Coulomb's Law

In this experiment, you will examine Coulomb's law by studying the interaction between two charged spheres. Coulomb's law is strictly valid for point charges; however, charged spheres will interact like point charges as long as their separation is large compared to their radii.

In investigating Coulomb's law, you will do three things. First you will find the torsional constant, \( \tau \), of your torsion balance. Next, you will find the relationship between electrostatic force and distance. And finally, you will determine the Coulomb constant and compare it to the accepted value \( (k = 9.0 \times 10^9 \text{ N\cdot m}^2/\text{C}^2) \)

**Apparatus**

You will need the following items for this experiment:
- Coulomb torsion balance
- High voltage power supply with probe
- Slide assembly with sliding sphere
- Lateral support tube
- Small masses and tweezers
- Small copper rings if not already on torsion balance

THE TORSION BALANCE IS A VERY DELICATE INSTRUMENT. Use care when handling because the torsion wire breaks easily. Be sure to clamp the balance when you are done with the experiment.

**Procedure**

**Important:** The procedure outlined here will help you through the lab. In your report, you must include all the details of your experiment. Do not just copy word for word the steps provided for you here. It’s a waste of time and will cost you points.

As with any electrostatic experiment, it is very difficult to obtain good results. However, the following precautions should help minimize errors:
- Be sure not to bump the table or cause any vibrations while measurements are being taken. Also, motion around the apparatus (even small air currents) will greatly affect your results.
- After charging the spheres, immediately remove the charging probe and place it far from the spheres.
- Perform your measurements quickly after charging to minimize the effects of charge leakage from the spheres.
- Recharge the spheres for each new measurement.

**A. Measuring the Torsional Constant, \( \tau \)**
The electrostatic forces that you will be measuring are very small. The best way to measure such small forces is with a torsion balance. The balance consists of a fine wire to which a rotational force is applied through a lever arm. The wire will provide a spring action against this force, which will be proportional to the angle through which the arm rotates. The constant of proportionality is known as the torsional constant, $\tau$. This must be found for your particular torsion balance. This simply involves placing various masses on the arm of the torsion balance and measuring the deflection. The slope of a plot of the applied weight versus deflection is then $\tau$.

1. Carefully place the torsion balance on its side, supporting it with the lateral support bar (identified with the orange color) by swinging this bar out 90°. Place the support tube under the sphere as shown in Figure 2.

2. Zero the balance by turning the dial to align the index lines. The sphere must not be touching the support tube. Record the angle in a table, calling it $\theta_1$.

3. Using the tweezers, carefully place the 20 mg mass on top of the sphere and adjust the dial until the index marks are once again in alignment. Record this angle as $\theta_2$. Also record the difference $\Delta \theta = \theta_2 - \theta_1$, which is directly proportional to the weight of the added mass.

4. Repeat steps (2) and (3) using 40 mg, 60 mg, and 80 mg masses.

5. Make a plot of mg versus $\Delta \theta$ and find the value of $\tau$ from the slope. Use SI units.

![Figure 2: Torsion balance on its side. When the index lines are aligned, the ball should not be touching the support tube.](image)
B. Force Versus Distance

Electrostatic forces, like gravitational forces, follow an inverse square law. This means that the field strength is inversely proportional to the square of the distance between the charges. The force between two charges will only be one-fourth as great when their separation is doubled, and only one-ninth as great when their separation is tripled. In this part of the experiment you will show this to be true. You will also obtain data for determining the Coulomb constant, $k$.

1. Attach the slide assembly to the torsion balance using the coupling plate and the thumbscrews. Your setup should look like that shown in Figure 3 (next page).

2. Make sure that the torsion knob is set so that the 0° mark is set to the index line.

3. Rotate the bottom torsion wire retainer [DO NOT LOOSEN THE THUMBSCREW] so that the index line on the counterweight vane aligns with the index on the arm.

4. Move the sliding sphere up close to the suspended sphere so that they are just touching. The centimeter scale on the slide assembly should read 3.8 cm, which is the actual distance between the centers of the spheres (see Figure 4 next page). This means that any reading that you take from the centimeter scale will give you the actual distance between the centers of the spheres. If the reading that you obtain is not exactly 3.8 cm, loosen the thumbscrew on top of the rod that supports the sliding sphere and adjust the position of the sphere until you do obtain a reading of 3.8 cm when the spheres are just in contact.

5. Move the spheres apart to their maximum separation. Turn on the high voltage power supply, making sure that the negative side of the supply is grounded. Adjust the supply voltage to a reading of 6 kV. Then charge each sphere by gently putting the probe in contact with it. After charging each sphere, place the probe far away from the balance.

6. Quickly position the sliding sphere at 20 cm and adjust the torsion knob until the index lines are aligned. Record the distance $r$ and the angle reading on the torsion dial $\theta$. Write these results in a table.

7. Move the spheres to the maximum separation and recharge them to the same voltage. Repeat the above procedure and obtain a second value of $\theta$ for $r = 20$ cm. Record your measurement in your table. Find the average value of $\theta$, and record that in your table, too.

8. Convert the average value of $\theta$ into a force using the torsional constant that you found in part A.

9. Repeat steps (5) through (8) for separations of 14 cm, 10 cm, 9 cm, 8 cm, 7 cm.

10. Plot $F$ versus $\frac{1}{r^2}$ and verify that you have a straight line graph. Measure the slope of this graph and record your results.
**Figure 3:** The Coulomb balance with slide assembly attached.

**Figure 4:** When the spheres are just in contact, the separation between their centers is 3.8 cm.
C. Determining the Coulomb Constant

The Coulomb constant can now be determined from the slope of the graph of $F$ versus $1/r^2$, provided you know how much charge is on the spheres. Since the spheres are each charged to an "electric potential" of 6 kV, they have the same charge. The charge $q$ on a sphere of radius $a$ at a given electric potential $V$ is given by

$$q = 4\pi\varepsilon_0 a V$$  \hspace{1cm} (1)

where $\varepsilon_0$ is the permittivity of free space, $8.85 \times 10^{-12}$ C$^2$/N·m$^2$. With this data it is easy to calculate $k$.

1. Calculate the value of the charge on each of the spheres when they are charged to a potential of 6 kV.
2. Determine the Coulomb constant from the slope of your graph and the value of the charge. Record your work and final answer. Using the standard value for $k$, determine the percent error in your measurement.

Additional Questions

1. Why would you expect your results to be more valid at larger separations of the spheres?
2. Suppose you charge the spheres and measure the deflection. Describe what happens to this deflection as time passes. Explain your answer.
3. Electrostatic forces are many orders of magnitude greater than gravitational forces. But why are the gravitational forces more apparent?

Other important things to consider

When doing electrostatics experiments, frequently the errors are very large. If the difference between your measurement of $k$ and the accepted value are very large (which it probably will be), you must explain it. Discuss the sources of error in this experiment and thing you could have done to reduce the error.