UNL2206, Nature's Threads: Tutorial 3

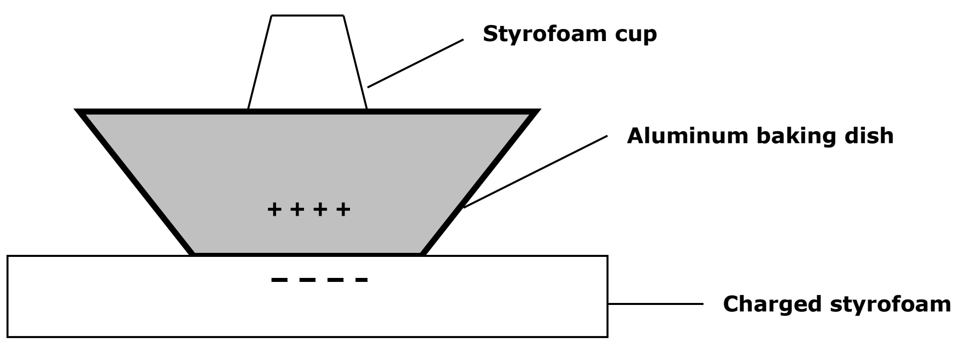
1) A negatively charged plastic rod is brought near (but does not touch) a grounded metal sphere. Next, the ground connection is removed. Finally, the negative rod is removed. Discuss the charge transfer and electrostatic induction at each step.

2) Three equal source charges $q_1 = q_2 = q_3 = Q$ are placed at the corners of an equilateral triangle. Let a 'test charge' q be placed at the centre of the triangle. What is the net force on the test charge?

Next, suppose that the test charge q is moved slightly away from the centre of the triangle; describe its subsequent motion. What can you conclude about the test charge at its original location? *(Hint: Draw a line from the centre of the triangle to one of its sides such that the line is perpendicular to and bisects the side. Then consider how the forces acting on the test charge change when it is placed at various positions along this line.)*

For the following, again form groups of 4-5 students. Each group should assemble the home-made devices outlined, perform the corresponding 'experiments' described below (and any further ones they can think of) noting carefully the various outcomes. Bring your working devices to class; groups will be expected to report on their collective results to the tutorial class.

Apart from inventing the battery that bears his name, the Italian scientist Volta invented in the late 1700's also invented a device he called the *electrofore perpetuo*, or electrophorus. A simple way of making one is to use an insulating cake (eg a styrofoam sheet) that may be charged up, assume negatively, by rubbing. A conducting metal plate (eg an aluminum baking dish) with an insulating handle (eg a styrofoam cup taped to the bottom of the dish) handle.

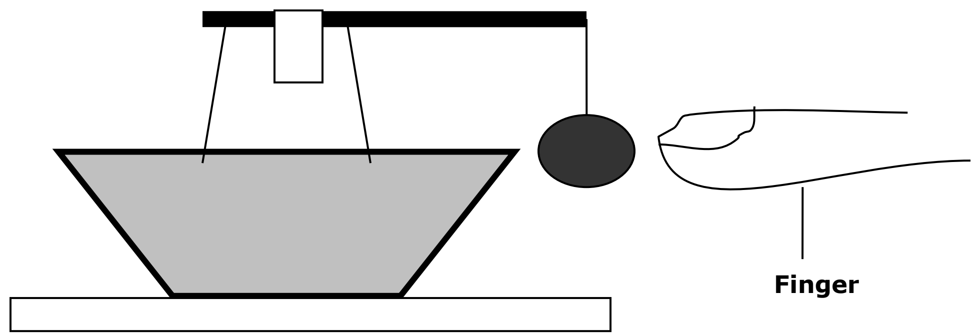


The idea of the electrophorous is that by using electrostatic induction on an external conductor (the aluminum dish), the charged insulating object (the styrofoam sheet) could be used repeatedly to charge other objects, without itself losing any charge. *NB To prevent charge coming off the electrophorous, you can try placing a thin plastic transparency sheet on it.* While the base of the aluminum dish is still in contact with the styrofoam (or plastic sheet), touch the rim of the dish with your finger to draw of some of the negative charge that has accumulated there. The dish should now have a net (positive) charge.

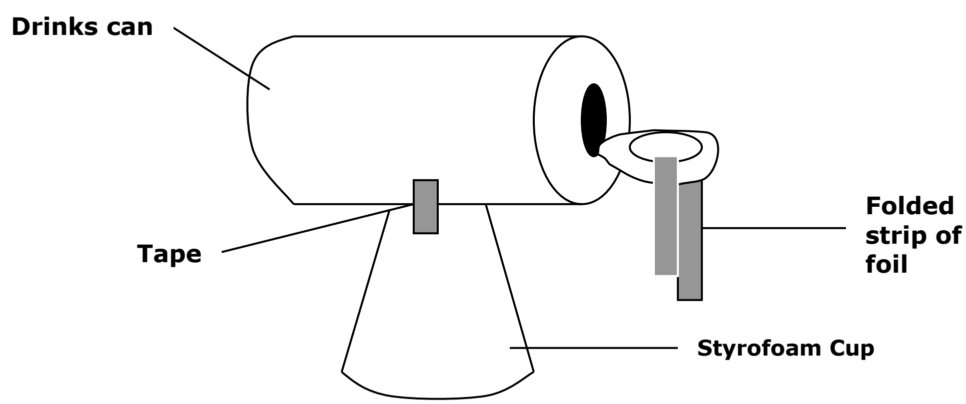
3) To check the above, charge up the styrofoam sheet by rubbing and then place the aluminum dish (be careful to hold it only by the 'handle') on the sheet and with the plastic transparency sheet in between. Lift the dish off again just by it's insulator handle and bring it near the pointer of a versorium. Repeat this a few times (being very careful not to discharge the dish by accidentally 'grounding' it) - explain what you observe.

4) Tape a drinking straw to the base of the styrofoam cup with a very small crumpled ball of aluminum foil suspended from the end of the straw by a thread. Charge up the styrofoam sheet and then place the aluminum dish assembly upon it as illustrated in the figure below. Bring your finger close to the ball (without actually touching it) and describe what happens. Also describe what happens if your finger touches the ball.

In fact, you have constructed a very simple electrical "motor" – explain how it works.



5) **Making a simple electroscope:** use a metal drinks can and tape it to an insulating base such as a styrofoam cup. Cut a strip of aluminum foil and fold it in half so as to be able to hang the foil through the tab of the can as shown below.



Now, repeatedly use your electrophorous to charge up the drinks can and observe carefully what happens to the two leaves of the aluminum strip as you repeat the process. Distinguish between the situations in which you bring the charged electrophorous a) close to the can (but being careful not to allow them to touch; and b) the electrophorous and can are in contact.

Using the Principle of Superposition to find the Coulomb force due to a continuous charge distribution

6) Say we would like to obtain the force **F** on a test charge q, placed at the origin, due to a net charge Q that is uniformly distributed over the line segment (a,- ℓ/2,0) to (a, ℓ/2,0) ie parallel to the y-axis.

A (numerical) solution to this problem can be obtained by approximating the problem by a sequence of approximate ones. To see how this works, take q = 10^{-9} C, Q = 5 x 10^{-9} C, a =1 m, and ℓ = 7 m.

First, approximate Q by assuming all of it is concentrated at the midpoint (1, 0, 0) of the line segment and compute the corresponding $\mathbf{F_1}$. Next, approximate Q by two charges each of Q/2, placed at (1, 7/4,0) and (1,-7/4,0) respectively and compute the corresponding Coulomb force $\mathbf{F_2}$. Then approximate the problem by placing three charges each of Q/3 at the points (1, 7/3,0), (1,0,0) and (1,-7/3,0) and now calculate $\mathbf{F_3}$. In general, we have n 'sub-charges', each of charge Q/n located at the positions (1, 7/2 - (1/2)·7/n, 0), (1, 7/2 – (3/2)·7/n, 0), (1, 7/2 – (5/2)·7/n, 0) and so on.

Set up an excel spreadsheet to compute the force $\mathbf{F_n}$ and record your results for n=1 to 12. What do you notice about this sequence of numbers for the magnitude of the force?

Optional: For those of you who know calculus, the exact result (try to derive it!) is

$$F_x = \frac{-\,k\,q\,Q}{a\sqrt{\{a^2 + (\ell/2)^2\}}}$$

Substitute a = 1 m, ℓ = 7 m, q =10^{-9} C and Q = 5 x 10^{-9} C in this formula and compare the result with your spreadsheet or numerical analysis of the problem.

What can you say about the situation when the length of the line segment ℓ is very much greater than its distance a to the origin?