Answers to questions

1. The circuit should be a series circuit so that the capacitor charges up through the resistor.
2. The experimenter does not have to look at two screens at the same time.
3. The square wave is much quicker, and so the values used can be much smaller. The oscilloscope also has a very high resistance and so will not discharge the capacitor itself.

Answers to exam-style questions

1. $I = I_0\ e^{\frac{-t}{RC}}$ where $I_0 = \dfrac{E}{R}$

$I_0 = \dfrac{15}{(50 ´\ 10^3)}$ = 0.30 mA **(1)**

$t = \pm\ \ln\left(\dfrac{I}{I_0}\right) \times RC$

So $t = \pm\ln\left(\dfrac{0.10}{0.30}\right) \times 22 \times 10^{\pm 6} \times 50 \times 10^3$ **(1)**

$t = \pm\ \ln(0.33) \times 1100 \times 10^{\pm 3}$ **(1)**
t = 1.2 s **(1)**

Sample data

R = 482×[illegible]   = 6.1×V

t/s	*V*/V
0	6.1
9.93	5.0
20.4	4.0
28.66	3.4
35.15	3.0
41.43	2.6
49.89	2.2
59.87	1.8
72.62	1.4
89.11	1.0
99.89	0.8

This gives a time constant of 50.5 s.

Hence $C = \dfrac{50.5}{(482 ´\ 10^3)}$ = 105× F.

Since this was labelled as a 100× F capacitor with a 20% tolerance, an error of 5% is well within tolerance.

Core practical 11: Display and analyse the potential difference across a capacitor as it discharges through a resistor

Objectives

- To measure the time constant for the discharge
- To observe the effect of changing the value of the resistor

Safety

- You are assessed against CPAC 3a and should produce an appropriate risk assessment.
- Do not exceed the voltage rating of the capacitor.
- All open circuit work should be carried out below 40 V DC.

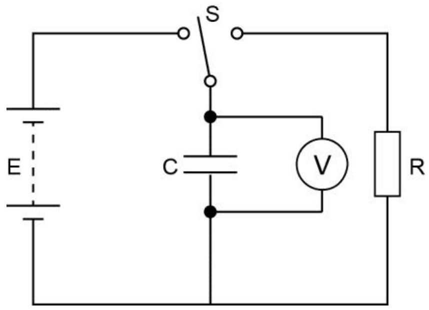
All the maths you need

- Recognise and make use of appropriate units in calculations.
- Recognise and use expressions in decimal and standard form.
- Use ratios, fractions and percentages.
- Use calculators to find and use power, exponential and logarithmic functions.
- Use an appropriate number of significant figures.
- Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers.
- Substitute numerical values into algebraic equations using appropriate units for physical quantities.
- Use logarithms in relation to quantities that range over several orders of magnitude.
- Translate information between graphical, numerical and algebraic forms.
- Plot two variables from experimental or other data.
- Understand that $y = mx + c$ represents a linear relationship.
- Determine the slope and intercept of a linear graph.
- Interpret logarithmic plots.
- Use logarithmic plots to test exponential and power law variations.

Equipment

- 100 μF electrolytic capacitor
- 5 μF non-electrolytic capacitor
- 470 kΩ 0.5 W resistor
- 1.2 kΩ, 470 Ω and 2.2 kΩ resistors, all 0.5 W
- multimeter with 2 MΩ scale – can be used as voltmeter
- batteries or power supply unit (PSU) to supply 6 V DC
- SPDT switch or flying lead
- oscilloscope
- stop clock
- source of square waves at 3 V

Diagram



Procedure

Measuring the time constant

1. Use the multimeter to measure the value of the resistor R.
2. Use the oscilloscope to measure a value for the EMF of the battery. If you are using a PSU, set the output to 6 V, and record the output potential difference (pd). Adjust the time base control of the oscilloscope until a continuous horizontal line is seen. It will be helpful if it lines up with the lowest horizontal line on the screen. The height of this line gives the voltage when the scale is taken into account. Adjust the vertical scale so that 6 V is near the top of the screen and check the calibration of the screen.
3. Set up the circuit shown in the diagram using the 100 μF capacitor, the 470 kΩ resistor, and the oscilloscope as the voltmeter.
4. Move the switch or the flying lead so that the capacitor C charges up and record this pd as V_0.
5. Change the switch, or move the flying lead, so that the capacitor begins to discharge and at the same time start the stop clock.
6. Use the lap timer facility on a stop clock to record the time when the pd falls to a pre-determined value. For example, record the time for the voltage to fall from V_0 to 5 V, then 4 V, then 3.5 V (say) using the lap timer each time and writing down the time. If you cannot do this quickly enough, record the time for the first fall, recharge the capacitor to V_0 and time the fall to the second pre-determined pd. You should repeat each of your readings.
7. Take sufficient readings to enable you to plot a graph of the results and calculate the time constant for the discharge.

Changing the value of the resistor

1. Set the alternating square wave supply (PSU) to deliver a 50 Hz square wave at 3 V and connect it to the oscilloscope. Adjust the controls to display the square wave. Disconnect the oscilloscope but do not vary the settings you have used to display the square wave.
2. Connect the PSU in series with a 5 μF capacitor and a 1.2 kΩ resistor. Connect the oscilloscope across the resistor so that it will read the potential difference across it – this also indicates the current in the circuit.
3. Sketch the trace you see on the oscilloscope and include voltage and time scales as axes.
4. Turn off the square wave supply and replace the 1.2 kΩ resistor with a 470 Ω resistor. Turn on the square wave supply and sketch the trace you see on the oscilloscope including voltage and time scales as axes.
5. Repeat part 4 above but replace the resistor with a 2.2 kΩ resistor.

Analysis of results

Measuring the time constant

1. Use your repeat readings to estimate the uncertainty in your values for time.
2. Plot a graph of your readings in order to determine a value for the time constant of the discharge.

3. By drawing a second line of fit, calculate a second value for the time constant and estimate the uncertainty in your value.
4. Use your value for the time constant to calculate a value for the capacitance and compare your value with the stated value of the capacitor. Consider your uncertainty to conclude whether the capacitor is within its tolerance.

Changing the value of the resistor

1. Use your sketches to explain the effect on the discharge of changing the resistance.
2. Use your sketches to estimate the time constant for each combination of capacitor and resistor.

Learning tips

- When using unfamiliar equipment, such as an oscilloscope, it is a good idea to make various adjustments to establish how to use the controls and to familiarise yourself with the device. Do this before using it to make measurements.
- Since the rate of discharge depends on how much charge is left, the discharge is exponential according to the formula $V = V_0\ e^{\frac{-t}{RC}}$. Taking logs to the base e of each side gives $\ln V = \ln V_0 + \frac{-t}{RC}$. This is similar to $y = mx + c$ and, since the value of the gradient will be $\frac{-1}{RC}$ which is a constant, the line will have a negative constant gradient and should be straight.
- You can draw error bars on your graph that will help you with uncertainties. You have found the uncertainty in your measurements of the time, Δ*t*, Use a mid-range value for *t* and determine the range of repeated readings for that value of *t*. This becomes the length of your error bars which you can then apply to each plot.
- The tolerance on the value of the capacitor – often 20% – is not a measurement uncertainty.

Questions

1. Draw the circuit that you could use to measure the time constant as the capacitor was charged.
2. Explain why the technique suggested for measuring the time is likely to reduce your uncertainties.
3. Give one advantage of using an oscilloscope to measure a potential difference.

Exam-style questions

1. In a circuit, to produce a delay such as the control circuit for the flashers in a car, a 22 μF capacitor is charged to a potential difference of 15 V and then discharged through a 50 kΩ resistor.

   Calculate the time taken for the discharge current to fall to 0.10 mA.

   (4)

Core practical 11: Display and analyse the potential difference across a capacitor as it discharges through a resistor

Objectives	Safety
• To measure the time constant for the discharge • To observe the effect of changing the value of the resistor	• Use of mains electrical equipment • Low voltages and energies present no hazard: normal laboratory practice is expected. • Do not exceed the voltage rating of capacitor. • All open circuit work should be carried out below 40 V DC.
Equipment per student/group	**Notes on equipment**
100 μF electrolytic capacitor 5 μF non-electrolytic capacitor	Working voltage above the maximum for the PSU.
470 kΩ 0.5 W resistor 1.2 kΩ, 470 Ω and 2.2 kΩ resistors, all 0.5 W	The resistors for the second part of the practical should be mounted to make swapping them in the circuit easy.
multimeter with 2 MΩ scale	Might also be used as voltmeter.
batteries or power supply unit (PSU) to supply 6 V DC	This is used to charge the capacitor at the start of the first part of the practical. The PSU need not be smoothed.
SPDT switch or flying lead	To make switching the capacitor easy
oscilloscope	This will be used to measure the potential difference across the resistor as the capacitor discharges through it. This will be for a DC discharge and an alternating square wave at 50 Hz.
stop clock	can be hand operated
source of square waves at 3 V	This can be at 50 Hz but need not be. The resistor and capacitor values will need to give a time constant of about a third of the period of the square wave. This might be shared between students.
Notes	