

## EXPERIMENT 1 COULOMB'S LAW

### I. THEORY

In this experiment we will study the electrostatic force of repulsion between identical charged spheres. We will vary the distance between centers of the spheres, and also the amount of charge on each sphere.

In the first part of the experiment, we will vary the distance  $r$  while holding the charges  $q_1$  and  $q_2$  constant. Assume that the force function in this case is of the form

$$F = A r^N$$

where the value of the constant  $A$  depends on the values of  $q_1$  and  $q_2$ , as well as on the units used. Taking logarithms of both sides of the above equation, we obtain

$$\log F = \log A + N \log r$$

$N$  is then the slope of a graph of  $\log F$  versus  $\log r$ . If Coulomb's measurements were correct, we expect the graph to be linear and to yield a slope of negative two.

In the second part of the experiment we will vary the charges  $q_1$  and  $q_2$ , while holding the distance  $r$  constant. Assume that the force function in this case is of the form

$$F = B (q_1 q_2)^M$$

where the constant  $B$  depends on the value of  $r$  as well as on the units used. Taking logarithms of both sides of this equation, we obtain

$$\log F = \log B + M \log(q_1 q_2)$$

$M$  is then the slope of a graph of  $\log F$  versus  $\log (q_1 q_2)$ . Again, if Coulomb's measurements were correct, we expect the graph to be linear and to yield a slope of positive one.

The apparatus used in this experiment actually measures the torsion angle and not the force. Since the net torque is equal to the force times the lever arm (which is constant throughout this lab) and the net torque is approximately equal to the torsion constant of the wire times the torsion angle, the force is directly proportional to the torsion angle. Therefore, in this experiment you will graph  $\log \theta$  instead of  $\log F$ . We will not actually calculate the charge on each sphere, but the charge will be proportional to the potential applied to each sphere. Due to the properties of the log function the graph of  $\log \theta$  vs.  $\log r$  will have the same slope as the graph of  $\log F$  vs.  $\log r$ . The same will be true for the graphs of  $\log \theta$  vs.  $\log(V_1 V_2)$  and  $\log F$  vs.  $\log(q_1 q_2)$ . The graphs of  $\log \theta$  vs.  $\log(V_1 V_2)$  and  $\log F$  vs.  $\log(q_1 q_2)$  will also have equal slopes.

Unfortunately, charge leaks continually from the spheres, especially under humid conditions. In order to minimize the leakage effects, the spheres should be recharged before each measurement and measurements should be performed as quickly as possible after charging.

In this experiment we will use a delicate torsion balance to investigate the force between the charged spheres. A conductive sphere is mounted on a rod, counterbalanced, and suspended from a thin torsion wire. An identical sphere is mounted on a slide assembly so it can be positioned at various distances from the suspended sphere.

To perform the experiment, both spheres are charged using a stable kilovolt power supply to ensure a reproducible charge throughout the experiment.

The charge on each sphere is directly proportional to the potential applied to the sphere. The sphere on the slide assembly is placed at fixed distances from the equilibrium position of the suspended sphere. The electrostatic force between the spheres causes the torsion wire to twist. The experimenter then twists the torsion wire to bring the balance back to its equilibrium position. The angle through which the torsion wire must be twisted to reestablish equilibrium is directly proportional to the electrostatic force between the spheres.

## II. LABORATORY PROCEDURE

1. The Coulomb Balance will be set up by the instructor before lab.
2. Make sure the spheres are fully discharged (touch them with a grounded probe) and move the sliding sphere as far as possible from the suspended sphere.
3. Set the torsion dial to  $0^\circ$ . Zero the torsion balance by appropriately rotating the bottom torsion wire retainer until the pendulum assembly is at its zero displacement position as indicated by the index marks. (This step may be done by the instructor before lab.)
4. With the spheres still at maximum separation, charge both the spheres to a potential of 5.0 kV, using the charging probe. (One terminal of the power supply should be grounded.) Immediately after charging the spheres, turn the power supply off to avoid high voltage leakage effects.
5. Position the sliding sphere at a separation of 16.0 cm. Adjust the torsion knob as necessary to balance the forces and bring the pendulum back to the zero position. Record the separation distance and the angle on your data sheet.
6. Separate the spheres to their maximum separation, recharge them to the same voltage, then reposition the sliding sphere at a separation of 16.0 cm. Measure the torsion angle and record your results again. Repeat this measurement several times, until your result is repeatable to within  $\pm 1$  degree. Record all your results.

7. Repeat steps 3-5 for separations of 14.0, 12.0, 10.0, and 9.0 cm.
8. With the spheres at maximum separation, charge both of the spheres to a potential of 5.5 kV, using the charging probe. (One terminal of the power supply should be grounded.) As before, immediately after charging the spheres turn the power supply off to avoid high voltage leakage effects.
9. Reposition the sliding sphere at 10.0 cm. This will be the separation used for all of the remaining measurements in the lab. Measure the torsion angle and record your results again. Repeat this measurement several times (recharging the spheres between measurements), until your result is repeatable to within  $\pm 1$  degree. Record all your results.
10. Repeat steps 7 & 8 for potentials of 5.0, 4.5, 4.0, and 3.5 kV.

### III. CALCULATIONS

1. For the first part of the experiment, in which distance was varied, make a table containing the following quantities: separation distance  $r$ ,  $\log r$ , torsion angle  $\theta$ , and  $\log \theta$ . The value of  $r$  should be in cm so that  $\log r$  will take positive values. (Can you show that the graph of step #2 will have the same slope if  $r$  is changed from cm to m?) Use common logarithms.
2. Plot a graph of  $\log \theta$  versus  $\log r$ . Draw the straight line which best represents the plotted points.
3. Use the method of least squares to calculate the slope of the graph of  $\log \theta$  versus  $\log r$ . Calculate the percent error between the slope and the expected value of the slope. The method of least squares can be found in the introduction. Make a table as on page I-10 of this manual, using all data points. Note the warning relating to rounding errors on that page.
4. Round off the slope to the nearest integer. Using the value of  $N$  thus found, write the equation for the force as a function of the separation distance.
5. For the second part of the experiment, in which charge was varied, make a table containing the following quantities: applied voltage  $V_1$  and  $V_2$ ; the product  $V_1V_2$ ,  $\log (V_1V_2)$ , torsion angle  $\theta$ , and  $\log \theta$ . Use common logarithms.
6. Plot a graph of  $\log \theta$  versus  $\log (V_1V_2)$ . Draw the straight line which best represents the plotted points.
7. Use the method of least squares to calculate the slope of the graph of  $\log \theta$  versus  $\log (V_1V_2)$ . Calculate the percent error between the slope and the expected value of the slope.
8. Round off the slope to the nearest integer. Using the value of  $M$  thus found, express the force as a function of  $q_1$  and  $q_2$ .