APH01 – Coulomb's Law

PHYS 232N
Instructor: Tyler Viducic

Submitted by:
Isaiah Bagwell
Jamie McLaulin

Submitted on: September 17, 2023
Resubmitted on: October 4, 2023

Introduction

Charged subatomic particles have properties that determine how they affect other particles and the field around them. The proton is a positively charged particle with an electric field that extends outward, and the electron is a negatively charged particle with an electric field withdraws inward. Coulomb's law allows one to calculate the electrostatic force that charged particles exert on each other based on the charges of each particle and the distance between them. This experiment will prove Coulomb's law by simulating two particles and various charges and distances apart. In doing this, it will allow for the calculation of an electric constant and the comparison to the standard electric constant.

In this experiment, the University of Colorado Boulder's PhET program was used to simulate the electric force between two charges and how changes to the charge and distance affected that force. By altering these factors, it was determined that the electric force is directly related to the magnitude of the charge and indirectly related to the distance between charges. To confirm this, k was calculated from the data gathered. The first set of data used to calculate k, obtained from the graph showing F_e vs $1/r^2$ (Figure 2), gave an accurate value for k. The second set, obtained from the graph showing F_e vs q^2 (Figure 3), gave a value for k that was not accurate, though it is believed that may be an error with Microsoft Excel. Regardless, the data collected supports Coulomb's Law.

Analysis

To examine Coulomb's Law (Figure 1), different scenarios were examined to determine the effect of various factors on force. In this equation, F_e represents electrical force in Newtons; k, the electric constant of 8.987551 x 10^9 $(Nm^2)/C^2$; q_1 and q_2, the charges; and r, the distance between the charges. The values of radius and charge were the variables altered over the course of the experiment, and the information gathered was used to determine the value of k to verify the equation. The University of Colorado Boulder's PhET program was used for this experiment.

$$F_e = \frac{kq_1q_2}{r^2}$$

Figure 1: Coulomb's Law

First, the characteristics of attractive and negative forces were determined. In the PhET program, both charges were made positive at varying values. As long as the charges were both positive, the resulting forces were directed away from the other charge. The same result was obtained when charges of varying values were both negative. However, if one charge was positive and the other negative, the resulting forces were directed toward the other charges, regardless of charge size. From this, it can be determined that positive charges exhibit attractive forces on negative charges and repulsive forces on positive charges. Likewise, negative charges exhibit an attractive force on positive charges and repulsive force on negative charges.

Next, various distances were used to determine the effect that changing *r* would have on the resulting force. Coulomb's Law indicates that F_e and *r* are inversely related, and any increase in *r* should result in a decrease in F_e. The distance used in this portion were from 3.00 cm to 10.00 cm in increments of 1 cm. The information, recorded in Table 1, shows that as *r* increases, F_e decreases. This is further supported by the graph in Figure 2, which shows a curve that would be expected from an inverse exponential curve.

$q_1 = 10 \times 10^{-6}$		$q_2 = -10 \times 10^{-6}$	
r (cm)	r^2 (m^2)	$1/r^2$ ($1/m^2$)	F_e (N)
10	0.0100	100.00	89.876
9	0.0081	123.46	110.957
8	0.0064	156.25	140.430
7	0.0049	204.08	183.419
6	0.0036	277.78	249.654
5	0.0025	400.00	359.502
4	0.0016	625.00	561.722
3	0.0009	1111.11	998.617

Table 1: Effects of Distance on Force

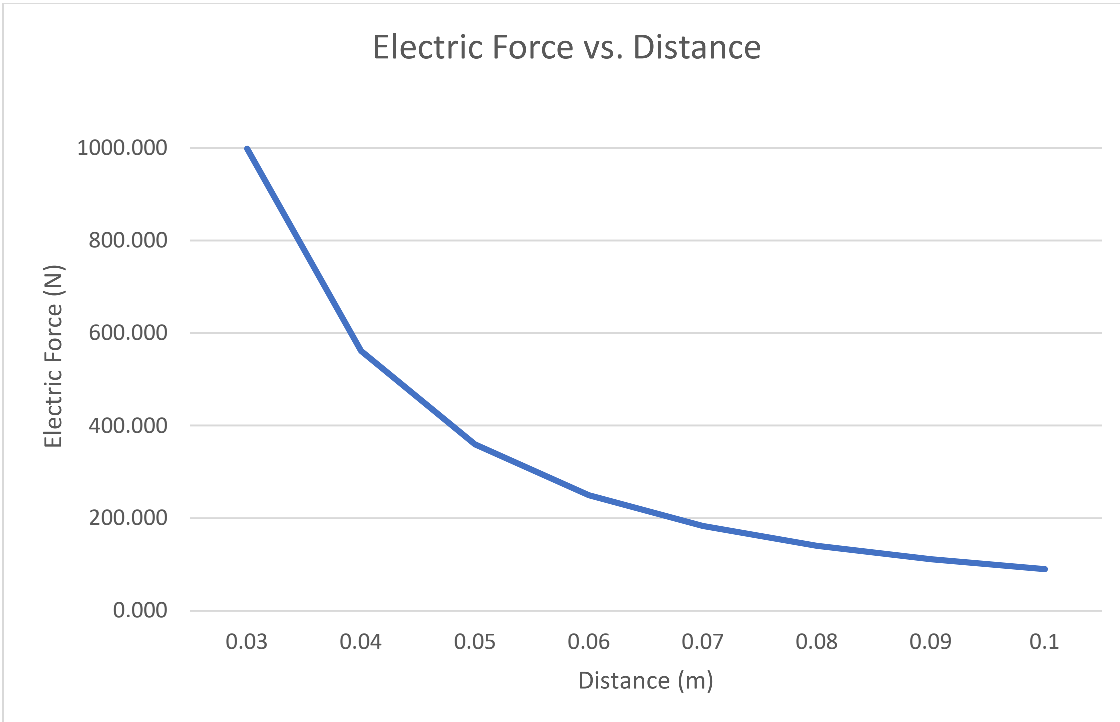

Figure 1: Electric Force versus Distance Graph

For the next part of the experiment, the relationship between F_e and $1/r^2$ was examined. Based on Coulomb's Law, F_e and $1/r^2$ should be directly proportional. This means that a larger r should result a smaller $1/r^2$ and a smaller force. Conversely, a smaller r should result in a larger $1/r^2$ and a larger force. The data in Table 1 supports this, as does Figure 2. Figure 2 shows a linear graph with a positive slope, which indicates a direct relationship.

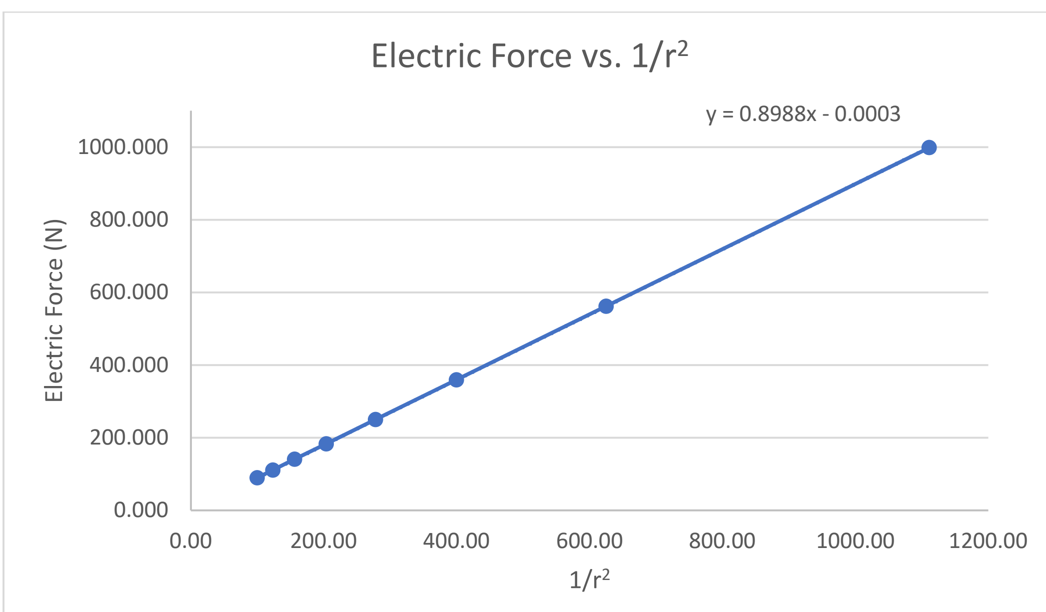

Figure 2: Electric Force versus 1/Distance^2 Graph

From this linear relationship, the electric constant k was determined (Calculations 1). To do so, Coulomb's Law was substituted into $y = 0.8988x - 0.0003$. The dependent variable F_e replaced y, the independent variable $1/r^2$ replaced x, and 0.0003 was ignored due to its size being negligible. This left 0.8988 to be set equal to kq_1q_2. The charges for this section of the experiment were 10×10^{-6} C and -10×10^{-6} C. As shown in Table 2, $k = 8.988 \times 10^9$ (Nm^2)/C^2 for this data. This is very close to the known value of k, with a percent error of only 0.00277% (Calculations 2).

k	Value
Accepted	8.987551×10^9 Nm^2/C^2
Your Value	8.988×10^9 Nm^2/C^2
Percent Error	0.00277%

Table 2: Electric Constant for Figure 2

The next step of the experiment was to examine how a varying charge would affect F_e. Table 3 documents the effect on force when q_1 remains 5×10^{-6} C, r remains 0.06 m, and q_2 moves from 3×10^{-6} C to 10×10^{-6} C. The data gathered shows that as q_2 increase, F_e also increases. As Coulomb's Law shows that both F_e and q_2 are in the numerator of the equation, it can be surmised that the two are directly proportional. This is further supported by Figure 3, which shows a graphing representation of the relationship between the two variables. This graph is linear with a positive slope which, as previously stated, indicates a direct relationship.

$q_1 = 5\ \mu C$	r = 6 cm
q_2 (μC)	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

Table 3: Effects of Charge on Force

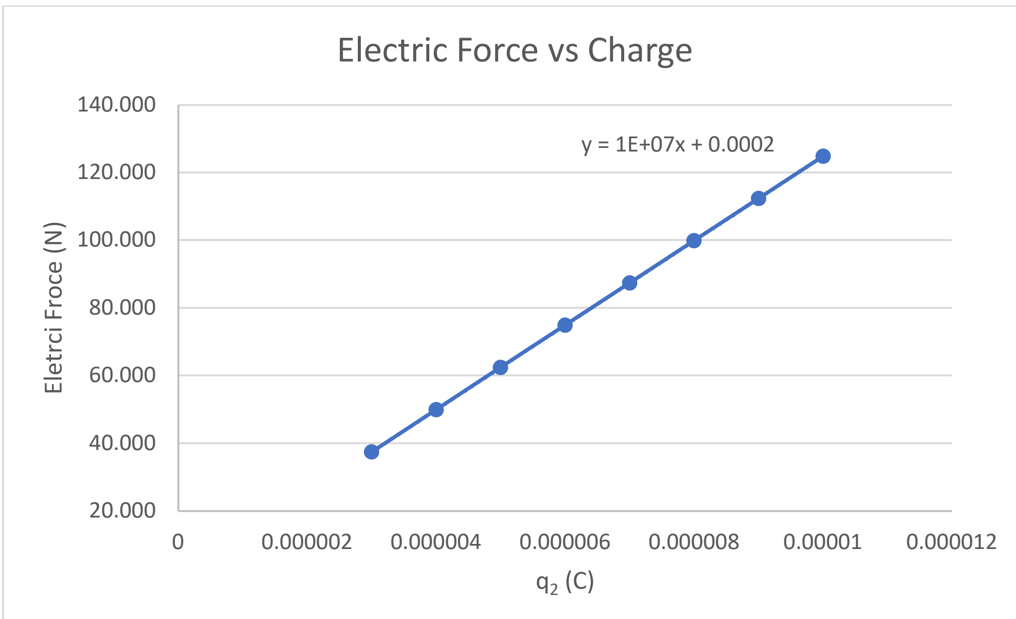

Figure 3: Electric Force versus Charge

Next, the electric constant k for this data was determined. As in the previous calculations, Coulomb's Law and the equation generated by the graph were compared. For the equation $y = 1 \text{ x } 10^7x + 0.0002$, F_e replaced y, q_2 replaced x, and 0.0002 was ignored as negligible. This left $(kq_1)/r^2$ to replace 1 x 10^7. The values for q_1 and r were 5 x 10^{-6} C and 0.06 m respectively. This information was used to calculate k (Calculations 3). The resulting value was 7.2 x 10^9 $(Nm^2)/C^2$.

k	Value
Accepted	8.987551×10^9 Nm^2/C^2

Your Value	7.2 x 10^9 Nm^2/C^2
Percent Error	19.89%

Table 4: Electric Constant for Figure 3

This value is significantly different from the accepted value of *k*, with a percent error of 19.89%, as seen in Table 4. To determine if this was caused by an error in the information or an error in the equation generated by Excel, this *k* value was compared to the *k* valued obtained from individual calculations using the data from Table 3. This process is detailed in Calculations 5. Once each *k* values for each of the F_e, q_1, q_2, and *r* sets was determined, the average *k* was found. This value was 8.987554286 x 10^9 $(Nm^2)/C^2$. The percent error for this value is 3.656 x 10^{-5}%.

This information indicates that either an error occurred in Excel or the one-to-one comparison used to determine the electric constant was not an accurate method of doing so. However, as this method did obtain an accurate *k* value for the information in Table 1, it seems more likely that an error occurred during the formation of the equation. More testing would be required to see if this problem persists with different information.

Other potential sources of error are limited, as the experiment was conducted through PhET. As a computer program, this limits the amount of real-world error that can be encountered. One possible example is that the distances for each part of the experiment were set manually using a mouse instead of being . The *r* values could be slightly off, which would impact the calculations. Another possible source error is that if the PhET program glitched or had any coding issues, that could impact the results. This one is not very likely, however, and the information gained from the program matches what we would expect using the same values and Coulomb's Law.

Conclusion

This experiment allowed for the comparative examination of Coulomb's law when given simulated particles. Coulomb's law as well as the qualities of attraction and repulsion were supported with the data collected. The data showed that the electric force emitted by the particles was proportional to the distance between them; specifically, the further away the particles were, the less the force of the electric field, and the shorter the distance, the greater the force. It was also concluded that the greater the charge of the particle, the greater the force on its environment and other particles. As previously mentioned, the percent error from calculating the electric constant was low when compared to the standard value, with a percent error of around 0.003% for the information in Figure 2. However, the electric constant for Figure 3 was less accurate, with a percent error of around 20%. This error is believed to have been caused by Excel, an inaccuracy in the equation used, and an error in the PhET program used. To determine an exact cause, more experiments would need to be conducted to determine the source of the error.

Calculations

$$0.8988 = kq_1q_2$$

$$0.8988 = k|(10x10^{-6})(10x10^{-6})|$$

$$\frac{0.8988}{|(10x10^{-6})(10x10^{-6})|} = k$$

$$k = \frac{0.8988}{1x10^{-10}}$$

$$k = \frac{0.8988}{1x10^{-10}}$$

$$k = 8.988x10^{9}$$

Calculations 1: Electric Constant of Table 1

$$Percent\ error = \left|\frac{8.988 \times 10^{9} - 8.987551 \times 10^{9}}{8.987551 \times 10^{9}}\right| \times 100$$

$$Percent\ error = \left|\frac{2.49 \times 10^{5}}{8.987551 \times 10^{9}}\right| \times 100$$

$$Percent\ error = \left|2.770498882 \times 10^{-5}\right| \times 100$$

$$Percent\ error = 0.00277\%$$

Calculations 2: Percent Error of Table 1

$$1x10^{7} = \frac{kq_1}{r^2}$$

$$1x10^{7} = \frac{k(5x10^{-6})}{(0.06)^2}$$

$$\frac{(1x10^{7})(0.0036)}{(5x10^{-6})} = k$$

$$\frac{3.6x10^{4}}{(5x10^{-6})} = k$$

$$k = 7.2x10^9$$

Calculations 3: Electric Constant of Table 2

$$Percent\ error = \left|\frac{7.2 \times 10^9 - 8.987551 \times 10^9}{8.987551 \times 10^9}\right| \times 100$$

$$Percent\ error = \left|\frac{1.787551 \times 10^9}{8.987551 \times 10^9}\right| \times 100$$

$$Percent\ error = |0.1988918895| \times 100$$

$$Percent\ error = 19.89\%$$

Calculations 4: Percent Error of Table 3

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

$$k_n = \frac{F_e(0.06^2)}{(5x10^{-6})q_2}$$

$$k_{10} = \frac{(124.827)(0.06^2)}{(5x10^{-6})(10x10^{-6})} = 8.987544x10^9$$

$$k_9 = \frac{(112.344)(0.06^2)}{(5x10^{-6})(9x10^{-6})} = 8.98752x10^9$$

$$k_8 = \frac{(99.862)(0.06^2)}{(5x10^{-6})(8x10^{-6})} = 8.98758x10^9$$

$$k_7 = \frac{(87.379)(0.06^2)}{(5x10^{-6})(7x10^{-6})} = 8.987554286x10^9$$

$$k_6 = \frac{(74.896)(0.06^2)}{(5x10^{-6})(6x10^{-6})} = 8.98752x10^9$$

$$k_5 = \frac{(62.414)(0.06^2)}{(5x10^{-6})(5x10^{-6})} = 8.987616x10^9$$

$$k_4 = \frac{(49.931)(0.06^2)}{(5x10^{-6})(4x10^{-6})} = 8.98758x10^9$$

$$k_3 = \frac{(37.448)(0.06^2)}{(5x10^{-6})(3x10^{-6})} = 8.98752x10^9$$

$$k_{avg} = 8.987554286x10^9$$

$$Percent\ error = \left|\frac{8.987554286 \times 10^9 - 8.987551 \times 10^9}{8.987551 \times 10^9}\right| \times 100$$

$$Percent\ error = \left|\frac{3.286 \times 10^3}{8.987551 \times 10^9}\right| \times 100$$

$$Percent\ error = |3.656168404x10\hat{}-7| \times 100$$

$$Percent\ error = 3.656x10^{-5}\%$$

Calculations 5: Individual Calculations for Electric Constant of Table 3