Capacitor safety

‘What is the maximum capacitance allowable for a capacitor that will be used by students?’ A query like this one was emailed to our helpline and, as is often the way of these questions, there turned out to be more to it than initially seemed to be the case.

Voltage

We can approach this from the ‘hazardous live’ perspective that we discussed in Bulletin 266 [1]. If the capacitor is fully charged by being connected to a potential difference of more than 30 V, this will exceed the safety limits set down by SSERC. However, the power supply doing the charging would also exceed these limits, so this is not something that is likely to happen in schools. Having said that, there are electronic circuits and methods of connecting charged capacitors together that can give voltages greater than that used for charging. These should not be used if they result in potential differences greater than 30 V.

Energy

A Van de Graaff generator, like a capacitor, has the ability to hold charge. We assess the risk of harm from these devices by considering the energy of the discharge rather than the voltage. Voltage, though initially well above 30 V, reduces to zero. There are some Advanced Higher experiments that involve charging a parallel plate capacitor using an EHT supply, but in these cases the capacitors have very low capacitances in the picofarad range. Using the capacitor energy formula $E = \frac{1}{2} CV2$, where C is the capacitance of the capacitor and V is the potential difference across it, the energy works out to be well below the 350 mJ limit for high voltage discharges. Note that only an EHT supply can be used for these experiments as it is current-limited. Although an HT supply has a lower output voltage, it is not current limited and must not be used for these activities.

Figure 1 - Electrolytic capacitors.

Supercapacitors

Is that the end of the story? Enter the supercapacitor. When there were only two channels on TV and Wagon Wheel biscuits were nearly as big as actual wagon wheels, the idea of a small 20 F capacitor would have been laughable. Now such supercapacitors are easy to obtain. Typically, they have an operating voltage of 2 or 3 V, though we have seen some that can be charged until the potential difference across them is 12 V. Such a capacitor has the potential to store a few hundred Joules. Were you to accidentally short-circuit such a charged capacitor with a piece of jewellery such as a ring, there could be a sudden, large amount of localised heating. Care is needed.

Other considerations

Some capacitors such as electrolytic capacitors are polarity sensitive. Connecting these the wrong way round can cause them to explode. The negative side of the capacitor is usually marked with a minus sign, and the leg on that side is shorter. Do not use such capacitors with ac. Very old paper-based capacitors may still be in use in schools. The ageing paper can break down at voltages below that for which the capacitors would have been rated as being safe when new. By this we mean that current can flow through the material that is supposed to act as an insulator between the plates. This can create a fire hazard.

You can find the summary in Table 1 below. ≪

Control measure	Rationale
The potential difference across a capacitor or an assembly of capacitors must not exceed 30 V.	This is to avoid anyone coming into contact with a ‘hazardous live’. See below for the special case of parallel plate assemblies.
Parallel plate capacitors must not be charged using HT supplies.	Unlike EHT supplies, HT supplies are not current-limited.
Take care not to short-circuit a charged supercapacitor with jewellery.	The energy in a supercapacitor, if transferred to a piece of jewellery during a short, could cause damaging localised heating.
Do not charge any capacitor to a value above its voltage rating. For an older paper-based capacitor, keep well below the maximum rated voltage.	Too large a voltage can cause a capacitor to break down, presenting a fire hazard.
Ensure that electrolytic capacitors are used only with dc and are always connected the correct way round.	Wrongly-polarised electrolytic capacitors can explode.

Table 1 - Summary.

Reference

[1] https://www.sserc.org.uk/wp-content/uploads/Publications/Bulletins/266/SSERC-bulletin-266p11_18.pdf.