E&M Lab 2: Coulomb's Law

Experiment Overview

In this experiment, you'll verify Coulomb's Law:

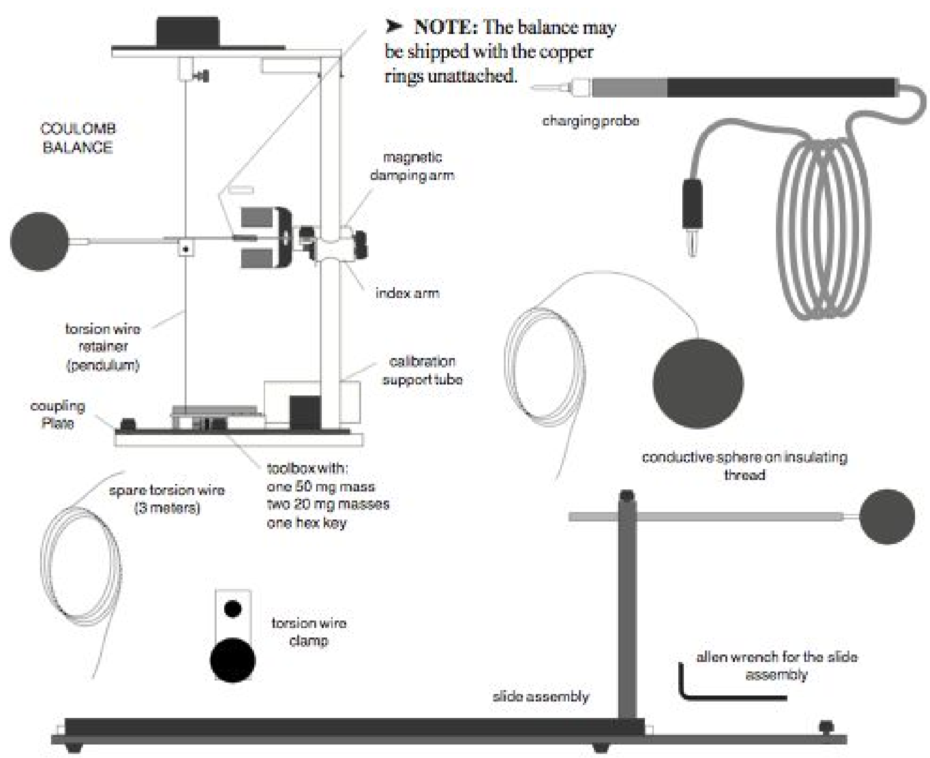
$$F_e = k\frac{q_1 q_2}{r^2} \quad (1)$$

You will do this by measuring the force between two charged spheres. You'll confirm that the force depends on the inverse square of the distance between the charged objects, that it depends on the product of their charges, and you will measure the value of the Coulomb constant *k*.

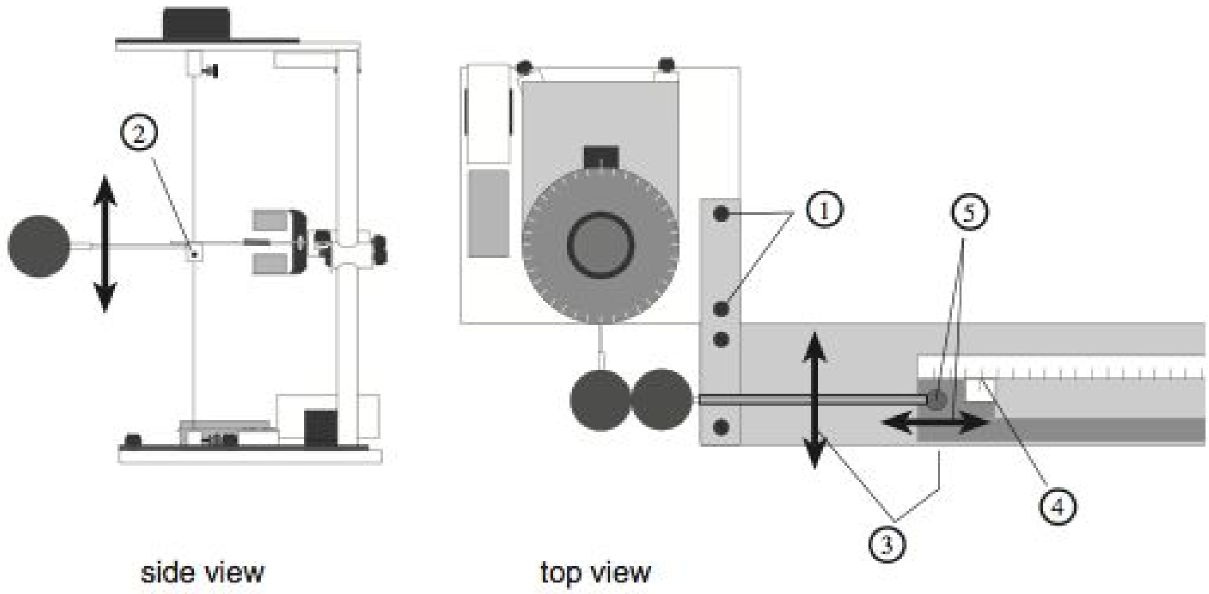
You will measure the electric force indirectly. One of the charged spheres is connected to a torsion wire: this wire acts like a spring obeying Hooke's Law, except it twists rather than stretching. You will measure the twisting angle needed to bring the charge into force equilibrium. Later in the experiment, you will determine the "spring constant" of the torsion wire by finding the twisting angle needed to counteract the gravitational force on a known mass.

Equipment

- Coulomb torsion balance
- Slide assembly
- Kilovolt power supply
- Charging probe
- Grounding wire
- 50 mg mass
- two 20 mg masses



Stand here



Setup

1. Touch both spheres with the ground wire to remove any residual charge on them.
2. Loosen the clamp on the index arm so that the torsion balance arm can rotate freely.
3. Set the degree scale on the top of the torsion balance to zero. The index mark on the torsion balance arm should line up with the mark on the index arm. If it doesn't, rotate the white plastic torsion wire retainer on the base of the balance very slightly until the index marks line up. (Go slowly!)
4. Position the apparatus on the table so that the sphere on the torsion balance is farthest from you, and the slide assembly is on your left. Connect the slide assembly to the torsion balance as shown in the figure above, using the coupling plate and thumbscrews to secure it in position.
5. Check that the spheres are aligned vertically, and the balance arm is centered between the jaws of the magnetic damper arm. If not, ask me for help.
6. Check that the spheres are aligned laterally. If not, align them by loosening the screw in the bottom of the slide assembly that anchors the vertical support rod for the sphere, using the supplied allen wrench (the vertical support rod must be moved to the end of the slide assembly, touching the white plastic knob to access the screw). Move the sphere on the vertical rod until it is laterally aligned with the suspended sphere and tighten the anchoring screw.
7. Position the slide arm so that the two spheres are just barely touching. The centimeter scale should read 3.8 cm (this distance is equal to the diameter of the spheres). If not, adjust the spacing between the spheres by loosening the thumbscrew on top of the rod that supports the sliding sphere and sliding the horizontal support rod through the hole in the vertical support rod until the two spheres just touch with the scale set at 3.8 cm. Tighten the thumbscrew.

You're now ready to begin the experiment.

Procedure

Read the "Tips for Accurate Results" at the end of this handout.

1. Move the sliding sphere as far as possible from the balance.
2. Turn on the kilovolt power supply, and set it for a potential of 4 KV. Charge both spheres to 4 KV by touching them with the charging probe, then immediately turn the power supply off.
3. Position the spheres 20 cm apart. Adjust the torsion knob on top of the balance to balance the forces and realign the index marks. Record the sphere voltage (V), distance (R) and angle (θ) in your spreadsheet.
4. Return to Step 1 and repeat the procedure a few times, until your result is repeatable to within ±2°. Record all your results.
5. Repeat steps 1-4 with R = 15, 10, 8, 6, 5 cm.
6. You may wish to do the first step of the Analysis section now, to confirm that your experiment is working.
7. Touch both spheres with the grounding wire to remove all charge from them. Now, charge the spheres to V = 3 KV, and repeat the entire experimental procedure with R = 15, 10, 8, 6, 5 cm.
8. Ground both spheres again, and repeat the procedure again with V = 2 KV, R = 8, 6, 5 cm.

Don't forget, you must recharge the spheres before every measurement, and you must always move the sliding sphere far away from the balance before you recharge.

Calibration: Measuring the Torsion Constant K_t

1. Your experiment measures the torsion angle θ. But how does that translate into a force? The torsion balance is designed so that the force on the sphere is proportional to the torsion angle:

   $$F = K_t \theta \qquad (2)$$

   We must now find K_t.
2. Disconnect the torsion balance from the slide assembly.
3. Extend the lateral support bar from the support rod nearest the plastic toolbox.
4. Remove the 20 and 50 mg masses from the toolbox. Remove the calibration support tube.
5. Turn the torsion balance on its side, so it's supported by its base and the lateral support bar.
6. Place the calibration support tube underneath the sphere.
7. Zero the torsion angle dial.
8. The sphere should hover just above the calibration support tube. If not, rotate the white torsion wire retainer on the base of the balance slightly until it does.
9. Place the 20 mg mass on top of the sphere, on the centerline. The sphere will sink down to rest on the support tube.
10. Turn the torsion angle dial until the sphere is suspended just above the tube. Record

the angle θ needed to achieve this.

11. Repeat this procedure with total masses of 40, 50, and 70 mg.

Analysis

1. For the V = 4 KV data, create a scatter plot with the torsion angle θ on the Y axis and the inverse square of distance ($1/R^2$) on the X axis. Confirm visually that the data lie along a fairly straight line, and thus the electric force is an inverse square law (provided force is proportional to θ).
2. Calculate the charge on the spheres for each experiment. This is surprisingly difficult to measure! For the purposes of this experiment, you should assume that

   $$q = C\,V$$

   where C = 2.11e-12 coulombs/volt. You will justify this value in a future problem set.
3. Create another graph showing the torsion angle vs q^2, for all experiments with R = 8 cm. Confirm visually that this is a fairly straight line, and thus the electric force is proportional to the product of the charges.
4. Calculate the torsion spring constant K_t:
   a. Calculate the gravitational force F_g from each of the masses.
   b. Use equation (2) to calculate K_t for each mass you tested. They should all be roughly equal.
   c. Take the average of the K_t.
5. Use the mean spring constant found in step 4c above to calculate the electric force F_e for each experiment.
6. Create a new column in your spreadsheet whose value is equal to

   $$\frac{q^2}{r^2}$$

   Don't forget any necessary unit conversions!
7. Use Equation (1) and the results from steps 4 and 6 to calculate a Coulomb constant k for each experiment.
8. Find and report the mean and 95% confidence intervals for your k.

Discussion Questions

1. Does your measured Coulomb constant agree with the accepted value? When I did this experiment, my answer was close, but too small. Let's try to figure out why.
2. Look at how the value of k you measured depends on the separation of the spheres. Is your result closer to the accepted value when the spheres are close together or far apart?
3. In doing this experiment, we're assuming that the charge on each sphere is evenly distributed. However, the spheres are conductors, so the charge is able to move around. What will happen to the charge on a positively-charged conductor when we bring another positively-charged conductor near it?
4. Explain how your answer to Question 3 might explain your experimental results.

Correcting the Data

A correction factor can be used to account for the redistribution of charge on a conducting sphere. Create a new column to hold a corrected angle $\theta_{corrected}$, calculated as follows:

$$\theta_{corrected} = \theta / B$$

where

$$B = 1 - 4\frac{a^3}{R^3}$$

where *a* is the radius of the spheres and *R* is their separation.

Reconstruct your graph of θ vs $1/R^2$, this time using $\theta_{corrected}$. Plot both versions on the same graph. Does the correction factor bring the data closer to an inverse-square-law relationship?

Now, recalculate the Coulomb constant *k* using $\theta_{corrected}$. Report its mean value and 95% confidence interval. With the correction, does your Coulomb constant match the accepted value? (I got $8.9 \pm 0.3 \times 10^9$ N m^2/C^2. Not bad!)

Tips for Accurate Results

- Always recharge the spheres between measurements.
- Always move the sliding sphere as far as possible from the balance before charging the spheres.
- Work slowly and be patient. The balance will be disturbed by air currents you create when you move around the room, and will take a while to reach equilibrium after you turn the torsion dial.
- Work quickly: humidity in the air will allow charge to slowly leak off the spheres over time. Yes, this contradicts the previous tip: nobody said science was easy.
- Avoid stray charges:
  - Turn off the kilovolt power supply when you're not using it.
  - Remember that your body is a good conductor, containing charges which can affect the experiment. Stay at arm's length from the experiment when possible.
  - Hold the charging probe near the back of the handle when charging the spheres.
  - Keep your computer away from the experiment.