Demonstrations of Coulomb's Law with an Electronic Balance

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Generally, measurement of Coulomb's force is done by means of a torsion balance.[1,2] However, it is possible to use an electronic balance to measure weak forces in a simpler and straightforward way.[3] The demonstrations described here use a very simple setup to measure the repulsion force between two electric charges. With this method students can prove that the force is directly proportional to the charge and inversely proportional to the square of the distance. As a bonus, the setup allows for demonstration of the phenomenon of electrostatic induction.

Materials

- 3 metalized Christmas-tree balls, each about 6 cm in diameter
- 3 Plexiglas™ tubes (30 cm in length, 1 cm in diameter)
- Electronic balance with a sensitivity of 0.01 g or better[4]
- Supports, nuts, hot glue, and a ruler

Setup

Use hot glue to attach one of the Plexiglas tubes to each of the balls. Fix a ball with its "handle" vertically on the plate of the balance, held by a nut, and put on the tare. Using a support stand, a nut, and a clamp, arrange another ball some centimeters over the first one, with its handle pointing to a vertical ruler, which will be used to measure the distance between the balls (see Fig. 1).

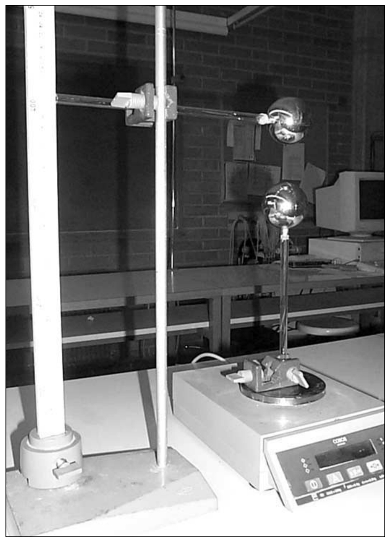

Fig. 1. Setup for measuring force of repulsion, using electronic balance and two charged balls.

Demonstrations

• ***To show that the electrical force is inversely proportional to the square of the distance.*** Charge the balls with an electrophorus.[5] Because the balls discharge, though slowly, it is advisable to take the measurements quickly.[6] So move the upper ball gradually, tabulating the reading of the balance against the distance between the balls. Figure 2 plots the readings of the balance at different distances. The fit of the values from several experiments to a function of the type $F \propto d^b$ gives values of b between -1.8 and -2.0, in good agreement with Coulomb's law.[7]

It is interesting and easy to complete the demonstration by measuring the charge and the potential of the balls, assuming the validity of Coulomb's law. We found the electrical charge of the balls in the experiment corresponding to Fig. 2 to be 76 nC and their potential 23 kV.

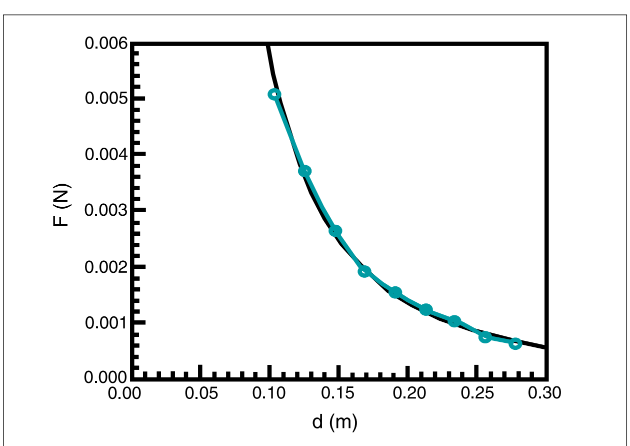

Fig. 2. Plot of sample readings of electronic balance vs distance between balls.

• ***To show that the electric force is directly proportional to the charge.*** Charge the balls and move them to a distance of about 9 cm (15 cm between centers). Write down the reading on the balance. Now touch the upper ball with a discharged third ball (Fig. 3). Half of its electrical charge will be removed from the ball; write down the new reading on the balance. Repeat this operation several times, each time draining half of the remaining charge. A plot of the readings on the balance versus the charge will be a straight line (Fig. 4), corresponding to a force directly proportional to the charge.

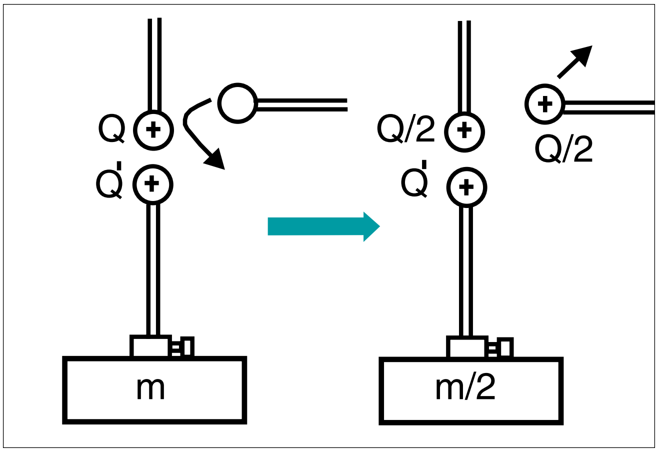

Fig. 3. **Touching upper ball with an equal and discharged ball demonstrates that force of repulsion is directly proportional to the charge.**

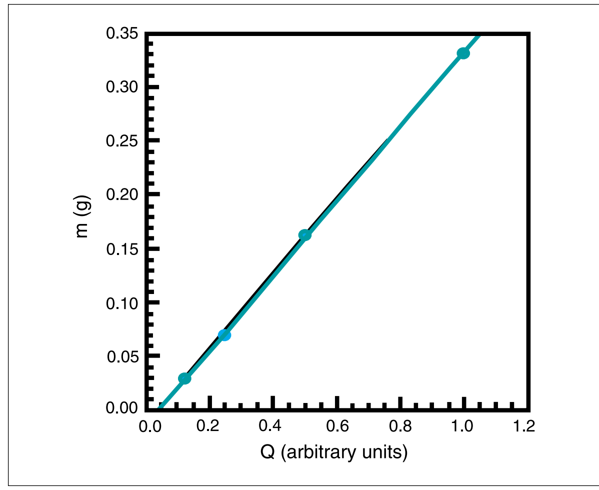

Fig. 4. **Linear correlation between reading of balance and charge of uppper ball.**

• ***To show that a charged body attracts a neutral one.*** First, charge the ball on the plate of the balance. Bring another discharged ball over the first to a distance of about 1 cm. The balance will show an attraction force (negative reading). Now touch the top of the upper ball with one finger; the attraction force increases. Figure 5 shows the interpretation of these electrostatic induction observations.

These demonstrations using an electronic balance are less complicated than measuring the angle between two balls hung by threads and make it unnecessary to purchase specialized (and expensive) equipment.

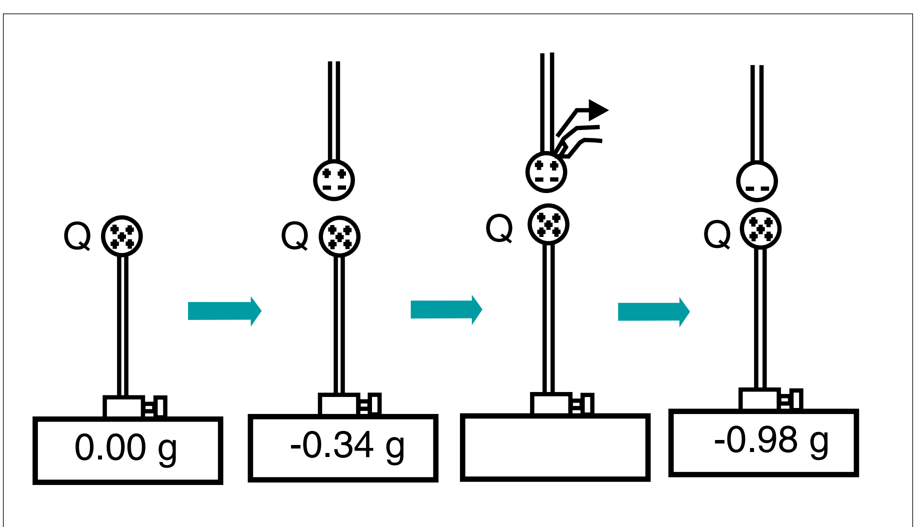

Fig. 5. **Electrostatic induction. Neutral conducting ball is "polarized" and attracted when put over a charged ball.**

References

1. E. M. Rogers, *Physics for the Inquiring Mind* (Princeton, New Jersey, 1960), pp. 541-542.
2. H. F. Meiners, *Physics Demonstration Experiments* (Ronald Press, New York, 1970), Vol. 2, Chap. 29.
3. A. Cortel, "Demonstrations on paramagnetism with an electronic balance," *J. Chem. Educ.* **75**, 61-63 (1998).
4. A balance with a sensitivity of 0.01 g is a standard piece of equipment that is easy to move and level, and can measure forces with a sensitivity of 10^{-3} N. Less sensitive balances are not suitable.
5. We use a plate of PVC that is rubbed with a sweater, and a disk about 10 cm in diameter that has an insulated plastic handle. If the charged balls are brought into contact, their electrical charge will be the same.
6. To minimize discharge of the balls, it is advisable to clean the Plexiglas handles with alcohol. We have observed that the main cause of the loss of charge is due to the point effect of small hairs or threads adhering to the balls, and so we prefer to use a sweater rather than fur to rub the electrophorus. Obviously, doing the demonstrations on wet days is to be avoided.
7. If the distance between the balls is less than 8 cm, the values do not fit well to a function of $F \propto 1/d^2$. The charge distribution will not be spherical because of the repulsion between the charges.