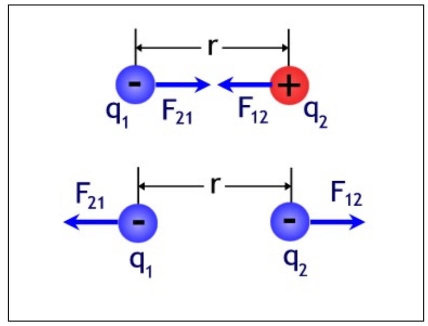
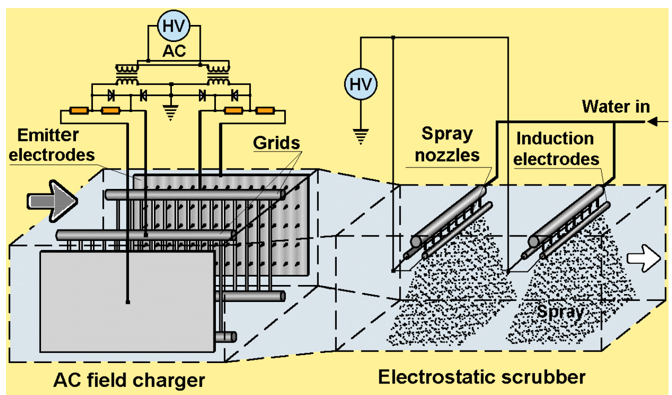
University of Calgary
Department of Physics and Astronomy
PHYS 259, Winter 2017

Labatorial 1: Electric Charges and the Forces between them

Electrostatics is the study of the forces between objects that carry an electric charge. Electric charges can either be positive or negative, and these charge can neither be created nor destroyed, but simply flow from one object to another. Any two charged objects exert an electric force on each other equal in magnitude and opposite in direction; opposite charges attract, like charges repel. The magnitude of the electric force between two point charges is given by Coulomb's law, $F_C(r) = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$. (Image from fisitech.wordpress.com)



An important application of the electric force is the electrostatic scrubber, shown in the figure on the right. It is used to remove dust, smoke, bacteria and other micrometer or submicrometer size particles from exhaust gases or indoor air: charged airborne particles are attracted by the oppositely charged scrubbing droplets. (Image from www.imp.gda.pl, where you can learn more about this procedure.)



Goals:

To understand how a macroscopic object acquires a net charge, and what that means on a microscopic level. To practice how to find the resulting force on a charge by using vector addition.

Preparation:

Halliday, Resnick, and Walker, "Fundamentals of Physics" 10th edition, Wiley: 21.1–21.3.

Equipment:

Scotch tape; ruler; Electric Fields from Point Charges applet
http://www.compadre.org/Physlets/electromagnetism/illustration23_2.cfm

1 "Static Electricity"

Question 1: As a precaution, the levers on gasoline pumps in many provinces in Canada must be manually operated at all times. One of the reasons for this is especially relevant in the winter time because the fabrics used for heavy clothing and coats makes it easy to build up a static electric charge. Explain why it could be dangerous to allow someone to have the gas continue pumping while they are doing something else; imagine what might happen when they come back and touch the pump.

2 Electric Charge and Charge Carriers

Question 2: What is an electric charge? Try to write down a definition.

Question 3: When an object acquires an electric charge, is the charge created and then placed on the object, or is the charge transferred from one object to another? Explain.

Question 4: Below are examples of matter that exist at different length scales. For each, state whether they can in principle be charged, or whether they are *always* charged (and what the sign of that charge is):

gold nugget

dust particle

atom

proton

neutron

electron

Question 5: Macroscopic objects are often electrically neutral. Does this mean that they are not carrying any charges?

Question 6: Consider a solid object that carries a net positive charge: to acquire that positive charge, are protons added to it, are electrons removed from it, or does that vary from case to case? Hint: think about atomic structure, in particular what the number of protons and electrons in an atom signify.

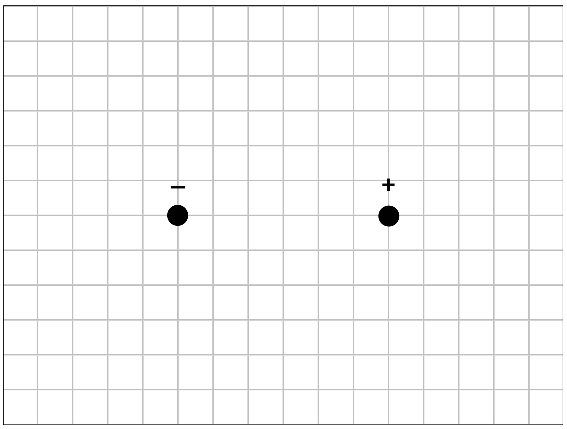
Question 7: Materials in which electrons move freely are called conductors, whereas materials in which electrons are stuck in place are called insulators. Is it possible to electrically charge both kinds of material? Explain and provide one example for each.

Question 8: An insulator can often acquire a net charge by rubbing it against another insulating material; one such example is when a plastic rod is rubbed against a piece of fur. Could a metal rod be charged by the same technique? Explain why or why not.

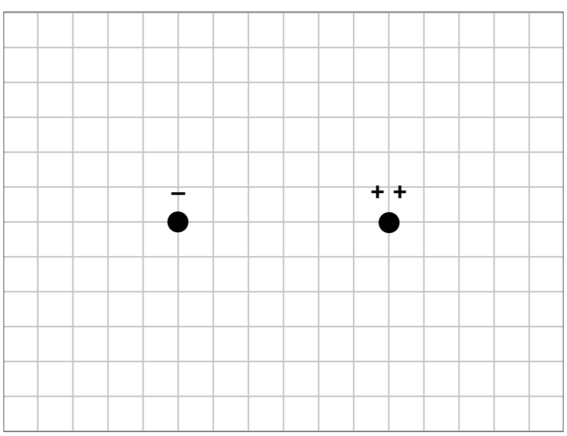
CHECKPOINT 1: Before moving on to the next part, have your TA check the results you obtained so far.

3 Electric forces between two point charges

Question 9: The figure below shows two point charges of $-1\mu C$ and $+1\mu C$. Draw the force vectors on each charge, making sure to accurately represent the relative lengths of the force vectors. How would the direction and magnitude of the force vectors change if the distance between the two charges were doubled?



Question 10: This time, consider two point charges of $-1\mu C$ and $+2\mu C$. Draw the force vectors on each charge. Is the force on the $-1\mu C$ charge greater than the force on the $+2\mu C$ charge? Why or why not?



Question 11: For the configuration of charges in Question 9, what would the distance between the charges have to be in order to double the magnitude of the force?

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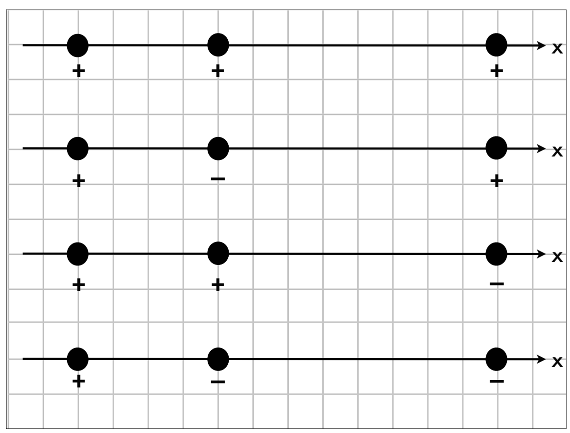
4 Superposition of electric forces in one dimension

Question 12: The figure shows four configurations of three charges in one dimension. For each configuration, draw the forces acting on the middle charge, then use a different colour to draw the net force on the middle charge. Note: the relative magnitudes must be correct.



Question 13: A charge $q_1 = +2.0$ nC is located at the origin, and a second charge $q_2 = +4.0$ nC is located at position $x = d$.

a) At what position x will a $q = -1$ nC charge experience zero net force?

b) In part (a), you should have found two mathematical solutions. Using a sketch, explain how you know which one is the physical solution. (You may use the Electric Fields from Point Charges applet http://www.compadre.org/Physlets/electromagnetism/illustration23_2.cfm to study the two situations.)

c) What physical situation does the other mathematical solution correspond to?

CHECKPOINT 2: Before moving on to the next part, have your TA check the results you obtained so far.

5 The Electric Force in Two Dimensions

Question 14: The electric force between the electrons and protons in an atom is what holds the atom together. In Bohr's model of the hydrogen atom, the electron orbits the proton on a circular path with a diameter of approximately 10^{-10}m. Use the Coulomb force to calculate the speed with which the electron orbits the proton in this model.

Question 15: In larger atoms, there are several protons inside the nucleus, and they are all positively charged. Calculate the minimum electrostatic force between two protons inside a nucleus of diameter 4×10^{-15} m.

Question 16: Is the force calculated in the previous question repulsive or attractive? How do you know?

Question 17: If there is such a strong repulsive force between the protons, there must be an even stronger attractive force between them to keep the nucleus together. Is this the gravitational force between the protons? Support your conclusion with a calculation.

Question 18: Calculate the ratio of the Coulomb force to the gravitational force, F_C/F_g, between an electron and a proton inside a hydrogen atom.

What is the ratio if they are 100 km apart?

Question 19: Take a piece of scotch tape that is 10 cm long, stick it on the table, and then rip it off quickly. Use the non-sticky side of this charged piece of scotch tape to lift small pieces of paper.
a)What is the maximum size you are able to lift with the scotch tape?

b) Describe the mechanism that makes the scotch tape attract the piece of paper.

c) Estimate the electric force between the scotch tape and maximum size piece of paper from part a). Hint: What are all of the forces acting on the paper? The area density of paper is about 75 g/m^2.

CHECKPOINT 3: Before moving on to the next part, have your TA check the results you obtained so far.

The problem that appears on the next page is to get you used to an element of these labatorials that will be implemented starting next week. You will be asked to solve an exam style question as a group that will then be submitted for grading by your TA: these grades will count toward your overall lab mark for the course. These problems are designed to help you succeed when you are later writing the exams by providing you with early feedback on how to logically and clearly answer written questions. The rubric for how these questions will be graded is provided on D2L; notice that it focuses more on the process of answering the question than on the correct answer. This is because how you approach problems and communicate your solutions are vital skills that will help you succeed on the exams.

Practice Problem

Four point particles form a square with edge length a. Beginning at the lower lefthand corner and going clockwise around the square, the charges alternate: $q_1 = q_3 = q$ and $q_2 = q_4 = Q$.

(a) What is the ratio Q/q if the net electrostatic force on particle 1 is zero?

(b) Is there any value of q that makes the net electrostatic force on each of the four particles simultaneously zero? Explain.

Last Checkpoint! Clean up your area, and put the equipment back the way you found it. Call your TA over to check your work and your area before you can get credit for the labatorial.

Equations and Constants

$$
\begin{aligned}
F_g(r) &= G\frac{m_1 m_2}{r^2} \\
U_g(y) &= mgy \\
K &= \frac{1}{2}mv^2 \\
v_x(t) &= v_{0x} + a_x t \\
x(t) &= x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \\
v_x^2(t) &= v_{0x}^2 + 2a_x(x(t) - x_0) \\
\omega &= \frac{d\theta}{dt} \\
v &= \frac{2\pi r}{T} = \omega r \\
a_{rad} &= \frac{v^2}{r} = \omega^2 r
\end{aligned}
$$

$$
\begin{aligned}
g &= 9.81\ \mathrm{m/s^2} \\
G &= 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2} \\
\frac{1}{4\pi\epsilon_0} &= 8.99 \times 10^{9}\ \mathrm{N \cdot m^2/C^2} \\
\epsilon_0 &= 8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2} \\
e &= 1.60 \times 10^{-19}\ \mathrm{C} \\
m_e &= 9.11 \times 10^{-31}\ \mathrm{kg} \\
m_p &= 1.67 \times 10^{-27}\ \mathrm{kg} \\
m_n &= 1.67 \times 10^{-27}\ \mathrm{kg}
\end{aligned}
$$

$$F_C(r) = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$ magnitude of the Coulomb (electrostatic) force between two charges

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$ solutions of the quadratic equation $ax^2 + bx + c = 0$