Junior Lab

Coulomb's Constant *k*

In this lab not only will you determine Coulomb's constant k, you will determine the form of Coulomb's law. Namely, that the force between two point charges varies as the magnitudes of the point charges and varies inversely as the square of their separation, or

$$F_{12} = k\, q_1\, q_2 / r^2 \, .$$

Of course even this equation is in some sense abstract, in that it deals with point charges. Any charges we play with in the lab are actually charged objects and we must think about how they will behave differently from point charges. (In fact, we will end up using a correction factor.)

Historically electrostatic repulsion, through the build up of charge on amber, was observed and described by the ancient Greeks. However, it was not until the mid 17th century that this phenomena was quantitatively understood. Note: this understanding followed the theoretical understanding of gravitation by Newton. To understand electrostatic phenomena, a method to measure very small forces was needed, and a method of reproducibly generating and handling static charges was needed.

The measurement of small forces was done using a torsion balance. This was developed independently by several people, Coulomb among them. This uses the restoring torque from a thin wire or hair as it is twisted to measure very small torques. Of course the torque is just due to a tangential force at a certain radial distance. The poster in the lab shows various torsion balances and the torsion balance you will use is out on the table. Torsion balances can measure very small forces. In fact, it is with a more sensitive version of this balance that Cavendish measured the universal gravitation constant G. *Think qualitatively about the design of* a *torsion balance. Specifically, how would the stiffness, thickness, length and tension, of the wire effect its restoring force.* To measure the absolute force between charged objects will require us to relate the forces to forces that we know. This requires the calibration of the torsion balance. *How should we do this?* Clearly this is a critical part of our experimental procedure.

Now what about the reproducible generation of charges. At the time of Coulomb high-precision, high-voltage power supplies were not available. Instead, Coulomb had to resort to the tools at hand: fur, cloth glass rods, ebonite or whatever for the generation of charge and metals for the storage and transfer of charges. *How do you think he made sure that the same charges were on the metal test balls? How do you think he could accurately vary the amount of charge on the balls?* We don't have to worry about this because we do have high-voltage power supplies. *How will we determine the amount of charge put on the test balls?*

History

Charles Augustin Coulomb (1736-1806) was a French Engineer and Physicist. He served in the Corps du Genie for twenty years before his health forced him to serve mainly in an advisory capacity which allowed him to permanently settle in Paris in 1781. It was during this time he did most of his work as a physicist. He published seven memoirs on electricity and magnetism. In the first memoir published in 1777 he makes mention of his theory of torsion. He believed that it could be used to measure small torces. In fact using this method he was eventually able to measure forces down to $l0^{-9}$ dynes.

In his second memoir, published in 1787, he utilized the dynamic oscillation method to measure the interaction of charged objects. This method involved a charged pith ball suspended trom a torsion balance and a second charged ball, in the same plane, on a stand. The torsion arm was deflected and the resulting period of oscillation was timed.

In doing this experiment Coulomb made two main assumptions. First was that the charges acted as if at a concentrated point and secondly that the line of action of the force was along the axis. Coulomb demonstrated with data that the force was proportional to $1/r^2$ but he only implied that force is proportional to the charges. He does define an electrical mass but does so qualitatively. Attached is a diagram of the apparatus used.

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Now you are ready come up with a procedure to do the experiment. As a guide break the procedure as shown below.

I. Calibration of the torsion meter.

II. Determination of the inverse square law.

Note can we assume the charged balls are point charges? In fact we need to make some sort of correction factor. Why? Try and determine what the correction factor is.

III. Determination of the charge dependence.

Clearly, here we must change the charge on the balls. *How will we do this?*

IV. Determination of charge produced from "everyday" actions

Now that we have calibrated the torsion meter and Coulombs constant we can determine the "typical" amount of charge produced by rubbing fur and rubber, nylon and glass, using the Wimhurst generator and peeling scotch tape. Investigate at least one and think of what is producing the charging.

Helpful Hints

This lab is quite straight forward, but follow the helpful hints closely.
Before taking a lot of data, it is useful to investigate the effects that will effect reproducibility, and then minimize their effect.
For example: wind currents in the air; the decay of the charge on the spheres, distance to nearest conductor or insulator. Get a feel for the effects of these.
How important is it to make are quick measurements,? How quick is quick?
What is the effect of your hand between the two balls? How about a piece of paper? Why does this happen?
How does freshly peeled scotch-tape affect the balance?

In the data analysis you are told to use a correction factor. It is very important that you understand what this factor is correcting. (That is the difference between a physicist and a sloppy cook.)
So what is the correction factor for?
First think qualitatively about the situation.
Where is its effect largest? The balls are conducting right?
Now try to quantify the situation.
The method of image charges may be useful here.

- This equipment is very sensitive to the surrounding environment. To get the best results metal (jewelry and watches) should not be on your hands or arms. Try to minimize the air currents. The door should be closed while working and keep movement to a minimal amount. Stand behind the equipment.
- Charge decay is a problem. To get the best accuracy in the result,; spend the same amount of time taking each measurement. It is suggested that a trial reading should be done first to see approximately how large the angle is and then three 'real' readings each one done in 30-45 seconds. This should allow for the same amount of decay during each measurement.
- Be sure to check that the equipment is zeroed. It is important that it is zeroed on its side as described in the setup section in steps 7 and 8. Check that the index arm returns to zero between each measurement. If the sliding sphere has not been aligned the recorded R will not be right.
- For the Coulomb balance to work properly, it is important that the charge sphere on the balance is seated fully on the rod. There can be a tendency to have the sphere move when you are charging the sphere with the electrical probe. This can be avoided if you touch the electrical probe to the sphere on the side away from the plastic rod. That way with each charging you make sure the sphere is properly seated.
- It is possible to get the measurements repeatable within + or -one degree. If this is proving difficult the balls are not receiving a good charge. Rub the tip of the probe in the Aerodag G powder.