Coulomb's Law Lab
PHY-222-AC01

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1 Theory

Coulomb's law describes a mathematical expression for the interaction of electrically charged objects. The electrical charge generates a force pair, F_E, with a magnitude that has been experimentally determined to such a degree that it is accepted as a universal law.

1.1 Definitions

Electrically charged object - Matter with more or less electrons than protons is negatively or positively charged respectively.

Force pair - The principal of Newton's third law in which every action force has a corresponding reaction force equal in magnitude and opposite in direction.

Coulomb's law -

$$F_E = k\frac{q_1 q_2}{r^2}$$

r - The distance between the charged objects measured in meters.

$q_1 q_2$ **-** The sum of the electrical charges of each object, measured in Coulombs.

k - The electric constant, the experimentally determined proportionality constant with a value of $k = 9.0 \times 10^9 \frac{Nm^2}{C^2}$

2 Objectives

First Objective
Experimentally confirm Coulomb's law.

Second Objective
Study how distance and charge affect the electric force.

Third Objective

Experimentally determine the value of the electric constant, k.

3 Experimental Data

3.1 Part One

Table 1:

$q_1 = 2\mu C$		$q_2 = 4\mu C$	
r(cm)	$r^2(m^2)$	$\frac{1}{r^2}(\frac{1}{m^2})$	$F_E(N)$
10	1.0×10^{-2}	1×10^2	7.190
9	8.1×10^{-3}	1.2×10^2	8.877
8	6.4×10^{-3}	1.6×10^2	11.234
7	4.9×10^{-3}	2.0×10^2	14.674
6	3.6×10^{-3}	2.8×10^2	19.972
5	2.5×10^{-3}	4.0×10^2	28.760
4	1.6×10^{-3}	6.3×10^2	44.938
3	9.0×10^{-4}	1.1×10^3	79.889

3.2 Part Two

Table 2:

$q_1 = 5\mu C$	$r = 6cm$
$q_2(\mu C)$	$F_E(N)$
10	124.827
9	112.344
8	99.862
7	87.379
6	74.896
5	62.414
4	49.931
3	37.448

4 Data Analysis

4.1 Part One

4.1.1 F_E with respect to r

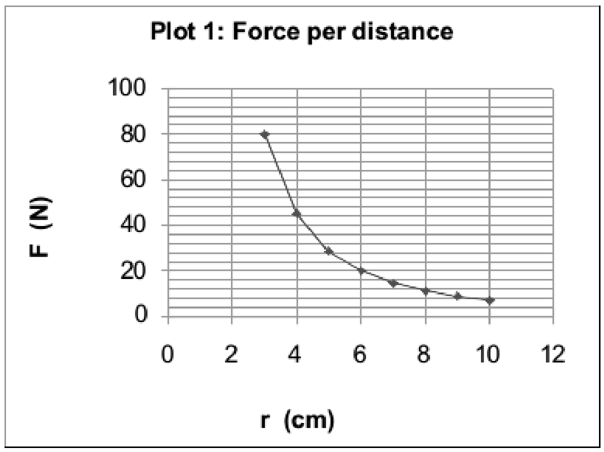

Figure 1: Force per distance

Comments on Figure 1: As the charged objects' distance (r) tends towards zero from the possitive direction, the force (F) tends towards infinity. As r tends towards positive infinity, F tends towards zero.

4.1.2 F_E with respect to $\frac{1}{r^2}$ to find k

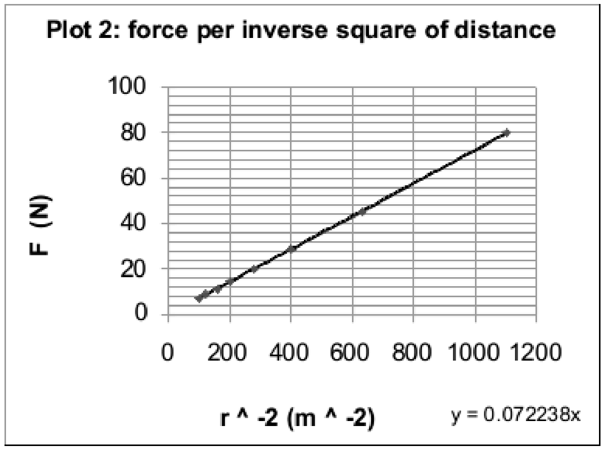

Figure 2: Force per inverse square of distance

Coulomb's Law - $F_E = k\frac{q_1 q_2}{r^2}$

Linear regression of Figure 2 data - y = 0.072238x

q_1 **-** $2\mu C$

q_2 **-** $4\mu C$

$$\begin{aligned}
F_E &= k\frac{(2\mu C)(4\mu C)}{r^2} \implies \\
F_E(N) &= k\left(8\times 10^{-12}C^2\right)\left(\frac{1}{r^2}\right)\left(\frac{1}{m^2}\right) \\
y &= 0.072238x \implies \\
F_E &= 0.072238\left(\frac{1}{r^2}\right) \\
0.072238\left(\frac{1}{r^2}\right)(N) &= k\left(8\times 10^{-12}C^2\right)\left(\frac{1}{r^2}\right)\left(\frac{1}{m^2}\right) \\
k &= \frac{0.072238\left(\frac{1}{r^2}\right)(N)(m^2)}{8\times 10^{-12}C^2\left(\frac{1}{r^2}\right)} \\
k &= \boxed{9.02975\times 10^9}\left(\frac{Nm^2}{C^2}\right)
\end{aligned}$$

4.1.3 Percent error in k

$$\%\text{ error } = \left|\frac{\text{theoretical } - \text{ experimental}}{\text{theoretical}}\right| \times 100\%$$

$$\%\text{ error } = \left|\frac{\left(9.0 \times 10^9 \frac{Nm^2}{C^2}\right) - \left(9.02975 \times 10^9 \frac{Nm^2}{C^2}\right)}{\left(9.0 \times 10^9 \frac{Nm^2}{C^2}\right)}\right| \times 100\%$$

$$\%\text{ error } = 0.330556\%$$

4.2 Part Two

4.2.1 F_E with respect to q_2

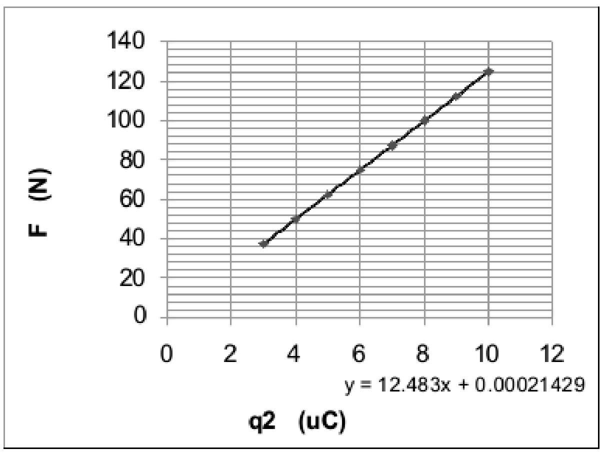

Figure 3: Force per magnitude charge on q_2

Comments on Figure 3: There is a positive linear relationship between the magnitude of charge on one object $q_2(\mu C)$ and electric force $F_E(N)$. Given the precision of F_E measurement, it appears to approach a lower bounds of $F_E = 0$ at $q_2 = 0$.

4.2.2 F_E with respect to q_2 to find k

Coulomb's Law - $F_E = k\frac{q_1 q_2}{r^2}$

Linear regression of Figure 3 data - $y = 12.483x + 0.00021429$

q_1 **-** $5\mu C$

r - $6cm$

$$
\begin{aligned}
F_E &= k\frac{(5\mu C)(q_2)}{(6cm)^2} \implies \\
F_E(N) &= kq_2(\mu C)\left(\frac{5\times 10^{-6}C}{3.6\times 10^{-3}m^2}\right) \\
y &= 12.483x + 0.00021429 \implies \\
F_E &= 12.483q_2 + 0.00021429 \\
(12.483q_2 + 0.00021429)(N) &= kq_2(\mu C)\left(\frac{5\times 10^{-6}C}{3.6\times 10^{-3}m^2}\right) \implies \\
k &= \frac{(12.483q_2 + 0.00021429)(3.6\times 10^{-3}m^2)(N)}{(q_2)(5\times 10^{-6}C)(10^{-6}C)} \implies \\
k &= \boxed{8.98776\times 10^9\left(\frac{Nm^2}{C^2}\right)} + 1.542888\times 10^5 q_2^{-1}\left(\frac{Nm^2}{C^2}\right)
\end{aligned}
$$

4.2.3 Percent error in k

$$
\begin{aligned}
\%\text{ error } &= \left|\frac{\text{theoretical } - \text{ experimental}}{\text{theoretical}}\right| \times 100\% \\
\%\text{ error } &= \left|\frac{\left(9.0\times 10^9\,\frac{Nm^2}{C^2}\right) - \left(8.98776\times 10^9\,\frac{Nm^2}{C^2}\right)}{\left(9.0\times 10^9\,\frac{Nm^2}{C^2}\right)}\right| \times 100\% \\
\%\text{ error } &= 0.136\%
\end{aligned}
$$

5 Results and Conclusions

6 Discussion of Experimental Uncertainty