

TAP 129- 3: Analysing the discharge of a capacitor

Looking forward

Use automated data capture to study the decay of potential difference across the terminals of a capacitor as it discharges through a resistor.

The exact procedure will have to be modified depending on what software is available with your particular data capture and analysis package. If you are handing out these instructions to pupils you will need to edit these instructions accordingly.

You should aim to process the results by some computer based method.

The option quoted here is to identify the mathematical form of the potential difference against time graph using a curve-fitting method, and to then evaluate the decay constant.

Alternatively, if you have covered log graphs, you could use a log plot to identify the decay constant.

You will need

computer, running data capture and analysis software

data capture and analysis software

data capture device

voltage sensor

capacitor 100 μF

clip component holder

resistance substitution box

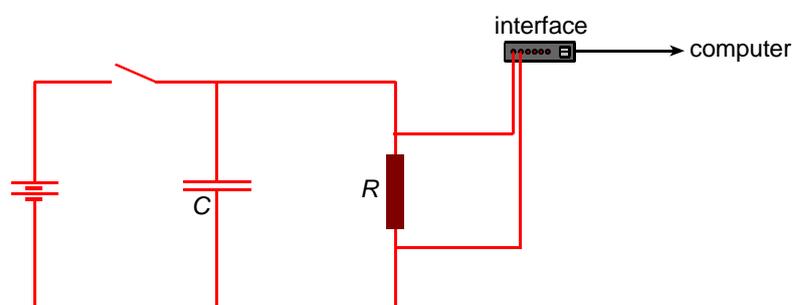
spst switch

power supply, 5 V dc

leads, 4 mm

Getting some data

Connect the capacitor C and resistor R in parallel as shown in the diagram. Add the switch and battery to the circuit as shown and attach the leads from the voltage sensor across the resistor. Check that the polarity of the capacitor terminals matches the + and – connections to the battery.



Prepare the computer program to record potential difference for 10 seconds. Conduct a trial run of the experiment as follows:

- set the program to start recording data

- close the switch to charge the capacitor
- open the switch.

As the capacitor discharges through the resistor, you can observe the graph of the decaying potential difference across the capacitor and resistor. If necessary, adjust the scale of the potential difference axis to give a large clear display of the graph.

You may wish to adjust the start condition for logging so that logging only begins when the potential difference falls below a chosen value. This is called a 'triggered' start. To identify a suitable value for the trigger potential difference, choose a value which is slightly less than the maximum potential difference shown on the trial graph.

Clear the previously collected data from the program set it ready to **start** logging and perform the experiment as you did in the trial run.

If your data analysis software has this function, select a trial fit. Choose the formula $y = a e^{bx} + c$ and adjust the buttons to fit and plot the data appropriately. You may find that a new curve is plotted directly over the data collected in the experiment. Make a note of the value of 'b' in the formula. This is called the **decay constant** of the curve. Notice that it is negative and record the value in the table.

Capacitance / μF	Resistance / Ω	$RC / \text{F} \times \Omega$	$1 / RC / \text{s}^{-1}$	Decay constant
100	10 000	1.0		
etc				

Repeat the experiment with different values of C and R, overlaying each new graph on the previous one to build a set of graphs.

Analysing the results

What is the connection between the **decay constant** and the shape of each graph?

The **decay constant** is a measure of how quickly the potential difference falls to zero. Look at the values calculated by the program to confirm that this is true.

Theory predicts that the decay constant is given by $1 / RC$. Do your results provide evidence for this? (The value of RC is known as the time constant of the circuit. Notice that, being the inverse of the decay constant, it is an indicator of **how long** it takes the voltage to decay rather than the rate of decay.)

Thinking about the theory

The potential difference across the resistor is given by $V = I R$.

Now the current I is due to the discharging capacitor where $I = - dQ / dt$.

For the capacitor $Q = C V$ and $dQ = C dV$. So we can say

$$V = - C \frac{dV}{dt} R$$

or

$$V = - RC \frac{dV}{dt}$$

Since R and C are constant in each experiment, this predicts that dV/dt is proportional to V . This can be put to the test by plotting a graph of V against dV/dt and looking for a straight line with a gradient of $-RC$.

(If you are using Insight, you can test this as follows.

Select 'Define' from the 'Edit' menu. If the potential difference data are stored in channel A, build a formula of the form dA/dt and store the calculated data in channel F. Adjust the axes to plot A versus F. This is equivalent to V against dV/dt . Select 'Gradient' from the 'Analyse' menu to find the gradient of the line. How does this compare with the value of $-RC$?)

You have learned

1. The graph of the potential difference across a discharging capacitor is an exponential function.
2. The decay constant of an exponential graph is a measure of how quickly the graph falls to zero.
3. The decay constant for a discharging capacitor is given by $1/RC$.
4. The rate of decay in the potential difference (dV/dt) varies in proportion to the potential difference (V).

Practical advice

This activity gives experience in using software for managing the collection of data, plotting graphs, analysing the data and calculating new data.

The purpose of the practice run is to allow the student to gain confidence in handling the equipment and software together and to enable necessary adjustments to be made to the axis scales.

Use the software to display the graphs of several experiments on the same axes. It is desirable to employ the 'triggered start' facility so that all the graphs obtained start from the same initial potential difference at time zero, or subsequently by software manipulation.

The curve-fitting method described here gives a novel way of evaluating the decay constant which emerges as one of the parameters calculated by the program in the fitting process. Students are encouraged to make a link between the decay constant and the shape of the curve; a quick discharge is associated with a relatively large decay constant and vice versa. The further link between the decay constant and the time constant (RC) is pointed out.

If the software allows it, (a "Ratio" or "Analyse" menu perhaps) measure the time constant directly as the time for the potential difference to fall to $1/e$ (37%) of an initial value. This can then be compared with the value of RC.

The further analysis of the data by calculating dV/dt and plotting a new graph might be regarded as an optional extension. This method follows the traditional analysis which seeks linearity and calculates RC from the gradient. Students can also be asked to use a 'Trial fit' to obtain a best fit straight line for the data. The program calculates the gradient as a parameter in the straight-line formula.

Alternative approaches

The same procedure may be used with a conventional voltmeter instead of the computer and interface. The data could be entered into a spreadsheet and manipulated to calculate speeds and plot graphs. However, the method described here considerably reduces errors due to taking readings in quick succession and removes the trouble of entering much of the data.

Be safe

Care should be taken to ensure that electrolytic capacitors are connected with the correct polarity and that the working voltage is not exceeded.

External references

This activity is adapted from Advancing Physics Chapter 10, 130E