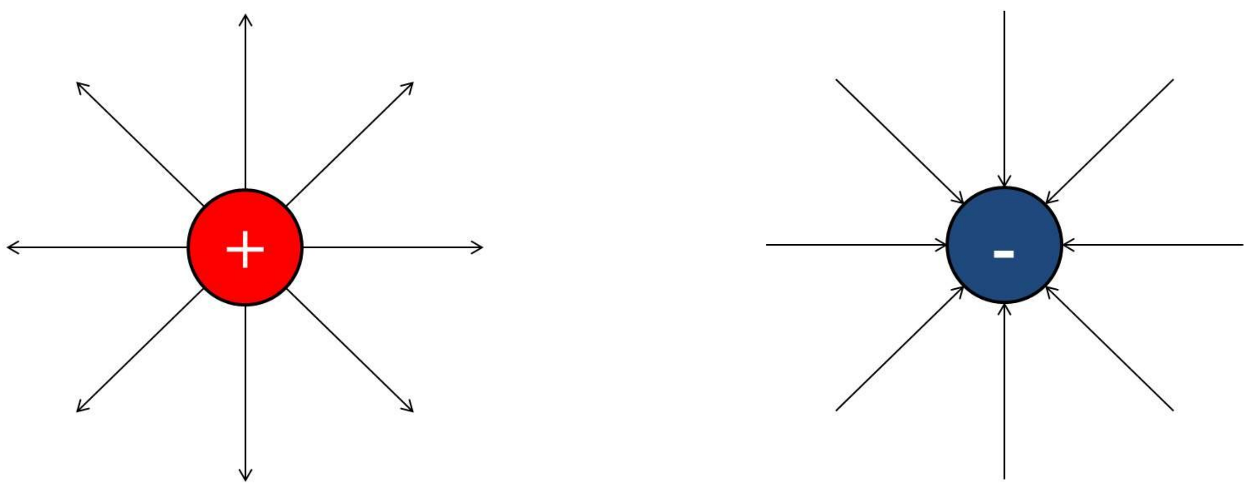
Electric Fields and Electric Potential

Goals and Introduction

An electrically-charged object affects the space around it, causing there to be an electric field in what would otherwise appear to be empty space. You have likely seen images in class, such as those shown in Figure 1(a), or Figure 1(b). These are representations of the existence of the electric field near a positively-charged sphere (a) and a negatively-charged sphere (b). In these images, the arrows merely indicate the direction of the electric field in the region around these objects. The magnitude of the electric field, E, decreases as function of distance, r, from the charged sphere, in either case, as given by Eq. 1, where k is Coulomb's constant ($k = 8.99 \times 10^9\ N \cdot m^2/C^2$).

$E = \frac{k|q|}{r^2}$ (Eq. 1)



(a) (b)

Figure 1

What you may notice is that the direction of the electric field is different depending on the sign of the electric charge, while the formula for calculating the magnitude of the electric field is the same in each case. This means that if you measured the electric field 1 m away from a sphere with electric charge 1 C, you would find the same magnitude if you measured the electric field 1 m away from a sphere with electric charge -1 C. Yet, we know from class that if we were to bring a second positively-charged object near either of the spheres in Figure 1 (a) or (b), the electric force that second charged object would experience would be repulsive in case (a), but attractive in case (b). This vector relationship is often expressed as seen, here in Eq. 2.

$$\vec{F} = q\vec{E} \qquad \text{(Eq. 2)}$$

This difference in the direction of the electric force on a charged object near either of these charged spheres is related to the direction of the electric field associated with each sphere, but it also speaks to a different change in the electric potential energy that the charged object would experience as it moved away from either sphere.

To use an analogy, when we think about the gravitational force between an object and the Earth, we had found that the gravitational potential energy of the object decreases as it gets closer and closer to the surface of the Earth. In that problem the gravitational potential energy decreases as the object moves in the direction of the gravitational force that it experiences. For the electric force and electrical potential energy, the story is the same – the electrical potential energy of a charged object moving near a charged source decreases as the object moves in the direction of the electric force it experiences. What is different, though, is that which direction the electric force points depends not only on the electric charge of the source, but the electric charge of the object moving! This means that we can't just say "the electric potential energy of an object decreases as it gets closer to a positively-charged source." It depends on the sign of the electric charge of the object!

Another way to try and resolve this quandary is to define the *electric potential*, *V*, at any location around the charged source. Consider a movable charged object near a charged source. As stated, there is some electrical potential energy in this arrangement (just like for a massive object at some height above the surface of the Earth). But, if we divide the electrical potential energy by the electric charge of the charged object, this creates a quantity that depends only on the source charge and the distance between the source and the object. This is the electric potential that we can define at that particular location away from the source. This idea is summarized in Eq. 3.

$$V = \frac{PE_e}{q} \qquad \text{(Eq. 3)}$$

The electric potential is measured in units of volts (V) and has a predictable behavior that does not depend on the sign of any of the charged objects. The electric potential an object experiences decreases as that object moves in the direction of the electric field. Just as was the case with gravity in the previous semester, we are free to choose the origin, or location where $V = 0$ to be wherever we would like. However, at times a logical choice can be made based on the arrangement of charged sources we would like to examine.

Consider the charged object from Figure 1(a). Because the electric potential depends only on the electric charge and the distance from the electric charge (per the analogy discussed above), it must be that all of the points that lie along a circle, centered about the charged source, have the same value of electric potential. When we map out and connect points with the same value of electric potential, we are drawing an *equipotential line*. In truth, most problems are three dimensional, and we would map out an equipotential surface, but given the lack of 3-D graph paper, we often settle for mapping a slice of the surface in a laboratory exercise, an equipotential line for each surface. An example of this is shown in Figure 2.

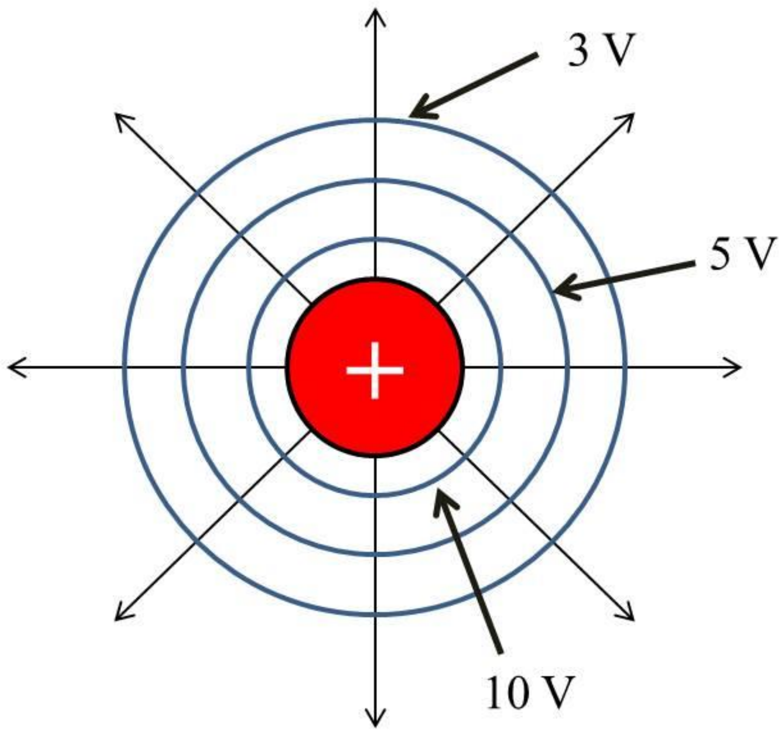


Figure 2

Of course, there exists a continuum of these surfaces, or lines. We often choose to map several of them to understand the trend, or behavior, of electric potential in a region of space. In some ways, you might think of these maps of equipotential lines to be like topographic maps, used in indicating changes in elevation across a region of the country. You might go so far as to say that when you map the electric potential in a region of space, you are mapping the “electric height” as a function of position.

There is another important aspect of the image in Figure 2 that should be noted. At every point on an equipotential line, the electric field at that point is perpendicular to the equipotential line at that point! This turns out to hold true in more complicated charged-source arrangements, as well. This means that the equipotential map has another layer of information beyond just the equipotential lines themselves. If we were to map those lines first, we can deduce which direction the electric field points across those lines, remembering that the electric potential decreases as you move in the direction of the electric field.

In simpler cases, or over small distances, where it might be fair to assume that the magnitude of the electric field is constant, we can use measurements of the electric potential on two equipotential lines, and the shortest distance between those lines, to calculate the magnitude of the electric field, as seen in Eq. 4.

$$E = \frac{\Delta V}{\Delta x} \qquad \text{(Eq. 4)}$$

In today's lab, you will attempt to map out equipotential lines and then sketch the electric field lines for two different charged-source arrangements. The charged sources will consist of conductive paint that will be electrically connected to a power supply. If you set the power supply to 5 V, one of the sources will have an electric potential of 5 V and the other will have an electric potential of 0 V. Thus, when you measure the electric potential between these points, you will observe values between 0 and 5 V.

Goals: (1) Become familiar with the measurement of electric potential between two points in space
(2) Sketch equipotential lines for arrangements of charged sources, based on electric potential measurements
(3) Sketch and describe electric field lines, based on the shape and values of the equipotential map for arrangements of charged sources

Procedure

Equipment – two different sheets of conductive-paint source arrangements, electrical contact board, 30 V-1 A DC wall power supply, two wires, voltmeter probe with leads, computer with the DataLogger interface and LoggerPro software

1) Connect the voltmeter probe to the DataLogger interface and open LoggerPro by clicking on the **Field Plotter** link on http://feynman.bgsu.edu/physics/phys2020/index.html.

2) The field mapping apparatus consists of special graphite impregnated paper with metallic electrodes painted on it to simulate the distribution of electric charge that creates the field. Be sure that one of these sheets is secured to the electrical contact board.

3) Check to make sure that the wall power supply is turned off and that the voltage knob is turned all the way counter-clockwise. Then, connect the two leads on the board to the wall power supply using the two wires (if it has not already been done for you).

4) Connect the black lead from the voltmeter to the lead on the board that has a wire running to the black connection on the wall power supply. You can do this by plugging it into the back of the wire that should be there already. See the Figure 3.

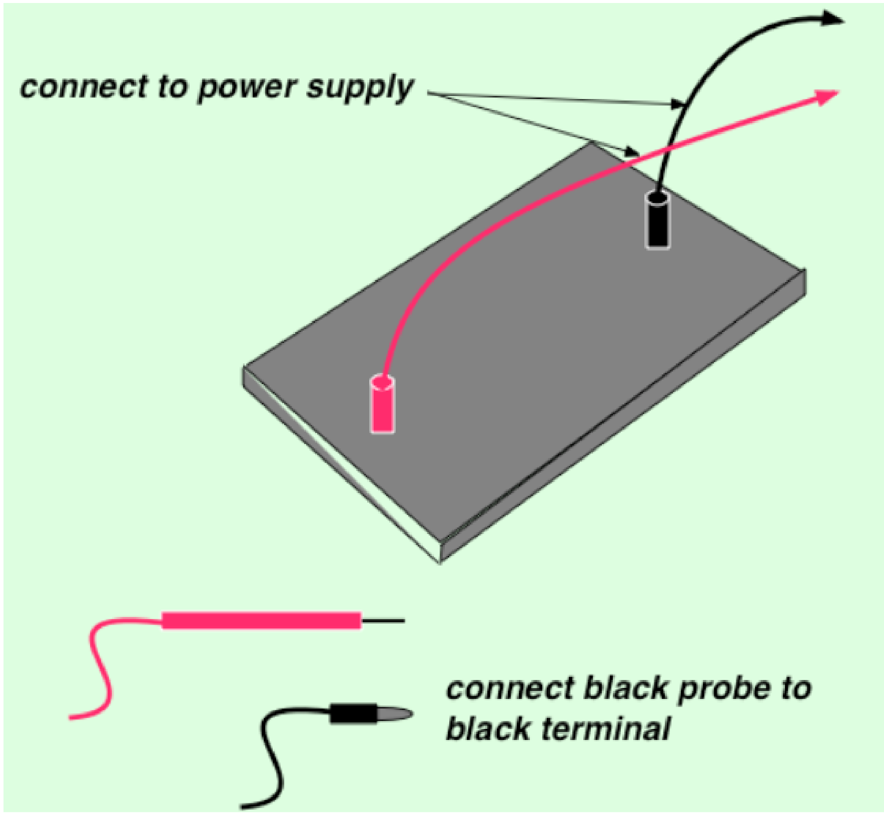
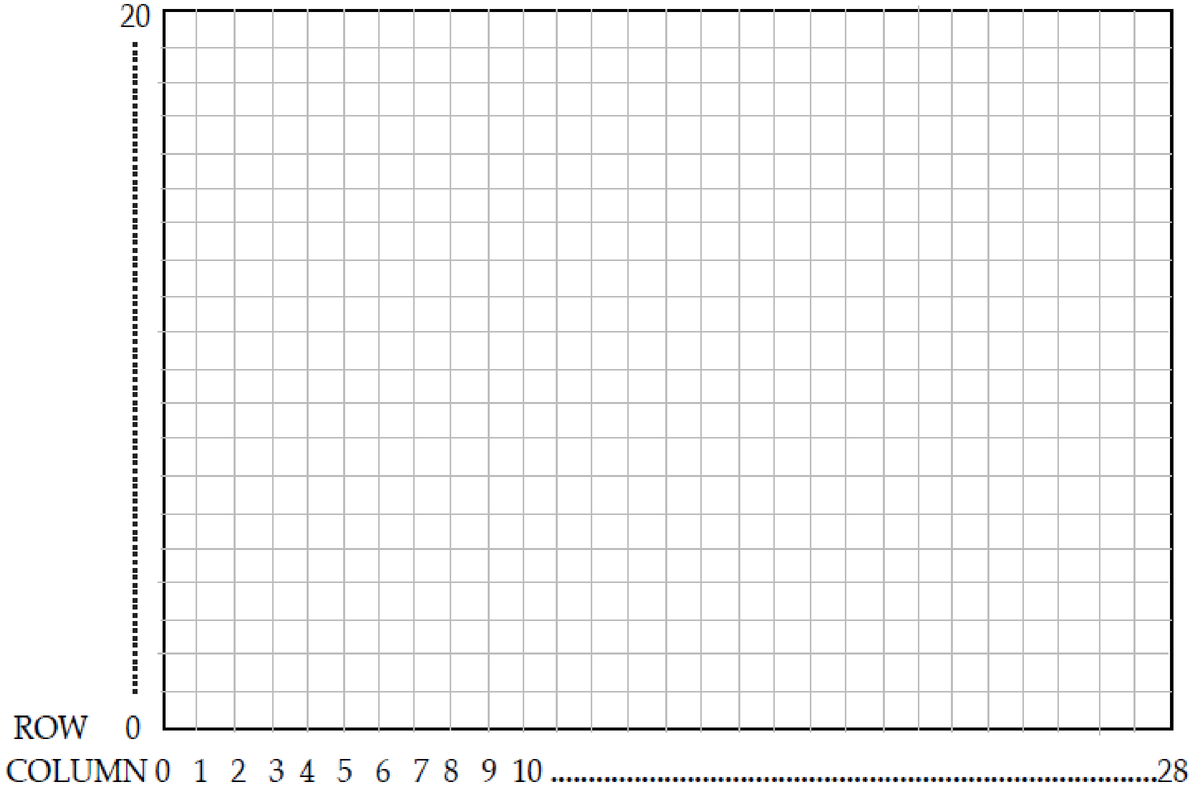


Figure 3

5) Touch the red probe lead to the other contact on the board, click “Collect” on the screen, and flip the switch that turns on the wall power supply. Slowly turn the knob clockwise and watch the voltmeter reading on the screen. Set the electric potential between the two contacts to be about 5.0 V. **Record** the exact value you achieve. Then you can move the red probe lead. Also, **sketch** the layout of the conductive paint on the sheet.



6) If you had stopped the voltmeter, click on “Collect” again to measure electric potential**.** Starting at the point in between both contacts, place the red probe lead on the crosshair. After the value stabilizes, record the value and position on your printed grid sheet.

7) Choose a voltage value between 1V and 5V. Begin using the probe (DO NOT DRAG THE PROBE ACROSS THE CONTACT PAPER) to find locations with that value of electric potential. **Record** these locations on the printed grid sheet. You should find an appropriate number of locations so that you can “see” the trend, and be able to draw an equipotential line through them.

REMEMBER to sketch in the charged regions (conductive paint) on the grid sheet, referencing the layout of the sheet in lab!

8) Repeat step 7 a total of at least five times, choosing a different value of electric potential than before.

9) On your grid sheet, make a sketch of at least five electric field lines (with no less than five distinct points) by following the procedure below:

- Pick a starting point anywhere along the middle-most equipotential line.
- Sketch a line from there to the next equipotential in such a way that your line is

perpendicular to both equipotential lines.
• Continue your line in the same way (perpendicular to the equipotential lines) to the next equipotential line.
• Repeat this process in both directions until your line reaches the regions where the conductive paint was located.

10) Repeat steps 7-9 for the other charged region layout.

Data Analysis

Question 1: Considering the field lines you drew, can you find examples from the internet, or your book that match the electric field you found? Share those, and describe what charged object or objects give rise to electric fields like those that you measured. Explain what is similar in your data to these examples, and note any differences.

Estimate the electric field strength at five representative points on each equipotential plot by using Eq. 4. Take the difference between two adjacent equipotential lines and divide by the straight-line distance between them to get the field strength at that location. Recall that the grid points on the charged sheets are spaced 1 cm apart. Record the electric field magnitudes directly on the equipotential plots at the appropriate location.

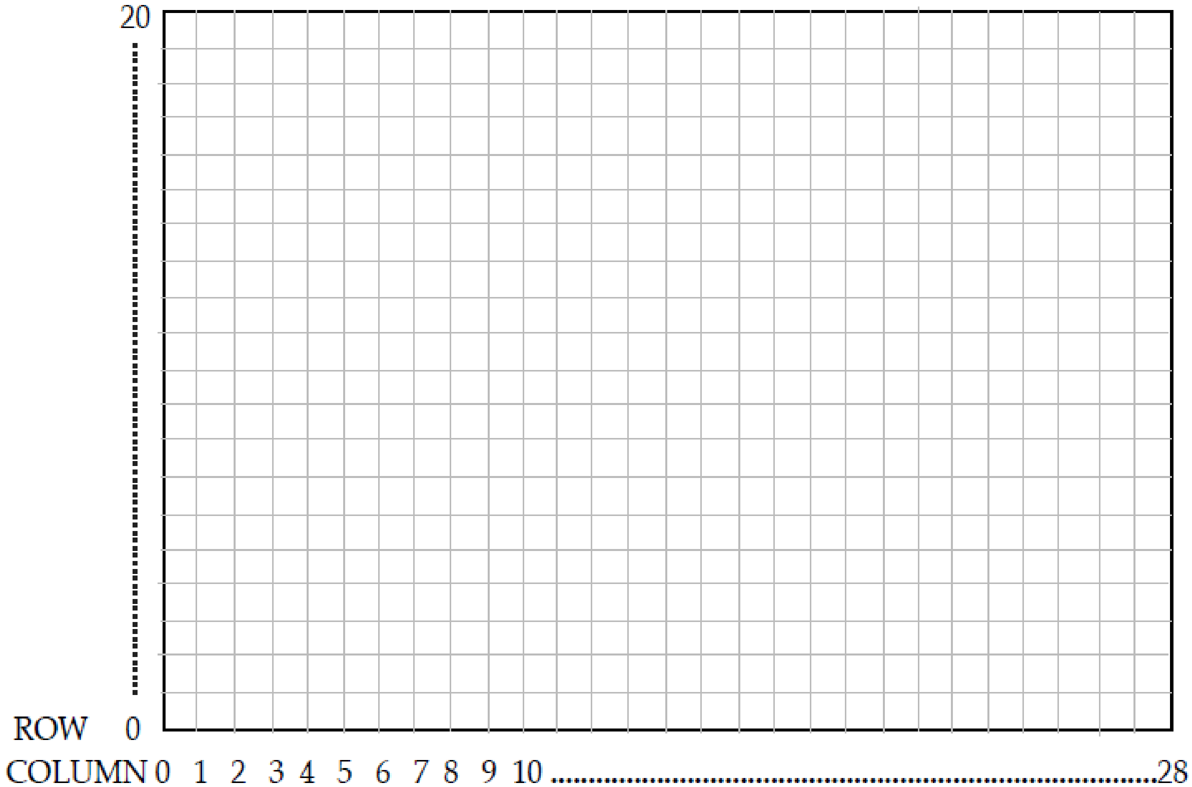
Question 2: Consider the calculations you made regarding electric field and any trends you notice in those results – for example, the shape of the equipotential lines and electric field lines. For each of the charged sheet configurations, where should the electric field be the strongest? Where should it be the weakest? How can you tell? Can you make measurements that verify this? If so, do that to support your answer.

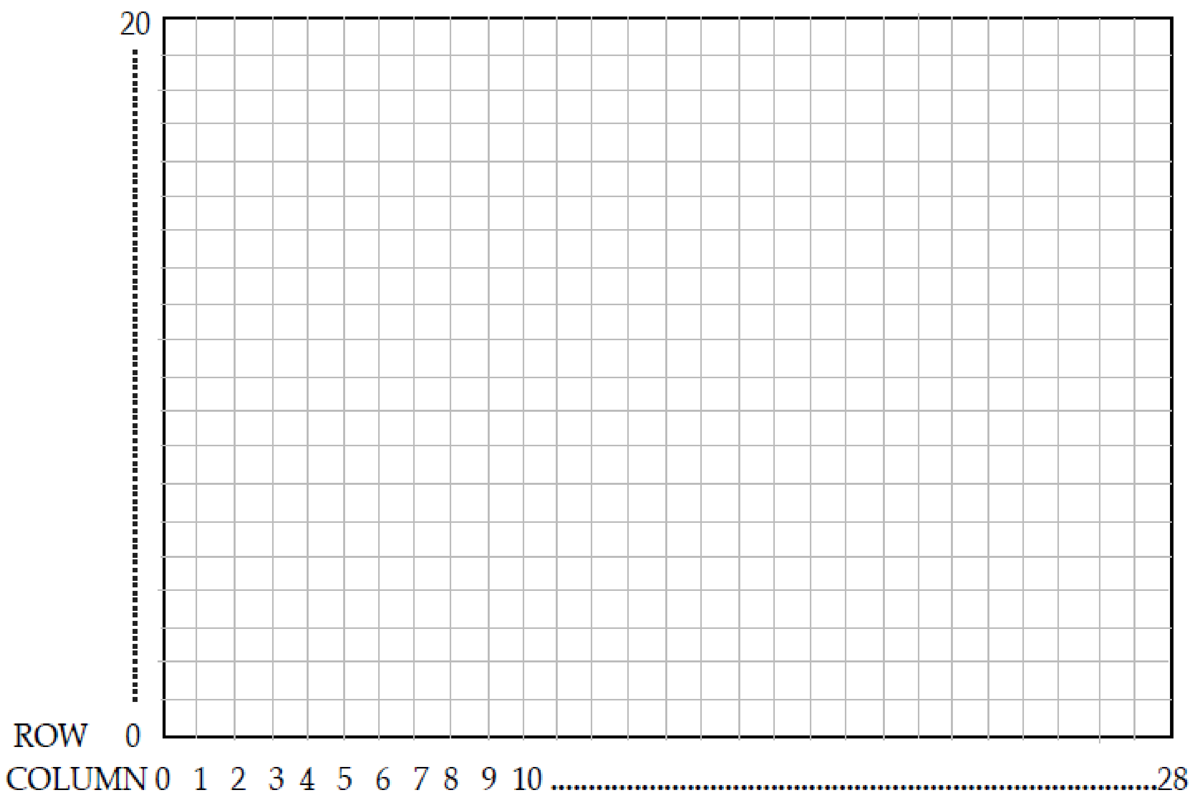
Error Analysis

There is no Error Analysis for this lab.

Questions and Conclusions

Be sure to address Questions 1 and 2 and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?


20
ROW 0
COLUMN 0 1 2 3 4 5 6 7 8 9 10 28


20
ROW 0
COLUMN 0 1 2 3 4 5 6 7 8 9 10 28

Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for "Electric Fields and Electric Potential," and submit it before the start of your lab section on the day this experiment is to be run.

PL-1) As a charged object moves opposite the direction of the electric field in a region of space, the electric potential is

A) zero.

B) increasing.

C) decreasing.

D) staying constant.

PL-2) A positively-charged object is near a positively-charged source. As the object moves away from the source

A) it moves in the direction of the electric field from the source and the electric potential increases.

B) it moves opposite the direction of the electric field from the source and the electric potential increases.

C) it moves in the direction of the electric field from the source and the electric potential decreases.

D) it moves opposite the direction of the electric field from the source and the electric potential decreases.

PL-3) Elmer has found that the electric potential at one location is 2.5 V and the electric potential at a nearby location is 1.0 V. The locations are 1.5 cm apart. What is the magnitude of the electric field between these two locations?

PL-4) Elmer measures the electric potential at his first location to be -0.50 V. He should

A) switch the black lead from the probe to the other board contact.

B) disconnect the board from the wall power supply.

C) connect the red probe lead to the other board contact.

D) cut the blue wire.

PL-5) Elmer tells you that he has measured an electric field to be 3.0 V/m between two locations on the board. The regions are 2.5 cm apart. What is the magnitude of the electric potential difference between the two locations?