3 - Potential Energy, Charge, and Electric Potential

MTVW 20-Jan-13

Objectives

1. To view voltage sources as a "charge escalators" that supply energy to separate charge.
2. To measure the electric field and electric potential difference (or voltage) on a plane when charge appears as two (approximate) point charges on the plane.
3. To measure the electric field and electric potential difference (or voltage) on a plane when charge appears as two parallel lines on the plane.
4. To observe the force between a charged sphere and charged parallel plates.
5. To relate the change in potential energy of a system consisting of two charges when one charge is moved relative to the second charge.

Equipment

1. Van de Graff generator and Leyden Jar,
2. Three multimeters
3. D-cell battery,
4. 12V and 5V DC power supplies (these are in the same case),
5. 1 cm probe separator,
6. Conductive paper with "point" charge distribution,
7. Conductive paper with "parallel line" charge distribution,
8. Two single pole single throw (SPST) switches,
9. Wooden support stand with adjustable cross piece and sliding protractor
10. One pair of large conducting plates on wooden backing,

Experiment

The Worksheets at the end of this document will be submitted for assessment.

1. Parallel Plate Capacitor

Position the two neutral rectangular aluminum plates such that they are parallel and a neutral conductive styrofoam ball (suspended from the wooden stand) is in contact near the midpoint of one of the parallel plates. Charge the conductive styrofoam ball using the Leyden jar. Connect a wire from the ground pin of the Van de Graff to the parallel plate furthest from the conductive ball. Connect another wire between the globe on the Van de Graff and the parallel plate closest to the conductive ball (see Figure 3.1). Turn the Van de Graff on momentarily.

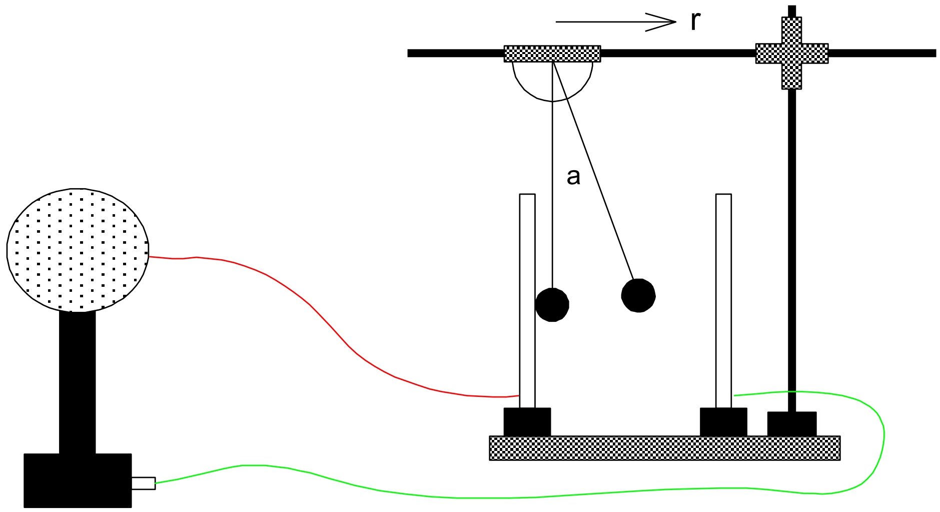

Figure 3.1. Apparatus to Observe the Electric Field between Charged Parallel Plates.

Observe the effect on the angle of the thread when the slider is positioned at different points between the parallel plates. How does the potential energy of the system change (greater than zero, less than zero or equal to zero) as the ball is moved further away from the plate attached to the sphere of the Van de Graff. How does the potential energy of the system change (greater than zero, less than zero or equal to zero) as the ball is moved further away from the plate attached to the ground pin of the Van de Graff?

1. Charge Separation and Electric Potential Difference

The Van de Graff generator acts as a voltage source or charge escalator; using mechanical energy to separate charge across the globe and ground pin. The separation of charge creates a significant electric field in the space around the generator and a very large potential difference (or voltage) between the globe and ground pin. The Leyden jar is an example of a capacitor in which energy is stored and then subsequently behaves like a voltage source. Note: touching the ball or interior of the Leyden jar when charged will cause an intense shock.

a) Firstly, touch the ball of the Leyden jar to the ground pin of the Van de Graff generator to ensure it is discharged. Turn on the Van de Graff generator momentarily. Secondly, touch the ball of the Leyden jar to the globe of the Van de Graff. Thirdly, touch the ball of the Leyden jar to the ground pin of the Van de Graff generator to discharge it. Write down your observations.

b) Relate the electrical behaviour of the three steps above to the state of the circuit equivalent in Figure 3.2 by identifying the sequence of switch positions and entering these into Table 1 a). For example, touching the Leyden jar to the globe is analogous to closing S1 and opening S2. The ground symbols indicate an implied electrical connection among the three branches.

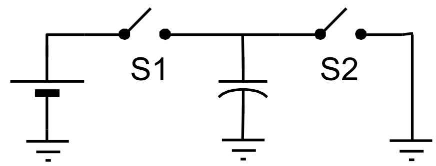

Figure 3.2. Equivalent circuit for a Van de Graff generator and Leyden jar system.

c) Other examples of DC voltage sources include: batteries, DC supplies, and solar cells. Batteries use stored chemical energy to separate charge across its terminals. A DC supply use electrical energy from the electric power system to separate charge across its terminals and a solar cell uses solar energy to separate charge across its terminals. The energy supplied per unit charge or the work done per unit charge to separate charge is constant for a DC voltage source.

Measuring Voltage: When configured as a voltmeter, a multimeter displays the work done per Coulomb in moving charge from one terminal (connected to the black lead of the voltmeter) to the other terminal (connected to the red lead of the voltmeter). To measure the voltage (also called electric potential difference), $V_{XY} = V_X - V_Y$, across the terminals X and Y of an electrical device: connect the red lead of the voltmeter to X and the black lead to Y. The voltmeter reading indicates the voltage at the point connected to the red lead relative to that at the black lead. For example, the red lead may be connected to a point that is at a potential of 5V above that at the black lead.

Configure one of the multimeters to display DC voltage on the 20V scale and complete Table 1 b) with the following measurements.

- Measure and record the voltage across the battery,
- Measure and record the voltage across the terminals of the (nominal) 5V, -5V and 12V DC supply,
- Measure and record the voltage across the terminals of the solar cell.

What happens if you reverse the connection of the leads? What does this indicate about the difference in potential energy of the charge at one terminal relative to the other?

2. Measuring an Electric Field in a 2-D Circuit

Under certain conditions the magnitude and direction of the electric field can be measured using a voltmeter. In the case of a Van de Graff generator, it is not possible. In the case of conductive paper it is possible to measure the E-field in a 2D plane. The measurement of the electric field using a voltmeter is governed by the relationship, $E = -\frac{\Delta V}{\Delta s}$. Let the spacing between the contact points of the probes be fixed at Δs. The procedure consists of centering the probes across the point where you want to measure the e-field. Rotate the probes around the point until the voltmeter reading, ΔV, has the largest positive value. The probes are now aligned in the direction of the electric field. The magnitude of the electric field in Volts per meter (V/m) at the centre point is given (approximately) by the voltmeter reading divided by Δs and the direction of the E-field is along the line *from* the point of contact with the red lead of the meter to the point of contact with the black lead of the meter.

a) Connect the 5V supply to the + and - contact points on the conductive paper, labeled #1, that resembles point charges. This causes a separation of charge between the contact points. In the space between the points of separated charge there exists an electric field. The electric field in V/m within the conductive paper can be measured using a volt meter with the special 1cm probe separator. Using the procedure, described above, measure the electric field at each of the white dots. Then sketch each of the associated field vectors in Figure 3.4.

b) Now consider a rectangular box that encloses the outermost white dots as illustrated in Figure 3.3 below. Use the voltmeter to measure the potential difference between adjacent points around the rectangular box and record these into Table 2 a). The positioning of the probes need not be exact but it is important to start at the exact end point of the previous measurement.

c) Repeat for the path B-D-F-B entering the measurements into Table 2 b). What does this indicate about the sum of the voltage reading around a loop and Kirchoff's voltage law?

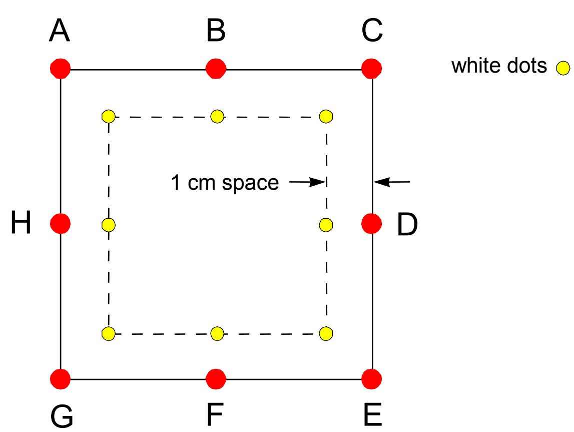

Figure 3.3. Points on a closed rectangular path on the conductive paper.

d) Connect the 5V supply to the contact points on conductive paper, labeled #2, that resembles parallel lines. Use the voltmeter to measure the electric field between the parallel lines and the electric field outside of the parallel lines as denoted by the dotted boxes in Figure 3.5 and denote on the Figure the magnitude and direction of the electric field.

Connect the common (black) lead of the voltmeter to the power supply common and use the other to probe the conductive paper. Experimentally find a position where the voltmeter reads 2.0 volts. Now, while watching the voltmeter closely, slide the probe along a path such that the reading remains at 2.0 volts. The path is called the 2.0V equipotential. Sketch the 2V equipotential on Figure 3.5 too.

Now consider the centre line that bisects the conductive sheet as shown in Figure 3.5. Slide the voltmeter probe across the sheet along this line beginning on the left edge of the paper and sketch the voltage reading versus position onto the Figure.

Worksheet - Potential Energy, Charge, and Electric Potential

1. ***Parallel Plate Capacitor.*** Between the plates of the parallel plate capacitor how does the angle, θ, vary as a function of displacement, r?

   How does the potential energy of the system change when the ball is moved away from the plate connected to the globe of the Van de Graff?

   How does the potential energy of the system change when the ball is moved away from the plate connected to the ground pin of the Van de Graff?

2. **Charge Separation and Electric Potential Difference**.

   a) Charging and discharging the Leyden jar — write down your observations:

Table 1 a)

Switch states in equivalent circuit related to action using Van de Graff generator and Leyden jar.

Action	S1 State	S2 State
Touch Jar to Globe		
Hold Jar away from Globe		
Touch Jar to Ground pin		

Table 1 b)

Voltmeter readings for sources in two orientations.

Voltage Source	Voltmeter Readings	With Reversed Leads
Battery		
DC Supply		
Solar Cell		

a) What happens if you reverse the connection of the leads?

b) What does this indicate about the difference in potential energy of the charge at one terminal relative to the other?

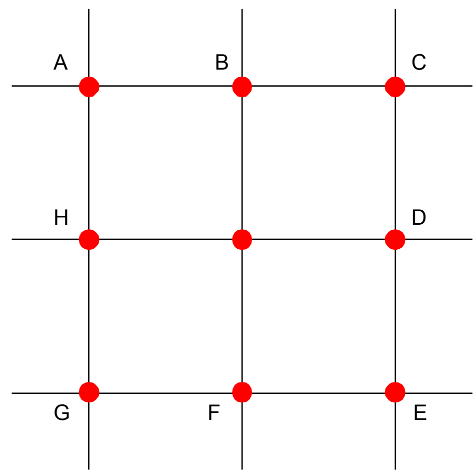

Figure 3.4. Draw the measured electric field vectors at the dots.

Table 2 a)

Voltage readings between pairs of points around the square on the conductive paper #1.

	V_{AB}	V_{BC}	V_{CD}	V_{DE}	V_{EF}	V_{FG}	V_{GH}	V_{HA}	Sum
Measured Voltage									
Comment on Sum									

Table 2 b)

Voltage readings between pairs of point around the alternate path on the conductive paper #1.

	V_{BD}	V_{DF}	V_{FB}	Sum
Measured Voltage				
Comment on Sum				

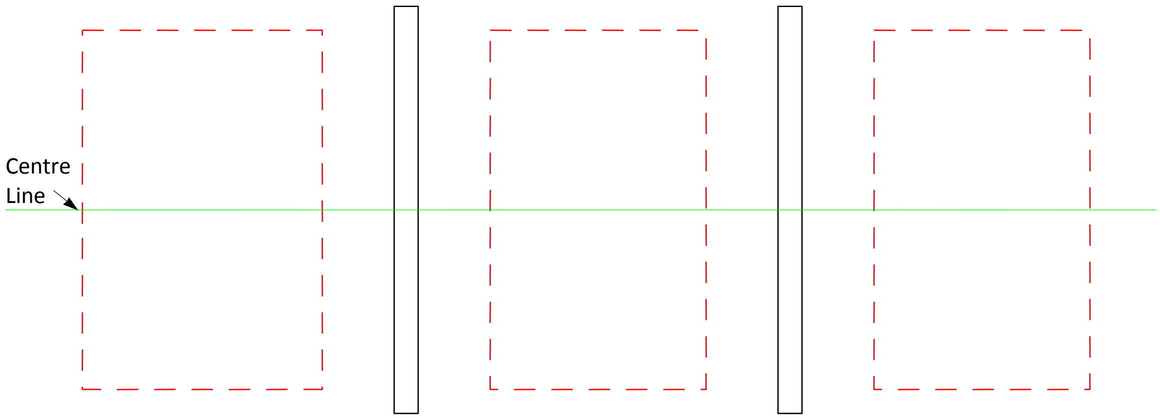

Figure 3.5. Field around parallel wires on conductive paper #2.