

# Electric Fields

**Object:** To understand how electric **fields** can be measured finding the electric **potential difference** between a number of locations.

**Apparatus:** DC power supply, voltmeter, connecting wires, corkboard, and 3 pieces of conducting paper on which conducting electrodes are drawn with metallic paint.

**Instructions:** After reading the introduction of the laboratory, perform the measurements of electric potentials for the three different configurations of conductors. Answer the questions related to the lab, and work out the problem in the back of the lab hand-out.

## INTRODUCTION

You have learned in class that electric charges produce electric **fields**, and that an electric field exerts a **force** on another charge (in the same direction as the field if the charge is +; opposite to the field if the charge is -). So, how can we **measure** the presence of an **electric field**?

Well, you could tie a charge to a string, and hold it in an electric field and see which way it moves and measure the force it takes to hold it in place. Except in very specialized situations, like Atomic Force Microscopy or classroom demonstrations, this is **not** practical at all.

Instead, we, and everybody else, determine the strength and direction of the electric field by measuring the **difference in electric potential**  $\Delta V$ , or **voltage difference** between two or more points separated by a known distance  $\Delta s$ .

1. If there is a voltage difference  $\Delta V$  between two points A and B separated by a distance  $\Delta s$ , then the strength of the **component of the average electric field** pointing in the direction of  $\Delta s$  is

$$E_s = -\frac{\Delta V}{\Delta s} \quad (1)$$

So in Fig. 1(a), suppose  $\Delta s = 20$  cm and the potential at Point A is 5 Volts higher (more positive) than that at Point B so that  $\Delta V = V_A - V_B = +5V$ . Then the **average** strength of the electric field component pointing from A to B is

$$E_s = -\frac{\Delta V}{\Delta s} = -\frac{5 V}{20 cm} = -25 V/m$$

The negative sign in the answer just reminds us that the electric field points from high potential to low potential, or in this case from A to B. Other than that, the minus sign has no significance.

2. Note that this approach **only** tells us about the **component** of the electric field in the direction of  $\Delta s$ . The actual electric field between these points could look like any of the field vectors in Figs. 1 (a-c) which all have the same component  $E_s$ ; this one measurement can't help you distinguish between them.

To find the direction of the electric field, you need to make a **map of the electric potential** in a region, and draw the contour lines of constant potential, or equipotential lines. They are analogous to the contour lines of constant altitude on a topographic map.

The electric field lines cross the equipotential lines at **right angles**, just like the downhill direction on a topographic map is perpendicular to the contour lines.

Recall that we can only measure **differences in electric potential  $\Delta V$** , we specify a **reference** location and declare its electric potential to be zero (just like we arbitrarily set the altitude of sea level to be zero even though it's 6,000 miles above the center of the earth). Then we measure the potential difference between this reference point and every other location we choose to make a map of the electric potential on an  $xy$ -plane.

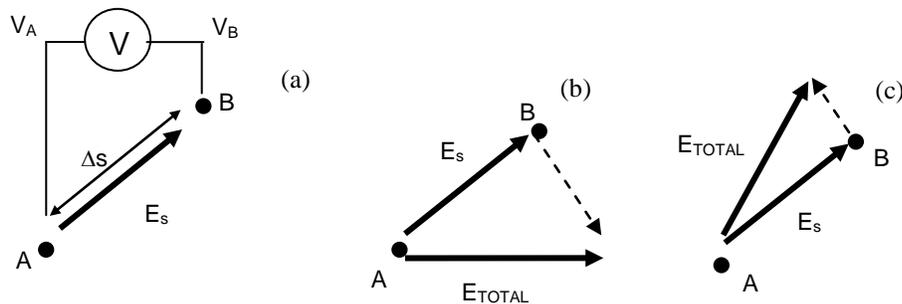


Fig 1 (a). Component of electric field determined by measuring  $V_A - V_B$  and the distance  $\Delta s$  between A and B. This does not give you the total field however; (b) and (c) are two possibilities of the total field vector

- Once you've found the direction of the electric field, its **magnitude** can be found or at least estimated from the separation  $\Delta s$  of the equipotential lines. In general, the electric field is **strong** in a region where the equipotentials are **close together** (just like closely-spaced contour lines on a topographic map indicate the presence of a steep slope). In a region where the **potential is the same** everywhere ( $\Delta V = 0$ ) the **electric field is zero**, as predicted from Eq. (1).

In a region where the equipotentials are **spaced by equal distances**, the electric field is **uniform**, and exact field strength in this region is the same as the average field given by Eq. (1). If you don't know the field to be uniform, Eq. (1) will give you the **average** field between two contours, but doesn't tell you anything about the field elsewhere. For example, Fig. 2 below shows the electric field vectors and equipotential lines near a small point charge  $+Q = +2 \text{ nC}$ .

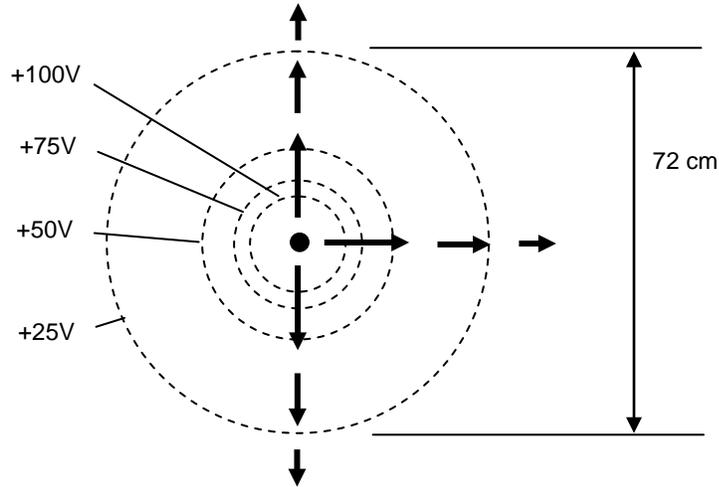


Fig. 2 Electric field vectors and equipotentials near a point charge +Q

Note that:

- A. the electric field vectors point directly away from the positive charge, as expected.
- B. the equipotential lines (dashed) are circles of constant radius since the **potential near a point charge** is given by:

$$V = k \frac{Q}{r}$$

- C. the electric field clearly points in a direction perpendicular to the equipotential lines.
- D. the electric field becomes weaker the farther one is from the charge. This is confirmed by the larger spacing of the equipotentials as one gets farther from the charge. A calculation of the field from the two innermost equipotentials could give you an approximate value of the field close to the charge, but a value that is completely wrong for the field far from the charge. So, think before you blindly use Eq. (1).

## PROCEDURE

### Part I. Electric Field between Parallel Conductors

#### Getting ready

1. Mount the conductive paper with the two parallel conductors to the corkboard by placing a plastic pushpin in each corner of the semi-conducting paper.  
**Please place the pushpins in existing holes to prevent damaging the paper and putting unnecessary holes in the conductor.**
2. Push an **aluminum** push pin into **each** of the two conducting electrodes (metallic stripes) on the paper. These aluminum push pins are electrically conducting, and are used to make connections to the electrodes.
3. Connect the (-) terminal of the power supply to one of the parallel conductors (the one on your left) and the (+) terminal to the one on your right using the banana-alligator clip leads.

A **power supply** is a source of voltage. It can be a battery, a cell phone charger, or a box like the one you will use. It has at least two output jacks to which you attach conducting wires. The knob on the power supply controls the difference in voltage, or electric potential difference, between the two jacks. While one always measures a voltage difference between two points, we often refer to one jack as “common” or zero voltage. So when we say a power supply “puts out 5 V” what we mean is that there is a difference of 5 V between the two output jacks.

4. The meter you will use can measure several things, and is called a “multimeter.” You will become more familiar with it over the next few weeks. It can measure voltage differences, currents, and resistance, Today, you will use it **only** as a **voltmeter** to measure the voltage difference between two points that you touch the voltmeter probes to.

**Connect the COM port of the multimeter to the aluminum pin on the left-hand (-) parallel conductor with an alligator clip, and connect the  $V\wedge$  port of the multimeter to a probe.**

Your setup should look like Figure 3. A schematic diagram is shown at left; a photo at right

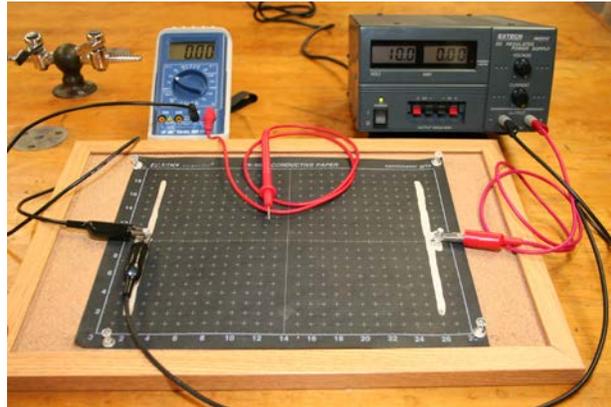
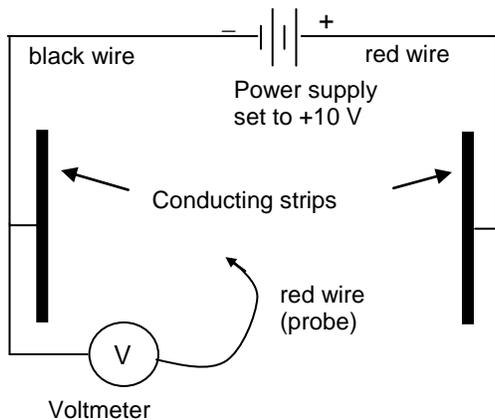


Fig. 3 (left) schematic diagram of experimental set-up. (Right) photo of typical set-up

### Checking things out

To start your first experiment, turn your power supply on. Turn the dial of the multimeter to 20 V and make sure it is set to DC (bar with dots underneath it).

6. Touch the probe connected to the  $V\Omega$  port of the voltmeter to the **aluminum** push pin that is connected to the (+) of the power supply. Adjust the voltage of the power supply so that the voltmeter reads 10.00 V. You may not get this voltage exactly, but it is sufficient to be within  $\pm 0.05$  V (between 9.95 V and 10.05 V). Do **not** rely on the voltmeter on the power supply. You may have to adjust the current to make the current limiting light turn off. If you have trouble with this part, ask your TA for help.
7. Now move your probe off from the pushpin to touch the probe to the electrode into which this pin is pushed (connected to the (+) of the power). Make sure that the voltmeter reads 10V in several locations along the electrode. If it doesn't, you probably have a poor electrical contact between the pushpin and the paper, and you need to gently push the pin down. Ask your TA for help if you can't get a reliable reading of +10 V.
8. Touch the probe to the electrode that is connected to the (-) of the power supply. Make sure that the voltmeter reads 0 V in several locations along the electrode.
9. At the back of this Lab Procedure, there are three sheets of paper that represent the electrode setups you will use today. Find the "map" with the two parallel bars. On this paper, label the right (+) electrode +10 V and the left (-) electrode 0 V.

## Doing the experiment

10. Now **gently** use the probe to find points on the semi-conducting paper that have a potential of +2 V. One of you should put the probe in the correct spots, while another marks down the location of these spots on the paper map. Find at least 8 widely-spaced points for this voltage of +2 V. The points that you find should have voltages within  $\pm 0.02\text{V}$  of the target voltage of +2 V.

Please be **very careful** using the probe. If you press too hard, the probe will create a hole in the paper. Holes in the semi-conducting paper will disrupt your field lines, and ruin the paper for future groups. Even deep impressions (dents) left in the paper will distort the field lines. Keep the probe perpendicular to the surface of the paper when you touch it to the paper, and do not touch the paper with your fingers (or any other part of your body...).

The conducting paper allows a small current to flow through it to enable the voltmeters to work properly. You will understand in future labs how this paper might work. For now, you can assume it allows you to measure the potential anywhere on its surface.

11. Use the points on your map that you have plotted to draw a smooth curve to represent the equipotential line corresponding to +2 V. Label this line "+2 V".
12. Repeat Steps 10 and 11 above for the voltages +4V, +6V, and +8V.

Note the symmetry of the equipotential lines from the top half of the page to the bottom half of the page.

13. Using this map you've made of the equipotential lines, now sketch at least five **electric field lines** on your map.  
Make use of the relation between the direction of the electric field and the equipotential lines.

Indicate the correct direction of the electric field on the lines, and recall that the electric field lines must "start" on positive charges and "end" on negative ones.

In addition to sketching the electric field lines on your map, you will estimate the electric field strength between equipotential lines.

## Part II. Conductor in an Electric Field

1. Remove the semi-conducting paper with the two parallel bars, and install the one that has parallel electrodes with a **conducting ring located in between them** on the board. As before, please use existing holes to prevent damaging the paper and putting unnecessary holes in the paper. Connect your power supply to the parallel conductors as before. **Do not connect your power supply to the ring** between the parallel electrodes. Check to see that your power supply is still set to  $10\text{ V} \pm 0.05\text{V}$ .

2. After using your voltmeter to first check your electrodes to make sure they are +10V and 0V (see Steps 7 & 8 in Part I), find the +2V, +4V, +6V, and +8V equipotential lines as before, and draw them on the paper map corresponding to this setup.

You can find at least five points for each voltage on the top half of the paper, and then use symmetry to extend the equipotential lines into the bottom half of the paper.

Touch the **conducting ring** with your probe and record its voltage on your map. Find and sketch an equipotential line for this voltage. With your probe, be sure to make some measurements of the potential **inside** the conducting ring.

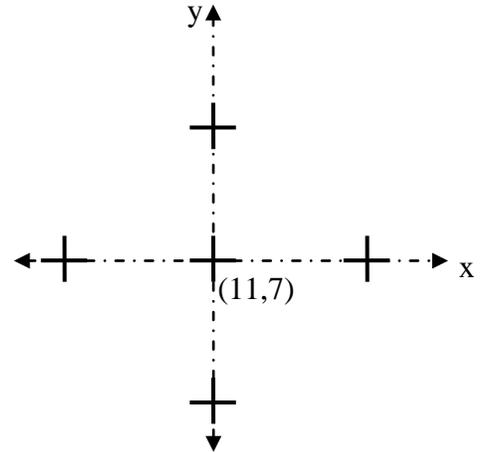
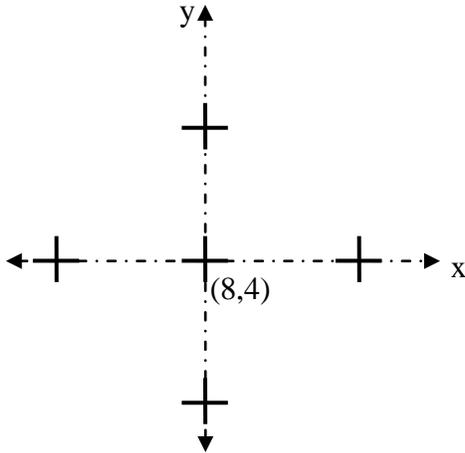
3. After sketching the equipotential lines, sketch at least five electric field lines for this configuration. Some should contact the ring conductor, others perhaps not. Indicate the direction of the electric field on the lines, as before.

### **Part III. Electric Field between two Concentric Circular Conductors**

1. Now install the last sheet of semi-conducting paper with the two concentric circles on your board after carefully removing the last sheet. Push an aluminum push pin in the outer circular conductor, and push the other aluminum push pin into the inner circle.
2. Connect the (+) of the power supply to the pin on the outer circle and the (-) of the power supply to pin on the inner circle. Your power supply should still be set to  $10 \pm 0.05\text{V}$ .
3. Find and sketch the equipotential lines for +2V, +4V, +6V, and +8V. Find at least five points for each equipotential line over a  $90^\circ$  sector of the circles (quadrant), and then use symmetry to extend the equipotential lines into the other quadrants.
4. After sketching the equipotential lines, sketch in several electric field lines in each quadrant.

### **Part IV. Measuring components of the electric field**

1. Using the concentric circle semi-conductive paper used in Part III, you will determine the electric field at two sets of ordered pairs (x, y).
2. With your probe, measure the voltage at the center of the crosshair directly to the right, left, above, and below each of the crosshairs located at the ordered pairs of (8,4) and (11,7).



3. On the actual semiconducting paper, the crosshairs are separated by 1 cm; use your voltage measurements to estimate the following at each of the ordered pairs:
  - (a).  $E_x$  (V/m)
  - (b).  $E_y$  (V/m)
  - (c).  $E_{TOT}$  (V/m)
  - (d). angle  $\theta$  electric field makes with x-axis
4. Turn the power supply and voltmeter off. Disconnect all wires from the power supply and voltmeter.

### Prepare your lab report

Make sure each lab partner has a copy of the 3 maps.

Each student prepares his/her own lab report

1. Fill in the Data and Calculation page and complete the accompanying problem.
2. Prepare lab cover sheet and summary.
3. Attach copies of equipotential maps

**PHYS 1510 Laboratory Report Cover Page**

**Name:** \_\_\_\_\_

**Date:** \_\_\_\_\_

**Title of experiment: ELECTRIC FIELDS**

**Partners' name(s):** \_\_\_\_\_

\_\_\_\_\_

After analyzing your data, answering the related questions and the problem, write several sentences below that **summarize** what the laboratory was about. What did it attempt to show? How did you use electric potential (voltage) measurements to determine the electric field? What sources of error did you encounter in making your measurements or trying to analyze them?

**DATA AND CALCULATION SUMMARY**

**Part I. Electric field between parallel conductors.**

Compare the distances from one equipotential line to the next equipotential line and comment on this distance.

Approximate and record the average distance between equipotential lines if the spacing between the crosshairs is one centimeter.

\_\_\_\_\_ (m)

Determine the magnitude of the electric field midway between the equipotential lines as specified below:

Row 14	Midway between the 0V and 2V potential lines	V/m
	Midway between the 4V and 6V potential lines	V/m
	Midway between the 8V and 10V potential lines	V/m
Row 10	Midway between the 0V and 2V potential lines	V/m
	Midway between the 4V and 6V potential lines	V/m
	Midway between the 8V and 10V potential lines	V/m
Row 6	Midway between the 0V and 2V potential lines	V/m
	Midway between the 4V and 6V potential lines	V/m
	Midway between the 8V and 10V potential lines	V/m

What is your conclusion concerning the uniformity of the electric field between the bar electrodes?

How do your electric field lines compare with the illustration of a parallel plate capacitor that can be found in your text book?

## **Part II. Conductor in an electric field**

What is your conclusion about the magnitude of the electric field just outside the central conductor as compared to the electric field near the electrode that is furthest away from the central conductor?

What is the value of the electric potential inside the conducting ring? Does it vary with position?

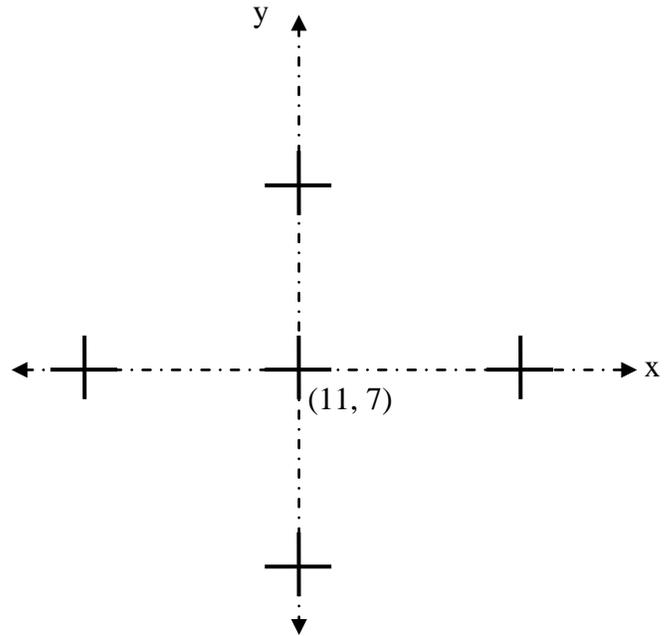
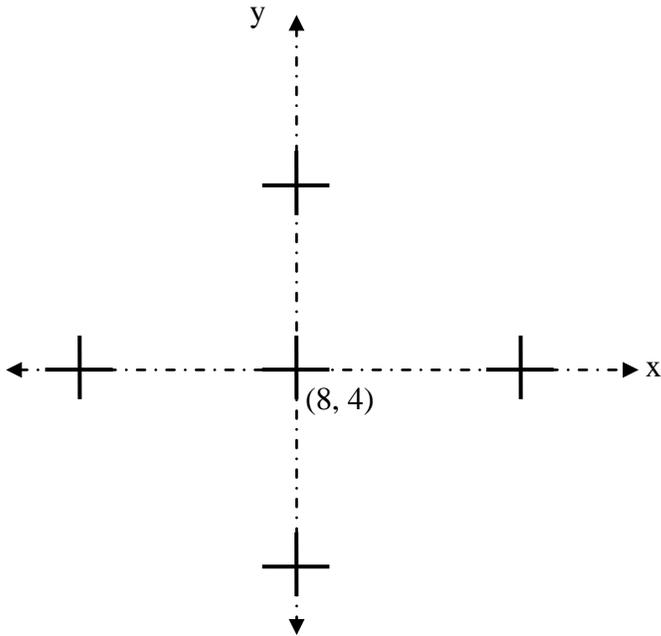
What is the magnitude of the electric field inside the conducting ring? Explain.

## **Part III. Electric Field between Concentric Circular Conductors**

What are your conclusions about the uniformity of the electric field created between the concentric circular electrodes? Where is it strongest? Where is it weakest? Describe its symmetry.

### Part IV. Measurement of electric field vector

Determine the magnitude and direction of the electric field about the ordered pairs (8, 4) and (11, 7). Note that the centers of the “crosshairs” on the semi-conducting paper are separated by one centimeter in the x and y directions.



	(8, 4)	(11, 7)
$E_x$	V/m	V/m
$E_y$	V/m	V/m
$E_{TOT}$	V/m	V/m
$\theta$		

Sketch the total electric field vector on the diagrams above. Also, sketch them on your concentric circle map from Part III.

How does the  $\theta$  you calculated at (8, 4) and (11, 7) compare?

How well does the  $\theta$  you calculated at (8, 4) and (11, 7) agree with the directions of the electric field you drew in Part III?

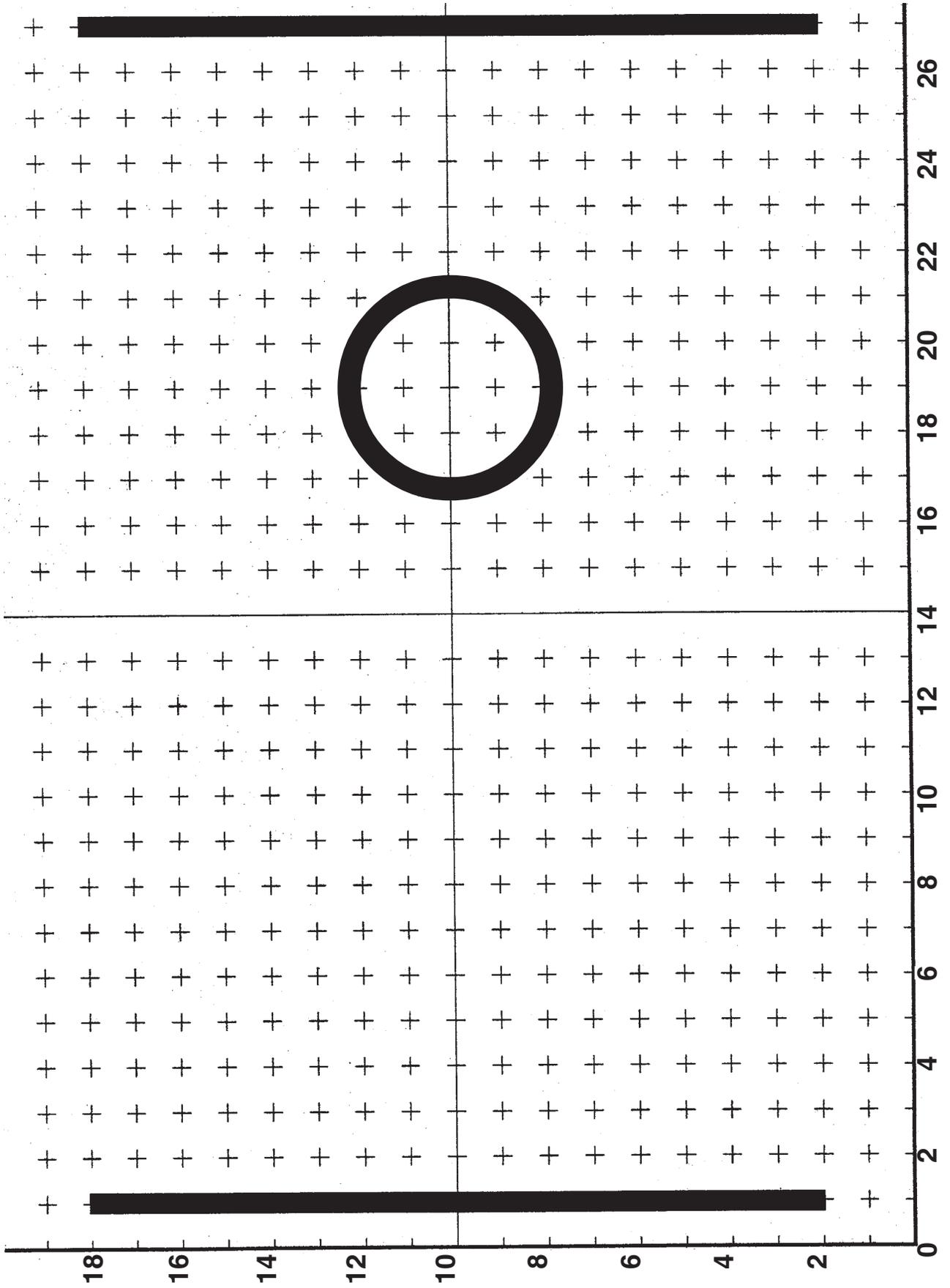
How do the magnitudes of  $E_{\text{TOT}}$  at (8, 4) and (11, 7) compare?

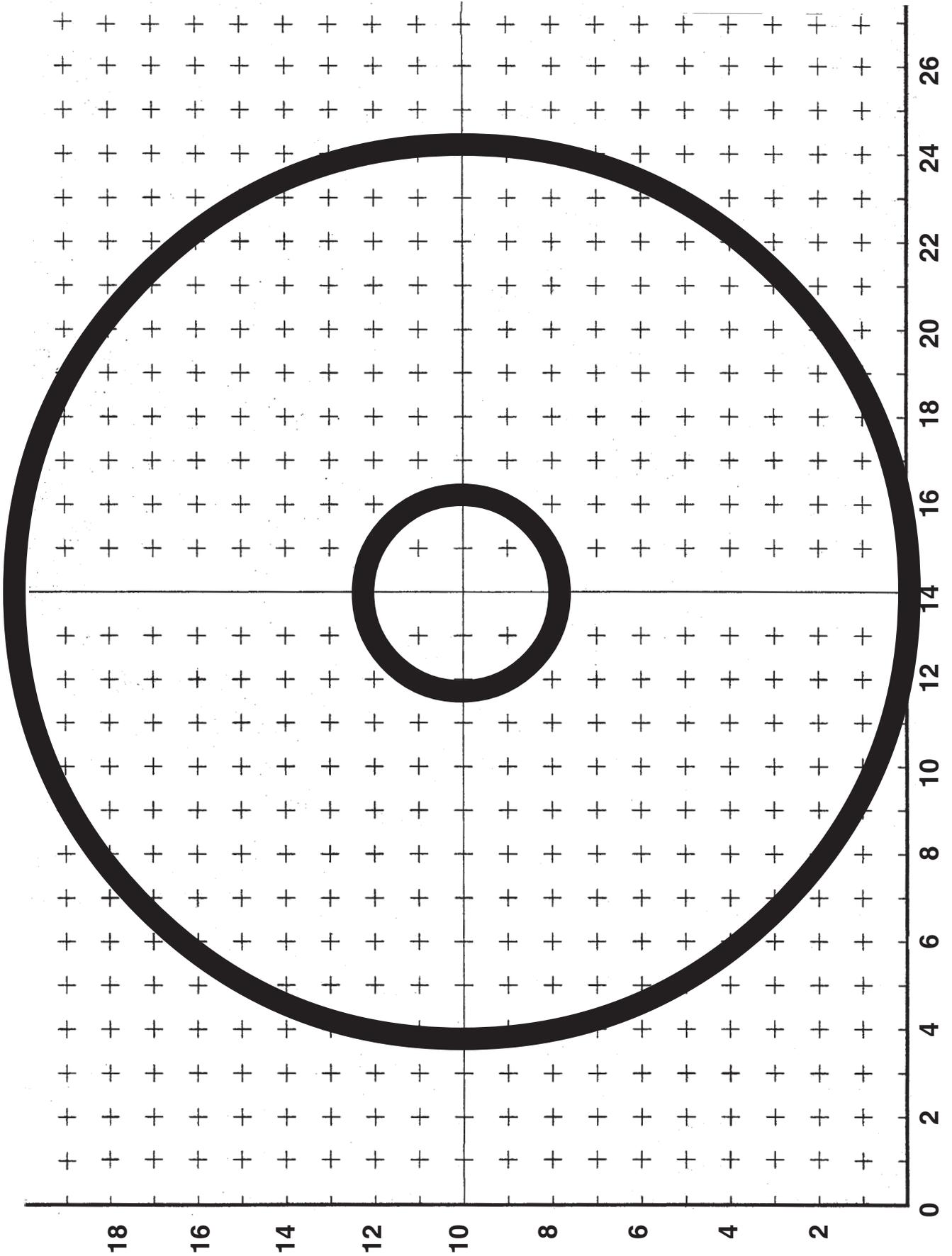
Does the magnitude of  $E_{\text{TOT}}$  at (8, 4) and (11, 7) support your conclusions about the uniformity of the electric field you made in Part III? Explain.

Questions for ELECTRIC FIELD lab to be answered after Data and Calculation Summary

1. In this lab, you do not measure the electric field directly, but you do it by measuring differences in the electric potential (voltage). Why do you need to know the potential (voltage) in at least **two** different places to determine the electric field?
2. In Part I, you likely found the strength of the electric field to be nearly the same everywhere between the two parallel lines. In Part III, why do you think the strength of the electric field near the inner circle is different from the electric field you measure near the outer circle?
3. No experiment can be done with perfect precision even when you think you know what you are looking for. What do you think are the main causes of error you encountered in trying to determine the electric field from your measurements?



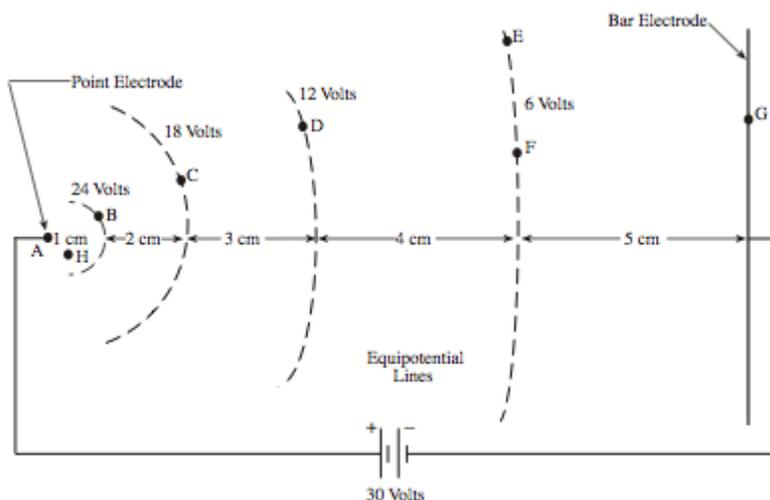




**Problem**

Consider the following electrode arrangement of a small spherical electrode at the left and a straight bar electrode on the right. A potential difference of 30 V exists between the two electrodes; take the potential of the negative electrode at right to be zero. The dashed lines indicate measured equipotential contours in the region between the two electrodes.

Please answer the following questions related to this configuration.



\_\_\_\_\_ 1. How much work (energy) will it take to move a particle with a charge of  $+2e$  particle from G to F? Recall that  $e = 1.6 \times 10^{-19}$  C, the magnitude of charge on an electron or proton. Give your answer in units of **electron-Volts (eV)**. The electron volt is defined in Sec. 16.3 of your book.

The work done by you is positive if you have to push the charge against an electric force, and negative if the electric force is pulling the charge in that direction anyway.

\_\_\_\_\_ 2. Assuming the electric potential energy of any particle at the bar electrode at right to be zero, what is the electrical potential energy (in eV) of this  $+2e$  charged particle when it is at F?

\_\_\_\_\_ 3. How much work, in eV, will it take to move this  $+2e$  charged particle from F to E?

\_\_\_\_\_ 4. How much work in eV will it take to move this  $+2e$  charged particle from E to C?

\_\_\_\_\_ 5. What is the electrical potential energy in eV of the  $+2e$  charged particle at point C?

\_\_\_\_\_ 6. What is the electric field strength in volts/m at H?

Hint: H is 1 cm from A. You can assume that close to A, the electric fields and potentials are “close enough” to that of a point charge (see Fig. 2) that you can use the description of point charge potentials (see Sec. 16.2) to answer this question and the next 2.

\_\_\_\_\_ 7. Which particle will feel the force of greatest magnitude at point H:  
 $q = +2e$  or  $q = -3e$ ?

- \_\_\_\_\_ 8. What force in Newtons would be exerted on the +2e charged particle by the electric field at point H?
- \_\_\_\_\_ 9. What is the electrical potential energy, in eV, of the +2e charged particle at point A?
- \_\_\_\_\_ 10. If the +2e charged particle is released from rest at Point A, what is its kinetic energy in eV when it gets back to the 12 Volt equipotential line?
- \_\_\_\_\_ 11. With what **speed**, in m/sec, will this +2e charged particle, released from rest at A, crash into the bar electrode? Take the mass of the particle to be  $M = 6.4 \times 10^{-19}$  kg.
- \_\_\_\_\_ 12. How much will a object of charge  $-3e$  change its electrical potential energy (include increase or decrease) in going from F to B.