Name ______________________________

Partner(s): ______________________________

Experiment 1 – Charges and Forces

Objectives To demonstrate, hands on, the validity of Coulombs Law by measurement of the force between charges on different spheres. Measurements of the charge and spacing dependence are used to evaluate the Coulomb constant, *k*.

Equipment
Computor with folder *Physics_120x_121x*
1 Vernier LabPro™ interface box (VLI)
1 Scout® *Pro* Balance with 0.01 gram sensitivity and 200 g capacity
2 Conducting spheres: to hold charge during measurement
Rod and fur to supply charge to spheres
1 Vernier Charge Sensor
Ground point
1 Ruler: to measure distance between the centers of the spheres

Preparation You will be pressed for time during the lab. Since successful completion of all lab activities counts towards your final lab grade it will be important to be well prepared by doing Pre-Lab assignments and reading the entire lab **before** attending the lab.

Pre-Lab Read the Pre-Lab introduction and answer the accompanying questions and problems **before** this Lab.

Points earned today

Pre-Lab	____
Lab	____
Total	____
Instructor Initials	____
Date	____

Pre-Lab for LAB 1

Intro

Charge is found in multiples of the basic unit of charge $e = 1.60 \times 10^{-19}$ C. The electron has charge $-e$ and the proton has charge $+e$.

We know charge exists because of the force that one charge exerts on another charge. Like charges repel; unlike charges attract. According to Coulomb's Law, two *point-charges* q_1 and q_2, separated by the distance r, exert equal and opposite forces on each other; the magnitude of each force being

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

where k is the Coulomb constant: $k = 8.99 \times 10^9\ \mathrm{N{\cdot}m^2/C^2}$. This equation also applies for forces exerted by *spherical distributions of charge* on each other, where r represents the center-to-center distance of those *spherical distributions*.

Charge is free to move on the surface of a conductor. Charge placed on a spherical conductor distributes itself uniformly over the surface of the conductor. Charge collects on the outer surface of a conductor; no charge is present in the inner surface of a conductor.

Pre-Lab for LAB 1

Problems

1. Two charges q_1 and q_2 , that are a distance *d* apart, repel each other with a force of 6.40 N. What would be the force between two charges $q_1' = 2q_1$ and $q_2' = 3q_2$ that are also a distance *d* apart?

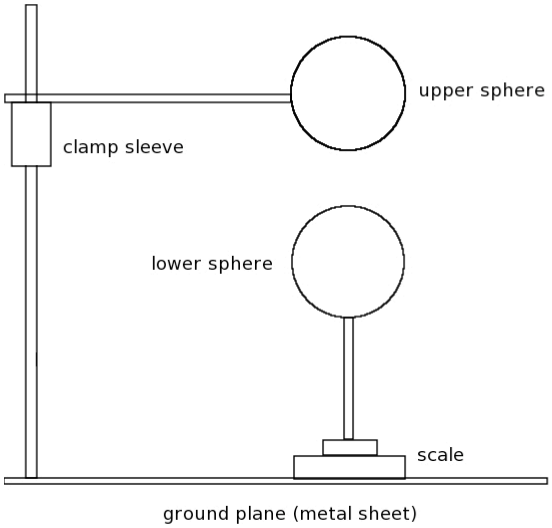
2. The charges $Q_1 = Q$ and $Q_2 = 4Q$, that are a distance *d* apart, repel each other with a force of 1.60 N. What would be the force between the charges $Q_3 = 2Q$ and $Q_4 = 7Q$ that are a distance *d*/3 apart?

3. Two small tiny conducing spheres, both initially having no charge, are brought into contact and given a total charge of 5.00×10^4 electrons. The spheres are then pulled apart until their centers are 12.0 cm apart. Assume the total number of electrons on the spheres remained the same as they were separated.

   a) What is the magnitude of the force that each sphere exerts on the other?

   b) Is the force attractive or repulsive?

Laboratory



Description of Apparatus Two conducting spheres are electrically isolated from each other and from their surroundings. The upper sphere is supported by a horizontal insulating rod that is clamped to a lab-pole; this rod may be rotated at its clamp so that the upper sphere moves in a horizontal plane. When the rod is rotated, a clamp-sleeve keeps the sphere in the same horizontal plane. The lower sphere is supported by a vertical insulating rod attached to a pedestal that sits on a weight-scale. The scale and the lab-pole are connected to a metal sheet, the ground plane.

Activity 1 **In this Activity you will learn how to measure the force between two charged spheres that are separated by a fixed distance.**

Getting Started

1. Check the ground plate (metal sheet). Check to be sure the ground plate is grounded. **The ground plate will serve as a reference for zero-charge.**

2. Open Logger *Pro* to Activate the Charge Sensor. Check that the Vernier LabPro™ interface box (VLI) is connected to your computer and that the Vernier Charge Sensor is connected to **CH 1** of the **VLI**. Double-click the Logger *Pro* icon on the desktop. (If, when the program opens, a dialog box entitled *Tip of the Day* appears; close the dialog box.) **A graph of *Charge vs. Time* should appear on your screen.**

3. **Learn how to properly use the Charge Sensor.** Because the sensor is a sensitive device, you must take careful steps to protect it from damage.

   a. How To Protect the Sensor: There are two input leads: **black** and **red**. If they are not already "grounded" (i.e., electrically connected to the ground plate or to any conductor connected to it) connect them to ground. **Whenever the sensor is not in use, "ground" both the red and black leads by connecting them to each other; this protects the sensor from high static charge.**

b. How To Ground – **Zero –** the Sensor: For a reliable measurement of charge, the probes of the sensor must be grounded immediately before use. “**Zeroing**” the sensor removes charge from a capacitor within the sensor. This internal capacitor must be discharged before each measurement, i.e., between measuring one sphere and the next. To discharge the capacitor, **touch** the **metal tip of the alligator clip** to **ground** (or to any part of the apparatus that is connected to the ground plate) for a couple of seconds. **For reliable measurements, the black lead must always remain connected to ground. Always check that the probe is grounded.**

c. Practice Measuring Charge: Follow the steps below. **A lab instructor will demonstrate the technique to be used to measure charge.**

i) **Charge** the spheres. Use the rod and fur (or whatever is available in lab) to charge both spheres.

ii) To take data, do the following:

(1) **Click** the green **Collect button** at the top of the screen to start the computer display of charge as a function of time.
(2) **Touch** your **fingers** to the **ground plate** to remove stray charge from them.
(3) **Pick up** the **charge probe** by its insulated handle. Keep your **fingers** as **far** as possible from the **metal alligator clips** at the other end; otherwise, not all the charge may collect in the capacitor. Manipulate the leads by the insulting rod, not the wires themselves.
(4) **Ground** the probe. Briefly **touch** its **metal tip** to the **ground plate** and **check** that the charge reading drops to zero; if it does not, **Press** and **hold** the **Reset button** for a few seconds, repeating if necessary.

Now you are ready to make actual measurements:

(5) **Touch** the **metal tip** to the **charged object** and **hold** it in contact for a couple of seconds, being careful not to touch the object with your fingers. [While the lead is touching the object, the computer reading will change, then stabilize.]

Note: When you bring the tip of the probe near an object, you may hear a hiss or crackle as change jumps from the object to the sensor. This is normal behavior; charge must transfer from the object to the capacitor in the sensor so that charge can be measured.

(6) To measure the charge on a second object, briefly **touch** the **metal tip** to the **ground plane** for a second or two [the computer reading should drop to zero – if not, press the **Reset button**] and then **touch** the probe to the **object**.

Note: Watch the *charge vs. time* graph as you collect data to be aware of any stray charge that accumulates before you touch the red lead to the object.

4. Practice placing charge on the spheres, and then checking for a force. Position the spheres so their centers are directly about each other and so there is a gap between them of a few centimeters. Press the “**Zero**” button on the weight-scale, and then place charge on the spheres. If you have placed like-charge on both spheres, they will repel and the scale reading will increase.

a. Observe how the reading of your weight-scale takes a few seconds to stabilize. The scale reading may take a few seconds to stabilize. When the scale reading is stable, an asterisk (*) will appear in the lower left corner of display. **As you proceed, be careful to protect the scale because it is very sensitive. The scale reads up a maximum of 200 grams. Do not push down on or even touch the weighing surface!** The scale is very sensitive, and will respond to very small vibrations of the lab table. Try not to touch the table during the force measurement.

b. Observe how quickly charge bleeds off. One way to learn how fast you will need to make the measurement is to charge the spheres and leave then in place with one directly over the other. Watch how the reading on the weight-scale changes with time. This change is due to charge leaking away from the high potential spheres.

5. Practice placing charge on the spheres, measuring the force, and then measuring the charge on the spheres. **A lab instructor will demonstrate the technique to be used to charge the spheres and to perform force and charge-measurements.**

6. Organize your group and practice the technique for charging an object and measuring its electric charge. Follow the procedure was demonstrated to you. Charge the spheres and measure the charge on both.

   a. Assign tasks: Split up the various tasks among your group; for example, one person could move the spheres, another charge the spheres and zero the scale, while a third would prepare and begin the charge measuring sequence. It is worth spending the time to work out a procedure and to practice it so you can do the overall measurement as efficiently as possible – if the process takes too long the results will be compromised by the bleeding of charge between one step and the next.

   b. Perform the total procedure as quickly as possible: Charge tends to “bleed” off the spheres because of their high electric potential, so it pays to perform the total procedure quickly.

Summary of the technique for measuring electric force:

A. Position the upper sphere so that its center is directly above the lower sphere at the separation you want; when they are in place, “**zero**” the weight-scale.

B. Charge the spheres. If there is an acceptable force reading, quickly swing the upper sphere out of position by more than 45 degrees, to move it away from the lower sphere, then quickly “**zero**” the weight-scale, and rotate the upper sphere back into place directly above the lower sphere.

C. Record the reading on the scale (in grams) after you have rotated the upper sphere back above the lower sphere.

D. Measure the charge on each sphere: After a force is measured, quickly move the spheres apart, and measure the charges on each sphere with the charge probe. Be sure to “**zero**” the charge sensor before each measurement. **Note: the process of measuring the charge discharges the spheres.**

Activity 2 **In this Activity you will investigate the dependence of force on the charge on the spheres for a fixed separation of the charged spheres.**

1. Measure *r*, the center-to-center distance of the spheres. Position the two spheres so that their centers are separated by roughly 6 centimeters. **Make sure the centers of the spheres are vertically aligned.** Record the value of *r* here.

   r = center-to-center distance =

2. Measure force and charges. **Follow the technique you practiced:** charge the spheres, check that the force is one you want to measure, separate the spheres, zero the weight-scale, re-align the spheres, record the electric force on the lower sphere (in grams), separate the spheres and measure the charge on each sphere (in nC). Record the measurements in the table below. **Remember to Zero the charge sensor and Zero the weight-scale before each measurement.**

Reminder: **When the sensor is not in use, the red and black leads should be grounded to protect the sensor from high static charge.**

4. Use your first set of measurements (**Trial 1**) to calculate values for the remaining cells of the row below. **Be careful with the units:** Remember that 1 nC = 10^{-9} C, and that to obtain a force in Newtons from the number of grams you need to use F = mg, so $F_{Newtons}$ = #grams * 1 kg/1000g * 9.8.

Trial	**Force (grams)**	q_1 **charge on upper sphere (nC)**	q_2 **charge on lower sphere (nC)**	Force (N)	q_1q_2 (C^2)
1					

5. Do more Trials: repeat steps 1 through 3 above. **Make multiple measurements, at least five or more, for different values of charge on the spheres; keep the distance between the spheres the same.** Try to get as large a spread of force values as you can. Record measurements of force and charges from all your Trials in the first three columns of **Table 1** below. DO NOT CALCULATE VALUES FOR THE REMAINING COLUMNS.

   Remember to Zero the charge sensor and Zero the weight-scale before each measurement.

The folder on the computer desktop, *Physics_120x_121x*, contains useful files.

6. From the folder ***Physics_120x_121x***, open the spreadsheet **P112_Lab1_Table1.xls** to help you fill out **Table 1.** After you have done all your Trials and recorded your measurements, enter all measurements in the spreadsheet **P112_Lab1_Table1**; this spreadsheet will calculate values for the remaining two right columns of **Table 1**.

   a) Check the values you calculated for the row on the previous page with the values the spreadsheet has calculated. Do they agree? If not, correct your calculations.

   b) Enter in **Table 1** the remaining calculated values from the spreadsheet.

Table 1: Force between spheres (fixed distance)

Trial	**Force** **(grams)**	q_1 **charge on upper sphere (nC)**	q_2 **charge on lower sphere (nC)**	Force (N)	q_1q_2 (C^2)
1					
2					
3					
4					
5					
6					
7					
8					
	Record your measurements above.			Use the spreadsheet **P112_Lab1_Table1** to fill out these two columns.	

7. Use the values from **Table 1** (generated by the spreadsheet) to plot the electric force F (in N, y-axis) versus the product of the two charges q_1q_2 (in C^2, x-axis).

   a) Be sure the graph includes an origin, (0, 0).

   b) Draw a "best-fit" straight line: make sure the line passes through the origin – use a ruler!

   Note that the graph has 50 horizontal and 50 vertical divisions.

☐ **Stop. Have your instructor check your progress before you proceed.**

Activity 3 Use the graph from Activity 2 to evaluate the Coulomb constant, *k*.

Recall that two *point-charges* q_1 and q_2, separated by the distance r, exert forces on each other; the magnitude of each force is given by Coulomb's Law:

Coulomb's Law $$F = k\frac{|q_1q_2|}{r^2} \qquad \text{(Eq. 1)}$$

where k is the Coulomb constant: $k = 8.99 \text{ X } 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$. This equation also applies for the forces exerted by *spherical distributions of charge* on each other, where r represents the center-to-center distance of those *spherical distributions*.

If the spheres of our experimental setup hold a spherical distribution of charge, then we can use our measurements to determine the value of the Coulomb constant k. We will assume that they do.

1. Refer to Eq. 1 above. Mathematically, how is the <u>slope</u> of the F *vs.* $|q_1q_2|$ graph related to the Coulomb constant k <u>when r is constant</u>?

2. Based on the line you drew on the graph, <u>evaluate the slope</u> of F versus q_1q_2. Use your slope to determine a value for k. Show your calculated value of k to your lab instructor. (Be careful about units!!)

Activity 4 Measure force between charged spheres for three other separations.

In **Activity 2**, you took force and charge data for a fixed center-to-center separation. In **Activity 4**, you will take more measurements of force and charge, this time for three different center-to-center separations of roughly 8 cm, 10 cm, and 12 cm. For each different separation, measure force and charge three times.

Discussion The effect of humidity on your experimental results.

Coulomb's Law (Eq. 1), which expresses how the force between two point charges depends upon the distance separating them, is well established; however, it is difficult to verify experimentally because the humidity of the air in a room can influence the ability of an object to hold charge: water molecules in the air are attracted to charged objects and these molecules tend to discharge a charged object. If you investigate the electric force exerted between objects on a "bad" day – a day with high humidity –you may have difficulty placing charge on the spheres, the force between spheres may be weak, and you results may be poor.

1. Transfer some data from **Table 1** to **Table 2.** Select three "good" sets of data from **Table 1** (data whose points lie close to the line you drew on the graph on page I-7) and record them in **Table 2** below: force (in grams), charges (in nC), and center-to-center distance (in m).

2. Change the separation of the spheres. Set the center-to-center separation of the spheres to roughly 8 cm.

3. Take and record data. Measure *r*, the center-to-center distance of the spheres. Charge the spheres according to the standard procedure. Measure the force between the spheres, and then measure the charges on the spheres. Repeat two times so that you will have a total of three measurements of force and charge for the same separation. Record the data in **Table 2**.

4. Repeat step 3 for a center-to-center separation of roughly 10 cm; after that, repeat step 3 again for a center-to-center separation of roughly 12 cm.

You now should have recorded in **Table 2** three sets of data for each of four different center-to-center separations.

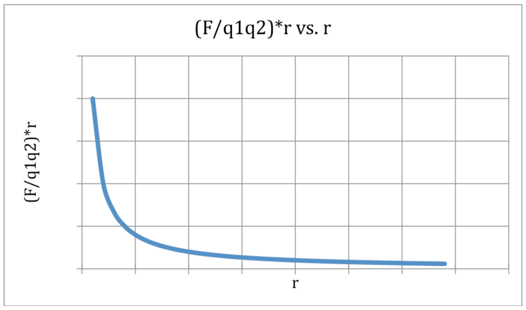
5. From the folder ***Physics_120x_121x***, open the spreadsheet **P112_Lab1_Table2.xls** to help you fill out **Table 2.** After you have taken all data, enter force, charges, and center-to-center distance measurements into the spreadsheet **P112_Lab1_Table2**; this spreadsheet will calculate the various values for the four right columns of **Table 2**.

Table 2: Force between spheres (different distances)

Trial	**Force** **(grams)**	q_1 **charge on upper sphere (nC)**	q_2 **charge on lower sphere (nC)**	**center-to-center distance, r (m)**	(F/q_1q_2) (N/C^2)	$(F/q_1q_2)\cdot r$ $(N/C^2)\cdot m$	$(F/q_1q_2)\cdot r^2$ $(N/C^2)\cdot m^2$	$(F/q_1q_2)\cdot r^3$ $(N/C^2)\cdot m^3$
1								
2								
3								
1								
2								
3								
1								
2								
3								
1								
2								
3								
Record your measurements above.					Use the spreadsheet **P112_Lab1_Table2** to fill out these four columns.			

We wish to establish the validity of Eq. 1 if the conditions in the lab room will allow. In lab, you can independently measure *F* (force), *r* (distance), and q_1 and q_2 (charges).

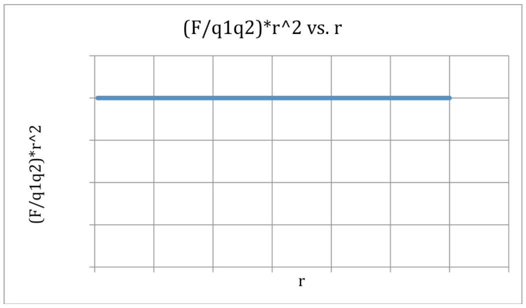
According to Eq. 1, the quantity $\frac{F}{|q_1 q_2|}\cdot r = \frac{k}{r}$; thus, if you use your measurements to calculate and graph $\frac{F}{|q_1 q_2|}\cdot r$ vs. *r*, the graph should be an *inverse* graph, $\frac{k}{r}$ vs. *r*, as shown in Graph 1.



Graph 1

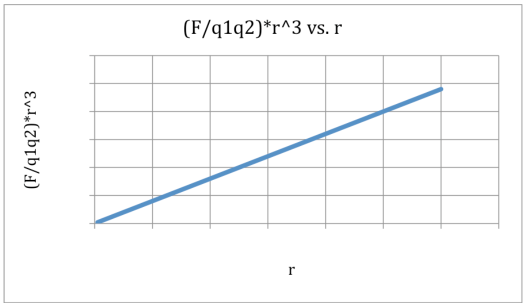
Similarly, the quantity $\frac{F}{|q_1 q_2|}\cdot r^2 = k$; thus, if you use your measurements to calculate and graph $\frac{F}{|q_1 q_2|}\cdot r^2$ vs. *r*, the graph should be a *constant* graph,

k vs. *r*, as shown in Graph 2.



Graph 2

The quantity $\frac{F}{|q_1 q_2|}\cdot r^3 = kr$; thus, if you use your measurements to calculate and graph $\frac{F}{|q_1 q_2|}\cdot r^3$ vs. *r*, the graph should be a *linear* graph, *kr* vs. *r*, as shown in Graph 3.



Graph 3

While you were entering your measurements into spreadsheet **P112_Lab1_Table2.xls**, those points will be plotted on graphs. (If the points did not appear on a graph, click on the graph.)

6. Examine the graphs in the spreadsheet. Do they look like any of the graphs on this page? If the conditions of the experiment were "good", the graphs on the spreadsheet should look like the graphs on this page.

7. Sketch below the best graph from the spreadsheet that is closest to "good" day of experimental results. Label the axes and include an origin.

☐ **Stop. Have your instructor check your progress and that your worktable is cleaned up before you leave the lab room.**