

Electrostatics: Coulomb's Law



Objective: To learn how excess charge is created and transferred. To measure the electrostatic force between two objects as a function of their electrical charges and their separation distance.

Apparatus: Copper sphere on rod (3, one with standing base), charging rod, capacitor, fake fur, scale, meter stick, ring stand, voltmeter, connectors and wires

Introduction

There are two types of electrical charge - positive and negative. Like charges (positive and positive, or negative and negative) repel each other, while unlike charges (negative and positive) attract each other. Materials through which charges are free to move, like most metals, are called *conductors*. Materials in which charges are not free to move, like most nonmetals, are called *insulators*. The charges that are mobile in conductors are *negative* charges – the free electrons that are not bound to any particular atoms. The charges that are static are *positive* charges – protons which are in the nuclei of the atoms that make up the material.

Charge is neither created nor destroyed (conservation of charge). The appearance of excess charge on an object happens when charge being transferred from somewhere else.

For instance, rubbing a piece of amber with a piece of fur results in the amber acquiring a net negative charge; however, the fur has acquired a net positive charge from the same interaction. In this experiment, you will produce excess charge by rubbing, and then transfer this charge to conducting copper spheres. The spheres are connected to insulated rods so that they can be handled without the charge leaking out. A scale on which one of the charged spheres is placed would then read heavier or lighter (giving us the Coulomb force magnitude) in the presence of another charged sphere, compared to its weight as an electrically neutral sphere. You will measure the distance between the spheres using a meter stick, and the charge on each sphere by discharging it into a capacitor, a device that stores a charge. Since the capacitor is connected to a voltmeter, you can then determine the charge that was on it from the equation:

$Q=CV$ where Q is the charge, C is the capacitance, and V is the voltage

Coulomb's Law, which determines the electrostatic force between objects 1 and 2 based on their electrical charges and separation distance, is written as follows:

$$F = k \frac{Q_1 Q_2}{r^2}$$

The constant of proportionality k has the units Newton-Meter²/Coulomb² and has the value $k = 9 \times 10^9 \frac{N \cdot m^2}{r^2}$

As in gravitational forces, the electrostatic force lies along the line connecting the center of the spheres. The **sign** of the *Coulomb force* will be either be positive, denoting *repulsion* or negative, denoting *attraction*. Note that if one of the charges in the equation is negative, the force will be attractive. If both charges are negative or positive, the force will be repulsive. As mentioned before, like charges repel while unlike charges attract.

How to charge objects

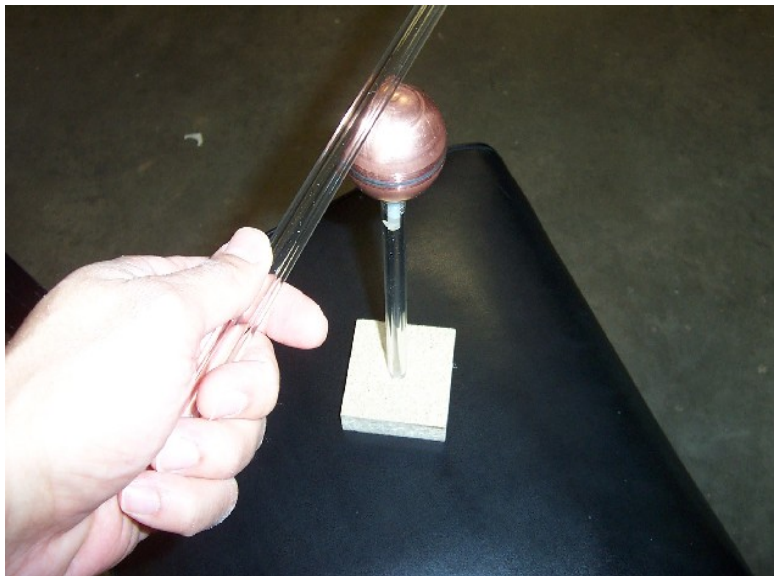
You can produce excess charge on objects by two methods:

1. *Charging by contact* involves charging an object that is electrically neutral by touching it with an object that is already charged. In this experiment, you will rub the charging rod to give it excess charge, then transfer that charge to a copper sphere using the following technique:

Pick up the charging rod – the clear cylindrical rod that is unattached to any copper sphere. Hold it by one end. Pick up the gray fake fur in the other hand and wrap it around the rod, covering as much of the it as you can. Rub the fake fur against the rod vigorously several times, along the length of the rod. You should hear crackling sounds as charges are being separated. **Do not rub so hard that your hands sweat or the fur gets hot, since that could diminish the transfer of charge.** You will then rub the length of the rod (rotating at the same time, since the charges on the rod are *static*) on the copper sphere with the rod, transferring the charge. See the photos below:

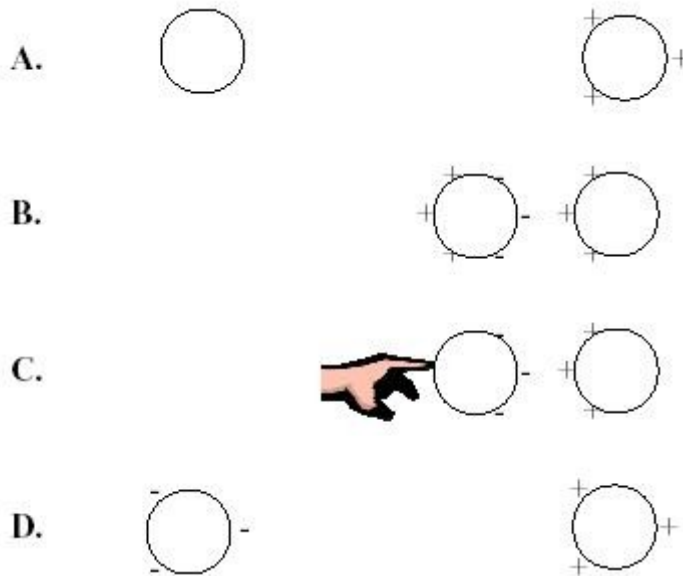


Rubbing the fur against the rod



Rubbing the surface area of the rod on the sphere

2. *Charging by induction* involves no contact, and relies on the fact an object with, say, positive charge brought close to, but not touching, a conductor, will draw negative charges toward the side that the positive object is on. Since the conductor was originally electrically neutral, positive charges will migrate to the opposite side, leading to a separation of charges. Such an object, which has its unlike charges separated but which remains electrically neutral, is electrically **polarized**. Here is an illustration of how to charge an object by induction:



Charging by Induction

In the illustration above, (A) a neutral sphere is brought close to an sphere with positive excess charge. (B) The positively charged sphere pulls the negative charges on the neutral sphere towards it. The positive charges on the neutral sphere are pushed away from it, leading to an electric polarization of the neutral sphere. (C) When one side of the electrically polarized sphere is touched, or **grounded**, charge from that side flows from the hand, down the toucher's body into the ground. (D) The previously neutral sphere now has excess negative charge. Note that the two spheres never touched.

This polarization effect can also explain why a charged object can exert forces on insulators – the electric force causes the positive and negative charges in the insulator to separate slightly, with the negative charges being pulled towards the positive (for example) rod and the positive charges being pushed away. Since Coulomb's law is distance-dependent, the two objects experience a net attractive force, since the unlike charges are closer than the like charges. Bear in mind that had a negatively charged rod been used, attraction would again result, because it would have drawn positive charges closer than the negative charges.

Note that a charged sphere touches an identical one that was previously neutral, charges flow from one to the other such that after the make contact, the initial charge Q is now shared equally between them, with each one having a charge $Q/2$.

To make a sphere electrically neutral again, simply touch it with your finger – the charges travel from the sphere through your body and down to the ground. So be careful, while you are doing your experiment, that you do not accidentally touch any spheres that ought to be charged – this will render them uncharged.

Activities

****FIRST STEP – USE THE HAIR DRYER IN THE LAB ROOM (OR GO TO THE MEN'S/WOMEN'S ROOM) TO DRY YOUR FUR AND CHARGING ROD. MOISTURE IS BAD FOR PRODUCING CHARGES****

A. Qualitative Observations (skip if you've already performed the Electrostatics I lab)

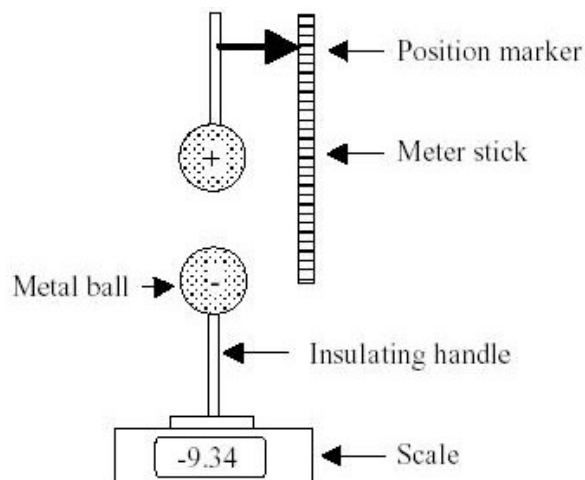
Find out what small objects (tiny pieces of paper, hair, etc.) a charged rod can attract and write in hand-in sheet. Since you used the fur to charge the rod, then the fur should have excess charge of opposite sign – can you pick up the same objects with the fur as well?

B. Dependence of Coulomb Force on Signs of Charge

Together with your lab partner(s), design an experiment to qualitatively prove that charges of the same sign repel and charges of opposite sign attract. Before you do that, read the little box below regarding the detection of the Coulomb force. Remember, to start off with an electrically neutral sphere, you will have to touch it to **ground** it. Also, bear in mind that spheres too close to each other will exchange charges, while spheres too far from each other may not exert forces high enough for the scale to measure.

Using the scale to measure the Coulomb Force of one sphere on another

The scale should be empty before you turn it on (remove the standing copper sphere). Turn on the scale by pressing the On button. If it reads “ERR”, try pressing the On button again and holding it down until you see “CAL” on the display. Let go and it should display a scale reading. Press the Mode button until the correct units is shown – choose “g” for grams. It will now display the mass of the sphere, connected rod and wood base. You will have to multiply this value by g, the acceleration of gravity, which is 980 cm/s^2 to yield the force in *Dynes*. You can also convert the grams to kilograms and multiply by 9.8 m/s^2 to yield the force in *Newtons*. Note that $1\text{N}=10^5\text{Dynes}$. Note down this “baseline” value – you will be subtracting it from subsequent readings to find out the change in mass (and hence force). **DO NOT TARE THE SCALE**. The converted reading will represent the electrostatic force (when multiplied by g) upon the sphere due to the sphere above: downward (repulsion) is positive, upward (attraction) is negative.



Measuring force and distance between two charged spheres (NOTE: setup may differ slightly from illustration)

C. Dependence of Coulomb Force on Distance

Design an experiment to determine how the Coulomb force varies with distance (doesn't vary? varies linearly? inversely? proportional to square? proportional to inverse square? exponentially? inverse exponentially?). Here are a few things to remember when measuring the force while changing the sphere separation:

- Loosen the clamp on the ring stand to adjust the height, then re-tighten. Make sure you are reading the distance **after** you have tightened the clamp, since a loose clamp will position the sphere lower than it should be.

-You need to work quickly, since charge will slowly leak from the spheres.

-Remember to multiply the mass by g to obtain the force.

You may use the curve-fitting features of Graphical Analysis to find the **F vs. d** dependence.

D. Dependence of Coulomb Force on Charge

Design an experiment to determine how the Coulomb Force varies with charge, without having to directly measure the charge (as you will later do with a capacitor and voltmeter). It will only be necessary to vary the charge on one of the spheres – think of how you can halve the charge on sphere, and continually do so.

E. Compare Theory to Experiment Using Measured Force, Distance and Charge

Measure the force between two charged spheres and compare it to the force as obtained from the Coulomb's Law equation. This time, measure not only the force and distance, but also the charge, as described below:

Turn on the orange voltmeter (multimeter) by turning the rotary knob to the first position to the right (clockwise) of the “Off” position. Whatever the voltmeter will read will be in units of mV. The voltmeter will be used to measure the charge on the spheres. Connect the black and red wires coming out of the voltmeter into each other – this will ensure that the capacitor does not contain any residual charge and is ready to receive charge from the spheres.

Locate the black and red multimeter leads (wire ends); touch them to one another so that whatever charge was in the capacitor is discharged and the meter reads “0.00”. The black lead should be touching something that is grounded; remember from Electrostatics I that your finger can ground things. Touch the red lead to one sphere and pull it away. You should hear the discharge pop resulting from the charge leaving the sphere; from there it will enter the wire and charge up the capacitor. Note the reading on the voltmeter and record in the hand-in sheet. Touch the black and red leads to each other again to discharge the capacitor, then repeat the reading on the other sphere. **Try to work quickly to beat the charge leakage from the spheres.**

Perform three separate readings, grounding and charging the spheres between each one.