

## Physics 111 - The Coulomb Balance

**Introduction** – In this experiment we will use the Coulomb balance shown in Figure 1 to determine how the force between two charges depends on the separation between the two charges and on the magnitude of the charges. The apparatus is a very delicate torsion balance. A conductive sphere is mounted on an insulating rod, counterbalanced and suspended from a thin torsion wire. An identical sphere is mounted on a slide assembly so that it can be positioned at various distances from the suspended wire.

To perform this experiment you will charge both spheres and place the sphere on the slide assembly at a fixed distance from the equilibrium position of the suspended sphere. The electrostatic force between the two spheres will cause the torsion wire to twist. You will then twist the torsion wire to bring the suspended sphere back to its equilibrium position. The torque experienced by the torsion wire is given by  $\tau = (\text{moment arm}) \times F_e = \kappa\theta \Rightarrow F_e \propto \theta$ , where  $\kappa$  is the torsion constant. Therefore the angle through which the torsion wire must be twisted is proportional to the electrostatic force between the two spheres.

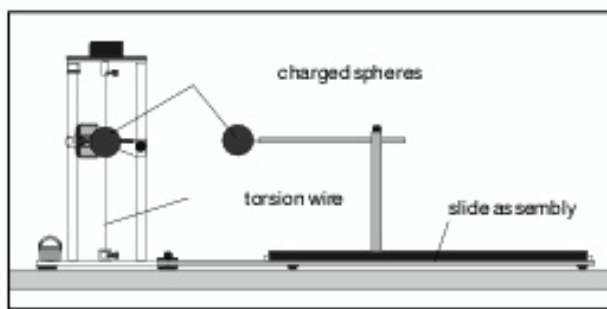


Figure 1: The Coulomb Balance apparatus.

The Coulomb balance is a sensitive instrument that must be properly adjusted before you make your measurements. Also, air currents, humidity, and static charges can affect your results. However, if you are careful and follow the steps below, you should be able to get good results.

1. Have the instructor inspect your Coulomb balance before you begin the experiment.
2. Roll up your sleeves and stand a maximum comfortable distance from the Coulomb balance when performing the experiment. This will minimize the effect of static charges on your clothing.
3. Do not make rapid movements around the Coulomb balance because this can create air currents.
4. When charging the spheres, turn the power supply on, charge the spheres, and then immediately turn the power supply off. Also, hold the charging probe near the end of the handle, so that your hand is as far from the sphere as possible.
5. Perform the measurements as quickly as possible after charging to minimize leakage effects.
6. Recharge the spheres before each measurement.

### **Activity 1: Force versus Distance**

1. Use a Vernier caliper to make several measurements of the diameter of the sphere on the slide assembly and record these values along with their uncertainty. Find the radius.

2. Touch each sphere with the grounding probe and move the slide assembly to separate the spheres as possible.
3. Free the arm of the torsion pendulum and check that the etched line in the metal plate connected to the sphere matches up with the line attached to the base when the system is at rest with no charge applied. If they don't line up, turn the torsion pendulum until they do. Read the dial on top and call this your "zero point." You will need to subtract this number for all your future angular displacement measures.
4. Slide the sphere on the slide assembly forward until it just touches the suspended sphere in the equilibrium position. Adjust the mark on the slide so that it shows the correct distance between the center of the spheres, which is the diameter.
5. Turn on the power supply and set the potential to 6.0 kV. Do not change the voltage knob on the power supply after this first adjustment until Activity 1 is completed. Just turn it on and off with the power switch each time you charge the spheres. Turn off the power supply.
6. Create a data table with the column headings  $r(m)$ ,  $\Delta r(m)$ ,  $\theta_1(\text{deg})$ ,  $\theta_2(\text{deg})$ ,  $\theta_3(\text{deg})$ ,  $\theta_{\text{avg}}(\text{deg})$ ,  $\Delta\theta_{\text{avg}}(\text{deg})$ .
7. Have your instructor or student helper check your set-up.
8. Move the sliding sphere as far as possible from the suspended sphere and discharge both spheres by touching them with the grounding probe.
9. Turn on the power supply; charge both spheres by touching each of them with the charging probe for a count of 5 seconds and **then turn off the power supply**.
10. Position the sliding sphere at the 10.0 cm mark and then adjust the torsion knob to bring the suspended sphere back to its equilibrium position. Record the position of the sliding sphere as  $r(m)$  and the angle measured on the torsion dial as  $\theta_i$  in your data table. The first time doing this it may take you a little bit of time, during which the balls may lose some charge to the humidity in the air. If so, charge the spheres again (turn the power supply back on and touch the spheres for a few seconds) and measure the torsion angle again.
11. Repeat steps 8 – 10 two more times and record the angle measurements as  $\theta_2$  and  $\theta_3$ . Consult your instructor if the angle measurements are not consistent within a few degrees.
12. Repeat steps 8 – 11 to fill in your data table for distances of separation 14.0, 10.0, 9.0, 8.0, 7.0, 6.0, and 5.0 cm.
13. Calculate the average angle,  $\theta_{\text{avg}}$ , for each value of  $r$  and record the values in your data table. Estimate the uncertainty in  $r$  and  $\theta$  and record these in the data table.
14. Use Excel to create a graph of  $\theta_{\text{avg}}$  as a function of  $r$ . From the introduction we have that  $F_e \propto \theta$ . Examining Coulomb's law, we see that the functional form of the relationship between  $\theta$  and  $r$  should be a power law. We have  $\theta = Cr^n$ , where  $C$  is a proportionality constant and  $n$  the exponent to be determined. From your Excel plot, click on each axis and change from a linear scale to a Log scale. If your relationship between  $\theta$  and  $r$  is truly a power law, on a Log-Log plot, you should see a linear relationship. Does your plot support this linear relationship? Display the equation of the line.
15. Print your plot.
16. An isolated, charged, conductive sphere acts as a point charge. The charges distribute themselves uniformly on the surface of the sphere so that the center of the charge distribution is at the center of the sphere. However, when a distance that is not large compared to the sizes of the spheres separates two charged spheres, the charges will redistribute themselves on the spheres so as to minimize the electrostatic energy. The centers of the charge distribution will be farther apart than the center of the spheres and the force between the spheres will be therefore less than it would if the charged spheres were actual point charges. The effect of the distorted charge distribution can be compensated for by applying a correction factor given by  $B = 1 - \frac{4a^3}{r^3}$ , where  $a$  is the radius of the spheres and  $r$  is the separation distance. Calculate the corrected angle for

each value of  $r$  using  $\theta_{corr} = \frac{\theta_{avg}}{B}$  in Excel.

17. Create a Log-Log plot of  $\theta_{corrected}$  as a function of  $r$  and determine the exponent  $n$  and print your plot.
18. How does the force between two charged spheres depend on distance?

### ***Activity 2: Force versus Charge***

1. Create another data table with the column headings  $V(V)$ ,  $\Delta V(V)$ ,  $\theta_1(\text{deg})$ ,  $\theta_2(\text{deg})$ ,  $\theta_3(\text{deg})$ ,  $\theta_{avg}(\text{deg})$ ,  $\Delta\theta_{avg}(\text{deg})$ .
2. Move the sliding sphere as far as possible from the suspended sphere and discharge both spheres by touching them with the grounding probe.
3. Make sure the torsion dial is set to 0 and that the suspended sphere is in the equilibrium position.
4. Turn on the power supply; charge both spheres by touching them with the charging probe, and then turn off the power supply.
5. Position the sliding sphere at the 10.0 cm mark and then adjust the torsion knob to bring the suspended sphere back to its equilibrium position. Record the position of the sliding sphere as  $r(m)$  and the angle measured on the torsion dial as  $\theta_i$  in your data table.
6. Repeat steps 2 – 5 two more times and record the angle measurements as  $\theta_2$  and  $\theta_3$ . Consult your instructor if the angle measurements are not consistent within a few degrees.
7. Repeat steps 2 – 6 to fill in your data table for potentials 5.0, 4.0, 3.0, and 2.0 kV.
8. Calculate the average angle,  $\theta_{avg}$ , for each value of  $V$  and record the values in your data table. Estimate the uncertainty in  $V$  and  $\theta$  and record these in the data table.
9. Use Excel to create a graph of  $\theta_{avg}$  as a function of  $V$ . Determine the functional form of the relationship between  $\theta$  and  $V$ .
10. Print your plot.
11. How does the force between two charged spheres depend on charge? What is your functional relationship?

### ***Activity 3: The Functional Form of the Electrostatic Force***

Put the results of Activities 1 and 2 together to state how the electrostatic force depends on the magnitude and separation of the two charges.