7.1 Properties of Electric Charge

A visit to a science museum can be, literally, a hair-raising experience. In **Figure 1**, the device that the child is touching is a Van de Graaff generator, which produces a large amount of electric charge. When you touch the generator, the electric charge spreads along your skin and onto each individual hair. The charges repel each other, so the hairs spread out and stand on end. How do electric charges move from one place to another and charge an object? In this section, you will learn the answers to this and other questions related to the properties of electric charges.

Figure 1 Electric charges on each strand of hair exert a repulsive force on the other strands, causing the hair to rise and spread out.

Electric Charge

About 2500 years ago, Greek scholars first reported that rubbing amber with a piece of animal fur caused the amber to attract dust particles. You can demonstrate this effect with modern materials, such as a plastic rod and small bits of paper (**Figure 2**). Note that neither the fur nor the rod attracts the paper pieces under normal conditions, but rubbing the two materials together seems to create an attractive force on each object. An even more remarkable feature is that the rod attracts the pieces of paper without making direct contact with them.

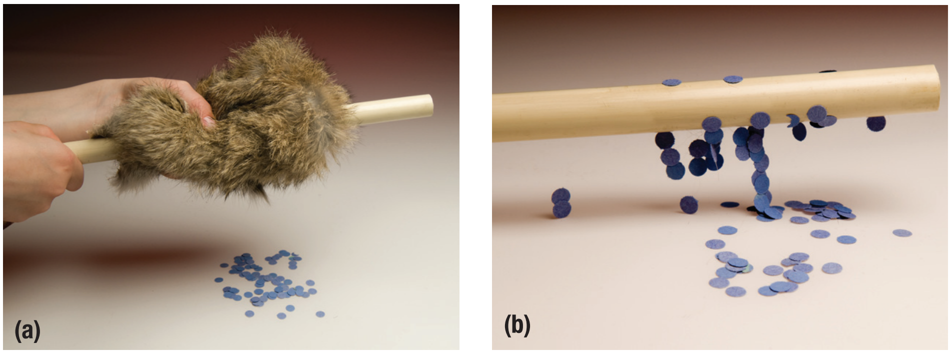

Figure 2 When a plastic rod is rubbed with fur (a), the rod acquires an electric charge. (b) The charged rod attracts small bits of paper and other objects.

By the early 1900s, physicists had identified the subatomic particles called the electron and the proton as the basic units of charge. All protons carry the same amount of positive charge, e, and all electrons carry an equal but opposite charge, $-e$. Charges interact with each other in very specific ways governed by the **law of electric charges** (**Figure 3**).

Law of Electric Charges

Like charges repel each other; unlike charges attract.

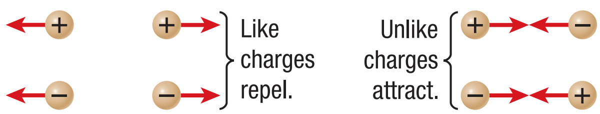

Figure 3 The electric force between two like charges (charges with the same sign) is repulsive, whereas the electric force between unlike charges (charges with opposite signs) is attractive.

An atom or a molecule is considered to have a charge of zero because the number of protons is equal to the number of electrons. Atoms and molecules can become charged to form ions. Ions can be positively or negatively charged. In a positive ion, or a cation, the number of protons must be greater than the number of electrons. Electrons are removed from an atom or a molecule to become a cation. Conversely, in a negative ion, or an anion, the number of electrons must be greater than the number of protons. Electrons are added to an atom or a molecule to make an anion.

When looking at objects larger than atoms and molecules, we consider the total charge. The total charge on an object is the sum of all the charges in that object and can be positive, negative, or zero, just as in the case for atoms and molecules. A deficit of electrons means that the object is positively charged, and an excess of electrons means that the object is negatively charged. An object is said to have a total charge of zero when the number of negative charges equals the number of positive charges. An object with a charge of zero is said to be neutral.

In addition, we know that charge can move from place to place, and from one object to another, but the total charge of the universe does not change. This is stated clearly in the **law of conservation of charge**.

Law of Conservation of Charge

Charge can be transferred from one object to another, but the total charge of a closed system remains constant.

What Is Electric Charge?

In the SI system, the basic unit of charge is called the **coulomb** (C), in honour of the French physicist Charles de Coulomb (1736–1806). The charge of a single electron, $-e$, is -1.60×10^{-19} C, and the charge of a single proton, $+e$, is $+1.60 \times 10^{-19}$ C. The symbol e often denotes the magnitude of the charge on an electron or a proton. In this text, e will have the positive quantity ($+1.60 \times 10^{-19}$ C).

coulomb the SI unit of electric charge; symbol C

The symbol q denotes the amount of charge, such as the total charge on a small piece of paper. To say that a particle has a charge q or that it carries a charge q is simply a way of saying that the total charge of the particle is q. For example, an alpha particle is a helium nucleus (a helium atom with no electrons). The helium nucleus has two protons, so its charge is $2e$, or 3.20×10^{-19} C ($2 \times 1.60 \times 10^{-19}$ C).

Conductors and Insulators

To understand how researchers observe electric forces, you need to understand the various ways that charge can be transferred from one material to another.

Conductors

In most metals, each individual atom is electrically neutral, with equal numbers of protons and electrons. When these neutral atoms come together to form a large piece of metal, one or more electrons from each atom are able to escape from the parent atom and move freely through the entire piece of metal. These electrons are called conduction electrons, and the metal is a conductor. A **conductor** is a substance in which electrons can move easily among atoms. Copper is a good example of a conductor. The conduction electrons leave behind positively charged ions, which are bound in place and do not move. By adding or removing electrons from a conductor, the conductor can acquire a net negative or positive charge.

conductor any substance in which electrons are able to move easily from one atom to another

Insulators

On the other hand, electrons in **insulators** cannot move freely from atom to atom or escape from the molecules, so no conduction electrons are available to carry charge through the solid. Extra electrons placed on the surface of an insulator do not move about freely. Instead, these added electrons stay where they were initially placed. Examples of insulators are amber, plastic, and quartz.

insulator any substance in which electrons are not free to move easily from one atom to another

Conductivity of Liquids and Gases

In the case of liquids, the atoms and molecules are free to move throughout the substance. Certain substances, such as table salt (NaCl), dissolve in water to form separately charged atoms, or ions. The sodium ion (Na^+) and the chloride ion (Cl^-) provide an electric charge in the salt–water solution. This property of salt water makes it a good conductor, which is especially important for marine animals that rely on bioelectricity for survival.

The conductivity of gases is similar to that of liquids. The constituent atoms and molecules of a gas are mostly neutral, but a few are present as ions and are able to carry charge from place to place. Some free electrons are usually present in a gas as well.

Placing Charge on an Insulator

To understand the electrical behaviour of an object, you must understand what happens when you add or remove charge from the object. Take, for instance, the case of an insulator such as quartz, when it is dry and surrounded by dry air. If you place a few electrons at a particular location on this insulator's surface, these electrons will stay in that location (**Figure 4(a)**). This is because there are no free electrons in an insulator, and the insulator does not allow the extra electrons to move about easily.

In reality, excess charge will not stay on an insulator indefinitely. If an insulator contains some excess electrons, they will attract the stray positive ions that are usually part of the surrounding air. These stray ions will combine with the electrons on the insulator and cause the net charge on the insulator to become zero.

Placing Charge on a Conductor

Metals are excellent conductors because electrons can move easily through a metal. We have to refer to the law of electric charges to understand what happens when an excess of electrons is present in a conductor. Electrons naturally repel each other. In a metal object, the electrons are free to move from atom to atom, but they will never end up moving toward other electrons. The electrons do not concentrate at the centre of the piece of metal; rather, they move as far away from one another as possible. Also, the electrons do not spontaneously leave the metal to get away from each other. There are attractive forces from the protons in the atoms preventing the electrons from leaving. Since the electrons must repel each other while staying within the metal, excess electrons on a piece of metal must all spread evenly on the metal's surface (**Figure 4(b)**).

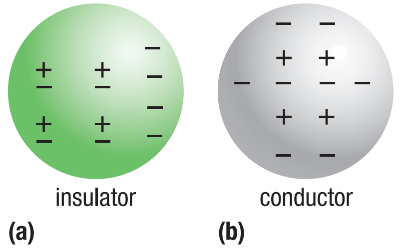

Figure 4 (a) When excess electrons are placed on an insulator, they generally stay where they are placed for a period of time. (b) Excess electrons placed on a conductor, however, spread out on the surface of the material immediately.

This does not mean that there are no charges within the metal. The interior of a neutral, uncharged metal contains equal numbers of positive and negative charges. These charges are present inside the metal at all times. Only the excess charge resides at the metal's surface. In Figure 4(b), excess charge on the metal surface distributes as negative charge, by adding electrons to the conductor, or as positive charge, by removing electrons from the conductor.

Charging an Object by Friction

Electricity was discovered when a piece of amber was rubbed with fur. The act of rubbing caused electrons to move from the fur to the amber. The amber thus acquired a net negative charge (an excess of electrons), whereas the fur was left with a net positive charge (an excess of positive ions). This process is called *charging by friction*. You can also charge a glass rod by rubbing it with a silk cloth, in which case electrons leave the glass and move to the silk, so the glass acquires a net positive charge. Through investigation, scientists have found that some materials have a stronger hold on their electrons than others. For example, glass has a weaker hold on its electrons than does silk. If you were to let glass and silk touch each other, some electrons would leave the glass and travel to the silk. Rubbing allows more surface to come into contact, and the friction it produces rips more electrons off the glass to go to the silk. **Figure 5** shows the electrostatic series, which indicates the relative hold on electrons that different materials have when being charged by friction.

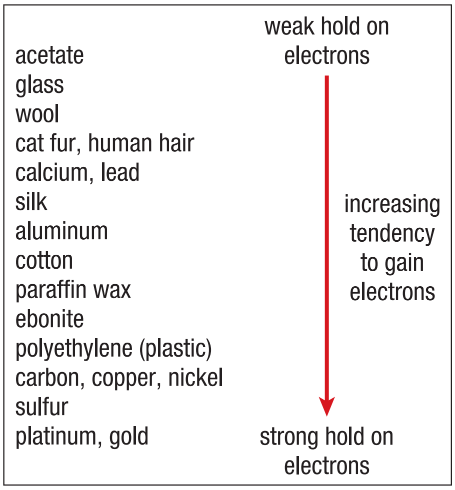

Figure 5 The electrostatic series

Charging an Object by Induced Charge Separation

If you look back at the example of using a charged plastic rod to attract pieces of paper, you may notice that something seems wrong. You now know that rubbing the rod with fur charges the rod. However, the pieces of paper start out neutral with a total charge of zero. How is the neutral paper attracted to the charged rod?

Although the paper is electrically neutral, the presence of the rod nearby causes some slight movement of the charges in the paper. The negatively charged rod repels electrons in the paper, which are then redistributed throughout the material. The electrons thus move a short distance away from the rod, as shown in **Figure 6**. A net positive charge remains on the portion of the paper nearest the rod, and a net negative charge stays on the paper opposite the rod. This process is called charging by *induced charge separation*.

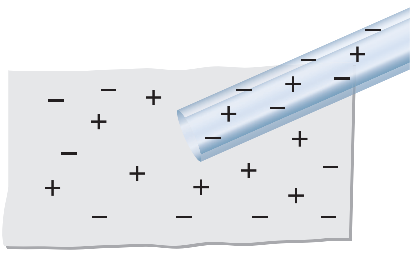

Figure 6 The negative charges in the paper have been repelled by the negative charges in the rod, leaving the area of the paper nearest to the rod positively charged and causing attraction between the paper and the rod.

Unlike charges attract, and the positive side of the paper is closer than the negative side of the paper to the negatively charged rod. This makes the paper attractive, overall, to the charged rod. In this way, an electric force pulls on an electrically neutral object once the object has undergone induced charge separation.

Another example of induced charge separation is shown in **Figure 7**. Ordinarily, the stream of water flows straight downward due to the force of gravity. However, if you place a charged balloon near the stream, it exerts a deflecting force on the water. The charged balloon induces a charge separation in the water molecules, producing an attractive force similar to that produced by the charged rod on the pieces of paper.

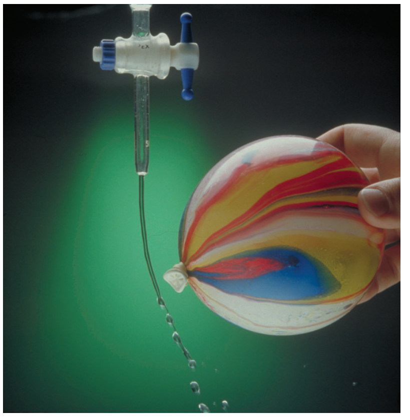

Figure 7 A stream of water is deflected by a nearby charged balloon.

Grounding

Suppose you place a charged rubber rod on a table. If you watch carefully with sensitive electronic measuring equipment, you will find that the excess electrons originally on the rod move to the table and then to other adjacent objects. Grounding occurs whenever any charge imbalance is cancelled out by either sending excess electrons into the ground or moving excess electrons from the ground into the object. Grounding works because Earth is so large that any extra electrons going into or out of the ground have an insignificant effect on Earth. The concept of grounding is used by electrical engineers to ensure that buildings and appliances are safe. Ground wires direct excess charges away from users, protecting them from electric shock. CAREER LINK

Charging by Contact and by Induction

How would you transfer some of the electrons on a negatively charged rubber rod to a piece of metal? You could do this by simply touching the rubber rod to the metal. The rod contains an excess of electrons, and some of these electrons will move to the metal upon contact (**Figure 8**). This is an example of *charging by contact*, or *charging by conduction*.

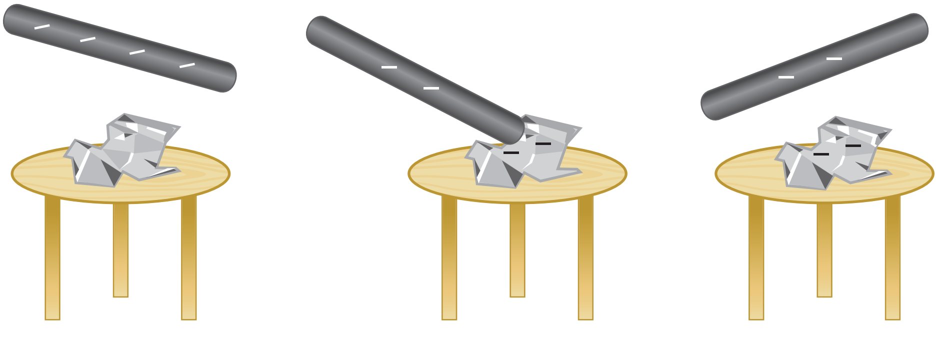

Figure 8 If one charged object touches a second object, the second object will usually acquire some of the excess charge. Hence, the second object is charged by contact. The stand in this illustration is an insulating stand.

Now suppose you want to give the metal a net positive charge using the same negatively charged rubber rod. This might seem an impossible task, but an approach called *charging by induction* will accomplish it. This approach uses the properties of induced charge separation and an electrical ground.

First, bring the negatively charged rod near the metal. This polarizes the conductor by moving conduction electrons to the side opposite the rod and leaving the side of the metal near the rod with a net positive charge (**Figure 9(a)**). Now, connect the negatively charged portion of the metal to an electrical ground using a metal wire. This allows electrons to move even farther from the charged rod by travelling into the electrical ground region (**Figure 9(b)**). Finally, after removing the grounding wire, the original piece of metal has a net positive charge (**Figure 9(c)**). Notice that no positive charges are transferred to the metal; instead, electrons are removed and the charge left on the metal is positive.

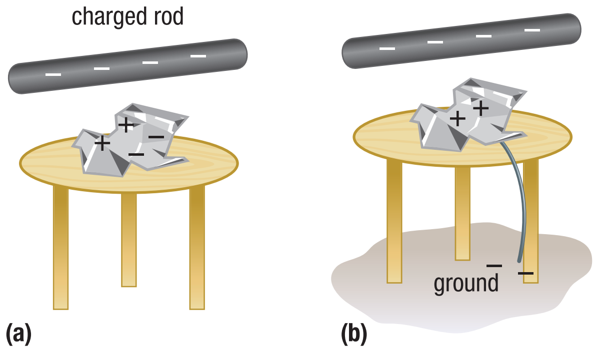

Figure 9 An object can be charged by the process of induction. (a) The object is first brought near a charged rod, separating the charges on the object. (b) The object is then connected to a ground; some electrons flow between it and the ground. (c) The object is left with an opposite excess charge when it is disconnected from the ground.

Mini **Investigation**

Observing Electric Charge

Skills: Controlling Variables, Performing, Observing, Analyzing, Communicating — SKILLS HANDBOOK A2.1

In this investigation, you will explore how different objects become charged. You will draw conclusions based on how these charged objects affect small pieces of paper.

Equipment and Materials: plastic pen; pencil; glass stirring rod; tissue paper; fabric

1. Tear a piece of tissue paper into several small pieces and gather them into a pile.
2. Charge the plastic pen by rubbing it on a piece of fabric, such as part of an old flannel shirt.
3. Bring the charged object near the pieces of paper.
4. Observe how the pieces of paper behave relative to the charged object used, and record your observations.
5. Gather the pieces of paper into a pile again, and repeat the steps, first using the pencil, and then using the glass rod. Record your observations.

A. Why does each charged object attract the pieces of paper differently? K/U T/I

B. Why do some pieces of paper fall off your charged objects after a short while? K/U T/I

C. If you used a metal sphere with a large charge, the pieces of paper would jump off instead of falling. Explain why this occurs. K/U T/I

7.1 Review

Summary

- Electric charges are either positive or negative. Objects that have more negative charge than positive charge are negatively charged. Objects that have more positive charge than negative charge are positively charged. Objects that have an equal number of positive and negative charges are neutral and have a total charge of zero.
- Electrons are the only subatomic particle capable of being transferred from one object to another. Protons are bound to the atomic nucleus.
- The law of electric charges states the following: Unlike, or opposite, electric charges attract each other. Like, or similar, electric charges repel each other.
- The law of conservation of charge states that charge can be created or destroyed, but the total charge of a closed system remains constant.
- Objects can be charged by friction, by induced charge separation, by contact, and by induction.

Questions

1. When you rub a glass rod with silk, the rod becomes positively charged; when you rub a plastic rod with fur, the rod becomes negatively charged. Suppose you have a charged object but do not know whether it carries a positive or a negative charge. Explain how you could use a glass rod and a piece of silk to determine the sign of the charge on the unknown object. K/U T/I
2. Explain how two objects attract one another due to an electric force, when one object has zero net charge. K/U C
3. Suppose children at a party rub balloons on their hair and then place the balloons on the wall. If the rubbing process puts excess electrons on the balloons, how do the balloons stay attached to the wall? K/U A
4. The end of a charged rubber rod attracts small pellets of foam plastic that, having made contact with the rod, quickly move away from it. Explain why this happens. T/I C
5. When two objects, such as a glass rod and a silk cloth, are rubbed together, electrons move from one object to the other. Can protons also move from one object to the other? Explain why or why not. K/U T/I
6. If you walk across a thick carpet on a cold, dry day, electrons will move from the carpet to your body. K/U
   (a) How does the charge on your body compare to the charge on the rug?
   (b) Which of the three methods of charging is demonstrated in this example?
7. A student upgrades the memory in her computer by replacing the memory chip. Before handling the chip, she first touches the metal casing of the computer. Why is this a good precaution? K/U A
8. Provide an example of how to give a neutral object a positive charge using only a negatively charged object. K/U C
9. In the following examples, describe the change in charge on each rod and charging material or object in terms of the movement of electrons. K/U
   (a) A glass rod is rubbed with a wool rag.
   (b) A plastic rod is rubbed with a silk scarf.
   (c) A platinum rod with a negative charge is touched with a similar rod with a positive charge.
   (d) A small metal rod touches a large positively charged metal sphere.
10. A student shakes hands with his father, who is wearing a wool sweater. As soon as they shake hands, a spark jumps between their hands. Explain what caused the spark. K/U
11. Fabric softener sheets are supposed to reduce the static cling between the clothes in a dryer. Research fabric softener sheets, and answer the following questions. K/U T/I
    (a) Why do clothes cling to each other when removed from a dryer?
    (b) How does a fabric softener sheet reduce the static cling among clothes?

WEB LINK