15.1 Electric Potential Difference

SECTION OUTCOMES

- Define and describe electric potential difference.
- Analyze in quantitative terms, problems involving electric potential difference and electric charge.

KEY TERMS

- conductor
- insulator
- electrostatics
- voltaic cell
- battery
- electrode
- electrolyte
- anode
- cathode
- potential difference

PHYSICS FILE

In addition to insulators and conductors, there is a group of materials called "semiconductors." This group includes substances such as silicon and germanium. Semiconductors, used in the construction of computer chips, make it possible to build the miniature electronic devices now on the market. "Silicon Valley" is the nickname for the area in California where its computer industry is centred. Ottawa, a centre for much of Canada's high-tech industry, has acquired the nickname "Silicon Valley North.".

When you comb your hair with a plastic comb, the comb becomes electrically charged and will attract bits of paper. If your comb is made of metal, however, the bits of paper are unaffected by the comb when it is held close to them. Why do metal combs *not* become charged?

Figure 15.1 Combing your hair with a plastic comb results in an electrostatic charge on the comb

Conductors and Insulators

Stephen Gray (1696–1736), an English scientist, made the first recorded explanation of electric conduction in 1729. He classified materials as **conductors** and **insulators**, depending on their ability to allow charges to flow. Although it was a novel idea for him, you probably take for granted that, in general, conductors are metals and insulators are non-metals. Gray also identified Earth as a conductor and coined the term "ground" to mean "provide a path for charge to escape." Even though Earth is not generally thought of as a metal, it is still a very good conductor, due to its size and the ions dissolved in the moisture in the soil.

The Voltaic Pile

Gray's discovery marked the first step of the journey from **electrostatics** (the study of charges at rest) to the control of electric current. The second, more crucial, step occurred in 1800, when Italian physicist Alessandro Volta (1745–1827) invented the electrochemical cell. Volta discovered that if he placed a layer of salt-water-soaked paper between disks of two different metals, such as silver and zinc, an electric charge appeared on each of the metal disks. When he made a pile of these cells (for example,

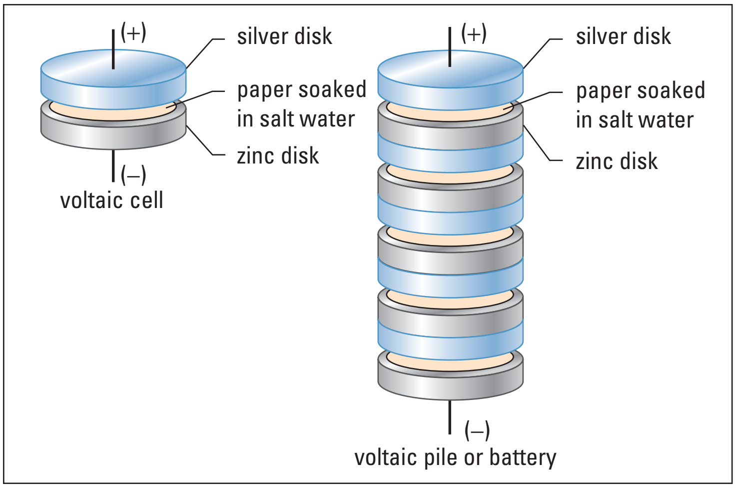

Figure 15.2 The voltaic pile, or battery, supplied scientists with a source of continuous charge flow. For the first time, scientists were able to experiment with steady currents, rather than with the brief bursts of intense charge flow provided by electrostatic generators.

Figure 15.3 Alessandro Volta was a professor at the University of Pavia when he invented the electrochemical (voltaic) cell. For his invention, Napoleon made him a Count of the French Empire. The unit of potential difference, the volt, was named in his honour.

silver/paper/zinc/silver/paper/zinc), the electric strength increased. One pair of such disks became known as a **voltaic cell**; the stack of disks became known as a voltaic pile or **battery** (see Figure 15.2). The metal plates in the cell are the **electrodes**, while the solution between them is the **electrolyte**.

Using an electroscope, Volta determined that the charges on the silver disk of his cell were positive, and the charges on the zinc disk were negative. Since the electron had not yet been discovered, physicists had no way of knowing what positive and negative charges actually were, or which type of charge was moving when they connected conductors to the poles of a voltaic pile. They agreed on the convention that positive charges were moving in electric conductors. Consequently, the positive pole of the battery must be considered to be at a higher electric potential energy than the negative pole. The positive pole would be repelling the positive charges and pushing them "downhill" toward the negative pole. Hence, the positive pole of the battery became known as the **anode** (Greek for "upper path") and the negative pole became the **cathode** (Greek for "lower path").

Language Link

The term "electrode" is derived from two Greek words, *elektron* for "amber" and *hodos* for "way" or "path." Electrode literally means "electric path." How did the Greek word for "amber," which is fossilized resin, become associated with electricity?

Potential Difference

If you imagine a model in which a positive charge moving through a circuit is going downhill, then the battery is analogous to a ski lift taking the charge back to the top of the hill. When you ride a ski lift from the bottom to the top of a hill, the lift uses energy from its motor's fuel and transforms that energy into gravitational potential energy of your body. You probably have gained a

PHYSICS FILE

An early theory of electricity suggested that substances had an "electric fluid" within them. The belief was that when two objects were rubbed together, friction would cause some of that fluid to be rubbed off, leaving one of the objects with an excess of the electric fluid and the other object with a deficiency of the fluid. Benjamin Franklin (1706–1790) was doing experiments in 1746 to verify the "fluid theory" of static electricity. Franklin arbitrarily decided that a glass rod rubbed with silk would gain electric fluid from the silk and become "charged with a positive amount of electric fluid." Simultaneously, the silk was "charged with a negative amount of electric fluid." Later, this came to be known simply as "positively charged" and "negatively charged." More than a century later, when the electron was finally discovered, it was found that the electron was repelled by objects that previously had been defined as negatively charged. Hence, today we think of the electron as having a negative charge and the proton as having a positive charge.

different amount of gravitational potential energy from other skiiers during your ride. However, you all gained exactly the same amount of gravitational potential energy per kilogram of your body mass.

By defining the **gravitational potential difference** as the difference in gravitational potential energy per unit mass, $\Delta E_g/m$, you can develop a term that no longer depends on an object's (skier's) mass. Gravitational potential difference depends only on the height of the hill (h) and the acceleration due to gravity (g).

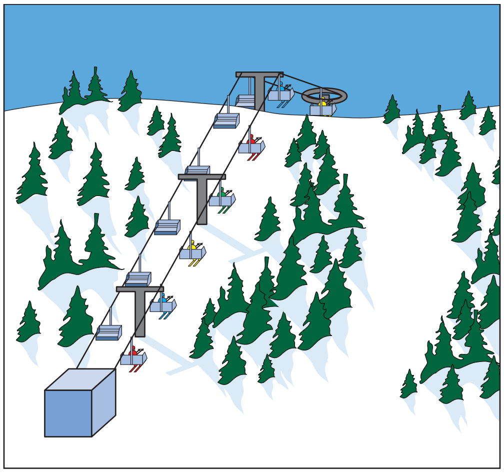

Figure 15.4 A skier of mass m riding up a ski lift to the top of a hill gains a potential energy of ΔE_g.

Conceptual Problems

- Think about the skier mentioned in the caption of Figure 15.4. Write the equation for gravitational potential energy. Use the equation to show that the gravitational potential difference, ΔE_g/m, depends on the height (h) of the hill and the gravitational acceleration (g), not the mass of the skier.
- How would the gravitational potential difference change under the following circumstances?
  (a) The skier went three times as far up the hill.
  (b) The skier's mass doubled.
  (c) The skier skied only halfway down the hill.

The skiers on our electric hill are similar to positive charges. The chemical action inside a voltaic cell takes positive charges from the cathode (bottom of the electric hill) to the anode (top of the electric hill), giving them electric potential energy. There is no special term or symbol for gravitational potential difference, but there is a special term for electric potential difference. The difference in electrical potential energy (ΔE_Q) per unit charge (Q) is defined as the **potential difference** (V), sometimes called the "voltage" of the cell, battery, or power supply.

DEFINITION OF ELECTRIC POTENTIAL DIFFERENCE

The electric potential difference between any two points in a circuit is the quotient of the change in the electric potential energy of charges passing between those points and the quantity of the charge.

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

Quantity	Symbol	SI unit
electric potential difference	V	V (volt)
change in electrical potential energy	ΔE_Q	J (joule)
quantity of charge	q	C (coulomb)

Unit Analysis

$$\frac{\text{(electric potential energy)}}{\text{(quantity of charge)}} = \frac{\text{J}}{\text{C}} = \text{V}$$

Note: One joule per coulomb is equivalent to one volt.

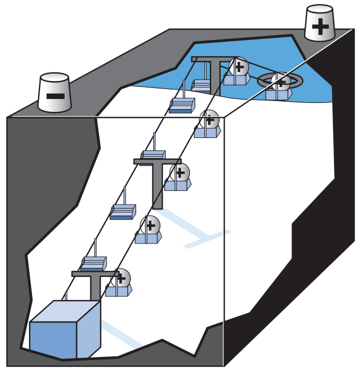

Figure 15.5 The chemical action of the cell gives electric potential energy to the charges deposited on the anode and cathode. This creates a potential difference between the anode and cathode.

One volt (1 V) of potential difference across the poles of a cell is created when the chemical action inside the cell does one joule (1 J) of work on each coulomb of charge (1 C) that it lifts internally from the cathode to the anode.

MODEL PROBLEM

Energy and Potential Difference

A battery has a potential difference of 18.0 V. How much work is done when a charge of 64.0 C moves from the anode to the cathode?

Frame the Problem

- Since the battery has a *potential difference* between the poles, chemical reactions in the battery did *work* to *separate* positive and negative *charges*.
- The *work done* transforms chemical potential energy into *electric potential energy*. Thus, the change in the electric potential energy is equal to the amount of *work* done.
- The expression that defines *potential difference* applies to this problem.

Identify the Goal

The amount of work, W, done to separate charges

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Variables and Constants

Known

$V = 18.0\ \text{V}$

$q = 64.0\ \text{C}$

Unknown

W

ΔE_Q

Strategy

Use the expression for potential difference.

Calculations

$$V = \frac{\Delta E_Q}{q}$$

Substitute first

$$18.0\ \text{V} = \frac{\Delta E_Q}{64.0\ \text{C}}$$

$$(120\ \text{V})(1440\ \text{C}) = \frac{\Delta E_Q}{\cancel{1440\text{C}}}\cancel{1440\ \text{C}}$$

$$\Delta E_Q = 1150\ \text{VC}$$

$$\Delta E_Q = 1150\ \text{J}$$

Solve for ΔE_Q first

$$Vq = \frac{\Delta E_Q}{\cancel{q}}\cancel{q}$$

$$\Delta E_Q = (18.0\ \text{V})(64.0\ \text{C})$$

$$\Delta E_Q = 1150\ \text{VC}$$

$$\Delta E_Q = 1150\ \text{J}$$

Solve for ΔE_Q.

Since $1\frac{\text{J}}{\text{C}}$ is equivalent to 1 V, then

$$\text{V} = \frac{\text{J}}{\text{C}}$$

$$\text{VC} = \frac{\text{J}}{\cancel{\text{C}}}\cancel{\text{C}}$$

$$\text{VC} = \text{J}$$

The work done is the same as the change in the potential energy.

$$W = \Delta E_Q$$

$$\Delta E_Q = 1150\ \text{J}$$

$$W = 1150\ \text{J}$$

If a charge of 64.0 C is transferred by a potential difference of 18.0 V, then 1.15×10^3 J of work are done.

Validate

The units cancel to give joules, which is the correct unit for work.

PRACTICE PROBLEMS

1. What is the potential difference of a battery if it does 7.50×10^{-2} J of work when it moves 3.75×10^{-3} C of charge onto the anode?
2. A 9.00 V battery causes a charge of 4.20×10^{-2} C to move through a circuit. Calculate the work done on the charge.
3. A 12 V battery does 0.75 J of work on a quantity of charge it moved through a circuit. Calculate the amount of charge that was moved.

CAREERS IN PHYSICS

TARGET SKILLS

- Communicating results
- Conducting research

Sara Goodchild is a science editor, and also a published author of science articles. She graduated from university with a degree in chemistry, and has combined her interests in both writing and science in her present career.

Robotics, global warming, the space station, genetically modified organisms, and cloning — these are just a few of the hot topics being reported in the media. The demand for science writers is increasing as radio, television, magazines, newspapers, encyclopedias, the Internet and even texts such as this one publish more and more reports on science. Science reporters must be able to distinguish between good and bad science and then present their findings in a clear well-written manner so that their point of view can be understood by the public.

Right now is a great time to be a science writer. Many science topics are becoming increasingly controversial. The ability to research stories and present an accurate balanced report will be extremely difficult and ever more important.

If you have an interest in science and a talent for writing, you may have a career in science journalism.

Going Further

1. Volunteer with a scientific organization like the Royal Astronomical Society to gain experience in writing and editing.
2. Attend meetings of and/or join professional organizations such as the Science Writers' Association of Canada, Periodical Writers' Association of Canada or the Editors' Association of Canada.
3. Submit reports for your local paper on science events such as the Science Fair.

15.1 Section Review

1. **MC** Why was very little known about current electricity and potential difference before the time of Alessandro Volta?
2. **C** Explain the difference between electric potential energy and electric potential difference.
3. **K/U** Which of the following changes would increase the gravitational potential energy of every skier at the top of a chair lift compared to the bottom of the lift?
   - **(a)** Increase the number of runs to accommodate more skiers.
   - **(b)** Extend the top of the lift to a location 20 m higher up the mountain.
   - **(c)** Install a new high-speed quad lift to carry more skiers to the top of the lift at a higher rate.

   Explain your reasoning.
4. **C** Develop another analogy, different from the ski lift, that would help a classmate understand the concept of electric potential difference.