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Lascells Free Experiments - RC Circuit

The aim of this experiment is to determine the time constant, τ of a capacitor.

The time constant, with units of seconds, is a measure of how quickly a capacitor can charge and discharge through a resistor.
The charging of a capacitor through a resistor is modelled using the following equation:

$$V = V_0(1 - e^{-tRC}) \qquad (1)$$

where V is the voltage at time t, V0 is the voltage at time $t = 0$, R is the resistance (in Ω), and C is the capacitance (in F). Similarly, the discharge of a capacitor is given by:

$$V = V_0 e^{-tRC} \qquad (2)$$

Equations 1 and 2 are both exponential functions, and are plotted in Figure 2.

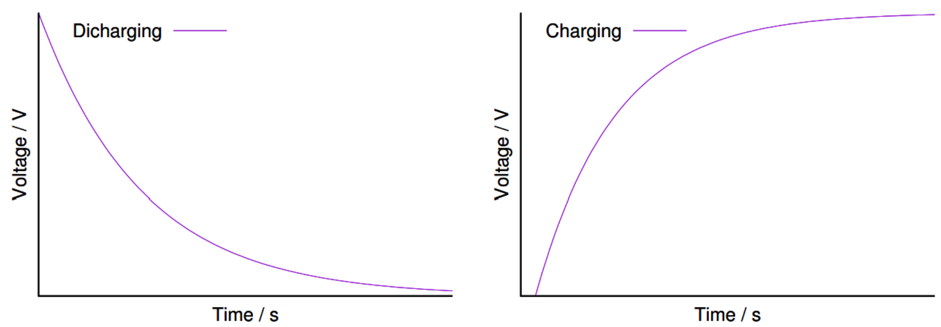

Figure 1: Plots showing the charging and discharging behaviour of a capacitor through a resistor as a function of time.

Log-linear plotting is a requirement of this practical for capacitor discharge - this means we need to linearise the expression that describes a capacitor discharge (Equation 2), by taking logs. Once linearised, the equation will have the form:

$$y = mx + c \qquad (3)$$

where a plot of y on the y-axis, against x on the x-axis, produces a gradient of m, and a y-axis intercept of c.

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The following is a step-by-step walkthrough on how to linearise Equation 2. To begin, divide both sides of Equation 2 by V0 to get the exponential term on its own:

$$V/V_0 = e^{-t/RC} \qquad (4)$$

Then, take the natural log of both sides of the equation:

$$\ln V/V_0 = -t/RC \qquad (5)$$

Using the log rule:

$$\ln A/B = \ln A - \ln B \qquad (6)$$

We can rewrite Equation 5 as:

$$\ln V - \ln V_0 = -t/RC \qquad (7)$$

By adding ln V0 to both sides we get:

$$\ln V = -t/RC + \ln V_0 \qquad (8)$$

Now we know we need to plot time on the x-axis, so we can rewrite Equation 8 to separate the time term:

$$\ln V = -1/(RC)\, t + \ln V_0 \qquad (9)$$

The time constant, Τ , is given by:

$$\mathrm{T} = RC \qquad (10)$$

and if we substitute Equation 10 into Equation 9, we get:

$$\ln V = -(1/\mathrm{T})\, t + \ln V_0 \qquad (11)$$

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By comparing Equation 13 to the straight line (linear) equation, $y = mx + c$, we can see that a graph of ln V on the y-axis, against t on the x-axis, will provide a gradient (m) of:

$$m = -1/T \qquad (12)$$

and a y-axis intercept (c) of ln V_0.

Equipment:

S100-897 Capacitor Investigation System
LA10-140 Lascells Digital Voltmeter
LA10-155 Lascells Digital Milliammeter
S100-905 Lascells Precision Variable Power Supply
Stop watch

Method: Charging

1. Attach the power supply, voltmeter, and milliammeter to the CIU. If you need help:
   (a) Attach the positive side of the power supply to the +5V terminal on the CIU.
   (b) Attach the negative side of the power supply to the 0V terminal on the CIU.
   (c) Attach the negative side of the milliammeter to the blue socket on the left of the ammeter symbol on the CIU.
   (d) Attach the positive side of the milliammeter to the red socket on the right of the ammeter symbol on the CIU.
   (e) Attach the positive side of the voltmeter to the red socket above the voltmeter symbol on the CIU.
   (f) Attach the negative side of the voltmeter to the black socket under the voltmeter symbol on the CIU. The circuit is now complete.
   (g) Ensure the switch on the CIU is set to DISCHARGE.
   (h) Set the voltage on the power supply unit to 5 V, and switch it on. Take a reading off the voltmeter for the first reading at time (t) = 0.
      (i) Now we will take readings every 10 seconds during charging. To do this:
      i. At precisely the same time, start the stopwatch and flick the switch on the CIU to the CHARGE position.
      ii. When the stop watch gets to 10 seconds, record the voltage on the voltmeter. Do this at 10 second intervals up to 180 seconds.

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Discharging

With the circuit still set up, once the voltage level has stabilised near the supply voltage, we can discharge the capacitor and take readings from the voltmeter as before.

To do this:

1. At precisely the same time, start the stopwatch and flick the switch on the CIU to the DISCHARGE position.
2. When the stop watch gets to 10 seconds, record the voltage on the voltmeter. Do this at 10 second intervals up to 180 seconds.

Sample Results - Charging

Time (s)	Voltage (V)
0	0.00
10	0.80
20	1.44
30	1.93
40	2.34
50	2.67
60	2.94
70	3.15
80	3.33
90	3.48
100	3.59
110	3.69
120	3.77
130	3.84
140	3.90
150	3.95
160	3.99
170	4.03
180	4.06

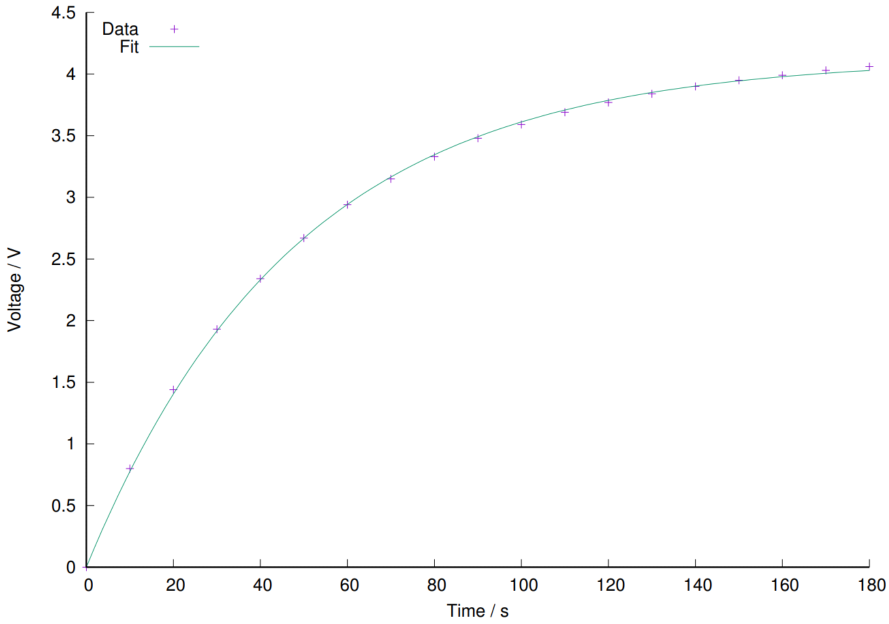

Figure 2: Plot of sample data for capacitor charging through a resistor. Data has been fitted using $V = V_0(1 - e^{-\frac{t}{RC}})$.

Discharging

Time (s)	Voltage (V)	ln Voltage (V)
0	4.45	1.4929
10	3.33	1.2030
20	2.71	0.9969
30	2.21	0.7930
40	1.80	0.5878
50	1.48	0.3920
60	1.21	0.1906
70	0.99	-0.0101
80	0.81	-0.2107
90	0.67	-0.4005
100	0.55	-0.5978
110	0.45	-0.7985
120	0.37	-0.9943
130	0.31	-1.1712
140	0.25	-1.3863
150	0.21	-1.5607
160	0.17	-1.7720
170	0.14	-1.9661
180	0.12	-2.1203

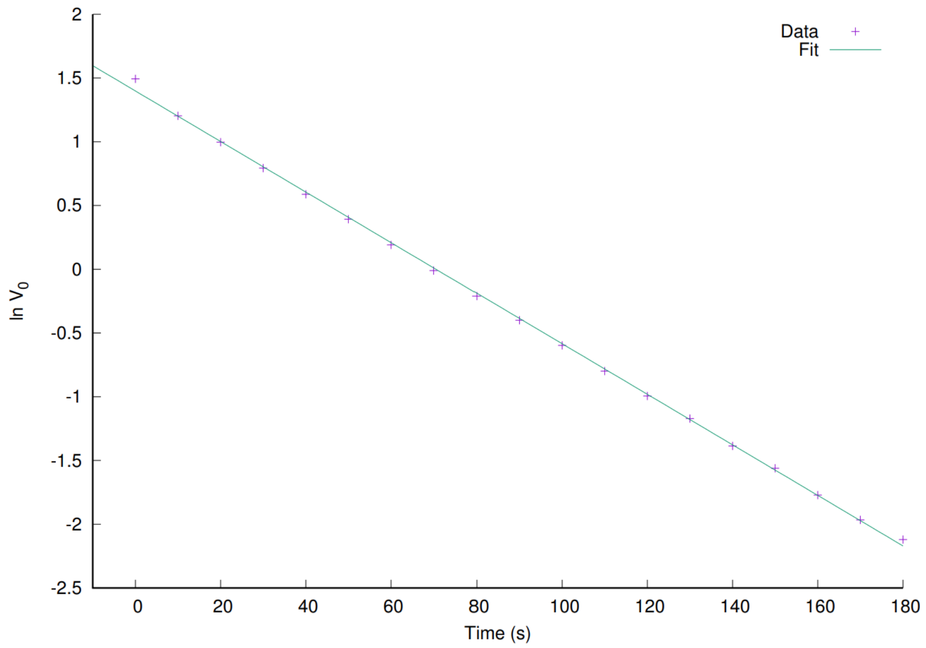

Figure 3: Log-linear plotting of discharging capacitor. Data has been linearly fitted with a resulting gradient of -0.0198276.

Taking the gradient of the fit shown in Figure 3, we can substitute this in to Equation 14 and rearrange for **τ** :

τ = − 1 m (13)

τ = − 1 −0.0198276 (14)

τ = 50 s (15)

We can calculate the actual value for **τ** using the known values for R and C, which are 4700 Ω and 10,000 μF respectively. Substituting these values into Equation 10 yields:

τ = 4700 x 10, 000 x 10−6 (16)

τ = 47 s (17)

This is in good agreement with our experimentally determined value.