## 19.1. OVERVIEW

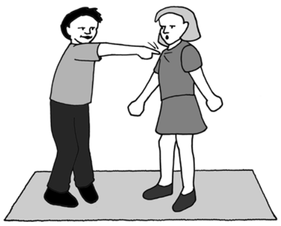


Fig. 19.1.

On cold, clear days, rubbing almost any object seems to cause it to be attracted to or repelled from other objects. After being used, a plastic comb will pick up bits of paper, hair, and cork, and people wearing polyester clothing in the winter walk around cursing the phenomenon dubbed in TV advertisements as "static cling." We are going to begin a study of electrical phenomena by exploring the nature of the forces between objects that have been rubbed or that have come into contact with objects that have been rubbed. These forces are attributed to a fundamental property of the constituents of atoms known as charge. The forces between particles that are not moving or that are moving relatively slowly are known as *electrostatic forces*.

We start our study in the first several sections by exploring the circumstances under which electrostatic forces are attractive and under which they are repulsive. This should allow you to determine how many types of charge there are. Then we can proceed to a qualitative study of how the forces between charged objects depend on the amount of charge the objects carry and on the distance between them. This will lead to a formulation of *Coulomb's law*, which expresses the mathematical relationship of the vector force between two small charged objects in terms of both distance and quantity of charge. In several later activities you will be asked to verify Coulomb's law quantitatively by performing a video analysis of the repulsion between two charged objects as they get closer and closer together.

Finally, at the end of the unit we will define a quantity called *electric field* that can be used to determine the net force on a small test charge due to the presence of other charges. You will then use Coulomb's law to calculate the electric field at various points of interest arising from some simply shaped charged objects.

# ELECTROSTATIC FORCES

## 19.2. EXPLORING THE NATURE OF ELECTRICAL INTERACTIONS

You can investigate some properties of electrical interactions with the following equipment. Each student should have:

- 4 Scotch tapes, approx. 10 cm long
- 2 small rod stands
- 2 threaded Styrofoam balls (with low mass)
- 2 threaded, metal-coated Styrofoam balls (with low mass)
- 1 hard plastic rod
- 1 piece of fur
- 1 glass rod
- 1 polyester cloth
- 2 metal rods
- 2 right angle clamps

| Recommended Group Size: | 2 | Interactive Demo OK?: | N |
| --- | --- | --- | --- |

The nature of electrical interactions is not obvious without careful experimentation and reasoning. We will first state two hypotheses about electrical interactions. We will then observe some electrical interactions and determine whether our observations are consistent with these hypotheses.

*Hypothesis One*: The interaction between objects that have been rubbed is due to a *property* of matter that we will call *charge*.* There are two types of electrical charge that we will call, for the sake of convenience, positive charge and negative charge.

*Hypothesis Two*: Charge moves readily on certain materials, known as conductors, and not on others, known as insulators. In general, metals are good conductors, while glass, rubber, and plastic tend to be insulators.

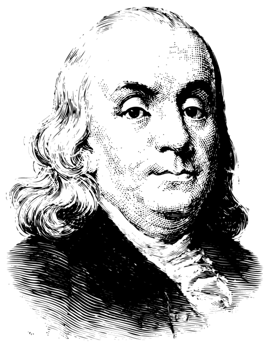
**Note:** In completing the following activities, you are not allowed to state results that you have memorized previously. You must devise a sound and logical set of reasons to support the hypotheses.

### Hypothesis One: Testing for Different Types of Charge

Try the following suggested activities. Mess around and see if you can design careful, logical procedures to demonstrate that there are at least two types of charge. Carefully explain your observations and reasons for any conclusions

* A property of matter is not the same thing as the matter itself. For instance, a full balloon has several properties at once—it can be made of rubber or plastic, have the color yellow or blue, have a certain surface area and so on. Thus, we don't think of charge as a substance but rather as a property that certain substances can have at times. It is easy when speaking and writing casually to refer to charge as if it were a substance. Don't be misled by this practice that we will all indulge in at times during the next few units.

**b.** What happens if you rub a glass rod with polyester and then bring it into the vicinity of the balls that were charged with the plastic rod?



Benjamin Franklin

**c.** Recalling the interactions between like and unlike charged objects that you observed before, can you explain your observations?

**d.** Touch the entire surface of each of the two charged Styrofoam balls with your hands. Now what happens when you let them hang again? Is there an interaction between them?

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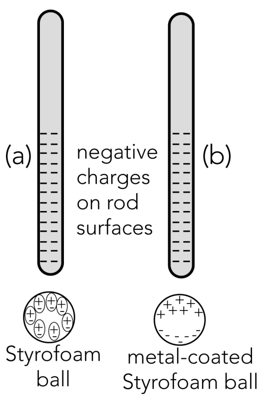



**Fig. 19.4.** Depiction of how excess electrons can influence a neutral insulator and a neutral conductor. (a) The electrons in the Styrofoam insulator are repelled from those in the rod but stay with their atoms. (b) Electrons in a metal-coated ball are repelled by the electrons in the rod and are free to move as far away from the rod as possible.

Benjamin Franklin *arbitrarily* assigned the term "negative" to the nature of the charge that results when a hard plastic rod (or, in his day, a rubber rod) is rubbed with fur. Conversely, the nature of the charge found on the glass rod after it is rubbed with silk is defined as "positive." (The term "negative" could just as well have been assigned to the charge on the glass rod; the choice was purely arbitrary.)

#### Hypothesis Two: Using Induction to Distinguish Conductors from Nonconductors

Scientists believe that most matter is made of atoms that contain positive and negative charges associated with protons and electrons respectively. When electrons in an atom surround an equal number of protons the charges neutralize each other and the atom does not interact with other charges outside the solid. In some types of solid materials, known as insulators, the electrons are tightly bound to the protons in the atoms and do not move away from their atoms. However, in other solids known as conductors, the electrons but not the protons are free to move under the influence of other charges. The process by which external charges can cause electrons in an object to rearrange themselves so that the positive and negative charges no longer neutralize each other is know as *induction*.

In the next activity you will study an interaction that involves induction and one that doesn't. You should observe the interaction between an uncharged non-metal-coated Styrofoam ball that is hanging freely and a charged plastic rod. You should also observe the interaction between the charged rod and an uncharged metal-coated Styrofoam ball that is hanging. Note: Before making each observation, touch each of your hanging balls to make sure they are not charged.

### 19.2.3. Activity: Insulators, Conductors, and Induction

**a.** What happens when you bring a negatively-charged plastic rod near an uncharged insulator consisting of a single Styrofoam ball?

**1.** Before the two objects touch:

**2.** After they touch:

**b.** Repeat observation a. using an uncharged metal-coated Styrofoam ball.

**1.** Before the two objects touch:

**2.** After they touch:

**c.** Use Hypothesis Two, which claims that charges move readily on conductors, to explain why the metal-covered ball is *attracted* to the rod *before* touching and *repelled after* touching it.

**d.** Use Hypothesis Two, which claims that if an object is an insulator, its electrons will stay in their vicinity of their atoms, to explain why the uncoated Styrofoam ball is repelled by the rod after touching it.

**Note:** We picture "uncharged" objects made up of a huge number of atoms having an equal number of negatively charged electrons that swarm around positively charged protons in the atomic nuclei. A "charged" object has either more electrons than protons or fewer electrons than protons. For this reason, we refer to a charged object as having "excess charge" or "a net charge."

## 19.3. FORCES BETWEEN CHARGES– COULOMB'S LAW

Coulomb's law is a mathematical description of the fundamental nature of the electrical forces between charged objects that are either spherical in shape or small compared to the distance between them (so that they act more or less like point particles). This law relates the force between small charged objects to the excess charge on the objects and the distance between them. Coulomb's law is usually stated without experimental proof in most introductory physics textbooks. Instead of just accepting the textbook statement of Coulomb's law, you are going to determine qualitatively how the charge on two objects and their separation affect the mutual force between them. These objects could be, for instance, two metal-coated balls, or perhaps a small metal ball affixed to the tip of an insulated rod and one metal-coated ball. For this set of observations you will need:

- 2 small rod stands
- 2 threaded, metal-coated Styrofoam (or ping pong) balls with low mass
- 1 hard plastic rod
- 1 piece of fur
- 1 glass rod
- 1 polyester cloth
- 2 metal rods
- 2 right angle clamps

| | | | |
|---|---|---|---|
| Recommended Group Size: | 2 | Interactive Demo OK?: | N |

**Note:** Coulomb devised a clever method for determining how much force charged objects exert on each other without knowing the actual amount of charge on the objects. Coulomb transferred an unknown amount of charge, $q$, to a conductor. He then touched the newly charged conductor to an identical uncharged one. The conducting objects would quickly exchange charge until both had a net or excess charge $q/2$ on them. After observing the effects with $q/2$, Coulomb would discharge one of the conductors by touching a large piece of metal to it and then repeat the procedure to get $q/4$ on each conductor, and so on.

### 19.3.1. Activity: Dependence of Force on Charge, Distance, and Direction—Qualitative Observations

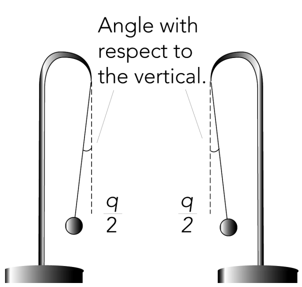
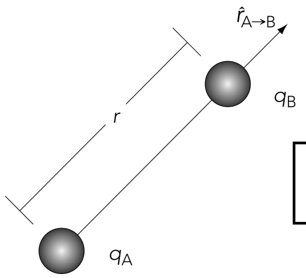



**Fig. 19.5.** Original position of pivots for 2 charged conductors.

Consider a pair of conductors, each initially having excess charge $q_A = q_B = q/2$. These conductors are hanging from strings in the configuration shown in Figure 19.5.

Use the following diagrams to sketch what you predict will happen to the angles the charged objects make with respect to the vertical as compared to their initial angles when $q_A = q_B = q/2$. In each case give the reasons for your prediction. Then make the observation and sketch what you observed.

by the equation following which represents the electrostatic force exerted on $q_A$ due to $q_B$.




$$\vec{F}^{elec}_{A\to B} = k\frac{q_A q_B}{r^2}\hat{r}_{A\to B} \qquad (19.1)$$

**Fig. 19.6.** Diagram showing the direction of the unit vector $\hat{r}_{A\text{->}B}$ used in the Coulomb force equation that describes the influence of charge $q_A$ on charge $q_B$.

The $\hat{r}_{A\text{->}B}$ with a "hat" over it is a unit vector directed from $q_A$ to $q_B$, $r^2$ is the square of the distance between the two charged objects in meters, $k$ is the Coulomb constant (8.99 × $10^9$ N·m$^2$/C$^2$), and $q_A$ and $q_B$ are the charges in coulombs.

### 19.4.1. Activity: "Reading" the Coulomb Equation

**a.** Draw the direction of the unit vector in the diagram below. **Note:** The direction of this vector does not depend on the signs or the magnitudes of the charges.


**b.** In the table below, indicate the sign of the product of $q_A$ and $q_B$ for each combination of positive and/or negative charges.

| Sign of $q_A$ | Sign of $q_B$ | Sign of $q_A \cdot q_B$ |
|---|---|---|
| + | + | |
| + | – | |
| – | + | |
| – | – | |

**c.** Use an arrow to indicate the direction of the force exerted by $q_A$ on $q_B$ if the charges are both positive or both negative.


**d.** Use an arrow to indicate the direction of the force exerted by $q_A$ on $q_B$ if the charges have opposite signs (that is, one is positive and one is negative).