The University of Hong Kong
Department of Physics

Experimental Physics Laboratory

Experiment No. xxxx-x
Coulomb's Law
Laboratory Report

Name: xxxx
University No: xxxxx

(a) Presentation

- Diagram of apparatus & procedures

Aims:

To investigate the Coulomb's law of electrostatics

Tasks:

1. The Leybold torsion balance is calibrated using the dynamical method, and the torsion constant is determined.
2. The attractive electrostatic force between two like charged spheres is measured for different separations of the spheres.
3. The charge of the sphere is measured directly using a Faraday's cup and a charge sensitive amplifier.

Background:

According to Coulomb's law, the force acting between two point-shaped charges Q_1 and Q_2 at a distance r from each other can be determined using the relation [1],

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2} \qquad (1)$$

where the proportionality constant $\frac{1}{4\pi\varepsilon_0} = 9.0\text{x}10^9\text{Nm}^2/\text{C}^2$. The same force acts between two charged spheres when the distance r between the midpoints of the spheres is much greater than the diameter of the sphere such that the uniform charge distributions on the spheres is not altered. For large distances, the spheres can be treated as points.

In this experiment, the electrostatic force between charged metal spheres is measured using a sensitive torsion balance and compared with equation (1). The charges on the conducting spheres are then deduced from the measurement of the force. Using a Faraday cup and a sensitive electrometer amplifier, the charge is also measured directly, and the results from these two methods compared.

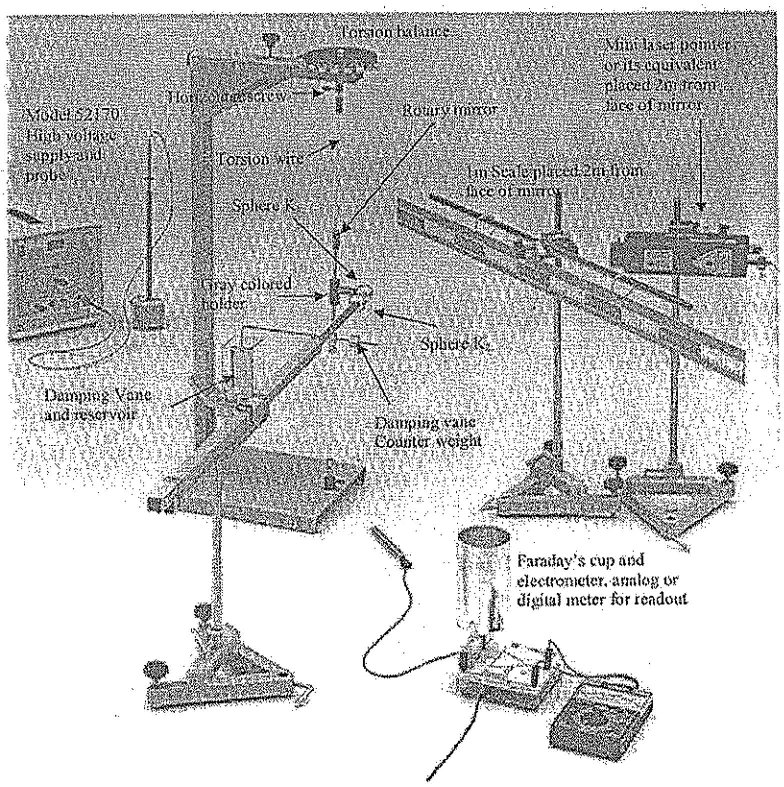
Experiment:

Apparatus

- High Voltage Power Supply and probe
- Laser pointer
- 1M Scale Ruler
- Torsion balance
- Faraday's cup
- Electrometer
- analog or digital meter
- Sphere K_1 with Gray colored holder
- Torsion wire
- Damping vane

Setup

(see Fig.1)



Confirming Coulomb's law – measuring with the torsion balance. Schürholz design

Figure 1. Coulomb's law experimental apparatus.

Procedure:

1. Determining the torsion constant by Torsion Balance and Its Calibration

The electrostatic force is to be measured using a sensitive torsion balance. One of the charged spheres is mounted on a horizontal arm of length l attached to a clamped vertical torsion wire, which restricts its motion to the horizontal plane. When the second charged sphere is brought into close proximity to the first, it produces a torque, which cause the torsion wire to twist. The amount of this twist can be magnified using a laser light pointer. The amount of twist in the torsion wire is proportional to the electrostatic force and is observed as a deflection of a laser beam, directed at a mirror also mounted on the torsion balance. This balance needs first to be calibrated to obtain the force in absolute terms.

The torque M, experienced by a vertical torsion wire twisted through an angle φ can be stated as

$$M = D\varphi\,, \qquad (2)$$

where D is the torsion constant [2]. The torsion constant is determined from the oscillation of a metal rod inserted into the gray colored holder mounted on the torsion wire (Refer to fig. 1 for a photo). The metal rod can be set to oscillate about the vertical axis of the torsion balance, with period of oscillation, T. If the moment of inertia, I, of the metal rod about the rotation axis, is also known, then the torsion constant D can be obtained from this period. Neglecting effects due to damping, the oscillation period can be expressed as $T = 2\pi\sqrt{\frac{I}{D}}$ (p. 661 in Ref. [2]).

1.1 A metal damping vane may be mounted at the lower end of the balance. Gently, remove this vane from the balance. The metal sphere, and its attaching arm, if already mounted on the gray colored holder on the balance must be removed. Gently loosen the screw, which locks the arm, and remove it from the torsion balance.

1.2 A metal bar, of diameter 6mm and length 24cm is provided. Take this metal bar and gently insert it into either one of the two holes located in the gray colored holder. Try to fit the bar at the center of the bored hole and then slowly tighten the fastening screw.

1.3Locate the hand held stopwatch, for timing the oscillation swings of the 24cm rod.

1.4 As a test try, first *gently* with one hand, rotate the 24cm bar about the axis of the balance as determined by the vertically hung torsion wire. The rotation angle should be between 45 to 90 degrees. Now, *slowly* let the bar swing free and don't purposely apply any push to the bar. A few practice swings of the bar may be helpful. As the bar swings back and forth in the horizontal plane, follow the motion of the bar and count the number of swings that occurred.

1.5 After some practice in setting the bar into motion, repeat step 1.4 above and use the stopwatch to time the period of oscillation of the bar. Allow the bar to swing for at least 10 cycles before pressing the stop button on the stopwatch. From the elapsed time on the stopwatch, find the averaged. Repeat this step a few times to get a consistent result for the period.

1.6 Find the torsion constant D, using equation (2) and the moment of inertia of the bar, $I = \frac{ml^2}{12} (= 2.72\text{x}10^{-4}\text{kgm}^2)$, where m is the mass of the bar and l its length (p. 646 in Ref. [2]). The contribution of the moment of inertia of the system itself can be neglected, it being less than 1% of the moment of inertia of the 24cm bar.

1.7 The angle of deflection of the laser beam is proportional to the applied force that acts to rotate the torsion wire. A deflection φ gives rise to a displacement of the reflected laser beam incident on a scale placed at a distance of $L \approx 2$ meters away of an amount a. We thus find a calibration of the force F, in terms of the displacement a, given by

$$F = ka \qquad (2)$$

with $k = D/2Ll$, $l = 50$mm the length of the torsion arm from the axis, and L to be measured.

From your result obtained for the torsion constant, D, calculate the value for k from equation (2). Your result for k should be of the order of $1\text{x}10^{-5}$N/cm.

2.Measurement of the Coulomb Force

In this section, the electrostatic force is measured as a function of the distance between two charged metal spheres. The deflection of a laser beam directed on a scale indicates the amount of attractive force between the two like charged spheres.

Refer to figure 1 for a diagram of the setup. Four major components are required: (1) A 10kVolts high voltage unit, (2) the torsion balance, (3) metal ruler and (4) a helium neon laser.

2a. Alignment of the laser pointer and damping vane

2a.1 Turn on the dehumidifier unit.

2a.2 Remove the metal rod used for calibration from the torsion balance. Place the metal sphere with its short insulating holder arm into one of the insertion holes located on the gray holder mounted on the torsion wire. Be sure to insert the short arm fully into the hole with an opening that aligns with the face of the small mirror.

2a.3 Turn on the laser unit. Manually direct the laser beam onto the rotary mirror. Using one hand slightly rotate the gray metal holder on the torsion wire, so that the mirror reflects the beam back to the small opening on the laser unit. To achieve this, both the laser unit and/or the base of the torsion balance may need adjustment. The height of the laser unit may need to be raised or lowered. Likewise, several pieces of paper can be inserted at the base of the torsion balance to align the laser beam.

2a.4 Next, rotate the mirror so that the beam is directed onto the scale. For good indication of the beam position, the beam should be directed onto the lower large markings on the scale. Simply, insert or remove pieces of paper at the base of the balance to do this.

2a.5 Measure the distance between the mirror and the ruler. It should be around 2meters.

2a.6 Gently fill the glass water reservoir to near its rim, without removing it from its position on the balance. Place the damping vane horizontally onto the lower holder that holds the torsion wire. There is a cut out notch on the holder that accommodates the handle of the damping vane. The damping vane has a metal piece that acts as a counter weight to balance the damping vane.

2a.7 Position the metal vane into the water reservoir submerged in the water so that it is *not* touching the glass wall. For good damping, submerge half of the vane into the water. The metal rod of the damping vane need not be horizontal, a small tilt may result in a better damping of the torsion balance.

2b Positioning the Spheres

2b.1 Position the laser beam spot on the scale. The torsion wire may need to be slightly twisted for this. Use your thumb to hold the top horizontal screw (w/black grip see location in figure 1 that fastens the torsion wire, and slightly rotate the screw in a horizontal plane. After which, allow the sphere (K_1), mounted on the torsion balance to come to rest.

2b.2 Slowly slide the ruler that holds the second sphere (K_2), mounted on a V-shaped adjustable stand, to about 1mm from the sphere K_1. The vertical height of the two spheres should be nearly the same. If not, adjust the height of the sphere K_2. Moving the V-shaped stand horizontally may also help. Record the ruler position of the sphere K_2. This position is the reference position for subsequent displacement of K_2. The diameters of the spheres are 30mm.

2b.3 Move sphere K_2 to 10cm away. Take a banana lead, with one end connected to ground (socket (8) in fig. 2) on the HV unit, and touch the two spheres, to first discharge the spheres of any residual charges. Only touch rotary sphere K_1 at its top, this should disturb its horizontal motion the least.

2b.4 Refer to figure 3 for details for the various connections and controls.

Important: The Leybold model 52170 is a low current high voltage unit. Please read the safety note for the model 521 70 in Appendix before proceeding further in the experiment.

2c. Charging the Spheres

2c.1 Turn on the Leybold, model 52170 high voltage (HV) power supply unit.

Important: Turn the high voltage control knob ((2) in figure 2) fully in the counter clockwise position.

2c.2 The Leybold model 52170 HV unit can produce high voltage output up to 10kVolts. The change over switch ((4) in fig. 2) should be in the center position for the maximum output of 10kVolts. The negative output of socket (7) should be connected to ground socket (8). A high voltage cable (Leybold model 50105), 1m long, and in red with black handles at both ends is provided. One end should be connected to the positive output of socket (6). DO NOT use any other cable in place of this cable, unless it is also a cable specified for high voltages. For operation in the 10kVolts range, do not make connection between the (+) output of socket (7) and the (-) output of socket (6). The other end of the cable should be inserted into the gray colored vertical insertion, when the high voltage output on the model 52170 is not being used.

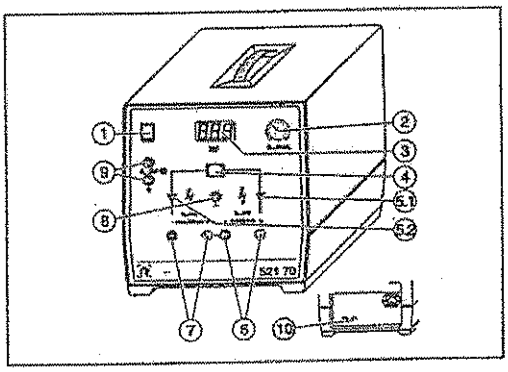


Figure 2. Leybold model 52170 10kV high voltage supply unit.

Important: For the operation of the high voltage unit to follow first consult a laboratory teaching assistant for a working demonstration and to check for proper connections in the Leybold model 52170 high voltage unit before proceeding further.

To reduce the possibility of discharge, ground yourself by touching the metal grounding rod connected to the Leybold model 53214 electrometer (see fig. 4. for details). The ground on the electrometer should be connected to the ground input (socket (8) in fig. 2) on the model 52170 high voltage unit.

2c.3 Slowly turn up the HV to about 8kVolts using potentiometer (2) (depending upon the room humidity and the stability of the balance, the amount of laser beam deflection may need to be increased for more reliable results, by applying voltages up to 10kVolts to the spheres). The digital readout should indicate about 8kVolts. Remove the HV probe from the gray colored insertion. Gently use the metallic tip of the probe to touch the spheres K_2 and K_1. Place the probe back into the vertical gray insertion and slowly lower the HV using potentiometer (2).

2c.4 At this point, the rotary sphere K_1 should move and oscillate somewhat. The laser beam spot should also move, as indicated on the metal ruler placed 2 meters away.

2c.5 Take the ground lead connected to socket (8) and touch the two spheres to discharge them.

3. Measurement of Charge using the Electrometer Amplifier and Torsion Balance

In this part of the experiment the charge on the spheres are obtained using the torsion balance method. The charge on the spheres can be obtained from the slope of the graph of the electrostatic force versus $1/r^2$ and using $\frac{1}{4\pi\varepsilon_0} = 9.0\text{x}10^9 \text{Nm}^2/\text{C}^2$. In addition, the charge is measured directly using a third sphere and a charge sensitive electrometer amplifier.

Identify the Leybold model 53214 electrometer amplifier and the attached Faraday's cup. A block diagram for the electrical connection of the electrometer is shown in figure 3. Charge is measured using a third sphere K_3 placed inside the Faraday cup.

The electrometer has unit gain and its output voltage, V, gives a measure of the charge collected, Q, on its input capacitor, C. The top plate of the capacitor is connected to a Faraday's cup. The simple relation, Q=CV is used to obtain a value for the charge placed inside the Faraday's cup. Use a 1nF capacitor at the input of the electrometer.

3a. Steps to Measure Charge from Coulomb's law and Leybold Electrometer

3a.1 Make the connections for the model 53214 electrometer as shown in figure 3. Place sphere K_3 mounted on a long handle, into the Faraday's cup. The meter needs to be grounded. To establish a ground connection on the hand held meter (analog or digital), take a banana lead, and connect one end to the negative input on the meter, and its other end to the ground input (socket (8) in fig. 2) on the Leybold model 52170 high voltage unit. Use the metal grounding rod to touch the Faraday's cup to discharge it of any residual charge. Some charges may return to the Faraday's cup and affect the reading of the meter.

3a.2 First, charge the two spheres as in step 2c.3 above, and record the laser beam deflection on the scale, for different separations of the two spheres. Do this starting at a sphere center-to-center distance of 10cm to 22cm in steps of 2cm.

3a.3 After a set of beam deflection measurement, for sphere displacements of 10-22cm, K_3 to K_2. Do this, using one hand to hold onto the metal grounding rod. With the other hand, take the handle connected to sphere K_3, after it has touched sphere K_2, and place it inside the Faraday's cup.

3a.4 Record the output value, V, from the Voltmeter. The charge q originally placed on the spheres K_1 and K_2 is then obtained from, q/2=CV, where C is the capacitance of the 1nF capacitor at the input of the electrometer. Notice how the output on the electrometer changes, as charges are being induced on the Faraday's cup while you bring the sphere K_3 close to it, without making any contact between the two.

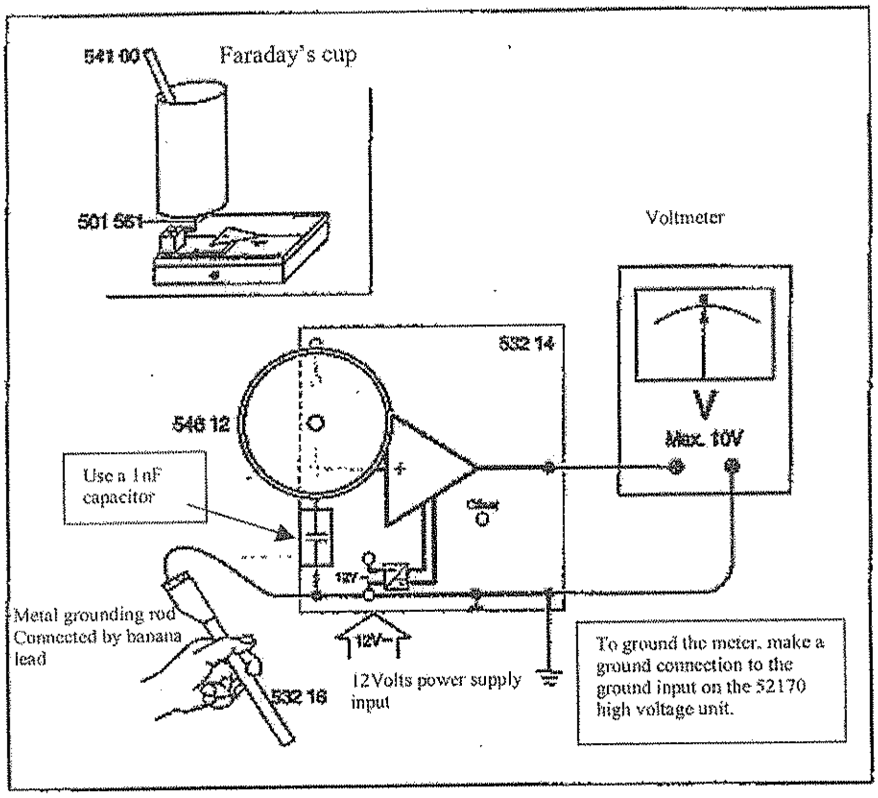


Figure 3. Diagram showing the connections for the Leybold model 53214 electrometer amplifier. The inset shows the connection of a Faraday's cup. Note: The voltmeter needs to be grounded by making a ground connection to the model 52170 high voltage.

3a.5 Repeat step 3a.2-3a.4 above for several sets of charge measurements using the torsion balance together with the electrometer method. For each set of measurement, plot a graph of the Coulomb force versus $1/r^2$. The graphs of your data should be straight lines with small y-intercepts. Make a least square fit using programs (e.g. Excel, Matlab, Sigma Plot etc . . .) to obtain the slope of the graph and the value for the charge placed on the spheres. Compare your fitted results for the charge, with that obtained directly using the electrometer and Faraday's cup.

Appendix:

Safety notes on the operation of Leybold model 52170 high voltage supply.

⚠ Read this Instruction Sheet carefully!

- When this device is used according to this Instruction Sheet, experimenting with high voltages represents no safety hazard!
- This device supplies contact-safe high voltage.
  In accordance with EN 61010-1 (VDE 0411), a part is deemed to be contact-safe when, at voltages greater than extra-low voltage (60 V DC voltage),
  the current through an induction-free resistance of 2 kΩ is not greater than 2 mA for DC
  and additionally, the charge for voltages up to 15 kV is less than 45 F128MmC.
- Do not connect capacitors with a capacitance ≥ 2.5 nF (at 10 kV), as according to VDE 0411 a danger of hazardous contact exists at 10 kV for capacitances above 4.5 nF (approx. 2 nF already exists in the high voltage power supply).
- Do not connect multiple power supplies in series.
- Always switch off the power supply before altering the experiment setup.
- Before switching on the device, turn potentiometer ② all the way to the left (output voltage 0).
- Connect only resistors in plastic housings suitable for high voltage (e.g. 536 25) to the outputs; do not use resistors in metal jackets (old design) or mounted in STE-housings (flashover!).
- Take the ground connection of socket ⑧ and the bottom socket of input ⑨ into consideration.
- Use high voltage cables (501 05), as the insulation of connecting leads designed for extra-low and low voltages are generally not high-voltage proof.
  If high voltage cables are not available, keep a minimum distance of 4 cm at 10 kV (or a correspondingly lesser distance for lower voltages) between the connecting leads and conducting surfaces (benchtop, experiment apparatus) in order to prevent high-voltage flashovers.
  You may need to incline the device on its folding feet to achieve a greater distance between the high voltage outputs and the benchtop.
- Set up the experiment so that it is not possible to touch either non-insulated parts or cables and plugs inadvertently.
- *Operating electron beam and gas discharge tubes:*
  As evacuated tubes can emit x-rays, these are subject in Germany to the applicable x-ray control regulation when operated at a voltage $U \geq 5$ kV; this regulation defines such arrangements as noise radiators. In Germany, such noise radiators may not exceed the legally mandated limit values for the dose rate (≤ 1 µSv/h at a distance of 0.1 m).
  As the current is internally limited to max. 100 µA at voltages ≥ 5 kV, the high voltage power supply, 10 kV makes an important contribution to preventing inadmissible x-ray radiation.
  In the case of some tubes, you will need to check whether the tube manufacturer permits the operation of the tube with the electrical data specified for the high voltage power supply 10 kV (this condition is fulfilled for the tubes listed on page 1).
  X-ray protection requirements may vary from country to country. If you are unsure about the regulations which apply to you, please consult your local authorities.
- If the mains connection voltage specified on the rating plate (rear of device) does not match your local power mains, return the device suitably packed for transport to Leybold Didactic for conversion.

References:

[1] David Halliday and Robert Resnick, *Physics Parts* 1 and 2, (Wiley & Sons, New York 1978) p. 568.

[2] A.P. French, *Newtonian Mechanics*, (W.W. Norton & Company, 1971).

[3] Harry F. Meiners, Walter Eppenstein and Kenneth H. Moore, *Laboratory Physics* (Wiley & Sons, New York, 1969) p.243. This book contains a brief description of the Coulomb's law experiment described in this manual.

Further Readings

[4] Peter Heering, "On Coulomb's inverse square law", Am. J. Phys. 60 (11), 988-994 (1992).

[5] Jack A. Soules, "Precise calculation of the electrostatic force between charged spheres including induction effects", Am. J. Phys. 58 (12), 1195-1199 (1990).

[6] Josip Slisko and Raul A. Brito-Orta, "On approximation formulas for the electrostatic force between two conducting spheres", Am. J. Phys. 66 (4), 352-355, (1998).

- Tabulation of results & Graphical Representation

1. Determining the torsion constant by Torsion Balance and Its Calibration

number of cycles	10	10	10	10	15	15	15	15
time elapsed (s) $\pm$ 0.1s	58.0	58.0	57.8	57.8	86.4	86.6	86.6	86.4
period (s) $\pm$ 0.1s	5.80	5.80	5.78	5.78	5.76	5.77	5.77	5.76

Average period, T= (5.78$\pm$0.0158)s, the sample standard deviation is taken as the error.

Distance between the scale and the mirror, $L = \left(2.0 \pm 5\times10^{-4}\right)m$.

The length of the torsion arm from the axis (given), $l = 50$mm.

From $$T = 2\pi\sqrt{\frac{I}{D}} \qquad D = \frac{4\pi^2 I}{T^2}$$ putting $I = \frac{ml^2}{12}$ (= 2.72x10^{-4}kgm^2) (given),

yielded torsion constant, $D = \left(3.21\times10^{-4} \pm 1.24\times10^{-6}\right)kgm^2s^{-2}$.

The error in D is calculated as follow:

$$\left(\frac{\delta D}{D}\right)^2 = 2\left(\frac{\delta T}{T}\right)^2$$
$$\delta D = D\sqrt{2}\left(\frac{\delta T}{T}\right)$$

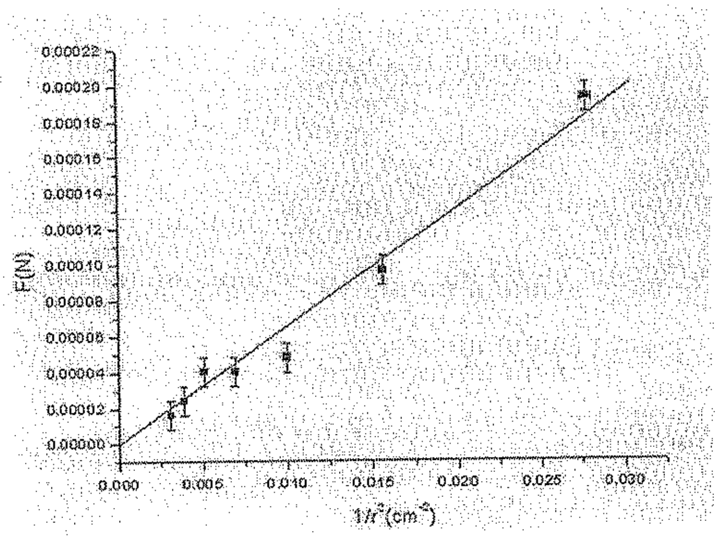
And $k = D/2Ll = \dfrac{3.21\times10^{-4}}{2\times2\times\left(\frac{50}{10}\right)} = (1.605\times10^{-5} \pm 6.21\times10^{-8})Ncm^{-1}$, the error in k is calculated as follow:

$$\left(\frac{\delta k}{k}\right)^2 = \left(\frac{\delta D}{D}\right)^2 + \left(\frac{\delta L}{L}\right)^2 + \left(\frac{\delta l}{l}\right)^2$$
$$\delta k = k\sqrt{\left[\left(\frac{\delta D}{D}\right)^2 + \left(\frac{\delta L}{L}\right)^2\right]}$$
$$\delta l = 0$$

2. Measurement of the Charge (by Torsion Balance)

set 1

r (cm) $\pm$ 0.05cm	6	8	10	12	14	16	18
$1/r^2$ (cm^{-2})	0.0278	0.0156	0.0100	0.00694	0.00510	0.00391	0.00309
error in $1/r^2$ (10^{-5} cm^{-2})	32.7	13.8	7.07	4.09	2.58	1.73	1.21
a (cm) $\pm$ 0.5cm	12.0	6.0	3.0	2.5	2.5	1.5	1.0
$F(10^{-5}$ N)	19.3	9.63	4.82	4.01	4.01	2.41	1.61
error in $F(10^{-6}$ N)	8.06	8.03	8.03	8.03	8.03	8.03	8.03



The graph of the Coulomb force F versus $1/r^2$

Using the *Origin* "Linear Fit" option, the slope of the fitting is (0.00655$\pm$2.31x10^{-4}) Ncm^2.
From the equation,

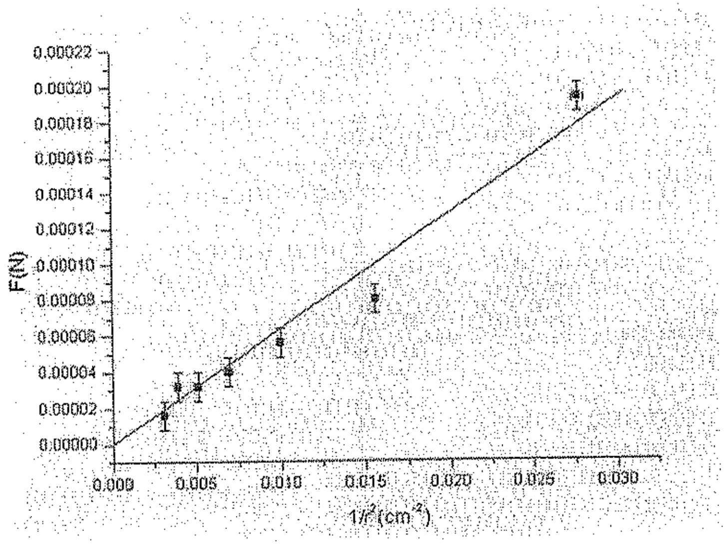
$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$$

yield $Q_1Q_2 = (4\pi\varepsilon_0)\cdot(65.5 \pm 2.31)C^2 = (7.29\times10^{-17} \pm 2.57\times10^{-18})C^2$

or $Q = \sqrt{(Q_1Q_2)} = (8.54\times10^{-9} \pm 2.13\times10^{-10})C$

set 2

r (cm) ± 0.05cm	6	8	10	12	14	16	18
$1/r^2$ (cm^{-2})	0.0278	0.0156	0.0100	0.00694	0.00510	0.00391	0.00309
error in $1/r^2$ (10^{-5} cm^{-2})	32.7	13.8	7.07	4.09	2.58	1.73	1.21
a (cm) ± 0.5cm	12.0	5.0	3.5	2.5	2.0	2.0	1.0
$F(10^{-5}$N)	19.3	8.03	5.62	4.01	3.21	3.21	1.61
error in $F(10^{-6}$N)	8.06	8.03	8.03	8.03	8.03	8.03	8.03



The graph of the Coulomb force F versus $1/r^2$

Using the *Origin* "Linear Fit" option, the slope of the fitting is (0.00640+2.31 x10^{-4}) Ncm^2. From the equation,

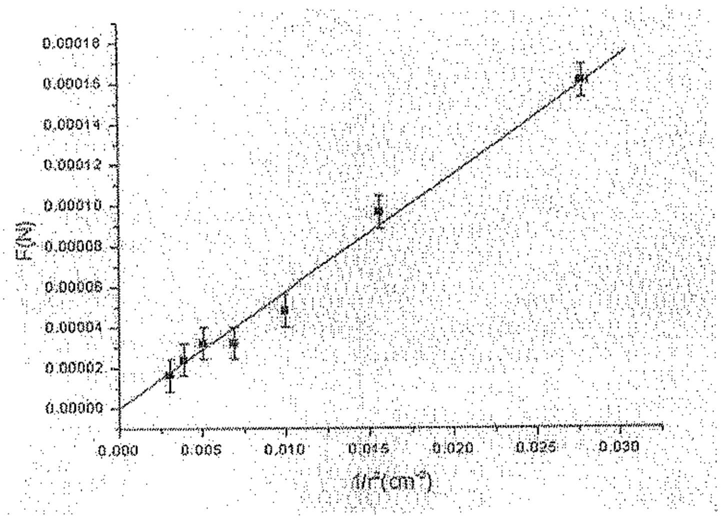
$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$$

yield $Q_1Q_2 = (4\pi\varepsilon_0)\cdot(64.0 \pm 2.31)C^2 = (7.12\times10^{-17} \pm 2.57\times10^{-18})C^2$

or $Q = \sqrt{(Q_1Q_2)} = (8.44\times10^{-9} \pm 2.15\times10^{-10})C$

set 3

r (cm) $\pm$ 0.05cm	6	8	10	12	14	16	18
$1/r^2$ (cm^{-2})	0.0278	0.0156	0.0100	0.00694	0.00510	0.00391	0.00309
error in $1/r^2$ (10^{-5} cm^{-2})	32.7	13.8	7.07	4.09	2.58	1.73	1.21
a (cm) $\pm$ 0.5cm	10.0	6.0	3.0	2.0	2.0	1.5	1.0
F(10^{-5} N)	16.1	9.63	4.82	3.21	3.21	2.41	1.61
error in F(10^{-6} N)	8.05	8.03	8.03	8.03	8.03	8.03	8.03



The graph of the Coulomb force F versus $1/r^2$

Using the *Origin* "Linear Fit" option, the slope of the fitting is (0.00574$\pm$2.31x10^{-4}) Ncm^2.
From the equation,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$$

yield $Q_1Q_2 = (4\pi\varepsilon_0)\cdot(57.4 \pm 2.31)C^2 = (6.34\times10^{-17} \pm 2.57\times10^{-18})C^2$

or $Q = \sqrt{(Q_1Q_2)} = (7.96\times10^{-9} \pm 2.28\times10^{-10})C$

The error in $1/r^2$ is calculated as follow:

$$\left(\frac{\delta\left(\frac{1}{r^2}\right)}{\left(\frac{1}{r^2}\right)}\right)^2 = 2\left(\frac{\delta r}{r}\right)^2$$

$$\delta\left(\frac{1}{r^2}\right) = \sqrt{2}\left(\frac{\delta r}{r}\right)\left(\frac{1}{r^2}\right) = \sqrt{2}\left(\frac{\delta r}{r^3}\right)$$

The error in F is calculated as follow:

$$\left(\frac{\delta F}{F}\right)^2 = \left(\frac{\delta k}{k}\right)^2 + \left(\frac{\delta a}{a}\right)^2$$

$$\delta F = F\sqrt{\left[\left(\frac{\delta k}{k}\right)^2 + \left(\frac{\delta a}{a}\right)^2\right]}$$

The error in Q is calculated as follow:

$$\left(\frac{\delta(Q_1Q_2)}{(Q_1Q_2)}\right)^2 = 2\left(\frac{\delta Q}{Q}\right)^2$$

$$\delta Q = Q\left(\frac{1}{\sqrt{2}}\right)\left(\frac{\delta(Q_1Q_2)}{(Q_1Q_2)}\right)$$

3. Measurement of the Charge (by Electrometer Amplifier)

r (cm) $\pm$ 0.05cm	10	12	14	16	18
V (V) $\pm$ 2.5V	6.0	4.5	5.5	6.0	6.5
q(nC) $\pm$ 5nC	12	9.0	11	12	13

The charge q originally placed on the spheres K_1 and K_2 is obtained from, q/2=CV where C is the capacitance (assume no error) of the 1nF capacitor at the input of the electrometer.

The error in q is calculated as follow:

$$\left(\frac{\delta q}{q}\right)^2 = \left(\frac{\delta V}{V}\right)^2$$

$$\delta q = q\cdot\frac{\delta V}{V}$$

(b) Data Evaluation & (c) Comments

Using the torsion balance method and from the above three sets of data in part 2, the average charge placed on the sphere was: $Q = (8.31 \pm 0.310)nC$ (the sample standard deviation is taken as the error). While using the electrometer method and from the data in part 3, the average charge placed on the sphere was: $q = (11.4 \pm 1.52)nC$ (the sample standard deviation is taken as the error). They are different by 27.1%.

The experiment of electrostatic depends on the humidity of the day of experiment. If the humidity is high (>90%, say), for example, the charges on the spheres may be discharged in air easily. In the second part of the experiment (Measurement of the Charge (by Torsion Balance)), I charged up the two spheres one by one. Charges on the first sphere may be discharged through air before I charging up the second sphere. So that the charges on these spheres may not equal and the magnitude of the forces produced were uncertain. Similar for the third part of the experiment (Measurement of the Charge (by Electrometer Amplifier)), voltage measurements on the electrometer were uncertain.

During my experiment (28^{th} Feb., 05), the mean relative humidity was 86 %, which was quite high. (source: Hong Kong Observatory - http://www.hko.gov.hk/wxinfo/pastwx/metob200502.htm). So that my results were quite bad.

Moreover, in the second part of the experiment, the torsion wire oscillated a lot (although it was damped), and so the reflected laser spot on the scale was never stable even I had not charged up the second sphere yet. Together with the very small displacement, it was very difficult to get the accurate values of the a, displacements.

For the second part of the experiment, in the lab manual, it said that for the separations of the two spheres, do this starting at a sphere center-to-center distance of 10cm to 22cm in steps of 2cm. I did two more distances: 6 and 8 cm. Because these displacements on the scale were much greater than those of longer distances. But the point charges approximation might not be validated.

In my opinion, the second part of the experiment was difficult. It needs dry weather and good experimental skills, especially in charging up the spheres. I suggest it should be modified the charging up method, so that horizontal motions of the rotary sphere should be distributed the least.