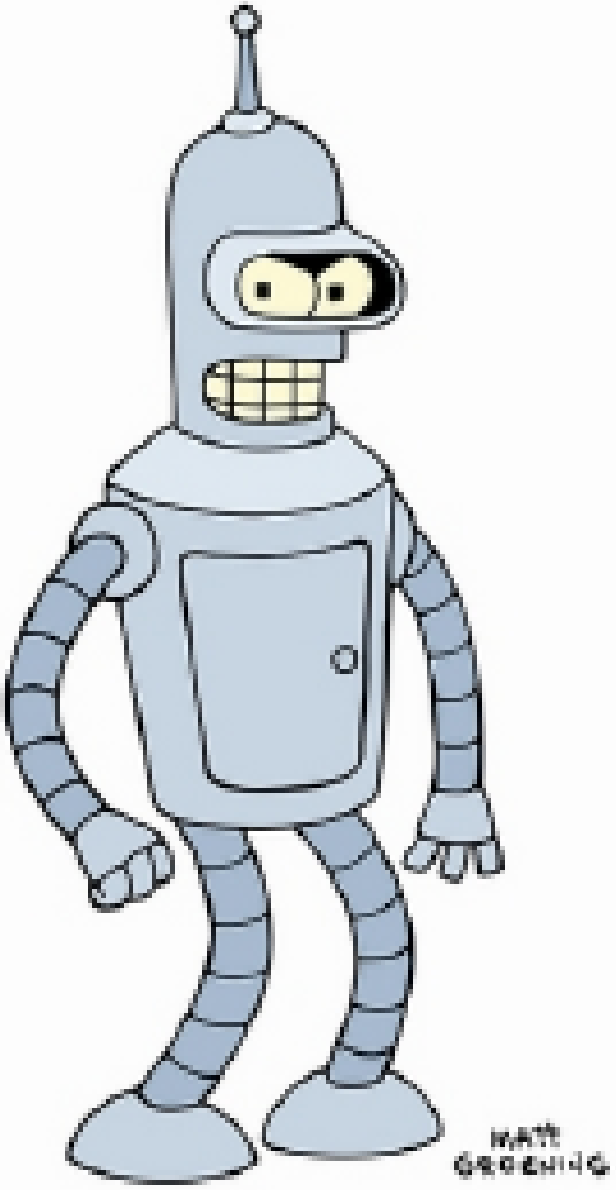
Coulomb's Law and Curve Straightening



POS Checklist:

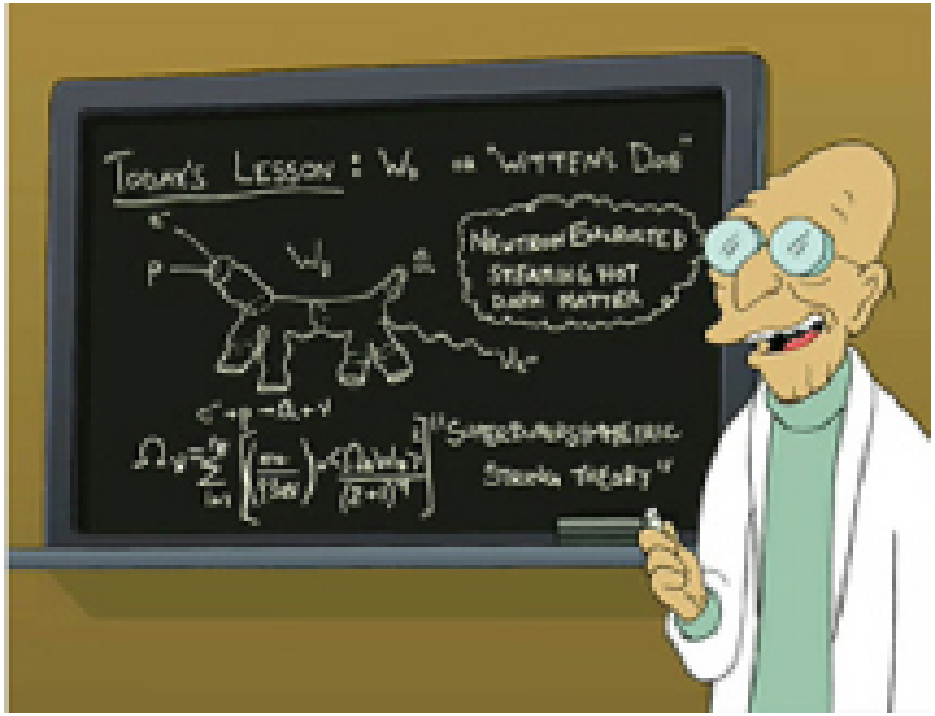
☐ infer, from empirical evidence, the mathematical relationship among charge, force and distance between point charges.

☐ use free-body diagrams to describe the electrostatic forces acting on a charge.

☐ use graphical techniques to analyze data; *e.g., curve straightening.*

Public Service Announcement:

Portions of today's lesson taking from the Education Alberta diploma bulletin:



[Physics Exam Bulletin]

Diploma Alert!

Use the following information to answer the next four questions.

> Charles Augustin de Coulomb performed a series of investigations on the quantitative nature of electrical forces. He was able to determine the effect of both distance and magnitude of charge on the electrostatic force between two charged metal spheres.

4. In order to determine the relationship between force and distance, Coulomb needed to

Ans: ■

A. keep the magnitude of one charge constant

B. keep the magnitude of both charges constant

C. keep the distance between the charges constant

D. vary the magnitude of one charge while varying distance between the charges

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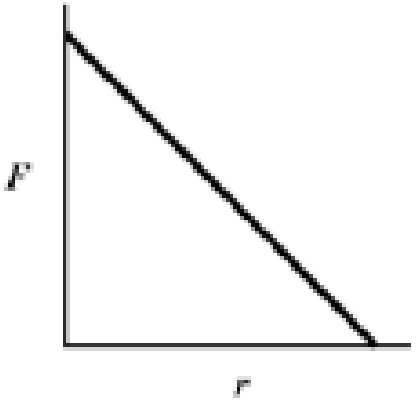
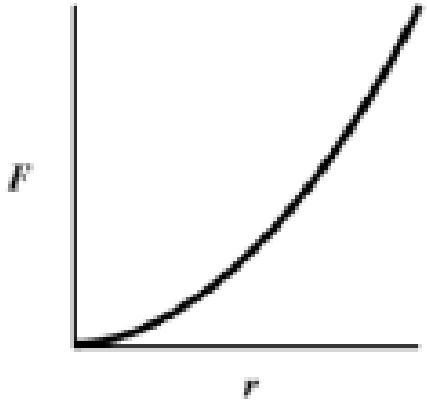
5. Which of the following graphs represents the relationship that Coulomb determined between force and the distance between two charged metal spheres?

A.

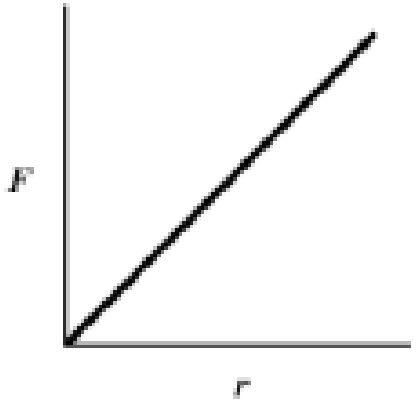


Ans:

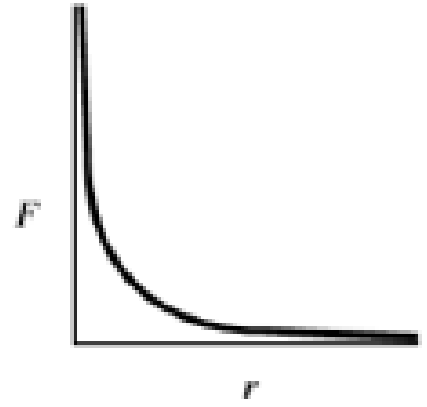
B.



C.



D.



Diploma Alert!

7. Coulomb again separated the identically charged spheres by distance r. The force between the spheres was F. Coulomb touched one of the spheres with a third, identical neutral sphere. The third sphere was then moved far away from the other spheres. If he then measured the force between the original spheres, the new force between the spheres would have been

A. $\frac{1}{2}F$

B. $\frac{1}{4}F$

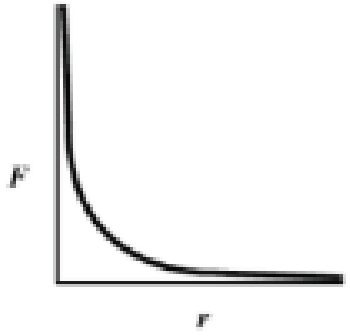
C. $2F$

D. $4F$

Ans:

Curve Straightening

- used to turn a curved graph ($y \propto 1/x^2$) into a linear graph ($y = mx + b$)



Recall the graph from a previous review question: force vs. separation in Coulomb's Law.

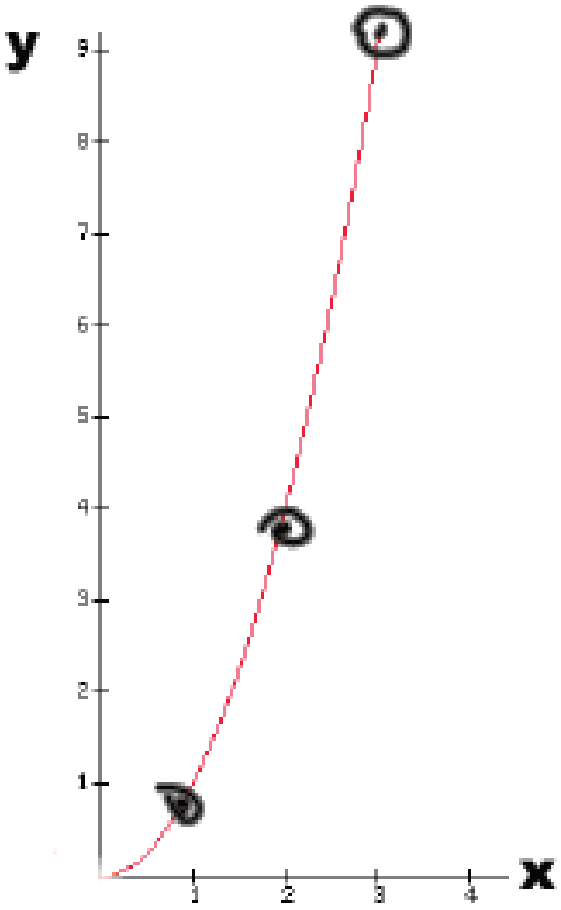
$$F_e = \frac{kq_1q_2}{r^2}$$

If we turn this graph into a linear graph, we can determine the graph's slope, which could tell us:

- **the experimental value of k**
- **the magnitude of the charges.**

Basic Example:

ex) Straighten the curve.



Data Table:

x	y
1	1
2	4
3	9

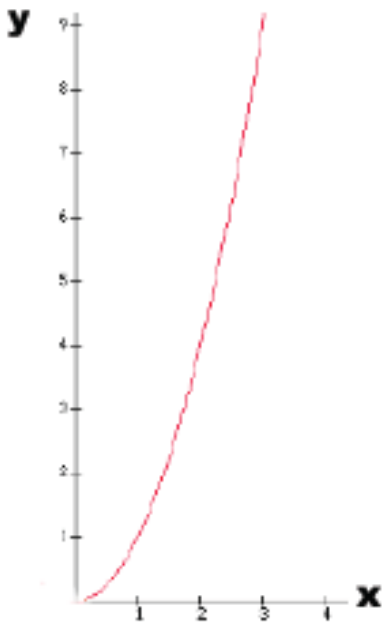
Step 1: Look at the graph and data. Determine the relationship. This is a squared relationship.

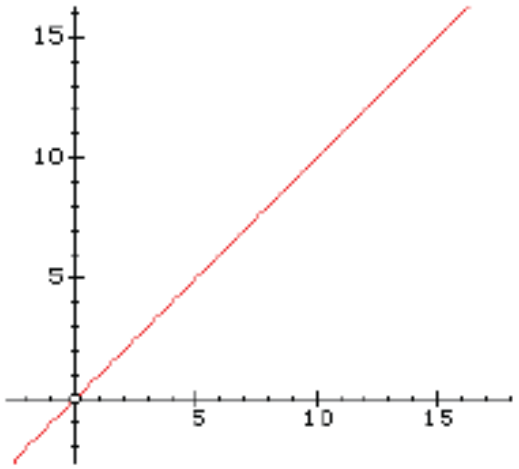
Step 2: Take all x-values and square them.

Data Table:

	x	y
1	~~1~~	1
4	~~2~~	4
9	~~3~~	9

Step 3: Re-plot the graph. It will now be a straight line.





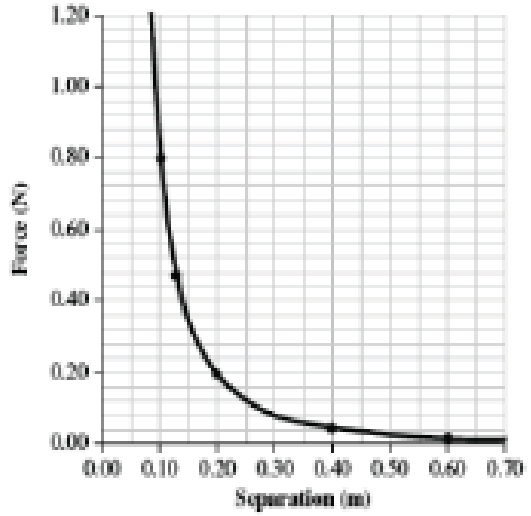
The straight graph will have many of the same quantities as the curved graph, only now we can do some simple mathematics (like slope calculations) with it.

Use the following information to answer the next question.

A student performed an experiment that verified Coulomb's Law of Electrostatics by measuring the repulsion between two charged spheres, A and B, as a function of the separation of the spheres. The spheres were identical in size and mass. The measurements are shown in the table of values and plotted on the graph below.

Separation (m)	Force (N)
0.10	0.790
0.13	0.480
0.20	0.200
0.40	0.050
0.60	0.022

Force of Repulsion as a Function of the Separation



Diploma Example:

We will straighten the curve, then graph and determine the slope. The slope will allow us to determine the charge.

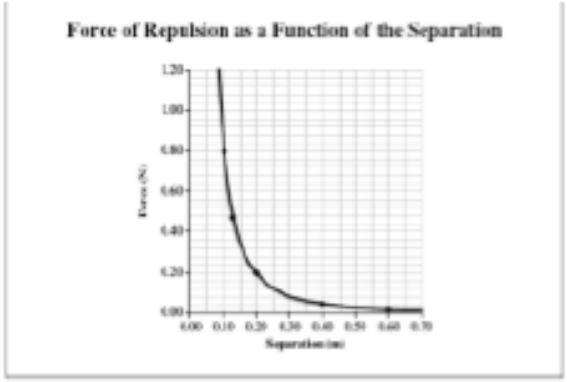
- Show that the results verify Coulomb's Law by manipulating the data and providing a new table of values that, when plotted, will produce a straight-line graph.

- Plot the new data with the responding variable on the vertical axis.

- Calculate the slope of your graph.

- Using the slope value, or another suitable averaging technique, determine the charge on sphere B if the charge on sphere A is 3.08×10^{-7} C.

- Show that the results verify Coulomb's Law by manipulating the data and providing a new table of values that, when plotted, will produce a straight-line graph.



Step 1: Look at the graph. This is an inverse-squared relationship. It came from the equation:

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

Separation (m)	Force (N)
0.10	0.790
0.13	0.480
0.20	0.200
0.40	0.050
0.60	0.022

Separation (m)		Force (N)
1.0 x 10^2	~~0.10~~	0.790
59	~~0.13~~	0.480
25	~~0.20~~	0.200
6.3	~~0.40~~	0.050
2.8	~~0.60~~	0.022

Step 2: Square then take the inverse of each x-value.

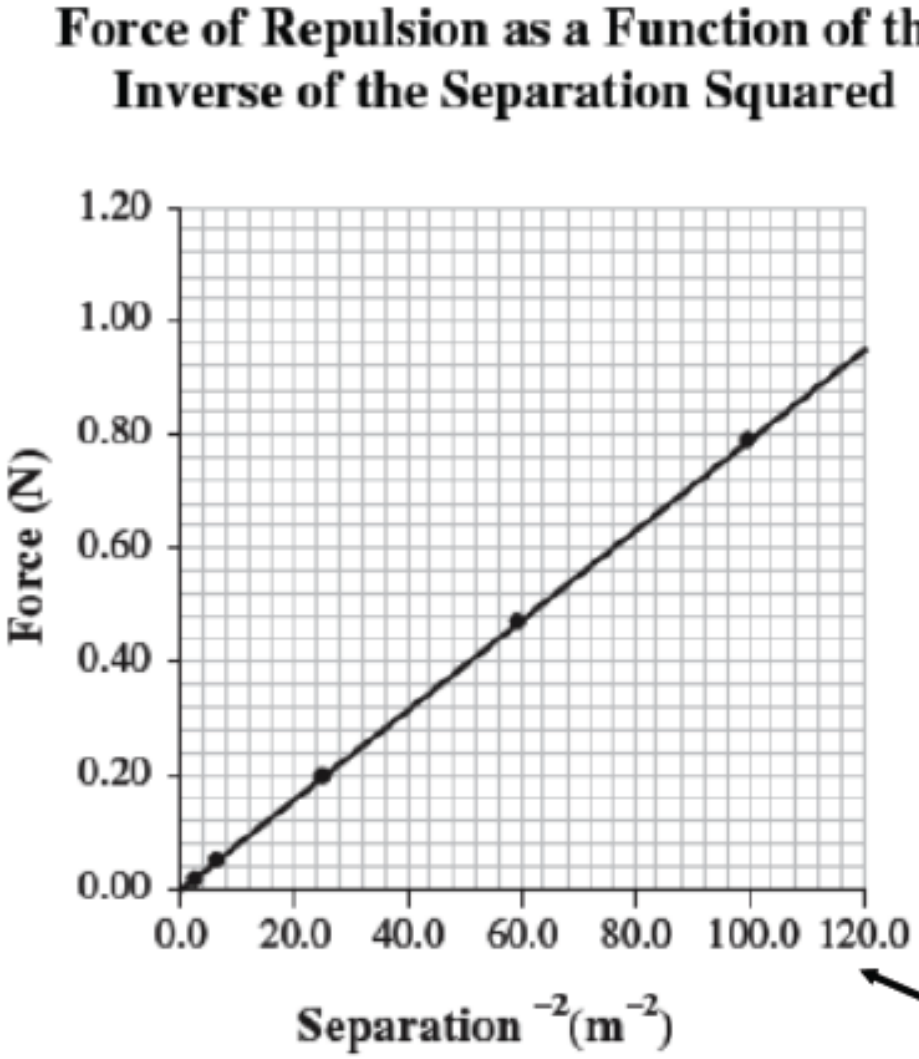
$$\frac{1}{(0.10)^2} = 100$$

$$\frac{1}{(0.13)^2} = 59.17$$

etc...

- Plot the new data with the responding variable on the vertical axis.

Step 3: Re-graph.



note the units have changed

- Calculate the slope of your graph.

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{(0.96\ N - 0.12\ N)}{(1.2 s^{-2} - 0.12\ s^{-2})} = \frac{1}{125}$$

- Using the slope value, or another suitable averaging technique, determine the charge on sphere B if the charge on sphere A is 3.08×10^{-7} C.

- using slope

$$m = \frac{\text{rise}}{\text{run}} = \frac{\vec{F}}{\frac{1}{r^2}} = \vec{F}r^2$$

So slope is the same as $\vec{F}r^2$.

$$\vec{F}_e = \frac{kq_1q_2}{r^2}$$

$$\vec{F}_e r^2 = kq_1q_2$$

$$\frac{1}{125\ \text{Nm}^2} = (8.99 \times 10^9\ \text{Nm}^2)(3.08 \times 10^{-7}\ \text{C})\ q_2 \quad \text{C}^2$$

$$= 2.89 \times 10^{-6}\ \text{C}$$

- Using averaging

Step 1: Using Coulomb's Law, determine the value of q_b in each trial.

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

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

$$q_2 = \frac{(3.79\,N)(3.10\,m)^2}{\left(8.99\times10^9 \frac{N m^2}{C^2}\right)(3.28\times10^{-4}\,C)} = 2.85\times10^{-6}\,C$$

$q_2 = 2.93\times10^{-6}\,C$

$q_2 = 2.89\times10^{-6}\,C$

$q_2 = 2.89\cdot10^{-6}\,C$

$q_2 = 2.86\times10^{-6}\,C$

Step 2: Average these values.

$$\frac{(2.85+2.93+2.89+2.89+2.86)}{5} = 2.88\times10^{-6}\,C$$

*Note: averaging the values of r and F and placing these averages into the eqn. will not yield correct results (which is why I recommend against this method).