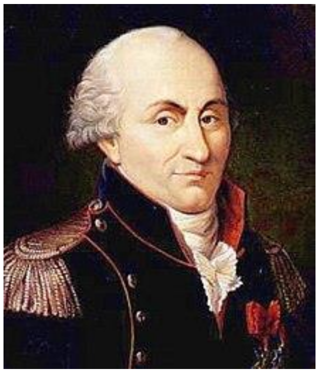


Lab Sim 08: Coulomb's Law

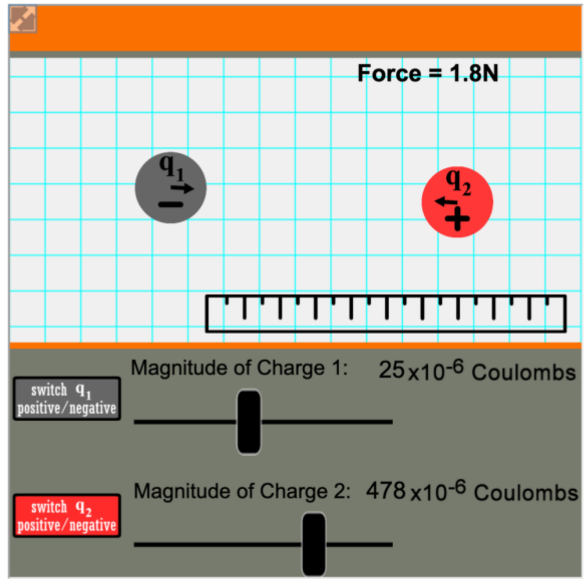
INTRODUCTION

The guy on the left, Charles Augustin Coulomb, was able to measure the electrostatic force between charges. In 1758. Not a typo. Considering that the electron itself was not discovered until 1897, this is a pretty impressive achievement.

What it clearly means is that the effects of electrical charges on each other can be measured. Once it's measured, you can extract a mathematical relationship (Surprise! It's an inverse-square!). And once you have that relationship, you can make predictions. And if you can predict the behavior, you can start thinking of all kinds of ways to use it!

OBJECTIVES

- Learn to use the Coulomb's Law simulator
- Observe the forces between charged particles
- Revisit the inverse-square mathematical relationship
- Measure the effect of changing the magnitudes of the charges
- Calculate the impact of varying the distance between the charges



EQUIPMENT

- Internet-capable device with the ability to run a browser
- Paper, pencil, calculator
- Patience—lots of patience

PROCEDURE

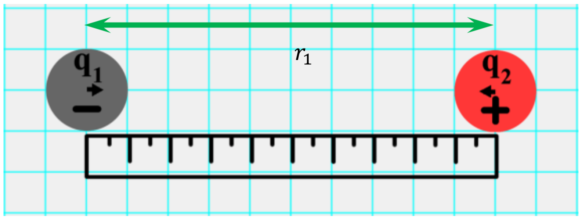
1. Read this handout completely before you try to dive in. It will save you time and frustration later. If you are able to print it, you will not have to tab between windows—you can look at this and the charge simulator at the same time.
2. Do you have paper and pencil handy? Go get it, I'll wait. Don't forget your calculator. If you use your phone as a calculator, you will need to rotate it into scientific mode. Typically, turning your phone from vertical to horizontal will change your calculator into scientific mode. You will need scientific notation because the charges are very, very small. And the force constant $k = 9 \times 10^{9} \frac{\mathrm{N{\cdot}m^2}}{\mathrm{C^2}}$ is quite huge!
3. In a browser window, navigate to the Coulomb's Law Interactive. Don't try to start doing the lab yet! Just verify that the interactive opens properly. Unfortunately, this particular sim does not have a downloadable App for your phone.
4. The figure above on the right shows what the interface looks like on the web page. You can pull on the lower right corner to re-size the window and make it bigger.
5. Notice what you can control: you can grab and move the charges to different locations; you can toggle the sign (+ or –) of each charge, and you can use the sliders to adjust the magnitude of each charge.
6. Pay attention to the position grid. We will be measuring the distance between charges center-to-center. Notice that each charge can be centered perfectly on a 2×2 square of the grid. Always measure the distance from the center of each charge.
7. Have you got your paper and pencil? I recommend answering the questions on paper while you run the sim. Trying to navigate between the sim, the handout, and the Google form will not be easy. Wait until you have answered the questions on paper, double-checked them, and are satisfied with your answers before filling in the Google form and submitting it.

QUESTIONS (2 POINTS EACH)

If you have not already, get your paper and pencil. And calculator.

Adjust only the charge sliders without changing the position or sign of either charge.

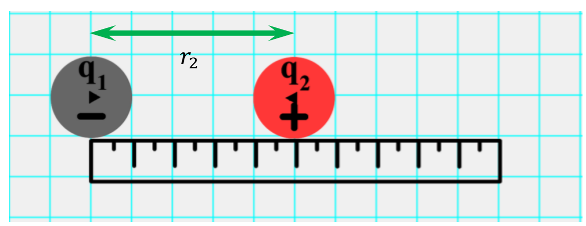
1. (1 point) When you increase only the size of q_1 (without changing q_2), what happens to the force exerted on q_1?
   A) Nothing. Both the magnitude and direction of the force stay the same.
   B) As q_1 gets larger, the force gets smaller.
   C) As q_1 gets larger, the force also gets larger.
2. (1 point) Did the force on q_2 change when you adjusted the q_1 slider? Yes or no?



Adjust the q_1 slider so that $q_1 = -50 \times 10^{-6}$C (max value). Now adjust the q_2 slider so that $q_2 = 200 \times 10^{-6}$C (min value). Now, position the charges by dragging them so that one ruler separates them. Notice that the ruler is unmarked; don't assume that this distance is one meter (it's not!). Remember to measure the distance r from the center of q_1 to the center of q_2.

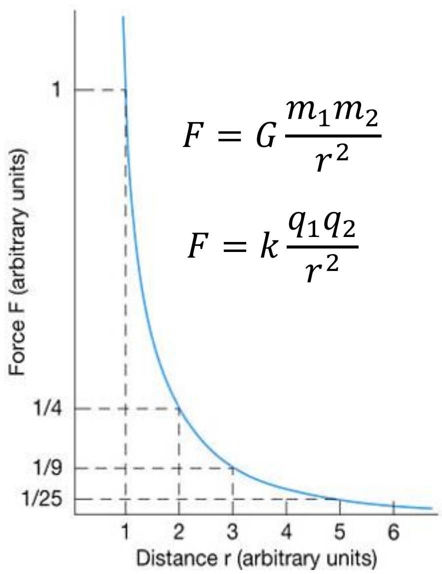
Adjust only the q_2 slider. Don't change either q_1 or the charge separation. As you increase the value of q_2, record the new value of the force for each value of q_2 listed in Questions 3–6. The initial force when $q_2 = 200 \times 10^{-6}$C should be $F = 1$N.

3. (1 point) What is the force when $q_2 = 300 \times 10^{-6}$C?
   A) $F = 0.25$N
   B) $F = 0.50$N
   C) $F = 0.75$N
   D) $F = 1.0$N
   E) $F = 1.25$N
   F) $F = 1.50$N
   G) $F = 1.75$N
   H) $F = 2.0$N
4. (1 point) What is the force when $q_2 = 400 \times 10^{-6}$C?
   A) $F = 0.25$N
   B) $F = 0.50$N
   C) $F = 0.75$N
   D) $F = 1.0$N
   E) $F = 1.25$N
   F) $F = 1.50$N
   G) $F = 1.75$N
   H) $F = 2.0$N
5. (1 point) What is the force when $q_2 = 500 \times 10^{-6}$C?
   A) $F = 2.25$N
   B) $F = 2.50$N
   C) $F = 2.75$N
   D) $F = 3.0$N
   E) $F = 3.25$N
   F) $F = 3.50$N
   G) $F = 3.75$N
   H) $F = 4.0$N
6. (1 point) What is the force when $q_2 = 600 \times 10^{-6}$C?
   A) $F = 2.25$N
   B) $F = 2.50$N
   C) $F = 2.75$N
   D) $F = 3.0$N
   E) $F = 3.25$N
   F) $F = 3.50$N
   G) $F = 3.75$N
   H) $F = 4.0$N
7. (2 points) Look at the pattern and predict: What will the force be if we increase q_2 to $q_2 = 800 \times 10^{-6}$C?
   A) $F = 3.50$N
   B) $F = 3.75$N
   C) $F = 4.0$N
   D) $F = 4.25$N
   E) $F = 4.50$N
   F) $F = 4.75$N
   G) $F = 5.0$N
   H) $F = 5.25$N
8. (1 point) Now predict the behavior in general: What would happen if we changed q_1 instead of q_2?
   A) Nothing. The force would remain constant for any value of q_1.
   B) If the value of q_1 is doubled, the force will also double.
   C) If the value of q_1 is doubled, the force will be cut in half.
   D) If the value of q_1 is doubled, the force will increase by a factor of four.
   E) If the value of q_1 is doubled, the force will decrease to ¼ its previous value.
9. (1 point) Toggle the sign of charge q_1, switching it from negative to positive. What happens to the force on the charges?
   A) Nothing. The magnitude of the force is unaffected, and the direction does not change.
   B) The magnitude of the force increases, but the direction does not change.
   C) The magnitude of the force does not change, but the force arrow now points in the opposite direction.
   D) The magnitude of the force decreases, and the force arrow changes direction, pointing straight up.
10. (1 point) True or false: Opposites attract. A (+) charge will be pulled towards a (–) charge, but it will be pushed away from another (+) charge.



Make sure that your charges are still separated by one ruler (you should not have moved them from the previous observation). Toggle charge q_1, switching it back to negative. Adjust the q_1 slider so that $q_1 = -50 \times 10^{-6}$C (max value). Now adjust the q_2 slider so that $q_2 = 400 \times 10^{-6}$C. The force between the charges should be $F = 2$N. (The force arrows shown on the right are not to scale!)

11. (2 points) Slide charge q_2 horizontally, positioning it so that it is at the midpoint of the ruler. What is the new force F_2?
    A) $F_2 = 0$N
    B) $F_2 = 0.5$N
    C) $F_2 = 1.0$N
    D) $F_2 = 2.0$N
    E) $F_2 = 4.0$N
    F) $F_2 = 8.0$N
12. (2 points) We don't know what the scale of our ruler is (yet). So, if the charges started out at $r_1 = 10$boxes, then they are now at $r_2 = 5$boxes. Predict the distance r_3 which will increase the force to $F_3 = 32$N.
    A) $r_3 = 0.5$boxes
    B) $r_3 = 1.0$boxes
    C) $r_3 = 1.5$boxes
    D) $r_3 = 2.0$boxes
    E) $r_3 = 2.5$boxes
    F) $r_3 = 3.0$boxes
13. (2 points) Go ahead and reposition one or both charges, keeping them in line horizontally (to make it easy to measure!). How far apart do the charges need to be for the force between them to be $F_4 = 1$N?
    A) $r_4 = 14$boxes
    B) $r_4 = 12$boxes
    C) $r_4 = 10$boxes
    D) $r_4 = 7$boxes
    E) $r_4 = 6$boxes
    F) $r_4 = 5$boxes
14. (2 points) Based on these observations, make a general prediction about the effect of the separation of the charges.
    A) As the charge separation r increases, the force increases. Twice the distance, twice the force.
    B) As the charge separation r increases, the force increases. Twice the distance, four times the force.
    C) As the charge separation r increases, the force decreases. Twice the distance, half the force.
    D) As the charge separation r increases, the force decreases. Twice the distance, 1/4 the force.



Congratulations, you have just proven another inverse-square law! The force between charges behaves mathematically like the force of gravity between masses. Notice one crucial difference: the force between charges might either attract or repel. The force of gravity only works one way: mass attracts mass. Gravity never repels.

Which force is stronger? Let's make a comparison. (HINT: Before you grab a calculator, write the equations out on paper! Seriously!)

15. (2 points) For gravity, the constant $G = 6.67 \times 10^{-11}\frac{\mathrm{N \cdot m^2}}{\mathrm{kg^2}}$. Place mass 1 ($m_1 = 1\mathrm{kg}$) at a distance $r = 1\mathrm{m}$ away from mass 2 ($m_2 = 1\mathrm{kg}$). What is the gravitational force F_G between these two masses?
    - A) $F_G = 0\mathrm{N}$
    - B) $F_G = 6.67 \times 10^{-11}\mathrm{N}$
    - C) $F_G = 1\mathrm{N}$
    - D) $F_G = 2\mathrm{N}$
    - E) $F_G = 6.67\mathrm{N}$
    - F) $F_G = 10\mathrm{N}$
16. (2 points) For charges, the constant $k = 9 \times 10^{9}\frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$. Place charge 1 ($q_1 = 1\mathrm{C}$) at a distance $r = 1\mathrm{m}$ away from charge 2 ($q_2 = 1\mathrm{C}$). What is the Coulomb (electrical) force F_C between these two charges?
    - A) $F_C = 0\mathrm{N}$
    - B) $F_C = 0.9\mathrm{N}$
    - C) $F_C = 1\mathrm{N}$
    - D) $F_C = 9\mathrm{N}$
    - E) $F_C = 9 \times 10^{9}\mathrm{N}$
    - F) $F_C = 6.67 \times 10^{11}\mathrm{N}$
17. (2 points) Here's where you need to use scientific notation! How many times stronger is the Coulomb force than the gravitational force? Calculate the ratio of (Coulomb force)÷(gravitational force):
    - A) $\frac{F_C}{F_G} = 1$: The forces are exactly the same.
    - B) $\frac{F_C}{F_G} = 1.35$: The Coulomb force is about 1.4 times stronger than the force of gravity.
    - C) $\frac{F_C}{F_G} = 1.35 \times 10^{6}$: The Coulomb force is about 1.4 million times stronger than gravity.
    - D) $\frac{F_C}{F_G} = 1.35 \times 10^{9}$: The Coulomb force is almost 1.4 billion times stronger than gravity!
    - E) $\frac{F_C}{F_G} = 1.35 \times 10^{15}$: The Coulomb force is about 1.4 quadrillion times stronger than gravity!
    - F) $\frac{F_C}{F_G} = 1.35 \times 10^{20}$: The Coulomb force is literally 135 quintillion times stronger than the gravitational force!

Let's go back to our charges, and let's look again at the distance between the charges. Adjust both charge sliders to their maximum values, $q_1 = -50 \times 10^{-6}\mathrm{C}$ and $q_2 = 600 \times 10^{-6}\mathrm{C}$. Position the charges so that the separation is $r = 7\mathrm{boxes}$. Why seven? Notice that you get a nice whole number for the force between the charges.

18. (1 point) With the charges in this position, what is the value of the force F?
    - A) $F = 0\mathrm{N}$
    - B) $F = 2\mathrm{N}$
    - C) $F = 4\mathrm{N}$
    - D) $F = 6\mathrm{N}$
    - E) $F = 8\mathrm{N}$
    - F) $F = 10\mathrm{N}$

Let's re-arrange the force equation and solve it for distance. Notice that we use the absolute value of the charges (because we can't take the square root of a negative number!). Use the value of F from your observation. You'll need your calculator.

$$r_1 = \sqrt{\frac{kq_1q_2}{F}} = \sqrt{\frac{(9 \times 10^9)(50 \times 10^{-6})(600 \times 10^{-6})}{F}}$$

19. (2 points) Calculate the actual distance r_1 between the charges:
    - A) $r_1 = 0\mathrm{m}$
    - B) $r_1 = 5.19\mathrm{m}$
    - C) $r_1 = 6.70\mathrm{m}$
    - D) $r_1 = 8.22\mathrm{m}$
    - E) $r_1 = 16.4\mathrm{m}$
    - F) $r_1 = 45.0\mathrm{m}$
20. (2 points) If you move the charges to a separation of $r_2 = 20\mathrm{boxes}$, what will be the new force F_2 between them? First, calculate the true separation r_2 in meters by using the scale you just found: $\frac{r_2}{r_1} = \frac{20\mathrm{boxes}}{7\mathrm{boxes}}$, which means that $r_2 = r_1\left(\frac{20\mathrm{boxes}}{7\mathrm{boxes}}\right) = 2.86r_1$. Calculate r_2 and use it to find $F_2 = k\frac{q_1q_2}{r_2^2}$. You have not changed the values for the charges: $q_1 = -50 \times 10^{-6}\mathrm{C}$ and $q_2 = 600 \times 10^{-6}\mathrm{C}$.
    - A) $F_2 = 0\mathrm{N}$
    - B) $F_2 = 0.337\mathrm{N}$
    - C) $F_2 = 0.537\mathrm{N}$
    - D) $F_2 = 0.737\mathrm{N}$
    - E) $F_2 = 0.937\mathrm{N}$
    - F) $F_2 = 1.137\mathrm{N}$

When you have completed the simulation, please be sure to submit your responses using the secure Google form!