VL-E1: VERIFICATION OF THE COULOMB'S LAW OF ELECTROSTATICS

Objectives:

- To determine how the electrostatic force between two charged conducting spheres depends on (i) the distance between the spheres, and (ii) the charge of the spheres.

System requirements:

Computer (Desktop/Laptop), Operating systems: Windows, Coulombs Law_vle (zipped) File.

Advise:

Students are advised to follow the **procedures written in this manual very strictly** while performing the experiment. D**o not try to explore anything else in the experiment.**

Theory:

Coulomb's law states that the magnitude of the electrostatic force of attraction or repulsion, F, between two-point charges, q_1 and q_2, is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them, r. The direction of the force is along the straight line joining them. If the two charges have the same sign, the electrostatic force between them is repulsive; if they have different signs, the force between them is attractive.

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r} \quad (1)$$

The proportionality constant $k = 1/4\pi\varepsilon_0$ is called the Coulomb's constant (sometimes called the Coulomb's force constant). The value of k = 9×10^9 Nm^2C^{-2} and the permittivity of free space $\varepsilon_0 = 8.85\times10^{-12}$ $N^{-1}m^{-2}C^2$.

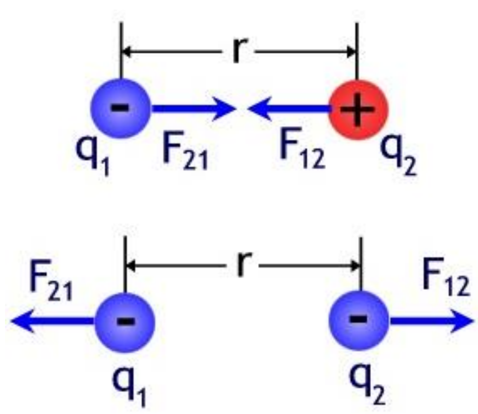

Fig 1: Attractive (upper figure) and repulsive (lower figure) force.

If both charges have the same sign (like charges) then the product q_1q_2 is positive and the direction of the forces on q_1 and q_2 are shown in above figure and the charges repel each other. If the charges have opposite signs then the product q_1q_2 is negative and the direction of the forces on q_1 and q_2 are also shown in above figure and the charges attract each other. Force on q_2 due to q_1 is $\boldsymbol{F}_{12}$, and force on q_1 due to q_2 is $\boldsymbol{F}_{21}$. Therefore, $\boldsymbol{F}_{21} = -\boldsymbol{F}_{12}$ and it is consistent with Newtons 3rd law.

The first part of this experiment looked at the relationship between the Coulomb's force and the distance between two charged spheres by keeping the magnitude of the charge on the spheres constant. As for simplicity, the sphere is considered as a point charge. Taking the logarithm on both sides of Eq. 1 and obtain,

$$\ln F = \ln\left(k\frac{q_1 q_2}{r^2}\right)$$

$$\Rightarrow \ln F = -2\ln r + \ln(kq_1q_2) \qquad (2)$$

In this experiment, the force cannot be measured directly. Here, Coulomb's force is proportional to the angle, θ, at which the movable charged sphere swings away from the other. Therefore, Eq. 2 can be rewritten as

$$\ln\theta \approx -2\ln r + \ln(kq_1q_2), \qquad (3)$$

This produces a linear relationship between the force and the distance, with a slope of -2 on a logarithmic plot.

The second part of this experiment looked at the relationship between the Coulomb's force and the product of the charge of the spheres by keeping the distance between the charges constant. Therefore, Eq. 1 can be rewritten by keeping the values of k and r are constant.

$$\ln F = \ln\left(q_1q_2\right) + \ln\left(\frac{k}{r^2}\right) \qquad (4)$$

In this experiment, the charge of the spheres cannot be measured directly. Here, both q_1 and q_2 are proportional to the voltage V by which the sphere is charged. Incorporating θ and V in Eq. 4 and obtain

$$\ln\theta \approx \ln\left(V^2\right) + \ln\left(\frac{k}{r^2}\right) \qquad (5)$$

Theoretically, the force and the product of the charge are linearly related, with a slope of 1 on a logarithmic plot.

Procedures:

1. At first unzip "**Coulombs Law_vle (zipped)**" File. Click on the executable file "**Coulombs Law_vle**" then a window will open as shown in Fig. 3.
2. To open your experiment, go to VPLab15_1 Protected > Electrostatics > Coulomb's Law.
3. Press the '**Add Damper**' button on the bottom left for reducing the damping of torsion wire (see the real instrument in Fig. 2 & compare with Fig. 3). Keep the No. of 2 mg masses at 0.
4. Use the large semi-transparent knob with the yellow pointer to adjust the position of the arm until the red marker on the arm lines up with the red reference mark (see Fig. 3).

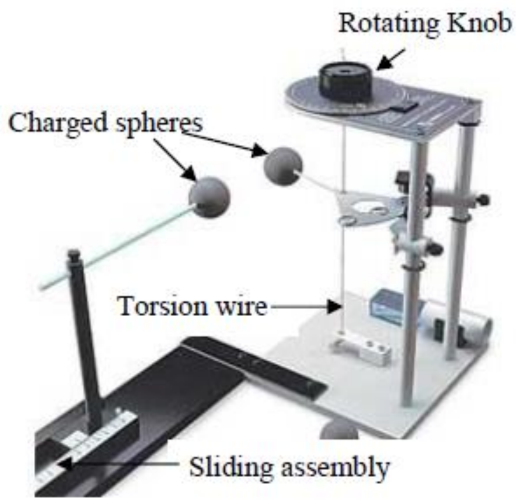

Fig. 2: PASCO Coulomb balance.

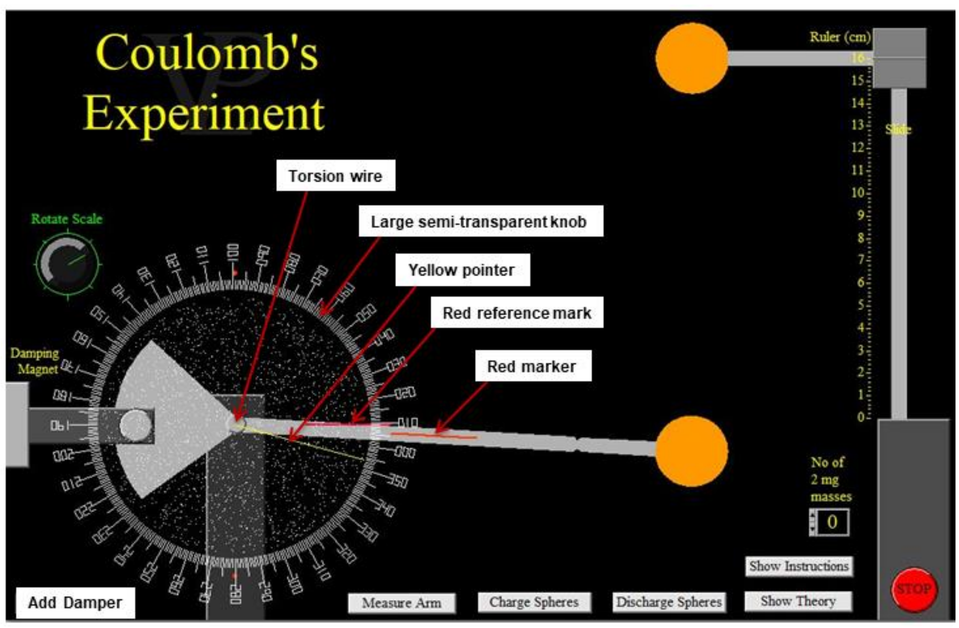

Fig. 3: Virtual Apparatus for Coulomb's Experiment.

5. Rotate the '**Rotate Scale**' using the small green knob until the zero is in line with the yellow pointer of the large semi-transparent knob.
6. To investigate the effect of distance: press the '**Charge Spheres**' knob and set to any particular potential (say 6 kV), then press the '**Remove Charger**' knob. You will notice the deflection of the arm caused by the electrostatic repulsion between the two spheres at a particular distance of separation between the charges measured from the ruler on the right side (say16 cm apart).
7. Adjust the large semi-transparent knob until the red markers are aligned again. Record the angle (measured by yellow pointer) by which the torsion wire needed to be rotated to balance the electrostatic repulsion.
8. Discharge the sphere by pressing '**Discharge Spheres**' knob. Adjust the large semi-transparent knob until the red markers are aligned again. Press the '**Charge Spheres**' knob and set again the same potential and then press the '**Remove Charger**' knob. Fixed the sphere at 15 cm position. Adjust the large semi-transparent knob until the red markers are aligned again. Record the applied voltage and the balancing angle of the torsion wire.
9. Repeat the step 8 for positions 14, 13, 12, 11, 10, 9, 8 and 7 cm.

10. Plot a graph with the $\ln(\theta)$ on the Y-axis, and the $\ln r$ on the X-axis. If this is a straight line with slope approximately 2, it indicates that the electrostatic repulsion follows an inverse-square law.
11. To investigate the effect of charging: The amount of different charges placed on the spheres are obtained by setting different voltages on the charger. After charging using 6 kV, press the '**Remove Charger**' knob. Keep the fixed sphere always at 16 cm position. Adjust the large semi-transparent knob until the red markers are aligned again. Record the applied voltage and the balancing angle of the torsion wire.
12. Discharge the sphere by pressing '**Discharge Spheres**' knob. Adjust the large semi-transparent knob until the red markers are aligned again. Press the '**Charge Spheres**' knob and set to 5 kV potential, then press the '**Remove Charger**' knob. Adjust the large semi-transparent knob until the red markers are aligned again. Record the applied voltage and the balancing angle.
13. Repeat step 12 for voltages 5, 4, 3, 2 and 1 kV (always keep the fixed sphere at 16 cm position).
14. Plot a graph of $\ln(\theta)$ on the Y- axis and the $\ln(V^2)$ on the X- axis. If the relationship is linear with slope approximately 1, it shows that the electrostatic force is proportional to the product of the charges on the spheres.

Data Collections:

Table 1: The distance dependent deflection angle.

No.	Distance r (m)$\times 10^{-2}$	Deflection angle θ	ln(r)	ln (θ)
1	16			
2	15			
3	14			
4	13			
5	12			
6	11			
7	10			
8	9			
9	8			
10	7			
11	6			

Table 2: The voltage dependent deflection angle.

No.	Voltage V (V)$\times 10^3$	Deflection angle θ	$\ln(V^2)$	$\ln(\theta)$
1	6			
2	5			
3	4			
4	3			
5	2			
6	1			

Draw Graphs:

The graphs of $\ln(\theta)$ vs $\ln(r)$ and the $\ln(\theta)$ vs $\ln(V^2)$ are shown in below.

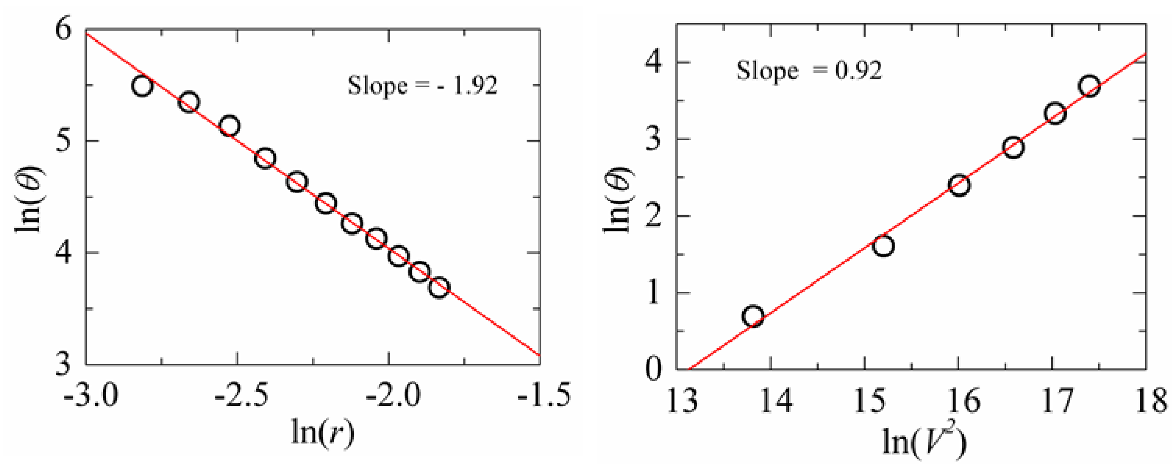

Fig. 4: The graph of *ln*(θ) with respect to *ln*(r) [Left graph]. The graph of $\ln(\theta)$ with respect to $\ln(V^2)$ [Right graph]. The open circle is the experimental data and the straight line (red colour) is the best fitting theoretical curve.

Calculations:

Calculate the slope of both the graphs.

Error analysis:

Calculate the percentage of error in both the cases.

Results:

The figure of $\ln(\theta)$ vs $\ln(r)$ produced a straight-line of slope ~ – 2. This value confirm that the Coulomb force is proportional to $1/r^2$, as indicated by Coulomb's Law.

The figure of $\ln(\theta)$ vs $\ln(V^2)$ produced a straight line of slope ~ 1. This indicates that the Coulomb force is proportional to the product of the charge of the spheres, as stated in Coulomb's Law.

Discussion:

Based on your understanding from this experiment, answer the following questions:

1) Do the results of the graph and slope indicate a “power law” ($y = x^n$)? If so, what is your best estimate of the exponent? How does your result compare with Coulomb’s Law?
2) Is it necessary to make a correction in theory if you do not consider the sphere as a point sphere in this experiment?
3) Why it is important to recharge the spheres before each measurement?
4) In real experiment using Coulomb balance, when charging the spheres, turn the power supply on, charge the spheres, then why immediately turn the supply off?
5) What types of cautions should be taken when perform the real experiment using Coulomb balance?