11.3 Electric Potential Difference

In Section 11.1, you learned that electrical energy is generated by transforming energy in a power plant. The amount of electric energy generated can be increased by adjusting the variables involved. For example, in a nuclear power plant, the reactor can be run at a higher temperature to produce more thermal energy. This extra thermal energy can be used to generate more electrical energy. In a wind turbine generator, the blades can be positioned so that they rotate faster for the same amount of wind. This extra kinetic energy can be used to generate more electrical energy. How is electrical energy transferred?

Figure 1 Electricity travels from the power plant to your home along transmission lines.

Electrical Energy Transfer

Electrical energy is transferred from a power plant to your home through conducting wires called transmission lines. Transmission lines radiate out from the power plant in many directions across the province and the country (**Figure 1**). The wires are made from a metal, usually aluminum. In a metal, electrons are free to move and they are the most important part of the conducting wires because they provide the means for the transfer of electrical energy. Without these freely moving electrons, the electrical energy could not be transferred from the power plant to your home.

In Chapter 5, you learned that there are different forms of energy, one of which is potential energy. Electric potential energy results from the separation of electrons, which are negatively charged, so they repel each other. To overcome this force and push the electrons closer together, energy must be transferred to the electrons, increasing their electric potential energy. The closer electrons are pushed together, the greater is the electric potential energy. The movement of electrons therefore requires a change in energy.

Mini Investigation

Modelling Electric Potential Energy

Skills: Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A2.1, A2.4

It is difficult to imagine what electrons are doing in a wire. You cannot “see” electrical energy. In this investigation, you will use a Newton’s cradle (**Figure 2**) to model electrical potential energy and the transfer of that energy through a wire. Only observe the initial forward motion of the spheres; ignore the back and forth motion. The spheres in the middle represent the electrons in the wire, and the spheres on the ends represent electric potential energy.

Equipment and Materials: Newton’s cradle

1. Raise one of the end spheres slightly and let it go. Record your observations of what happens to the spheres on each end as well as the spheres in the middle.
2. Repeat Step 1, but this time raise the end sphere higher before you let it go. Record your observations.
3. Pull the middle spheres to one side so that they are not suspended between the end spheres. Raise one end sphere and then release it. Record your observations.

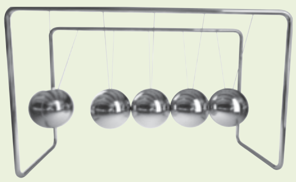

Figure 2 Newton’s cradle

A. The height by which you raised the end sphere represents the amount of electric potential energy. How did the amount of electric potential energy change the outcome? T/I

B. How did the speed of the energy transfer compare to the speed of the middle spheres? T/I

C. How did moving the middle spheres to one side affect the results of the investigation? T/I

D. This is a model of electric potential energy and its transfer. State one possible limitation of this model. T/I

Electric Potential Difference

Electric potential is the measurement of the electric potential energy associated with charges (in this case, electrons). You can think of electric potential as the amount of energy needed to move a quantity of electrons closer to one another. In a circuit, electrons are closely packed together in the conducting wires. Moving the electrons closer together increases their electric potential. The more work that is done to move the electrons closer together, the larger is the electric potential.

electric potential the amount of electric potential energy associated with charges

Electric potential measures both the electrical energy and the quantity of electrons. The unit for measuring electric potential is the joule per coulomb (J/C). The joule (J) is a measurement of the electric potential energy, and the coulomb (C) is a measurement of the number of electrons or amount of charge. This unit is more commonly known as the volt (V), in honour of scientist Alessandro Volta. 1 J/C is equal to 1 V.

Instead of measuring electric potential at one point in a circuit, it is more useful to measure the difference in electric potential between two different points in the circuit. Differences in electric potential exist because energy is transformed in an electric circuit. For example, the electrons at a battery have a different amount of electric potential energy than the electrons at a light bulb. This gives rise to a quantity called the electric potential difference. **Electric potential difference** is the difference in electric potential energy associated with a coulomb of charge at two different points in a circuit. Electric potential difference is also referred to as voltage (V). A positive electric potential difference is sometimes called a voltage gain. A negative electric potential difference is sometimes called a voltage drop. Electric potential difference can be represented by the following equation:

electric potential difference (*V*) the change in electric potential energy associated with charges at two different points in a circuit

$$V = \frac{\Delta E}{Q}$$

where V = electric potential difference (joules per coulomb or volts), ΔE = change in electric potential energy (joules), and Q = the amount of charge (electrons) (coulombs). In the following Tutorial, you will use this equation to calculate the electric potential difference in electric devices.

Tutorial 1 Using the Electric Potential Difference Equation

Electric potential difference can be calculated given the change in electric potential energy in joules and the amount of charge (electrons) in coulombs. In the following Sample Problem, we will calculate electric potential difference.

Sample Problem 1

Calculate the electric potential difference between the negative and positive terminals of a battery if 1500 J of electric potential energy is transformed to move 125 C of charge between the terminals.

Given: $\Delta E = 1500$ J; $Q = 125$ C

Required: V

Analysis: $V = \frac{\Delta E}{Q}$

Solution:
$$V = \frac{\Delta E}{Q} = \frac{1500 \text{ J}}{125 \text{ C}}$$
$$V = 12 \text{ V}$$

Statement: The electric potential difference of the battery is 12 V.

Practice

1. A computer processor chip transforms 120 J of energy while moving 52 C of electrons. Calculate the electric potential difference of the chip. T/I [ans: 2.3 V]

voltmeter electrical device that measures electric potential difference

CAREER **LINK**

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Measuring Electric Potential Difference

A **voltmeter** is used to measure electric potential difference in circuits. A computer technician uses a voltmeter to see if the power supply to a computer is working properly. If your car does not start when you turn the key, an automotive repair technician uses a voltmeter to test if the starter motor is working properly. An electrician uses a voltmeter to test if a circuit is "live," so it can be shut off before work begins. At home, you can use a voltmeter to test if a battery has enough electrical energy to make a flashlight work.

In Grade 9, you learned that circuits can have one complete path (series circuits) or more than one complete path (parallel circuits). The two types of circuits are shown in **Figure 3**. Voltmeters only work accurately if they are connected in parallel in the circuit. To connect in parallel, you must create a separate path for the electrons to follow in the circuit. This separate path allows only a very small amount of electrical energy to go into the meter. The majority of the electrical energy is in the rest of the circuit. The circuit symbol for a voltmeter is —(V)—.

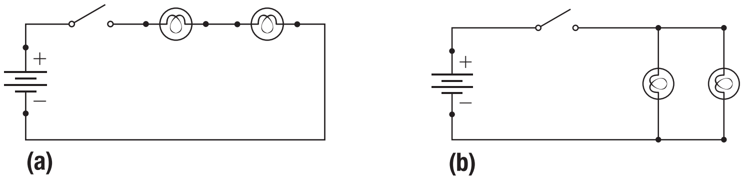

Figure 3 (a) Series circuit (b) Parallel circuit

Circuits contain sources of electrical energy (such as a battery or power supply), connecting wires, control devices (such as a switch), and loads (such as a lamp or a motor). You can think of sources as the parts of the circuit that cause an increase in the electric potential, or a voltage gain. You can think of loads as the parts of the circuits that cause a decrease in the electric potential, or a voltage drop (**Figure 4**).

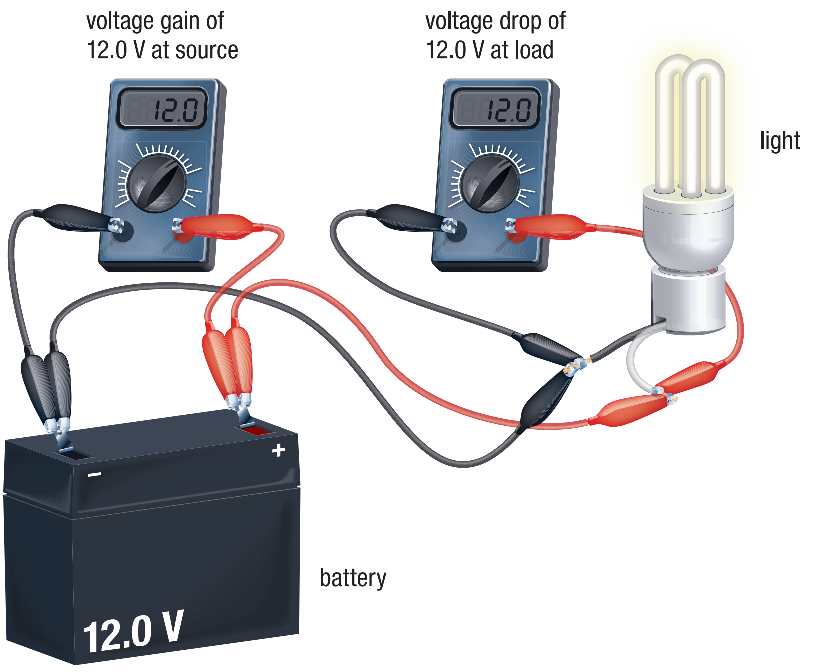

Figure 4 Sources cause an increase in electric potential (voltage gain), and loads cause a decrease in electric potential (voltage drop).

In an ideal circuit, the connecting wires and control devices do not affect the amount of electric potential and therefore do not cause a voltage drop. However, in a real circuit, the connecting wires and control devices can cause a voltage drop.

11.3 Summary

- Free electrons that are able to move are essential for the transfer of electrical energy.
- Electric potential is a measure of how much electric potential energy is associated with charges.
- Electric potential difference, or voltage, indicates the difference in electric potential energy of the charges (electrons) between two points in a circuit.
- The equation for electric potential difference is $V = \frac{\Delta E}{Q}$.
- Electric potential difference is measured in joules per coulomb (J/C) or volts (V).
- The amount of charge or number of electrons (Q) is measured in coulombs.
- Voltmeters measure electric potential difference and are connected in parallel in a circuit. They have the circuit symbol —(V)—.
- Sources of electrical energy cause an increase in the electric potential (voltage gain), whereas loads cause a decrease in the electric potential (voltage drop).

11.3 Questions

1. Calculate the electric potential difference if 1750 J of electric potential energy is transformed to move 3.1 C of electrons. T/I
2. Calculate the energy transformed in a 15 V adapter that has 0.075 C of electrons moving through it. T/I
3. How much charge is travelling through a 3.7 V cellphone that transforms 6.0 J of electrical energy? T/I
4. (a) A 7.0 W CFL bulb is on for 2.5 h. During that time, 525 C of electrons move through the bulb. Determine the electric potential difference of the CFL bulb. (Hint: you will need to use the power equation from Section 11.1.)
   (b) Each coulomb has 6.2×10^{18} electrons in it. Calculate the number of electrons that were moved through the CFL bulb in part (a). T/I
5. In medical television shows, doctors use defibrillators to try and establish a normal rhythm in a patient's heart. To do this they shock the heart with approximately 130 J of electrical energy at an electric potential difference of 710 V. Determine the amount of charge that is delivered to the heart. T/I
6. A student connects a circuit that contains a battery, a switch, and an LED lamp. K/U
   (a) In which part(s) would you expect to observe a voltage gain, and in which part(s) would you expect to observe a voltage drop?
   (b) Is there any part of the circuit where you would expect no voltage drop or gain? Explain your reasoning.
7. Do the following electrical devices cause an increase or a decrease in electric potential? State whether each device causes a voltage gain or a voltage drop. K/U
   (a) power plant
   (b) digital camera
   (c) game console
   (d) wind turbine
   (e) solar panel
   (f) calculator
8. Identify what is wrong with each of the following statements, and rewrite it so that it is correct: K/U C
   (a) A voltmeter must always be connected in series.
   (b) A series circuit has more than one complete path.
   (c) Connecting a voltmeter in series will allow only a small amount of electrical energy to travel through it.
   (d) A parallel circuit can only have two complete paths.
   (e) A complete circuit contains a source of electrical energy and a load.
9. Redraw the circuit diagrams from Figure 3 on page 512 with a voltmeter connected properly to the first lamp. T/I