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Electrical circuits - 2

Introduction to the capacitor

A capacitor will allow current to flow into it, until the capacitor is fully charged. The charge that a capacitor can contain, is given by

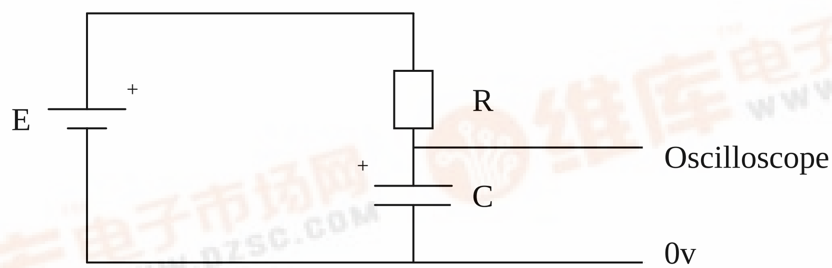
$$Q = CV \qquad (1)$$

where Q is the charge, C is the capacitance and V is the voltage that is applied across the capacitor. If a capacitor has a charge Q in it (and initial voltage V_o across it) and it is discharged through a resistor R, the charge will flow out of the capacitor and thus the voltage V will fall. The equation which describes the voltage across the capacitor as it discharges through a resistor is:

$$V = V_o \exp(-t / RC) \qquad (2)$$

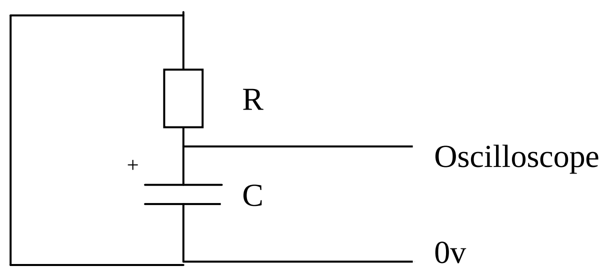
where t is the time. It is seen, that when t=RC then the voltage is simply $V=V_oe^{-1}$ (where e=2.718). The value RC is thus called the 'time constant'.

Experiment 1: Direct measurement of the RC time constant



<u>**Tasks for student**</u> **(2 marks):**

(a) [2 marks] Set up the circuit above using R=100kΩ and C=100µF, with the DC power supply set to around 5V. Because 100µF is quite a large value, an *electrolytic* capacitor must be used. You must **ensure that the polarity is correct,** i.e. note which end of the capacitor is indicated (by the arrow) as being negative. Measure the voltage V across the capacitor using the oscilloscope on the 'DC input' setting. As soon as the connection to the circuit is made current begins to flow, and the capacitor will begin to charge up. The time it takes to charge depends on the value RC. You will see the voltage across the capacitor rise, quickly at first, then more slowly until the voltage V approaches its maximum level. This will take one or two minutes. When the capacitor is fully charged, the experiment can begin. Record the initial voltage across the capacitor, V_o. In order to see how the capacitor discharges, the power supply is now taken out of the circuit, and the capacitor is allowed to discharge through the resistor, i.e. the circuit becomes:



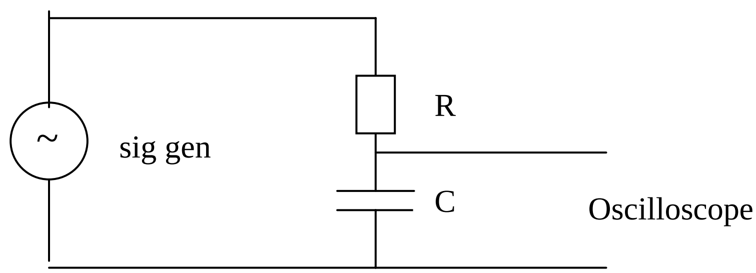
The easiest way to do this is to unplug the positive lead **at the DC power supply end**, and plug it into a negative (0v) terminal (leaving all other connections as before). Think about what circuit you are making in doing this... **do not short circuit the power supply!**

As soon as you make the circuit above, the capacitor will start to discharge (rapidly at first). Try and record the voltage across the capacitor every 5 seconds for about a minute. Estimate the error on each of your readings (you will find that your first reading will have a much larger error as it is quite tricky to estimate as the voltage is dropping quite fast). Tabulate your results. [If you 'miss' data, or find it tricky, repeat whole process a few times. You can improve your voltage estimates from using a mean of several attempts, although ensure the capacitor is fully charged before taking readings.]
(b) [2 marks] Plot a graph of voltage V across the capacitor, against time t, and draw your 'by eye' best fit through the data. Note your data points should have your estimated error bars on them. From your graph, deduce a value of the time constant (i.e., when the voltage drops to V_o/e), and compare this value with the value of RC you would expect.
(c) [3 marks] By rearranging equation 2, you can obtain an expression which has a straight-line form, y=mx+c. The expression is thus

$$\log_e(V) = (-1/RC)\, t + \log_e(V_o)$$

Plot $\log_e(V)$ against t, and deduce the time constant RC from the gradient of the graph. Is this method more accurate than the method used in part (c)? [Note that $\log_e$ refers to natural logs as opposed to base ten logs, $\log_{10}$].
(d) [2 marks] Using your derived time constant (i.e., the measured value of RC), calculate what voltage V you would expect at t=1, 2, 3, 4 and 5 seconds. Plot these points on the first graph you drew in part (c), and comment on how well your 'by eye' fit worked (do not redraw your fit!).

Experiment 2: Another look at charging and discharging



<u>Tasks for student</u> (9 marks):

(a) [2 marks] Set up the circuit above using R=10kΩ and C=0.022μF. The capacitance value is much smaller than before and so we do not need to use an electrolytic capacitor i.e., it is not polarised and you can connect it up in any direction. Set the signal generator to 500Hz and a peak-to-peak voltage of 1V. Also set the signal generator to the **square-wave** setting. Use the other channel of the oscilloscope to display the output from the signal generator, so that you can compare directly this 'input' to the RC system and the voltage you see across the capacitor. Sketch the waveforms displayed on the oscilloscope screen, and explain why the voltage across the capacitor should look like this.

(b) [1 mark] Equation 2 described how the capacitor discharges. However, consider where the capacitor is charging up. What do you think is the equation for the voltage across the capacitor as it is charging up?

(c) [3 marks] Reduce the frequency of the signal generator to 100Hz. Sketch the waveforms displayed on the oscilloscope screen. Now increase the frequency of the signal generator to 2 kHz. Sketch the waveforms displayed on the oscilloscope screen Explain the shape of the traces.

(d) [3 marks] Increase the frequency of the signal generator to 20kHz. The waveform of the voltage across the capacitor now looks like a 'sawtooth' waveform. Calculate what you would expect the peak-to-peak voltage of this sawtooth waveform to be, and compare this with what you actually see.