Electric Potential and Field

EXPERIMENT

GOAL.

• to map out equipotential curves for a dipole arrangement
• to map out equipotential curves for a more complicated arrangement
• to investigate the relationship between electric potential and electric fields

EQUIPMENT.

• electrically conductive paper with electrodes (2 sets): one with a dipole arrangement, another with a more complicated arrangement
• power supply
• voltmeter
• probes
• 4 electrical leads

THEORY.

This experiment investigates the electric potential and field produced by different arrangements of charge. An electric charge alters the space around it, creating an electric field \( \vec{E} \). Though this field is invisible, we know it exists because when a second electric charge \( q \) (a test charge) is placed in the field, it feels a force \( \vec{F} \). This force (the Coulomb force) is determined by the electric field – in fact, the electric field is defined as the force per unit charge,

\[
\vec{E} = \frac{\vec{F}}{q} .
\]  

(Eq. 1)

The electric field strength at a distance \( r \) from a point charge \( q \) is

\[
E = \frac{K|q|}{r^2} ,
\]  

(Eq. 2)

where \( K = 9.0 \times 10^9 \) Nm\(^2\)/C\(^2\). The electric field due to a distribution of charge(s) will, in general, be more complicated. A relationship analogous to Eq. 1 exists for the electric potential energy. An electric charge \( q \) alters the space around it by creating an electric potential \( V \). When a second electric charge (test charge) is placed in that potential, there is a potential energy \( U \) of the two-charge system. This potential energy is determined by the electric potential – the electric potential is defined as the potential energy per unit charge:

\[
V = \frac{U}{q} .
\]  

(Eq. 3)

The electric potential at a distance \( r \) from a point charge \( q \) is

\[
V = \frac{Kq}{r} .
\]  

(Eq. 4)
Again, the electric potential due to a distribution of charge(s) will, in general, be more complicated.

There are several important differences between the electric field and the electric potential. The electric field (like force) is a vector field – it has a direction at each point in space. The electric potential, on the other hand, is a scalar quantity, like energy – it is a directionless quantity. Another thing to remember is that one charge does not have potential energy – potential energy is a property of a system of two (or more) charges. Finally, you will recall that you can choose the zero for potential energy to be anything you like, since the difference in potential energy is the physically important quantity. Similarly, the zero of electric potential can be defined at any point you like.

Q1. Imagine sitting a distance $r$ from a charge $q$. You measure both the electric field and electric potential. Now imagine that the charge is halved and you move three times as far away. You measure the field and potential again. By what factor has the electric field changed? By what factor has the electric potential changed? Are the factors the same? If so, why? If not, why not?

For a given charge distribution, it is of particular interest to find points in space that have the same value of electric potential. On a two-dimensional surface, drawing a curve through these points gives an equipotential curve. Each equipotential curve has the same value of electric potential associated with it. Equipotential curves are analogous to contours on a topographical map. Depending on the charge distribution, the equipotential curves will have different shapes.

Q2. Sketch two equipotential curves around a single positive point charge. Label the one with higher electric potential $V_+$ and label the one with lower potential $V_-$. Explain, in sentences, why you drew this particular shape.

The electric field and electric potential are also related to each other. The electric field always points from high to low potential, along the direction in which the potential changes fastest. The potential will change fastest when you travel perpendicular to the equipotential curves. (To be convinced, consider the opposite – how would the electric potential change if you traveled parallel to an equipotential curve?)

Q3. Draw the electric field vector at a point between the two equipotential curves you sketched in Q2. You can check your answers to Q2 and Q3 using the Charges and Fields simulation package from the Electric Field lab you did previously.

The first part of this experiment is to map out the equipotential curves in the region around two charges of equal magnitude and opposite sign. This arrangement of charges is known as a dipole and is shown along with the experimental set up in Figure 1. To find the equipotential curves, you will use a probe connected to a voltmeter. The voltmeter will read the value of the electric potential at the point being probed. Simply find the set of points on the paper that have the same potential reading, and this is the equipotential curve.
PART I. PROCEDURE.

- Acquire a piece of conductive paper with the dipole arrangement (as shown in Figure 1).
  
  **DO NOT DRAW ON THE BLACK CONDUCTING PAPER!!**

- Connect the two leads from the power supply to the metal electrodes as shown in Figure 1.
- Connect the negative terminal on the power supply to the negative terminal of the voltmeter. This defines the negative electrode as the point of zero electric potential.
- Connect the single probe to the positive voltmeter terminal.
- Set the power supply to 20 volts (V). Touch the probe to the positive electrode – this should also read 20 V. If there is disagreement, make sure that the voltmeter reading is at 20 V.
- With the probe, find a set of points on the paper that are at an electric potential of 2 V. Draw these points on the white grid paper. Connect the dots to make an equipotential curve. Be sure to label this equipotential as 2 V.
- Repeat the above step for even potentials (4 V, 6 V, etc.) through 18 V. Each equipotential curve should either make a complete loop or should end at the boundary of the paper. This means that some equipotential curves will extend behind the electrode!
- Now open the *Charges and Fields* computer simulation used in the Electric Field lab. Set up a dipole arrangement- choose two single charges separated by 2 m.
- By placing the crosshairs of the voltmeter at different points around the charges and using the “plot” button on the voltmeter, obtain the equipotential curves. Try to place the voltmeter at points on the screen that correspond to points lying on the equipotential curves from your white grid paper. Note that the actual values of the electric potential in the simulation may be quite different from those obtained experimentally.
- Sketch or print out the map of equipotential curves. Don’t close the simulation.
Q4. How do the shapes of the simulation equipotential curves compare with those obtained experimentally? Comment on any specific similarities or differences.

- Next choose an equipotential curve in your simulation and use the E-field sensors to measure the electric field at different points around the equipotential curve.

Q5. What general features do you notice about how the orientation and direction of the electric field vector relate to the geometry/orientation of the equipotential curves? Is there a connection between the magnitude of the electric field and equipotential curves? If so, describe it.

PART II.

Study the electric potential for a more complicated charge distribution - you can obtain one from your instructor. Some of the things you could do as part of your investigation are:

- **Experimentally** map out the equipotential curves for the more complicated charge distribution. Comment on the shape of equipotential curves near the edges of the charge distributions.
- Use the computer simulation to construct a charge distribution similar to your experimental one. Report on similarities and differences between the maps of equipotential curves obtained experimentally and with the simulation.
- Using the simulation, investigate and report on the relationship between the electric field vectors and the equipotential curves. Comment on the direction of the electric field near the edges of the charge distributions.

You can also explore other aspects and try other ideas too!