Lab 1: Coulomb's Law

1 Introduction

Coulomb's law describes the electrostatic force between two point charges. It is encountered whenever there is a charge build up (as in a lightning storm), or when charges are stripped off by frictional forces (static during winter months).

When two point charges, q_1 and q_2, are separated by a distance r, the force between them is described by Coulomb's law

$$F = \frac{kq_1q_2}{r^2} \tag{1}$$

The Coulomb constant k is defined as

$$k = \frac{1}{4\pi\varepsilon_0} \tag{2}$$

where, $\varepsilon_0 = 8.85 \times 10^{-12} C^2/Nm^2$ is the permittivity of free space. This constant specifies the strength of the electrostatic force, and is related to the speed of light in vacuum.

The strength of the Coulomb force falls off with the inverse square of the distance between the charges. It is interesting to note that the gravitational interaction between two masses ($F = \frac{Gm_1m_2}{r^2}$) is also characterized by an inverse square law.

Although the inverse square law is encountered in other areas of Physics (for example, the variation of light intensity as a function of distance from a point source), it is often presented as a fundamental rule, and seldom verified in a laboratory!

During this lab, you will have the opportunity to test the prediction of Coulomb's law by measuring the force between two charged spheres as a function of their distance of separation. You will also be able to test the dependence of the electrostatic force on the charges on the spheres. Finally, you will learn about how to analyze your results by rescaling your data in appropriate ways.

EXERCISE 1 PERTAINS TO THE BACKGROUND MATERIAL AND EXERCISES 2-11 PERTAIN TO THE EXPERIMENTAL SECTIONS.

2 Background

The experiment involves the use of a torsion balance to measure the electrostatic force between two charged spheres. The balance consists of a thin torsion wire that suspends a conducting sphere on a rod with a counter weight on the other side. There is a dial on the top of the balance that allows you to twist the wire through a given angle. Two sighting lines, one on the counter weight, and the other on the stand, allow you to adjust the balance to a known position. The wire can also be twisted using the screw on the base, which can be used to zero the balance.

Figure 1 is a sketch of the apparatus. The figure labeled top view shows the setup observed looking down from beneath the dial. For a photo of the apparatus, refer to Appendix E.

Caution: This balance is very fragile. The torsion wire should be handled with care. When you need to adjust the dial or the screw at the base of the balance, turn them slowly. There are two other screws, one under the dial and the other below the counter weight, that shouldn't be touched.

There are two spheres, one suspended from the balance, and the other that is held on a sliding stand. It is possible to charge these spheres independently. With no charge on either of the spheres (i.e. with the spheres 'grounded'), the balance should be zeroed. To achieve this turn the dial to zero degrees. Next, using the screw at the base twist the wire until the two sighting lines align. When the spheres are charged and brought close together, the electrostatic force will result in a torque on the wire, which rotates the rod holding the suspended sphere. This will cause the two sight lines to move apart. The torsion wire can be twisted using the dial on the top so that the sight lines coincide again. The scale on the dial will allow you to measure the restoring torque. This torque is proportional to the force between the charged spheres.

The apparatus has damping magnets that are necessary to stabilize the weight and bring it to rest rapidly. The counter weight has three metal rings attached to it (refer to figure) that allow the magnet to slow down the sphere. For instance, if the dial is turned through 10° the sphere will rotate accordingly. If the rings and the magnets were not enclosing the counter weight, the sphere would continue oscillating. The magnets are essential for damping out these oscillations quickly.

Exercise 1: When the charged spheres are brought close to each other, it is advisable to make sure that the rods supporting the spheres are initially at right angles to each other. Explain why this is necessary.

The power supply that will be used to charge the spheres has three terminals. The center terminal is at ground potential. The voltage on the power supply meter is the potential difference between the terminals on either side of the central terminal. Thus, if the meter reads 6 kV, the terminal on the right is 3 kV above ground and the terminal on the left is 3 kV below ground.

Turn on the power supply. To ground either sphere, plug the probe into the middle terminal of the power supply and touch the other end to the sphere. To charge a sphere, first ground the sphere. Then connect the probe to one of the terminals on either side of the central terminal and touch the probe to the sphere.

When the probe touches the sphere, charge flows from the probe (which is at the same electric potential as the terminal of the power supply) to the sphere that is at ground potential (0 V). The flow of charge will stop when the sphere is at the same electric potential as the power supply. Thus, the sphere is left with a net charge. The sign of the charge depends on the power supply terminal that is brought in contact with the sphere.

The sphere has a capacitance C, which is a measure of its ability to store charge. Charging the sphere is like charging a capacitor. The charge on the sphere is given by $Q = CV$, where V is the power supply voltage. The surface of the sphere acts as one plate of the capacitor. The other plate is assumed to be at infinity. It is therefore easy to recognize that the two spheres should be far apart when they are being charged. If this is not the case, the amount of charge on the sphere will be different. No other charged object should be in the vicinity.

Although dry air is a poor electric conductor, the charge on the sphere will dissipate (be conducted away). This is due to air currents and the presence of water droplets (humidity) in the room. These factors can discharge the spheres rapidly. It is therefore recommended that you make the measurements immediately after the spheres are charged. A useful technique to obtain reliable results is to repeat each measurement (for a fixed distance between the spheres) more than once until you obtain a consistent data set. The data can be averaged to get a reasonable value for analysis.

3 Suggested Reading

Refer to the chapter on Electric Charge and Coulomb's Law,

R. Wolfson and J. Pasachoff, **Physics with Modern Physics** (3rd Edition, Addison-Wesley Longman, Don Mills ON, 1999)

D. Halliday, R. Resnick and K. S. Krane, **Physics** (Volume 2, 5th Edition, John Wiley, 2002)

4 Apparatus

Refer to Appendix E for photos of the apparatus

- Torsion balance with mounted sphere
- Sphere mounted on sliding stand
- 3kV 'center tapped' DC power supply with probe

5 Experiment I: Force vs. Distance

Zero the balance and ground both spheres. Make sure that the rod supporting the sphere on the stand is at a right angle to the rod holding the sphere on the torsion balance. Move the sphere on the stand until it is touching the sphere on the balance. Verify that the scale on the stand now reads 3.8 cm. The distance between the centres of the spheres is then the sum of their radii. The scale on the stand can now be used to measure the distance between the centres of the two spheres.

With the two spheres separated as far as possible, apply a voltage of +3kV to each of the spheres. Bring the charged spheres to a known distance of separation.

Make sure that that the distance of separation is fairly small. The electrostatic force will cause the rod supporting the sphere on the balance to move from the zero position. Adjust the dial on the balance until the sight lines coincide once again and record the angle through which the dial was turned. The angle is a measure of the torque. The torque is proportional to the force between the spheres.

Always charge the spheres as far apart as possible before bringing them to the desired distance for the measurement. Also make sure that the experiment is shielded from air currents.

Exercise 2: Record the distance of separation r and the corresponding angle of twist Θ for a range of distances between spheres. As the distance between spheres becomes larger, decrease the number of data points. Tabulate your results.

Exercise 3: Does the sign of the charges on the two spheres make a difference to the results? Is there an advantage if the sign of the charge is the same for both spheres?

Exercise 4: Plot a graph of Θ versus r. Given the equation

$$\Theta = \frac{A}{r^2} \tag{3}$$

find the value of A that best fits your results. Plot equation 3 on your graph using this value of A. This is the best fit to the data. You can use Maple to produce the graph.

Exercise 5: The analysis of data can often be simplified by rescaling your graphs. Plot a graph of Θ versus $\frac{1}{r^2}$.

Exercise 6: Describe the shape of the graphs obtained in Exercise 4 and Exercise 5. Interpret the graphs.

Exercise 7: If you did not suspect that the force is proportional to $\frac{1}{r^2}$ you would not have attempted exercise 5. It is possible to infer the power law relationship specified by exercise 5 by doing a log-log plot. If $\Theta = br^n$, then $log\Theta = logb + nlogr$. Plot a graph of $log\Theta$ versus $logr$. From this graph, find b and n.

6 Experiment II: Force vs. Charge

In experiment 1, we determined the relationship between force and distance. We will now determine the relationship between force and charge. For this experiment, we will vary the charge on the sliding sphere and keep the charge on the suspended sphere at a fixed value. We will also fix the distance of separation between the spheres.

Exercise 8: Fix the distance of separation at 10 cm. First charge the sphere on the torsion balance by applying +3kV to it. Then charge the sliding sphere by applying a voltage between 0 V and +3 kV to it. Record the angle Θ in each case. Tabulate the data.

Exercise 9: Plot a graph of Θ versus V. Since Θ is proportional to the force between the spheres, and the voltage is proportional to the charge, your graph will give you the relationship between the force and the charge. Interpret your graph.

Exercise 10: The capacitance of a sphere is given by the equation $C = 4\pi\varepsilon_0 R$, where R is the radius of the sphere. Estimate the capacitance of the spheres used in this experiment. If a voltage of +3 kV is applied to one of the spheres, what is the magnitude of the charge on that sphere?

Exercise 11: Discuss how this experiment can be modified to measure Coulomb's constant. What are the additional measurements that should be carried out? **Hint:** Think about what information can be obtained by turning the apparatus on its side and adding weights to the sphere. How can this information be combined with data you have collected?

Your lab report should include:

Answers to exercises 1-11 with relevant data tables, graphs, figures and qualitative comments.

Refer to Appendix D for Maple worksheets.

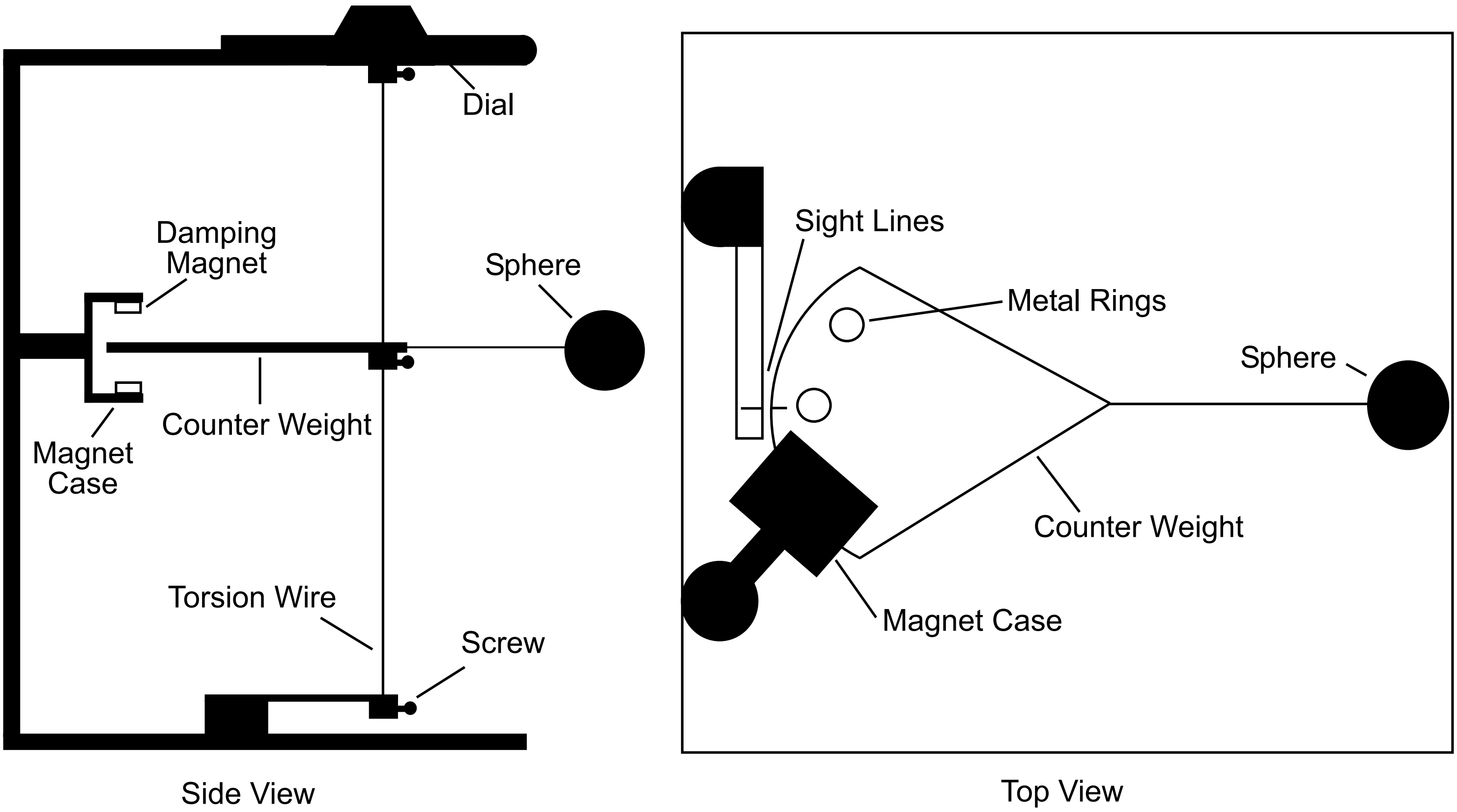

Figure 1: Torsion Balance