Capacitance

As the charge on a conducting sphere in a vacuum increases, the electric potential rises. In simple terms, more work must be done against electrostatic repulsion to add the next charge. The potential V is found to be proportional to the charge q. The potential of a charged sphere is given by … $V = 1/4\pi\varepsilon_0\ q/r$. The capacitance of the sphere is defined as the ratio q/V. In free space …

$$C = 4\pi\varepsilon_0 r$$

Appling this relationship, and remembering that ε_0 *the permittivity of free space* is 8.85×10^{-12} farads per metre, the capacitance of a metal sphere with a radius of 10 cm is 11 pF, and the earth has a capacitance of just 710 μF. [The picofarad (pF) is 10^{-12} farads and the microfarad (μF) is 10^{-6} farads.] The small value of capacitance for an isolated sphere is a consequence of the very large SI unit of electrostatic charge, the coulomb.

Demonstration 1

A device that stores charge with less rise in potential (voltage) is made with parallel oppositely charged metal plates separated by a thin layer of dielectric (insulator). The chosen dielectric may be air, mica, paper, plastic etc. The components of a self-assembled demonstration capacitor on a lab bench are shown below.

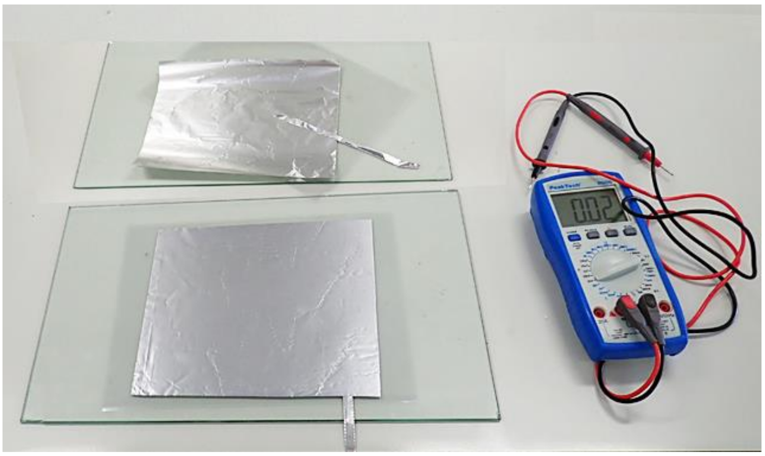

Fig 1 – the components of a parallel plate capacitor.

Aluminium foil that is covered with a sheet of cellulose acetate (transparent photocopy material) rests on a glass plate. Contact to the metal is provided to a digital capacitance meter with a strip of foil. To assemble the capacitor (below), the top metal sheet is laid over the acetate, a second contact strip is added, and the layers are flattened and held in place under the second sheet of glass.

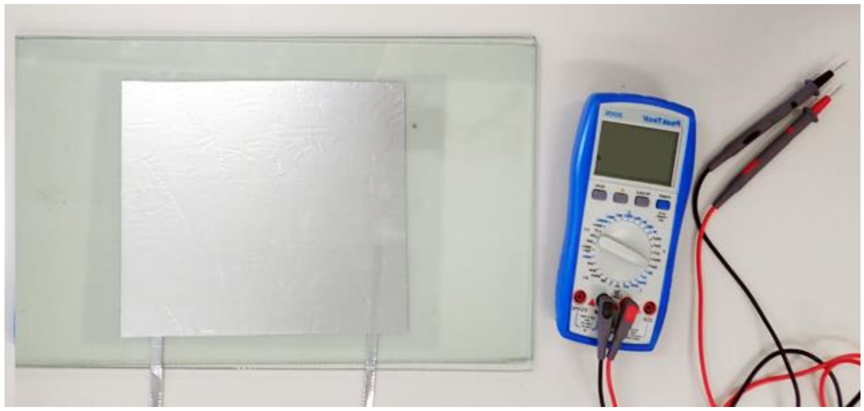

Fig 2 – the demonstration capacitor and digital capacitance meter.

In figure 2 the foil sheets were 20x28 cm in area and the acetate sheet used was 0.30 mm thick The measured capacitance was 6.2 μF. (It is interesting to calculate the radius of a conducting sphere that has the same capacitance.)

The capacitance of parallel oppositely charged plates is, by Gauss's law, given by …

$C = \varepsilon A/d$ … where ε is the permittivity of the dielectric, A is the plate area, and d is the separation.

Adding acetate sheets one at a time and measuring the reduced capacitance will give a data plot of capacitance against 1/*d* similar to that below.

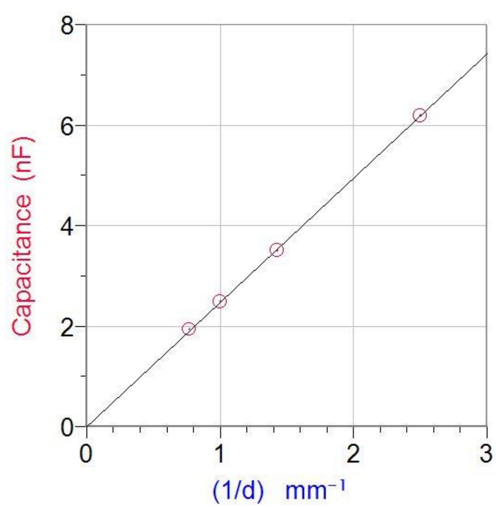

Fig 3 – capacitance versus the inverse of separation for acetate sheets.

Note: *if the foil is not flat and everywhere in contact with the dielectric a line-fit to data points will not pass through the origin. Use only new foil and apply pressure by hand to the top plate for all measurements of capacitance.*

Halving the area of overlap will reduce the capacitance by half as expected.

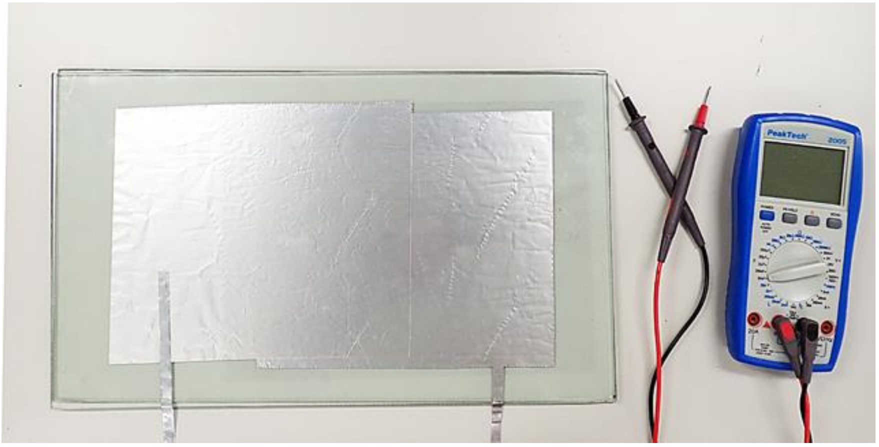

Fig 4 – the capacitor reassembled with just half the original area of overlap.

Relative permittivity $\varepsilon/\varepsilon_o$

Values of permittivity for dielectrics are normally expressed as the ratio $\boldsymbol{\varepsilon/\varepsilon_o}$

With the components used here, $\varepsilon/\varepsilon_o$ for the acetate sheet was found to be 5.0.

Substituting copy paper with a thickness of 0.1 mm changes the value of both the plate and separation and ε. For demonstration purposes three sheets at a time can be used so that the change is in ε only. Again a linear plot of C vs. $1/d$ will pass through the origin if pressure is applied by hand to the top plate.

With the components used here, $\varepsilon/\varepsilon_o$ for copy paper was found to be 2.3.

Additional demonstrations

1 The capacitor can be reassembled to find $\varepsilon/\varepsilon_o$ for glass, waxed paper, cling wrap etc.

2 A multi-layer capacitor can be assembled and the effective plate area found.

3 A large old-style metal-plate tuning capacitor can be examined.

The capacitance can be measured, and estimated with a calculation.

4 Using two flat metal plates separated in air allows the value of ε_o to be found.

5 To show the effect of rolling up a parallel plate capacitor (to increase the effective plate area) a foil and paper capacitor can be assembled with glue and rolled tightly on a pencil or similar. For good effect this must be done carefully. See demonstration 2 below.

Demonstration 2

The demonstration requires two strips of foil and a reel of wider double-sided tape.

If doing this with a class watching it pays to have practiced before-hand.

Step 1 The first strip of foil is laid along the middle of a strip of tape on the bench.

The white paper under the left hand end of the tape will make it easier to lift the final assembly off the table. The foil has been folded on the right to make a contact point in the final product.

Step 2 A second layer of tape has been added and the second strip of foil is in place.

Step 3 The layers are lifted off the bench and turned over with the exposed aluminium surface underneath. The layers are rolled *tightly* on a plastic drinking straw.

The rolled capacitor.

Values

The strips of foil were 1.5x27 cm in area. The capacitance unrolled (step 2) was measured as 2.13 nF. The capacitance of the rolled capacitor was 4.08 nF.

Questions

i Estimate the capacitance at step 3 above when half the capacitor is rolled.

ii Why was the capacitance (approximately) doubled by rolling?

iii Would rolling the layers on a drinking straw of half the diameter increase the capacitance further?

iv The thickness of the tape and glue was 0.06 mm. Find the average permittivity.

v What is the advantage of using double-sided tape (not acetate strips) to demonstrate the increase in capacitance due to rolling?