

## Experiment 7:A. Equipotential Lines

(PHY2054L General Physics and PHY2049L University Physics Labs)

### Purpose

To map equipotential lines of point charges in a resistive medium.

### Equipment

Transparent water tray  
Electrode assortment  
Computer System  
Graph Paper (3 sheets)

### Discussion

The electric field at any point in space shows the direction in which a small positive test charge  $q$  would move if placed at that point. The force on the test charge placed in an electric field  $\mathbf{E}$  is given by

$$\mathbf{F} = q \mathbf{E}$$

So if the test charge is positive, the direction of  $\mathbf{F}$  and  $\mathbf{E}$  are the same. If  $q$  is negative, the direction of  $\mathbf{F}$  is opposite to the direction of  $\mathbf{E}$ . The positive charge “rolls downhill” under the influence of the electric field, going from a region of higher electric potential to lower electric potential. In this process the force on the charge does some work, just as the weight of a body performs work when a body rolls downhill. So the force on the positive test charge, and therefore the electric field at every point in space, is pointing in the direction of decreasing potential.

If instead of moving in the direction of the field, the charge moves perpendicular to it, so that the field does no work on the charge, then the charge remains at the same electric potential it had originally. The surface connecting all these points of equal potential is called an “equipotential surface”, and in a plane, you can think of equipotential lines. This family of lines serves as an alternate means for describing space near charges. At every point in space, equipotentials cross the electric field at right angles, so if you know the shape of equipotential surfaces, you can draw the field configuration, and vice versa.

The point charges in this experiment are provided by two electrodes (A and B) connected to the output of the Power Amplifier II which comes with the computer interface. For this experiment, the output of the Power Amplifier is set at +9.0 V. The electrodes are immersed in water, which serves as a resistive medium. The equipotential lines are mapped with two additional electrodes (C and D), whose relative positions are changed until the computer indicates that they are at the same potential, so that there is no potential difference (voltage) between them.

## Procedure

### Part 1

1. Prepare two graph sheet with identical axes or numbered reference lines. Fill the transparent tray with a quarter-inch of tap water and place it over one of the graph sheets, which can serve as a positioning reference. We will call this the reference sheet.
2. Connect the output of the Power Amplifier II to two of the electrodes (A and B) as shown in the diagram and position the electrodes in the water so that they are about 10 inched apart. Mark their position on the second graph sheet (called the working sheet), using the first sheet as reference.
3. Open Experiment 7 from your desktop by double-clicking on the icon. The display has the usual Data Window, Signal Generator Window, and two digital meters, one for the Voltage Output and one for Channel A.
4. Set the signal Generator output to 9.0 V DC and leave it OFF.
5. Connect the measuring electrodes (C and D) to Channel A, so that the potential difference between them can be seen on the Channel A meter.
6. Place electrode C at any convenient point in the water tray and note its position on your working graph sheet. Suggestion: place electrode C between A and B, on the line joining A and B, say one inch away from A. Position C at a nearby point.
7. Click the signal Generator and the Monitor button ON. Notice that the Botage Output meter shows 9.0 V (which is the voltage between A and B) and the Channel A meter shows the voltage between C and D. Keep C fixed and move D around and notice that Channel A output changes. Move D around slowly, and locate a point at which Channel A shows zero. Mark this location of D on your working sheet. Points C and D are now at eh same potential, and therefore lie on the same equipotential line.
8. Without moving your first electrode C, find another equipotential point and mark it. Proceed with more points until you have enough to draw an equipotential line. You may have to RUN the computer procedure several times in this process.

9. Move to a neighboring equipotential line by repositioning your first measuring electrode C. Proceed to map that line of equipotential as you did in 10. Continue this process until you have located and drawn 6-8 equipotential lines.
10. Draw the corresponding lines of electric field between the two charge centers A and B. You can do this by carefully drawing lines, which are everywhere perpendicular to the equipotential lines, which you drew.

Question: How do these field lines compare with the field configuration that you drew in part 1.?

## **Part 2**

1. Prepare a second working sheet as in Part 1, #1.
2. Locate your charge electrodes (A and B) 2 inches apart near one end of your tray so that most of the tray is in the region “behind” one of the electrodes.
3. Map the equipotentials for this arrangement, paying special attention to the region “behind” one electrode.
4. Draw the lines of electric field for this arrangement as well.

### **Experiment 7:B. Electric Fields of point Charges** (PHY2049L University Physics only)

**Purpose:** To plot and study configurations of electric fields generated by point charges.

#### **Equipment:**

Computer with Excel Spreadsheet  
Rectangular graph paper  
Ruler, protractor

#### **Discussion**

The electric field  $\mathbf{E}$  due to a point charge  $q$  at a point which is at a distance  $r$  from the charge is given by

$$\mathbf{E} = k \left( \frac{q}{r^2} \right) \hat{\mathbf{r}}$$

where

$$k = 1/(4\pi\epsilon_0) = 9.0 \times 10^9 \text{ Nm}^2/\text{C}^2$$

$q$  is the charge in coulombs,

$r$  is the distance from the charge,

and  $\hat{r}$  is a unit vector pointing radially outward from the charge.

The electric field is a vector with both magnitude and direction. As shown in eq. (1), we will represent vectors by boldface letters (like  $\mathbf{E}$ ). The magnitude of a vector is represented by the same letter without the boldface (like  $E$  is the magnitude of  $\mathbf{E}$ ). The unit of electric field is Newtons per Coulomb (N/C). The figure below (on the left) shows the electric field at a point A, due to a positive charge  $q$ , located at the point O. The figure on the right shows the field of a negative charge. (Make sure you understand, the charge is not at A. The field at A is generated by the charge, which is somewhere else, at O).

The field of a positive point charge points away from it, and that of a negative charge points toward it. So at different points in space around a positive charge, the electric field vectors should be pointing out from the charge (like the quills on a porcupine!).

### Questions:

- (a). Calculate the magnitude of the electric field of a point charge of  $5.2\mu\text{C}$  at two different points. One point is 2 cm away from the charge, and the other is 4 cm away. What is the ratio of these two fields? Can you find this ratio without calculating the values of the field?
- (b) The field of a point charge at a certain distance is 50 N/C. What is the field at a distance 3 times the original distance?

### Procedure 1: To plot the electric field of a positive point charge.

1. Take a graph sheet and mark the position of the point charge. For a good all around view, put the point charge at the center of the sheet. In your notebook, give a value to the charge, say,  $q = 5.0 \times 10^{-14} \text{ C}$ . With this lone charge at the origin, draw coordinate axes  $x$ - and  $y$ - on the sheet. Mark a scale on the axes, say, 1cm on the sheet = 1mm actual distance.
2. Pick out any point on the graph sheet, defined by its  $x$  and  $y$  coordinates, say, the point (3mm, 4mm). You will calculate the electric field at that point, due to the charge at the origin.
3. Calculate the magnitude of the field at the point

The distance  $r$  from the charge to the point (3,4) is

$$r = \sqrt{(x^2 + y^2)} = 5 \times 10^{-3} \text{ m}$$

4. Represent the field on the graph sheet.  
Decide on a reasonable scale for the length of the arrow. In this case you may feel that a 1cm length of arrow should represent a field of 10 N/C. So starting from the point (3,4), draw an arrow of length 1.8 cm to represent 18 N/C. What is the direction of the arrow? The field should be along the line joining the charge to the field, and should point away from the charge since the charge is positive. Draw such an arrow.
5. You should draw the arrows representing the field at several points, say 40 different points (10 in each quadrant). That looks like a lot of work but if you use a spreadsheet, it will do all the calculations for you. You just have to draw the arrows. Of course, you will have to tell Excel how to do the calculations, in other words you will enter the formula you used into Excel.
6. Start Excel. Fill the table as shown below. Save the file as a:\EFieldPlot.xls on your disk. Use the values generated in the spreadsheet to draw the arrows representing the electric field at different points.

#### Electric Field of a Single Point Charge

Constant							
k(Nm <sup>2</sup> /C <sup>2</sup> )	Charge ( C)						
9.00E+09	5.00E-14						
			Sample				
			Calculation:				
			x(m)	y(m)	x <sup>2</sup>	y <sup>2</sup>	r <sup>2</sup> =(x <sup>2</sup> +y <sup>2</sup> )
			3.00E-03	4.00E-03	9.00E-06	1.60E-05	2.50E-
Enter another set here	—————▶		5.00E-03	2.00E-03	2.50E-05	4.00E-06	2.90E-
Enter another set here	—————▶						

**Question:** In the above calculations, why did we not use a z coordinate also? Is it necessary? Once you plot the field of a point charge in one plane, can you give the field in any other plane passing through the charge?

A sample graph sheet, showing some of the electric field arrows is attached to your handout.

## Procedure 2: To plot the electric field of a dipole:

**If there are two separate point charges in a certain region, the net electric field at any point in that region is the vector sum of the fields of each charge, separately calculated as though the other charge were not present. This is called the principle of superposition.**

Let us take the case of two point charges, equal in magnitude and opposite in sign, separated by a distance  $d$ . The magnitude of each charge is  $q$ . Such a charge configuration is called a dipole.

At any point in space, we can find the electric field of each charge separately, as we did in Procedure 1, and then vectorially add the two fields.

In the figure,  $\mathbf{E1}$  and  $\mathbf{E2}$  are the fields at the point P, of the charges  $+q$  and  $-q$  (note the directions),  $\hat{\mathbf{r}}_1$  and  $\hat{\mathbf{r}}_2$  are the unit vectors directed radially outward from each charge, and the vector sum  $\mathbf{E} = \mathbf{E1} + \mathbf{E2}$  has been found by using the parallelogram law for the addition of vectors.

In this case, it is easier to do the problem algebraically by taking components of the individual fields and adding them.

Let us see how these calculations are done:

Position of positive charge  $+q$ :  $(x_1, y_1)$

Position of negative charge  $-q$ :  $(x_2, y_2)$

Location of the field point P:  $(x, y)$  (We want the field at this point.)

Distance of P from  $+q$ :  $r_1 = \sqrt{(x - x_1)^2 + (y - y_1)^2}$

Magnitude of field at P due to  $+q$ :  $E_1 = \frac{kq}{r_1^2}$

Distance of P from  $-q$ :  $r_2 = \sqrt{(x - x_2)^2 + (y - y_2)^2}$

$$E_2 = \frac{kq}{r_2^2}$$

Magnitude of field at P due to -q:

Note: Remember, the total field is not just the sum of  $E_1$  and  $E_2$ , which are just the magnitudes of the fields  $E_1$  and  $E_2$ . To find the resultant field  $E$ , we will use components:

The vector addition  $E = E_1 + E_2$ , means the same as

$$E_x = E_{1x} + E_{2x}, \text{ and } E_y = E_{1y} + E_{2y}$$

So let us find the components:

$$E_{1x} = E_1 \cos \theta = E_1 \frac{(x - x_1)}{r_1}$$

$$E_{1y} = E_1 \sin \theta = E_1 \frac{(y - y_1)}{r_2}$$

Where  $\theta$  is the angle between the x- axis and the line joining +q to P.

Similarly find  $E_{2x}$  and  $E_{2y}$  :

$$E_{2x} = E_2 \cos \theta = E_2 \frac{(x - x_2)}{r_2}$$

$$E_{2y} = E_2 \sin \theta = E_2 \frac{(y - y_2)}{r_2}$$

Where  $\theta$  is the angle between the x- axis and the line joining -q to P.

Now calculate  $E_x$  and  $E_y$ .

**Question:** Why did I put a minus sign for the components of  $E_2$ ?

The magnitude of the total field:  $E = \sqrt{E_x^2 + E_y^2}$

The direction of the total field vector (angle with x-axis):  $\alpha = \tan^{-1}(E_y / E_x)$

**Question:** Two charges  $\pm 10 \mu\text{C}$  are at the points (0, 8mm) and (0, -8mm). Find the electric field at the point (80mm, 50mm). Draw a diagram showing the field of each charge and the total field.

**Using the Spreadsheet:**

A sample calculation of the field of a dipole is given in the file "lab07.xls" which you can copy onto your disk.

Prepare a graph sheet similar to procedure 1.

Mark the positions of the two charges.

Note the magnitudes of the charges:  $q = 5.0 \times 10^{-14} \text{ C}$

Note their position coordinates.

Choose any point on the graph sheet.

Use the spreadsheet to calculate the field.

Choose an appropriate scale to represent the field by an arrow.

Plot the field at that point using the value of  $\alpha$  for direction.