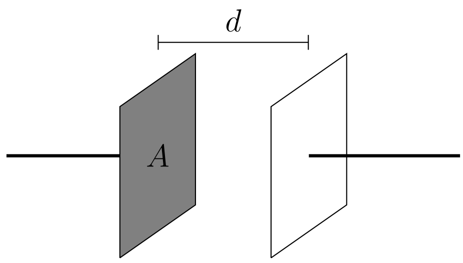
On capacitors

A.C. Norman
ACN.Norman@radley.org.uk

Warm-up problems

1. Draw a labelled diagram of a simple capacitor comprising two metal plates, and explain how it works.



A capacitor makes a break in a circuit (because it includes an insulating gap) and therefore does not allow direct current to flow. However, when a battery is first connected, some current will flow initially, even though the capacitor plates are separated by an insulator. As current flows, charge builds up on the plates of the capacitor—some electrons are forces onto one plate, and dragged off the other—meaning that some charge can be stored on the plates.

2. Give the definition of capacitance, its SI unit, and what it is **usually** measured in (i.e. what unit would you see written on a capacitor and how and why is it different from the standard SI unit?)

The capacitance is how much charge is stored per volt across the capacitor. Capacitors are usually rated in microFarad µF or picoFarad pF. This is because the Farad is a very large unit of capacitance (1 coulomb of charge—a large charge—stored when the p.d. is only 1 V).

Regular problems

3. What is the charge stored when the voltage across

(a) a 100 000 µF capacitor is 10 V,

$$\begin{aligned} Q &= CV \\ &= 100\,000\,\mu\text{F} \times 10\,\text{V} \\ &= 1\,\text{C} \end{aligned}$$

(b) a 50 µF capacitor is 9 V?

$$\begin{aligned} Q &= CV \\ &= 50\,\mu\text{F} \times 9\,\text{V} \\ &= 4.5 \times 10^{-4}\,\text{C} \end{aligned}$$

4. Two parallel metal plates are set up opposite each other. One plate is charged and the other plate is earthed. What happens to the capacitance and the potential if

   (a) the plates are brought closer together but the overlapping area is kept the same?
   In this case, the capacitance increases. The charge on the plate cannot change, so by $Q = CV$ the voltage must decrease. In bringing the plates closer together, the capacitor does work (imagine a spring between the plates beign compressed as they come closer together) because the plates attract each other. This means there is less energy per coulomb at the end (and the voltage has gone down).

   (b) the plates are kept the same distance apart but the area of overlap of the plates is increased?
   In this case, the capacitance has increased. The charge on the plate cannot change, so by $Q = CV$ the voltage must decrease.

   (c) the plates have a piece of wax inserted between them?
   In this case, the capacitance has increased. The charge on the plate cannot change, so by $Q = CV$ the voltage has decreased.

5. What is the capacitance of a capacitor which stores 12 µC of charge when connected to a 12 V battery?

$$\begin{aligned} V &= \frac{Q}{C} \\ &= \frac{12\,\mu\text{C}}{12\,\text{V}} \\ &= 1\,\mu\text{F} \end{aligned}$$

6. Work out the voltage across the plates of a 10 µF capacitor when it has a charge of 50 µC.

$$\begin{aligned} C &= \frac{Q}{V} \\ &= \frac{50\,\mu\text{C}}{10\,\mu\text{F}} \\ &= 5\,\text{V} \end{aligned}$$

Extension problems

7. (from *Advanced questions on Everyday physics*, Susan Williams) Read the following passage and answer the questions that follow

Early experimenters with electrostatic machines regarded working with electricity as an interesting activity which generated showy demonstrations but which would never have any real use! They did discover, however, that they could achieve much bigger sparks if they incorporated a long rod of iron into their design. Somehow it seemed to allow them to build up more charge before a spark developed. This idea of storing charge was developed by Pieter van Musschenbroek, who stored charge in a hand held bottle of water containing a brass wire. This ideas was later developed into the *Leyden jar*, which comprise a glass jar with an inner and outer coating of metal foil.

(a) What was happening when the experimenters used an iron rod? Discuss.
The passage talks about bigger sparks when an iron rod was used. This happens because the iron rod can store some charge in it, thus allowing the charge to build up to a greater amount before a spark is formed. This meant the sparks were bigger. In effect, adding the iron rod had increased the capacitance, meaning more energy could be stored.

(b) The *Leyden jar* was one of the earliest forms of capacitor. Explain how it worked in terms of what you know about capacitors.
A Leyden jar comprises a glass jar with metal foil coatings on the lower parts of the inside and outside surfaces of its walls (these are the plates of the capacitor), and a metal terminal projecting through the jar lid to make contact with the inner foil (this is one of the contacts; the other is the outer foil). Charge is stored between these outer and inner electrodes. The glass of the jar provides the electrolyte.

(c) How do you think the design and use of the Leyden jars was improved to give bigger sparks?
Capacitors have a large capacitance with a greater area of overlap and a smaller distance between the plates. Leyden jars could be made larger, have thicker plates, have plates which go further up the sides, have thinner glass, or be made of a material with a higher dielectric constant.

(d) Imagine you have six Leyden jars. To get the maximum possible charge stored. do you connect them in series or parallel? Justify your answer.
The jars should be connected in parallel, as this effectively increases the total area of the Leyden jar plates.

Except where otherwise noted, this work is licensed under
http://creativecommons.org/licenses/by-nc-sa/4.0/