Coulomb's Law

Purpose

a. To determine how the electrostatic force between two charged conducting spheres depends on the distance between the spheres and
b. To determine how the electrostatic force between two charged conducting spheres depends on the charge on the spheres.

Theory

Electrostatic force between two charges is (a) directly proportional to the magnitude of the product the two charges and (b) inversely proportional to the square of the distance between their centers.

If Q_1 and Q_2 are the magnitude of the two point charges, and R is the distance between their centers, electrostatic force between them is expressed by the equation below.

$$F = k\frac{|Q_1||Q_2|}{R^2} \quad (1)$$

where k is a constant of proportionality, called Coulomb's constant, $k = 8.99 \times 10^9$ N.m^2/C^2. In this experiment, you are going to verify the Coulomb's law by using a Coulomb balance.

Apparatus

High Voltage Power Source (0- 6 kV), PASCO Coulomb Balance

Description of Apparatus

You will be using a Pasco Coulomb balance in this lab which is shown in Fig. 1. The Coulomb Balance is a delicate and very sensitive torsion balance that can be used to investigate the nature of the electrostatic force between charged objects. You will use two identical conductive spheres in this experiment. One conductive sphere is mounted on a rod which is counter-balanced and suspended on a thin torsion wire. An identical conductive sphere is mounted on a slide assembly so that it can be positioned at various distances from the suspended sphere. The spheres are held by plastic support rods for electrical insulation. The ruler on the slide assembly measures the distance between the centers of the two spheres when the suspended sphere is at its equilibrium position. When the conducting spheres are charged, the sphere suspended on torsion wire gets deflected due to electrostatic force. Rotating knob is used to bring the charged sphere back to equilibrium position.

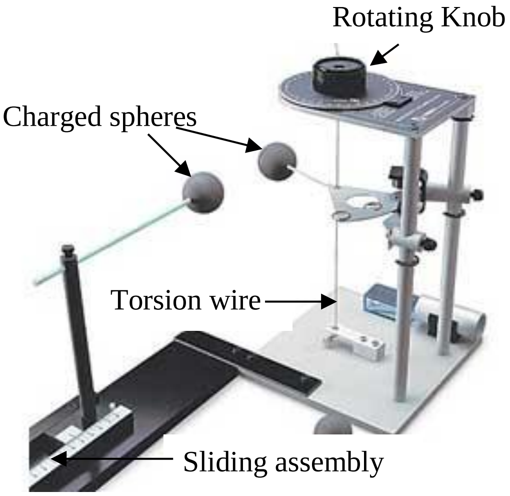

Fig. 1. PASCO Coulomb balance

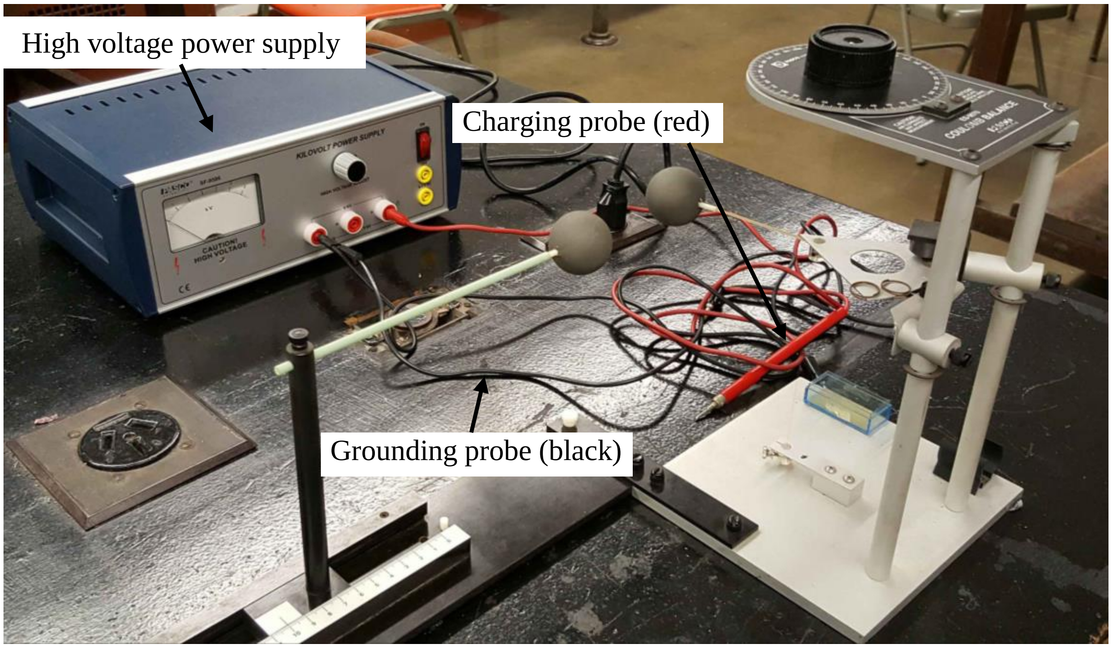

Fig. 2. Experimental set up

Complete experimental set up is shown in Fig. 2. The spheres are charged by means of a very stable high voltage (kilovolt) power supply and a charging probe. The electrostatic force between the spheres causes the torsion wire to twist. The torsion balance can be brought back to its equilibrium position by twisting the torsion wire in the opposite direction using the rotating knob. **The angle through which the torsion wire must be twisted to reestablish equilibrium is directly proportional to the electrostatic force between the two spheres.**

$$F \propto \theta \tag{2}$$

The proportionally constant depends on the torsional constant of the wire.

By varying the distance between the spheres and the amount of charge on the spheres, it is possible to verify Coulomb's Law. Although it is possible, using this apparatus, to measure the value of the constant, k, appearing in Coulomb's Law, we will not attempt to do so in the present experiment. We will attempt to verify that the value of the exponent of R is 2 and that the force is proportional to the product of the two charges.

Procedure

! CAUTION !

THE APPARATUS IS VERY DELICATE AND MUST BE HANDLED WITH CARE. Please pay close attention to using proper technique. Do not touch the spheres with your hands. Do not disturb the table where the Coulomb balance is sitting. If in doubt about any procedure, ask!

!!Be careful working in this lab since you are using a Kilovolt power supply!!

To avoid high percentage error in your data, note the following tips.

- When performing experiments, stand behind the balance at a considerable distance to prevent the effect of static charge of your clothing on the experiment
- Wear proper clothing, such as short sleeve cotton shirt. Do not wear fabrics that acquire large amount of static charge. A grounding wire connected to the experimenter is helpful.
- To charge the spheres, turn the power supply on, charge the spheres, and then immediately turn the supply off. This is to prevent leakage of charge which affects the torsion balance.
- Keep your hands at the end of the handle and away from the sphere. Your hand has a capacitive effect on the sphere, increasing its charge. Minimize this effect to accurately reproduce the charge when recharging.
- To prevent charge leakage via surface contamination, avert touching the rods supporting the charged spheres and wipe with alcohol when necessary.
- There will always be some charge leakage. Perform measurements as quickly as possible after charging to minimize the leakage effects. Recharge the spheres before each measurement.

Part I. Force versus Distance

In this part of the experiment, you will keep the charge on the spheres constant and measure the force by varying the distance of the charged spheres.

1. Move the sliding sphere to maximum separation. Make sure that you and the spheres are fully discharged by grounding momentarily (a grounding probe is provided). Always touch the probe to the suspended sphere very gently from below. Set the torsion dial to 0^o and check that the torsion balance is properly zeroed as shown by arrows in the Fig. 3. If not, ask for assistance from the instructor.
2. Set the voltage control on the kilovolt power supply at maximum. Do not turn it on until you are ready to charge the spheres. Charge both spheres by touching each one momentarily (1 second is more than enough time) with the charging probe. Always touch the suspended sphere very gently from below. Immediately after charging the spheres, turn off the power supply but leave the dial set at maximum.

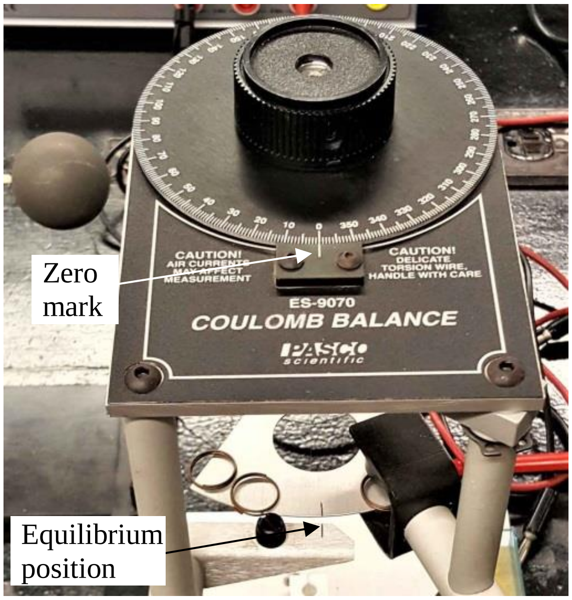

Fig. 3. Setting up torsional balance.

3. Position the sliding sphere at a distance of 20 cm. You will see the charged sphere attached to the torsional wire moved away. Slowly adjust the torsion dial so as to bring the balance back to its equilibrium position. Try not to overshoot the equilibrium position, so as to avoid time consuming oscillations! When equilibrium is achieved, record the value of the angle, θ, as read on the dial to the nearest half degree or better.

4. Move the sliding sphere back to maximum separation and repeat step 2, to recharge the spheres. This must be done between measurements to minimize the effects of charge leakage.
5. Repeat step 3. Do not look at the dial while you are rotating it! Try to obtain honest, independent measurements. Repeat this measurement several times until you have obtained three measurements which agree within two degrees. Use the average of those three measurements as your final result (expressed to the nearest tenth of a degree) and record in table 1.
6. Repeat steps 1-5 for distances R = 14, 10, 7, 6, and 5 cm. If the zero has shifted, you will have to repeat the previous set of measurements.

Part II. Force versus Charge

In this part of the experiment, you will keep the distance between the spheres constant and measure the force for different values of the charge, keeping $Q_1 = Q_2$ always.

1. Keep the separation between the spheres held constant at R = 5 cm,
2. The charge transferred to a sphere is proportional to the charging voltage. Thus, you can produce different charges on the spheres by adjusting the voltage of the power supply. Use meter settings of 6 (for 6 kV). Always ground both spheres before charging and make sure that they are at maximum separation during charging. Follow the same procedures outlined in part A and record the data in table 2.
3. Repeat the above step for meter settings 5, 4, 3, 2, and 1. You will obtain six data points by this method.

Computation and Analysis

Because you are using charged spheres rather than point charges to test Coulomb's Law, the effective distance between the charges is not equal to the distances between the centers of the spheres. An approximate expression for the corrected distance (R'), adequate for our purposes, is given by

$$R' = R\,(1 + 2.3\,\beta) \qquad (3)$$

with $\beta = \frac{a^3}{R^3}$ and a = 1.90 cm

where R is the distance between the centers of the spheres and a is the radius of each sphere. It is assumed here that the conducting spheres are identical and carry identical charges.

For each value of R used in part I, calculate R' using the above expression. Also tabulate your data for $1/(R')^2$, $\ln R'$, and $\ln\theta$.

1. Plot a graph of $\ln\theta$ versus $\ln R'$ from your data in Table 1. Draw the best straight line from the scattered data point and determine the slope of this line. Estimate the uncertainty in this slope.

   Question: What does the slope of this line tell you?
   Hint: If $\theta = b\,(R')^{-n}$ then $\ln\theta = \ln b - n \ln R'$

2. Plot θ vs $1/R'^2$. Draw a best fitting straight line that you can through your data points.

Question: Should this straight line pass through the origin? What can you conclude from this graph?

3. From the data in Table 2, plot a graph of angle of deflection (θ) versus the product of Q_1 and Q_2, $(Q_1 x Q_2)$. Make a best fit-curve to the plotted data. Explain your results in the report.

Questions to be answered in your report

1. Explain, qualitatively, why the effective distance between the spheres, R', is always greater than the distance, R, between their centers. A diagram, showing the distribution of charges on each conducting sphere, should be included as part of your explanation.
2. When the spheres are very far apart, the correction to R is very small, i.e., $R' = R$. However, as the spheres are brought closer together the correction becomes larger, i.e., $(R' - R) / R$ increases as R decreases. Explain, on physical grounds, why this must be so, referring to your answer to question 1.
3. Identify as many possible sources of errors in these measurements as you can think of and, in each case, suggest ways in which the error might be reduced experimentally or corrected for in some fashion.

Data Sheet

Date experiment performed:

Name of the group members:

Table 1. **Force versus Distance**

Number of observation	Distance between the center of spheres (R) cm	Angle at equilibrium (θ) deg	Corrected distance between the charged spheres (R') cm	$1/R'^2$	lnR'	$ln\Theta$
1	20					
2	14					
3	7					
4	6					
5	5					

Table 2. Force versus charge

R = 5 cm (Constant)

Number of Observations	Q_1 (Arbitrary Unit)	Q_2 (Arbitrary Unit)	Q_1x Q_2 (A.U.)	θ *(deg)*
1	6	6		
2	5	5		
3	4	4		
4	3	3		
5	2	2		
6	1	1		