

Experiment 1: Coulomb's Law

Introduction to Coulomb's Law

In 1785 Augustin de Coulomb investigated the attractive and repulsive forces between charged objects, experimentally formulating what is now referred to as Coulomb's Law: "The magnitude of the electric force that a particle exerts on another is directly proportional to the product of their charges and inversely proportional to the square of the distance between them." Mathematically, the magnitude of this electrostatic force F acting on two charged particles (q_1, q_2) is expressed as:

$$F = k \frac{q_1 q_2}{r^2} \quad (1)$$

where r is the separation distance between the objects and k is a constant of proportionality, called the Coulomb constant, $k = 9.0 \times 10^9 \text{ Nm}^2/\text{C}^2$. This formula gives us the magnitude of the force and we can get the direction by noting a positive force as repulsive and a negative force as attractive. Noting that like charges repel each other and opposite charges attracting each other, Coulomb measured the force between the objects, in the form of small metal coated balls, by using a torsion balance similar to the balance used to measure gravitational forces, as shown in Figure 1a.

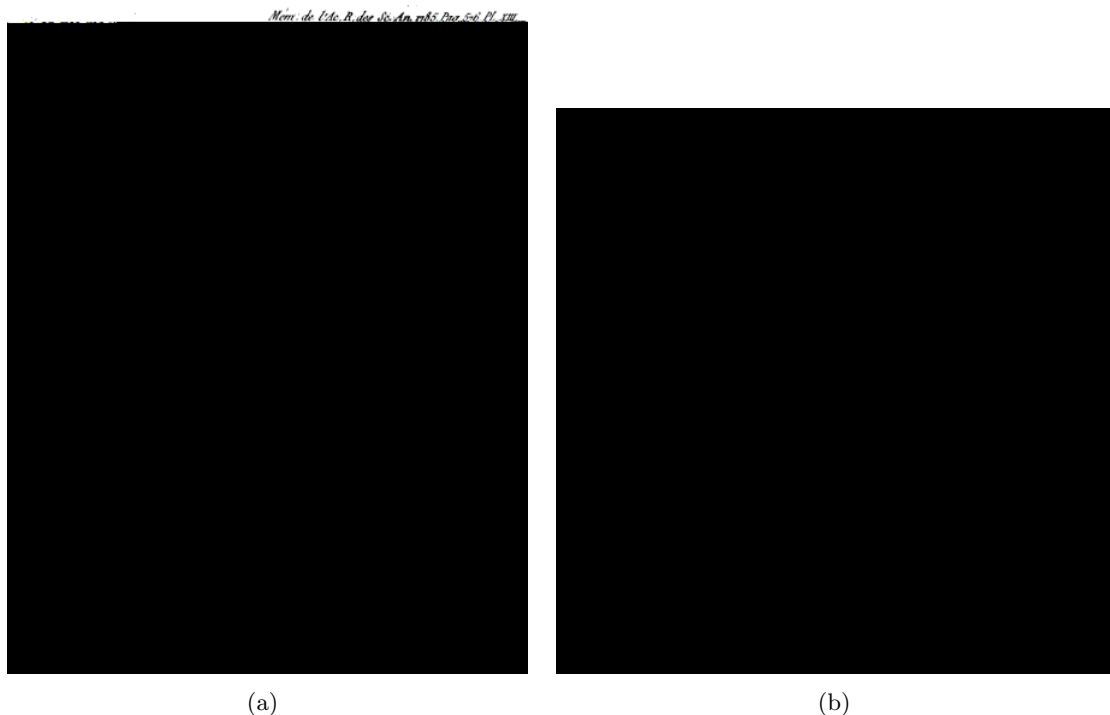


Figure 1: (a) Coulomb's torsion balance: A pith ball (lower right corner) is attached on a rotating beam with a counterweight on the opposite end. When a second pith ball (upper left corner) of equal charge is brought near the first ball, they will repel, and the beam starts to rotate (Source: Coulomb, 1785). (b) A pith ball electroscope. (Source: Luken, A., 1878).

In this lab, we will study Coulomb’s law and measure the electric charge transferred from one object to another using a pith ball electroscope. A simple electroscope is a device used to measure the presence and magnitude of electric charges. The pith ball electroscope in Figure 1b, for example, shows the attraction between two charged objects - a pith ball (a light weight object that can easily be charged) and a charged rod. There are two ways to displace charges an object: conduction or induction. Charging by conduction involves direct contact while induction requires no contact. Rubbing dissimilar materials, for example, can remove or deposit electrons. This process is referred to as triboelectricity (or frictional electricity) since the materials are charged by friction. For example, rubbing a neutral glass rod with silk “rips” charges off one of these surfaces and makes them stick to the other. Whether a material is an electron donor or acceptor depends on its electronegativity. Figure 2 shows the relative electron affinities for several popular materials. The materials listed towards the positive end donate electrons while the materials towards the negative end accept electrons. If a PVC rod is rubbed with silk, the rod will acquire a negative charge. If nylon is rubbed with silk, it will acquire a positive charge.



Figure 2: A relative electronegativity ranking for some common materials. Here “+” is electron donating, “-” is electron accepting. The further apart the materials, the greater the charge transferred, resulting in greater static charge.

In this lab, the pith ball electroscope consists of two small balls (the pith balls) suspended by threads, as shown in Figure 3a. The pith balls may be charged by transferring charges from the positive or negatively charged rod. If the charges have the same sign, the Coulomb force is repulsive, separating the balls a distance “r” away from each other. A free body diagram for the right ball is shown in Figure 3b, where F is the acting electric force, T is the tension in the thread, θ is the resulting equilibrium angle, and W is the weight of the pith ball ($W = mg$).

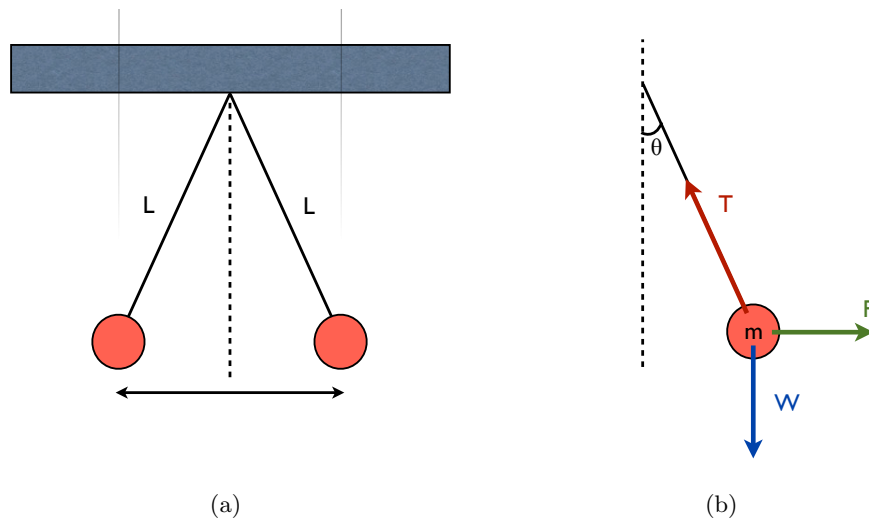


Figure 3: (a) A simple electroscope with two equally charged objects of mass “ m ” hanging from threads of length L . (b) Free body diagram for the right pith ball.

Experimental Procedure:

In this lab you are given colored pith balls each with a mass of 0.04 grams. You also have several types of conduction rods as shown in figure 2. Use the following materials to triboelectrically charge the rods: wool/felt, silk, plastic bag sheet (polyethylene), your own hair, and mystery fur. Charge the pith balls by dragging the rod across the metal support where the string is tied. Avoid touching the pith balls or support with your hand (that will discharge the balls). Note that once the pith balls are charged they will slowly (or quickly, if it’s humid) start to discharge. A mirror scale is provided to measure the separation distance “ r ”. If the pith balls discharge too quickly, both lab partners should estimate a value for the distance.

- Using the pith balls, devise and carry out an experiment to measure the amount of charge transferred to each pith ball by the rods and the Coulomb force between them. Repeat the experiment with different rods charged by different materials.
- Knowing that the acrylic rod acquires a positive charge when rubbed with silk, devise an experiment to conclude what kind of charge (\pm) the other rods obtain when rubbed with silk. Repeat this for plastic, wool or mystery fur.

Answer the following questions in your lab write up:

1. Using the free body diagrams of Figure 3, derive an expression for the charge in terms of the pith ball mass m , and the separation distance “ r ”.
2. Calculate the charge on the pith balls for each rod/soft material combination. How many millions or billions of electrons reside on each pith ball?
3. Compare the extremely small gravitational attraction between the two pith balls with the repulsion of the electrostatic force.
4. Develop a way to determine if the mystery fur is from a rabbit or cat. If you have time, try your method out, to see if it works. If time is short, or humidity is too high, describe how one could carry out the method in conditions with lower humidity.