11.4.1: Voltage (Electric Potential)

Figure 16.1.1

Often the star of science shows and museum installments, Tesla coils create magnificent displays of light and sound. They have low electrical current but incredibly large electric potentials.

The Electric Potential in a Uniform Field

Electric Potential

In the study of mechanics, the concept of energy, and the conservation thereof, was extremely useful. The same will be true for the study of electrical interactions. The work done moving a charged particle in an electric field can result in the particle gaining or losing both kinetic and potential energy.

Lifting an object in a gravitational field requires work and increases the object's potential energy. A similar situation occurs when you move two charged objects relative to each other. We already know that each object has an electric field surrounding it, which effects the other charge. If the two charged objects have the same charge, they repel each other. Moving these two objects closer to each other requires working against the repulsive force, which increases the potential energy of the system. Conversely, moving two like charges apart will decrease the potential energy. If the objects attract each other, the opposite situations occur: if you pull them apart, you do work against the force, which increases the potential energy of the system, but bringing attractive charges closer together decreases the potential energy.

It is often easy to think of the change in energy as a mountain or an inverted cone, depending on the situation. Imagine a positive point charge, with the corresponding electric field around it. If you are moving another positive point charge, the situation is like a mountain, with the original point charge at the peak. As the second charge moves towards the first, it must go up the mountain. This requires work, and increases the potential energy of the system. If, however, the second charge is a negative point charge, the two charges attract each other and the situation is like a cone: the second charge easily falls towards the first, decreasing the potential energy. It would then require work to get the second charge up and out of the cone, away from the first charge.

Uniform Electric Fields

As we know from Coulomb's law, the electric field around a point charge decreases as the distance from the point increases. However, it is possible to create a constant electric field between two large, flat conducting plates parallel to each other. If one of the plates is positively charged and the other negatively charged, the space between the plates will have a constant electric field except near the edges of the plates.

Diagram of a uniform electric field created from two uniformly charged plates

Figure 16.1.2

Voltage, which measures the electric potential difference across two points, based on the unit volt (V). To measure the voltage across some distance, it is necessary to pick a position to be the relative zero, because voltage is the change in potential difference. Any point in a system can be given the value of zero volts, but it is typically the point of a point charge or one plate in a uniform electric field as shown above. The voltage is commonly referred to as the **electric potential difference** and can be measured using a voltmeter.

The electrical potential difference between the two plates is expressed as V=Ed, the electric field strength times the distance between the plates. The units in this expression are Newtons/coulomb times meters, which gives the final units Joules/coulomb. Voltage is an expression of the amount of potential energy per unit charge. The work done moving a charge against the field can be calculated by multiplying the electric field potential by the charge, W=Vq.

Examples

Example 16.1.1

Two large parallel metal plates are 5.0 cm apart. The magnitude of the electric field between them is 800. N/C.

(a) What is the potential difference between the plates?

(b) What work is done when one electron is moved from the positive to the negative plate?

Solution

(a) V=Ed=(800. N/C)(0.050 m)=40. J/C=40. V

(b) $W=Vq=(40.0\ J/C)(1.6\times10^{-19}\ C)=6.4\times10^{-18}\ J$

Example 16.1.2

A voltmeter measures the potential difference between two large parallel plates to be 50.0 volts. The plates are 3.0 cm apart. What is the magnitude of the electric field strength between the plates?

Solution

E=V/d=50.0 volts/0.030 m=1700 N/C

Have you ever wondered what causes lightning to strike? Launch the simulation below and adjust the Charge Separation slider to high, the Cloud Separation slider to low, and be sure to turn the Lightning Rod on (to protect the people in the building). Then, press play and see what happens:

Summary

- The work done moving a charged particle in an electric field can result in the particle gaining or losing both kinetic and potential energy.
- The difference in electric potential energy is measured with a voltmeter in units called volts.
- A constant electric field can be produced by placing two large flat conducting plates parallel to each other.
- The electrical potential difference in a uniform electric field is given as V=Ed.
- The work done moving a charge against the field can be found by W=Vq.

Review

1. Two large parallel plates are 0.00630 m apart and the voltage across them is 10.0 volts. What is the electric field strength between the plates?
2. The potential difference between points A and B in an electric field is 25.0 volts. How much work is required to transfer 10.0 coulombs of charge from A to B?
3. 10.0 J of work are required to transfer 2.00 coulombs of charge from point X to point Y in an electric field. What is the difference in potential between these two points?
4. The electric field between two parallel plates connected to a 45 V battery (which produces a 45 V difference in potential between the plates) is 1500 N/C. How far apart are the plates?
5. How much kinetic energy will an electron gain if it accelerates through a potential difference of 23,000 volts in a cathode ray tube?

Explore More

Use this resource to answer the questions that follow.

1. If you do work to move a charged object in an electric field, where does the work go?
2. Points A and B in an electric field have a difference in potential energy. This difference in electrical potential energy is called ___________________.

Additional Resources

Study Guide: Electrical Systems Study Guide

Videos: Electrical Potential - Overview

Real World Application: Faraday Cage

Interactive: Electric Analogies