11.3.1: Electric Charge and Electric Force

Multiple lightning discharges from a single cloud

Figure 15.1.1

Lightning is the discharge of static electricity that has built up on clouds. Every year, the earth experiences an average of 25 million lightning strikes. Lightning bolts travel at speeds up to 60,000 miles per second, and can reach temperatures of 50,000°F, which is five times the temperature of the surface of the sun. The energy contained in a single lightning strike could light a 100 Watt light bulb 24 hours per day for 90 days.

Forces on Charged Objects

Electric charges exist within the atom. At the turn of the 20th century, J. J. Thomson and Ernest Rutherford determined that atoms contain very light-weight negatively charged particles called **electrons** and more massive, positively charged particles called **protons**. The protons are lodged in the **nucleus** of the atoms, along with the neutrally charged particles called **neutrons,** while the electrons surround the nucleus. When the number of electrons in the electron cloud and the number of protons in the nucleus are equal, the object is said to be **neutral**.

Changes to the nucleus of an atom require tremendous amounts of energy, so protons are not easily gained or lost by atoms. Electrons, on the other hand, are held fairly loosely and can often be removed quite easily. When an object loses some electrons, the remaining object is now positively charged because it has an excess of protons. The electrons may either remain free or may attach to another object. In that case, the extra electrons cause that object to become negatively charged. Atoms that have lost electrons and become positively charged are called **positive ions,** and atoms that have gained electrons and become negatively charged are called **negative ions**.

Electrons can be removed from some objects using friction, simply by rubbing one substance against another substance. There are many examples of objects becoming charged by friction, including a rubber comb through hair, and a balloon on a sweater. In both these instances, the electrons move from the second object to the first, causing the first object to become negatively charged and the second one positively charged. Friction between the tires on a moving car and the road cause the tires to become charged, and wind causes friction between clouds and air which causes clouds to become charged and can result in tremendous bolts of lightning.

Illustration of charged sweater and balloon

Figure 15.1.2

A common method of producing charge in the lab is to rub cat or rabbit fur against stiff rubber, producing a negative charge on the rubber rod. If you hold a rubber rod on one end and rub only the tip of the other end with a fur, you will find that only the tip becomes charged. The electrons you add to the tip of the rod remain where you put them instead of moving around on the rod. Rubber is an **insulator.** Insulators are substances that do not allow electrons to move through them. Glass, dry wood, most plastics, cloth, and dry air are common insulators. Materials that allow electrons to flow freely are called **conductors.** Metals have at least one electron that can move around freely, and all metals are conductors.

Forces are exerted on charged objects by other charged objects. You've probably heard the saying "opposites attract," which is true in regards to charged particles. Opposite charges attract each other, while like charges repulse each other. This can be seen in the image below. When two negatively charged objects are brought near each other, a repulsive force is produced. When two positively charged objects are brought near each other, a similar repulsive force is produced. When a negatively charged object is brought near a positively charged object, an attractive force is produced. Neutral objects have no influence on each other.

Attraction and repulsion of charged objects

Figure 15.1.3

Use the PLIX Interactive below to try to predict the attractive and repulsive forces exerted on one charged object by another charged object:

A laboratory instrument used to analyze and test for static charge is called an **electroscope.** Seen below, an electroscope consists of a metal knob connected by a metal stem to two very lightweight pieces of metal called leaves, shown in yellow. The leaves are enclosed in a box to eliminate stray air currents.

Uncharged electroscope

Figure 15.1.4

When a negatively charged object is brought near the knob of a neutral electroscope, the negative charge repels the electrons in the knob, and those electrons move down the stem into the leaves. Excess electrons flow from the rod into the ball, and then downwards making both leaves negatively charged. Since both leaves are negatively charged, they repel each other. When the rod is removed, the electroscope will remain charged because of the extra electrons added to it.

Electroscope that has been negatively charged by conduction

Figure 15.1.5

Conversely, if the rod is brought near the knob but doesn't touch it, the electroscope will appear the same while the rod is near. That is, the negative charge in the rod repels the electrons in the ball, causing them to travel down to the leaves. The leaves will separate while the rod is nearby. No extra electrons were added to the electroscope, meaning that the electrons in the electroscope will redistribute when the negatively charged rod is taken away. The leaves return to neutral, and they stop repelling each other. If the rod touches the knob, the electroscope leaves are permanently charged but if the rod is brought near but does not touch the knob, the electroscope leaves are only temporarily charged.

If the leaves are permanently charged and the rod removed, the electroscope can then be used to determine the type of unknown charge on an object. If the electroscope has been permanently negatively charged, and a negatively charge object is brought near the knob, the leaves will separate even further, showing the new object has the same charge as the leaves. If a positively charged object is brought near a negatively charged electroscope, it will attract some of the excess electrons up the stem and out of the leaves, causing the leaves to come slightly together.

Similar to the results of a negatively charged rod, if a positively charged rod is brought near the knob of a neutral electroscope, it will attract some electrons up from the leaves onto the knob. That process causes both of the leaves to be positively charged (excess protons), and the leaves will diverge. If the positively charged rob is actually touched to the knob, the rob will remove some electrons and then when the rob is removed, the electroscope will remain positively charged. This is a permanent positive charge.

Electroscope that has been positively charged by induction

Figure 15.1.6

Charging an object by touching it with another charged object is called **charging by conduction.** By bringing a charged object into contact with an uncharged object, some electrons will migrate to even out the charge on both objects. Charging by conduction gives the previously uncharged object a permanent charge. An uncharged object can also be charged using a method called **charging by induction**. This process allows a change in charge without actually touching the charged and uncharged objects to each other. Imagine a negatively charged rod held near the knob, but not touching. If we place a finger on the knob, some of the electrons will escape into our body, instead of down the stem and into the leaves. When both our finger and the negatively charged rod are removed, the previously uncharged electroscope now has a slight positive charge. It was charged by induction. Notice that charging by induction causes the newly charged object to have the opposite charge as the originally charged object, while charging by conduction gives them both the same charge.

Summary

- Electric charges exist with the atom.
- Atoms contain light-weight, loosely held, negatively charged particles called electrons and heavier, tightly-held, positvely charged particles called protons.

- When the number of electrons and the number of protons are equal, the object is neutral.
- The loss of electrons gives an ion a positive charge, while the gain of electrons gives it a negative charge.
- Materials that allow electrons to flow freely are called conductors, while those that do not are called insulators.
- Opposite charges attract, and like charges repel.
- Charging an object by touching it with another charged object is called charging by conduction.

Review

1. How does friction generate static electricity?
    1. Friction heats the materials, thus causing electricity.
    2. Rubbing materials together displaces atoms, causing sparks to fly.
    3. Rubbing materials together can strip electrons off atoms, causing one material to become positive and the other to become negative.
    4. Rubbing materials together causes neutrons and electrons to trade places.
    5. None of the above.
2. What electrical charge does an electron have?
    1. A negative charge.
    2. A positive charge.
    3. A neutral charge.
    4. May be any of the above.
    5. None of the above.
3. What happens when opposite charges get close to each other?
    1. They repel each other.
    2. They attract each other.
    3. Nothing happens.
    4. They attract surrounding objects.
    5. They repel surrounding objects.
4. What is an electrical conductor?
    1. A material that allows electrons to travel through it freely.
    2. A material that doesn't allow electrons to travel through it freely.
    3. A material that melts at low temperature.
    4. A material that creates free electrons.
    5. None of the above.
5. Which of the following is a good insulator of electricity?
    1. Copper
    2. Iron
    3. Rubber
    4. Salt water
    5. None of these.

Explore More

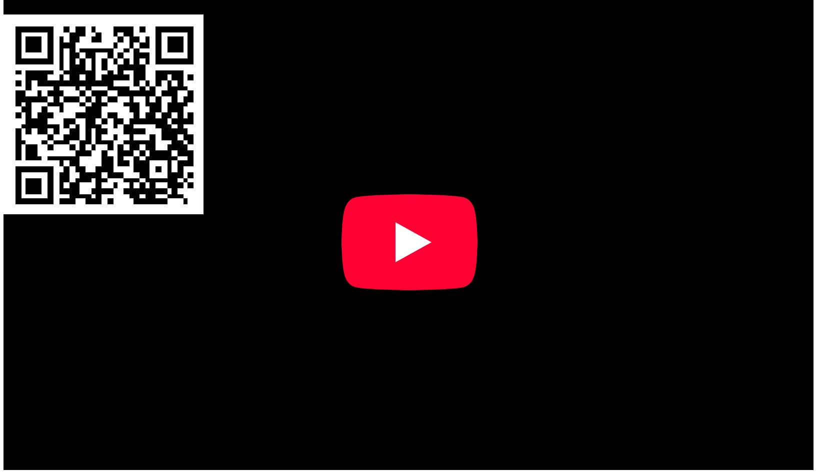
Use this resource to answer the questions that follow.

1. What will happen to Barbie's hair when the lady touches the Van de Graaff Generator?
2. Why do you think this happens to Barbie's hair?

Additional Resources

Study Guide: Electrostatics Study Guide

Video: Introduction to Electric Forces - Overview



Real World Application: Extreme Electrical Discharge

Interactive: lightning-rod

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