Coulomb’s Law

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Objective

The purpose of this laboratory exercise was to verify Coulomb's law. To do so, we utilized a torsion balance to ensure that the electric force, *F*, between two charged points had a magnitude that was proportional to the product of the of the charges and inversely proportional to the distance squared, r^2.

Theory

In 1786, French scientist, Charles Augustin de Coulomb utilized a torsion balance of his design to observe the effects of charges interacting with one another, which lead to the development of his law known as *Coulomb's Law*. In his efforts, his discovered that the electric force on each individual charge was directed along the line which joined them and that the charges that were unlike attracted, whereas those that were alike repelled. In addition, he observed that the magnitude of the electric force observed between the interactions of the point charges was directly proportional to the product of said charges. On the other hand, the magnitude of the electric force between the charges was inversely proportional to the square of the distance between them. In conclusion, Coulomb's findings can be represented as an equation as follows:

$$F = \boldsymbol{k}\frac{q_1\, q_2}{r^2},$$

Where *k*, is the constant of proportionality and is 8.987551787×10^9 Nm^2/C^2, which is closely related to the speed of light in a vacuum.

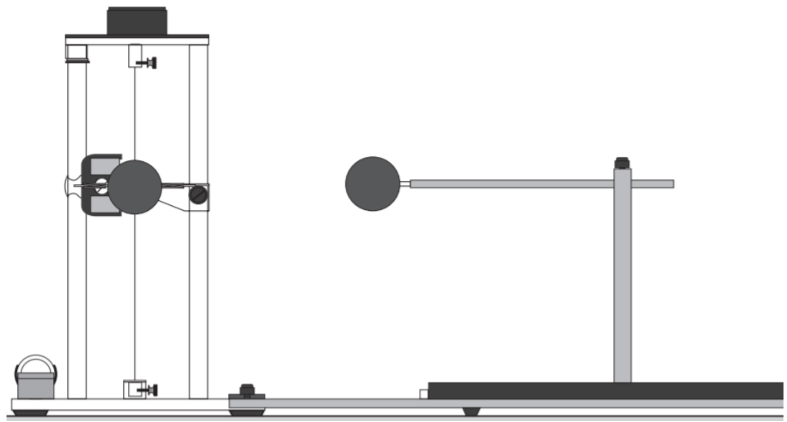
Materials

Coulomb Balance Apparatus	DC kV Power Supply
Charging Probe	Grounded Probe

Procedure

The Apparatus

A conductive sphere in mounted onto a rod and suspended from a torsion wire, while counterbalanced. Another sphere identical to the other is attached to a slide assembly, which enables one to vary the distance, *r,* with respect to the sphere attached to the torsion balance.



Part 1: The force as a function of the value of charges

In this portion of the experiment, the distance between the spheres, *r*, is held at a constant 8 cm. Then we varied the potential of the spheres and measured the resultant force by measuring the angles. After collecting the data we graphed the angle vs. potential to observe the relationship between the charges and force.

First we moved the sphere attached to the sliding assembly as far away from the suspended sphere and discharged each of them by contacting each sphere with the ground probe.

Next, we rotated the bottom torsion wire retainer until the pendulum was at the zero displacement position- this process can be referred to as "*zeroing the torsion balance*". When then grounded one terminal of the kilovolt power supply and plugged it in.

Once the spheres are placed the maximum distance apart from each other, we charged the sphere attached to the torsion wire to a maximum potential of 6 *k*V with a charging probe. Without further delay, we turn off the power supply to avoid high voltage leakage effects.

Afterwards, we charged the sliding sphere to a potential of 3 *k*V using a charging probe and immediately turned off the power supply for the same purposes.

Then we changed the position of the sliding sphere such that the distance between the spheres is 8 cm and adjusted the torsion knob to balance the force and returned the pendulum to its zero position. We recorded the potential *V* value and angle θ and repeated this 3 times, to have enough data to determine the average angle value, θ.

Finally we varied the sliding sphere potential with values of 4,5,5.5, and 6 *k*V and maintained a constant distance of 8 cm.

Part 2 : The force as a function of the distance between the charges

In this part of the laboratory exercise we verified the proportionality between the electrostatic forces between two point charges and the distance squared (r^2) between the charges. To do so we will charge both spheres to a maximum constant of 6 *k*V and vary the distance, *r* , between the two spheres and measure the resultant force for each separation via angle measurement. After collecting the data of the angle corresponding to the distance varied we plotted the graph- angle θ vs. $1/r^2$, which enabled us to observe the relationship between the electrostatic force and distance between the two point charges.

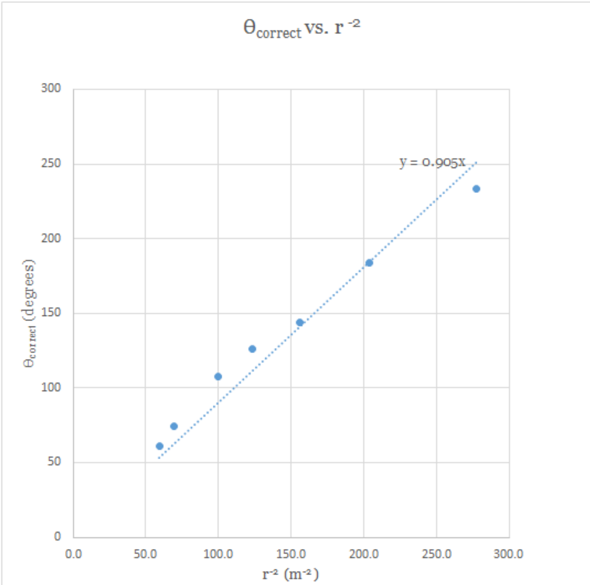
First, we started off by moving the sliding sphere as far away from the suspended sphere and fully discharge both by contacting them with a ground probe.

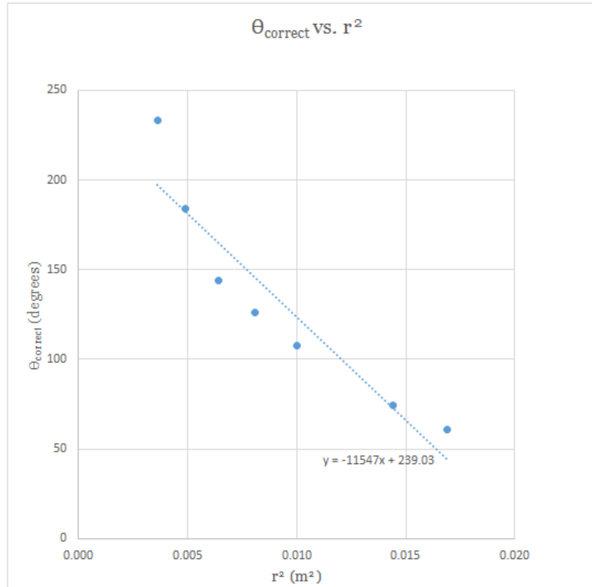
Then we zeroed the torsion balance, and charged both spheres (while separated) to a maximum potential of 6 *k*V by contacting each sphere with the charging probe, individually.

Next we put the sliding sphere in a position 13 cm from the sphere attached to the torsion wire.

Afterwards, we adjusted the torsion knob such that the force is balanced and reset the pendulum to its zero position. We varied the angle ±1 degree and recorded the distance r and the angle θ. We continued to slide the "sliding" sphere in various distances of 12,10,9,8,7, and 6 cm -while adjusting the torsion knob as necessary to maintain balance and zeroing the pendulum's position. We measured and recorded the corresponding angle for each distance decrementation. As done in part 1 we, repeated each angle measurement for its corresponding distance three times.

Data





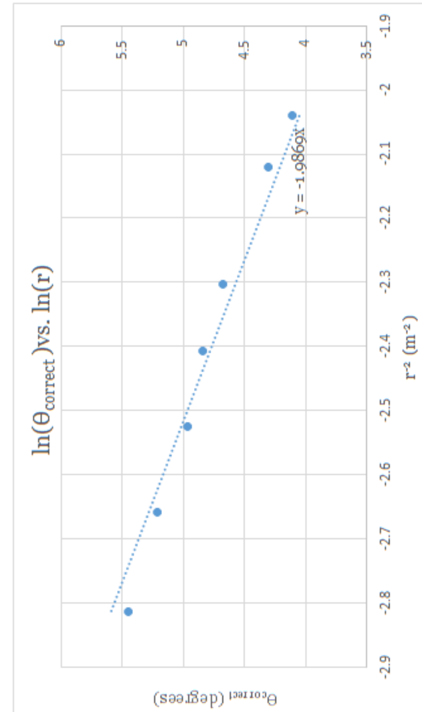


Table 1. The force as a function of the value of charges

Potential of the Sliding Sphere V, kV	Angle, *degrees* θ_1	θ_2	θ_3	Average Angle θ, *degrees*
3	56	76	70	67
4	101	90	93	95
5	117	109	110	112
5.5	121	126	125	124
6	138	134	136	136

Table 2. The force as a function of the distance between the charges

Radius of the sphere $a=$ 0.019 m Potential of each sphere $V=$ 6 kV

Distance r, *meters*	Angle, *degrees* θ_1	θ_2	θ_3	Average Angle θ, *degrees*	$1/r^2$	$B=1-4a^3/r^3$ Correction Factor	Corrected Avg. Angle θ, *Degrees*
0.13	52	72	56	60	59.2	0.988	61
0.12	75	75	70	73	69.4	0.984	75
0.1	101	106	108	105	100.0	0.973	108
0.09	128	116	121	122	123.5	0.962	126
0.08	138	134	136	136	156.3	0.946	144
0.07	176	169	163	169	204.1	0.920	184
0.06	209	211	191	204	277.8	0.873	233

Calculations

Electrostatic Force

$$F = k\frac{Q_1 Q_2}{r^2} = \frac{8.99 \times 10^9\ \frac{\mathrm{Nm}^2}{\mathrm{C}^2} \times 1.60218 \times 10^{-19}\ \mathrm{C}\ \times 1.60218 \times 10^{-19}\ \mathrm{C}}{(1\mathrm{m})^2} \cong 2.307\ \times\ 10^{-28}\ \mathrm{N}$$

Gravitational Force

$$F = G\frac{m_1 m_2}{d^2} = \ 6.673\ 10^{-11}\ \frac{\mathrm{Nm}^2}{\mathrm{kg}^2} \times \frac{9.109\ 10^{-31}\ \mathrm{kg}\ \ \times\ 9.109\ 10^{-31}\ \mathrm{kg}}{(1\mathrm{m})^2} \cong 5.537\ \times\ 10^{-71}\ \mathrm{N}$$

Ratio of Electrostatic and Gravitational Force

$$\frac{\mathrm{F_E}}{\mathrm{F_G}} = \frac{2.307\ \times\ 10^{-28}\ \mathrm{N}}{5.537\ \times\ 10^{-71}\ \mathrm{N}} = 4.165 \times 10^{42}$$

$$\frac{\mathrm{F_E}}{\mathrm{F_G}} = \frac{k\frac{Q_1 Q_2}{r^2}}{G\frac{m_1 m_2}{d^2}} = \frac{k\frac{Q_1 Q_2}{\cancel{r^2}}}{G\frac{m_1 m_2}{\cancel{d^2}}} = \frac{k{Q_1}^2}{G{m_1}^2}$$

Questions

1. Does Coulomb's law hold for all charged objects?

No, it may be applied to static charged particle-like objects and spherical shells that are uniform in charge, but not for moving particles.

2. What similarities do electrostatic forces have to gravitational forces? What are the most significant differences?

Both electrostatic forces and gravitational forces are independent of the path they take but depend on its final and initial positions [thus they are both conservative], and follow the inverse square law. In Coulomb's Law, the force can either be repulsive or attractive due to the dual nature of charges, whereas gravitational forces are always attractive.

3. Two identical tiny spheres carrying the same charge are 1.0 *m* apart center-to-center in vacuum and experience an electrical repulsion of 1 *N* .What is the charge?

$$F = k\frac{Q_1 Q_2}{r^2}$$

Given F= 1 Newton & k= 8.987551787E9 Nm^2/C^2 & r= 1m:

$$1\,N = 8.987751787\text{ E }9\,\frac{Nm^2}{C^2}\,\frac{Q_1 Q_2}{(1m)^2}$$

Since $Q_1 = Q_2$:

$$1\,N = 8.987751787\text{ E }9\,\frac{Nm^2}{C^2}\,\frac{{Q_1}^2}{(1m)^2}$$

$${Q_1}^2 = \frac{1}{8.987751787\text{ E }9}C^2$$

$$Q_1 = \sqrt{\frac{1}{8.987751787\text{ E }9}C^2}$$

$$Q_{1=}\,Q_2 \approx 1\text{ Coulomb}$$

4. Find the ratio of the electrostatic and gravitational forces between two electrons when they are 1 *m* apart.

$$\frac{Kq^2}{Gm^2}$$

See **Calculations**

Conclusion

In this laboratory exercise, we were successful in verifying the presence of an electrical force between the interactions of two charged spheres, as well as the proportionality between the magnitude of the force, product of charges and the distance (inverse squared).