constant and $r$ is the distance from the center of the cylinders. To verify this formula we will plot the Potential ($V$) vs. logarithm of $r$.

Our distance measurement ($x$) is related to $r$ via a constant: $r = x - x_0$ (or $r = x_0 - x$ depending on your set-up). To determine $x_0$ from your data read the $x$ value for the probe positioned 1.5cm away from the electrode center $r = 0.015$m (i.e. the initial position) and calculate $x_0 = x - 0.015$ (or $x_0 = x + 0.015$). Create a new variable for $r$. This is accomplished by clicking on "Data" → "New Column" → "Formula". Enter the name of the variable (e.g. "r") in the "Name" box under "Options" in the pop-out window. Under "Definition" go to "Variable" menu and click on "Distance". Then complete the "Equation" line by typing the minus sign and the value of the $x_0$ that you have determined (follow the similar procedure if your $r$ is $x_0 - x$). Finally select "X Axis" for "Graph Column On" and click "OK".

**F-3.** Now create a new variable to hold $ln(r)$. Click on "Data" → "New Column" → "Formula" again. Name your variable (e.g. "lnr") and enter the definition by finding "ln()" under the "Functions" menu. Then find your "r" variable under the "Variable" menu. Select "X Axis" for "Graph Column On".

**F-4.** To plot the Potential vs. ln($r$) click on what it used to be Potential vs. Distance graph. Its set-up may have already changed when you were creating new variables. To restore display of the potential on the vertical axis click on the vertical title of this axis. In the pop-out selection window make sure that the "Potential" is checked in and all other variables are not (scroll down the list to see all variables). Then click "OK" to close it.

Change the horizontal axis to display "lnr" rather than distance: click on the horizontal axis title and select "lnr".[1] Copy the graph onto the Report Sheet III–6 and answer the question.

[1] If this does not work, select "Potential" first in the pop-out list, then scroll down the list, and then change the selection to "lnr".

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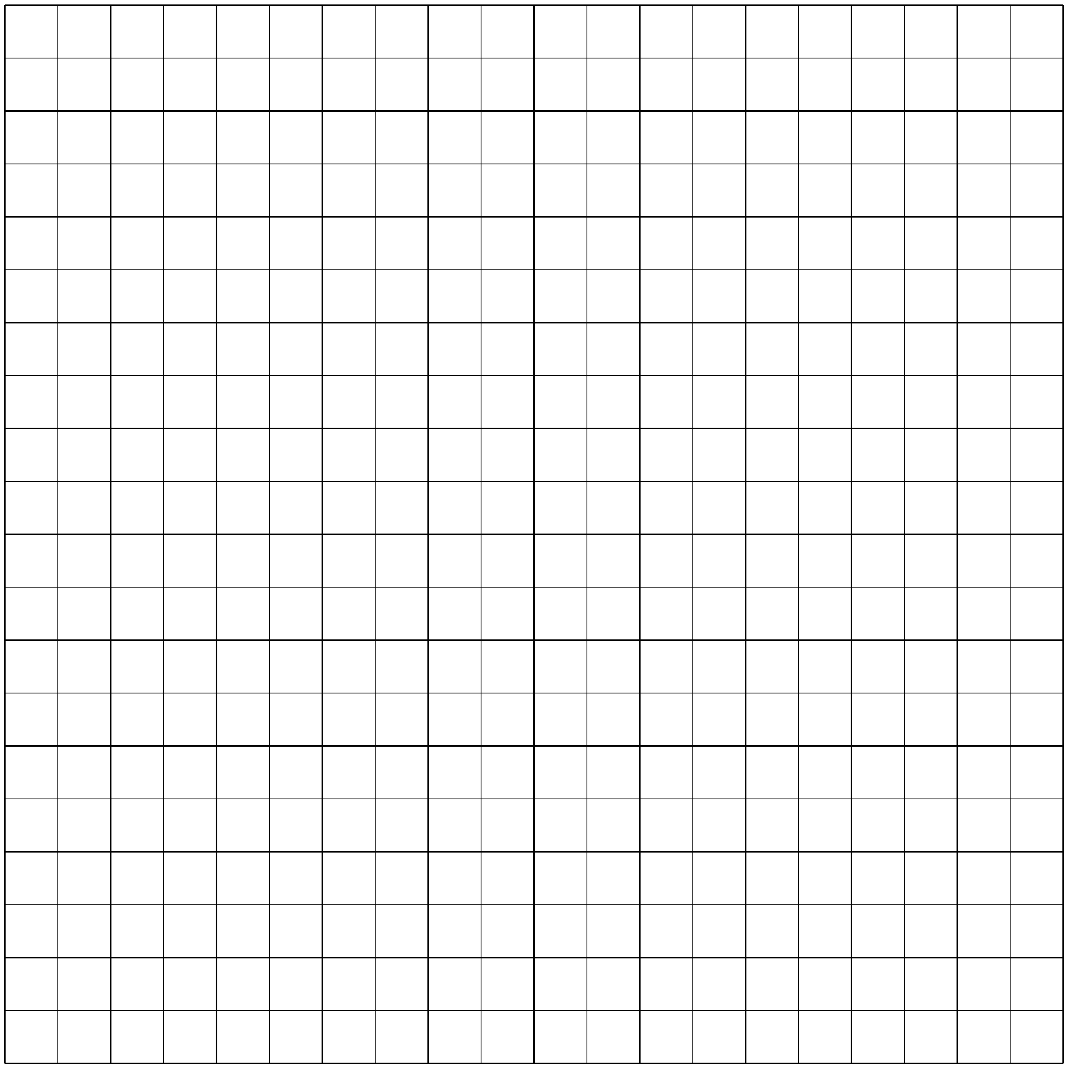
## REPORT SHEET III–6

Date____________________ Name____________________

Instructor____________________ Partner(s)____________________

**F.**(optional) Potential vs. $\ln(r)$

$V$ (V)



$\ln(r)$

Does your graph roughly agree with the theoretical expectation? Explain.