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, this electrostatic force acting on two charged particles \( (q_1, q_2) \) is expressed as

\[
F = k \frac{q_1 q_2}{r^2} \tag{1}
\]

where \( r \) is the separation distance between the objects and \( k \) is a constant of proportionality, called the Coulomb constant, \( k = 9.0 \times 10^9 \ \text{N} \cdot \text{m}^2/\text{C}^2 \). This formula gives us the magnitude of the force as well as direction by noting a positive force as attractive and a negative force as repulsive. Noting that like charges repel each other and opposite charges attracting each other, Coulomb measured the force between the objects, 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).](image-url)
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 glass rod. There are two ways to charge an object: conduction or induction. Charging by conduction involves direct contact while induction requires no contact. Rubbing several materials, for example, removes or leaves electrons. This is 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 accepter 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. For example, if a PVC rod is rubbed with silk, the rod will acquire a negative charge. However, 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 insulating 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 Objectives:**

In this lab you are given beige colored pith balls each with a mass of 0.04 grams. You also have the following types of conduction rods: hard nylon (dark grey), a plastic rod (white rod with rounded ends), acrylic/lucite (clear rod), hard rubber (black) and acetate/rayon (white rod with flat ends). 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 one at a time, and avoid touching them with your hand (that will discharge the balls). Note that once the pith balls are charged they will slowly start to discharge. A mirror scale is provided to measure the separation distance “r”.

- 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. Remember to do several trials for each rod to keep any errors to minimum. 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 (±) the other rods obtain when rubbed with silk. Repeat this for plastic and wool.

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 angle between the threads $\theta$. *Tip:* Make use of small angle approximation.

2. Calculate the charge on the pith balls for each trial. How many electrons reside on each pith ball?

3. Compare the gravitational attraction between the two pith balls with the repulsion of the electrostatic force.

4. Will the angles of the two pith balls ever be different? Explain.