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ENGS124 Electricity and Magnetism Lab Section B

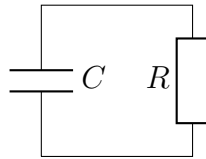
Investigating RC discharge circuits and capacitor combinations

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1 Theory

When we connect a charged capacitor and resistor, the capacitor starts to discharge. However, depending on the resistance, the current changes.



After applying Kirchhoff's voltage law, the following equation is reached:

$$IR = \frac{Q}{C}$$

The current is denoted the direction of positive charges, and the current is slowly decreasing, as the capacitor discharges. Therefore we get $I = -\frac{dQ}{dt}$:

$$-\frac{dQ}{dt}R = \frac{Q}{C} \implies \frac{dQ}{Q} = -\frac{dt}{RC} \implies \ln(Q) = -\frac{t}{RC} + c$$

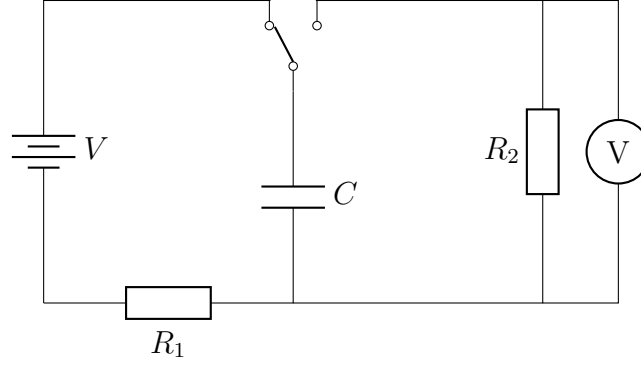
At $t=0$, denote the initial charge Q_0 :

$$\therefore Q = Q_0 e^{-\frac{t}{RC}}, V = V_0 e^{-\frac{t}{RC}}, I = I_0 e^{-\frac{t}{RC}}$$

An experiment was carried out to test this equation, and investigate the capacitance of parallel and series connections of capacitors.

2 Single Capacitor

The following circuit was assembled, with $R_1 = 265\Omega$ and $R_2 = 19630\Omega$. The first resistor was chosen to limit the charging current, and the second value was chosen to make the experiment both accurate and not take an eternity. The voltage was taken a constant $7.5V$. The capacitor was firstly charged, then the discharge on the second resistor was measured, during set intervals.



Instrument or material	Description
Voltmeter	A voltmeter
Lab bench power supply	With sufficient voltage range
Resistors	For current limiting and discharge limiting
Capacitors	In the order of a few millifarads
Switch	Three pole switch
Stopwatch	To measure time
Cables	For the multimeter and power supply

Table 1: List of instruments and materials

Variable	Value	Resolution
Time	Measured	0.5s
Voltages across resistor	Measured	0.01V

Table 2: List of variables

$$\ln \left(\frac{V_{R_2}}{V_0} \right) = -\frac{t}{R_2 C}$$

$V_{\text{all}} \text{ (V)}$	$R_2 \text{ (}\Omega\text{)}$	$V_R \text{ (V)}$	$t \text{ (s)}$	$\ln \frac{V_R}{V_{\text{all}}}$
7.51	19630	7.51	0.00	0.00
7.51	19630	6.72	5.00	-0.11
7.51	19630	6.13	10.00	-0.20
7.51	19630	5.60	15.00	-0.29
7.51	19630	5.15	20.00	-0.38
7.51	19630	4.73	25.00	-0.46
7.51	19630	4.31	30.00	-0.56
7.51	19630	3.94	35.00	-0.65
7.51	19630	3.65	40.00	-0.72
7.51	19630	3.30	45.00	-0.82
7.51	19630	2.99	50.00	-0.92
7.51	19630	2.71	55.00	-1.02
7.51	19630	2.51	60.00	-1.10
7.51	19630	2.28	65.00	-1.19
7.51	19630	2.10	70.00	-1.27
7.51	19630	1.90	75.00	-1.37
7.51	19630	1.74	80.00	-1.46
7.51	19630	1.57	85.00	-1.57
7.51	19630	1.44	90.00	-1.65
7.51	19630	1.33	95.00	-1.73
7.51	19630	1.21	100.00	-1.83
7.51	19630	1.11	105.00	-1.91
7.51	19630	1.00	110.00	-2.02
7.51	19630	0.92	115.00	-2.10
7.51	19630	0.85	120.00	-2.18
7.51	19630	0.77	125.00	-2.28
7.51	19630	0.71	130.00	-2.36
7.51	19630	0.64	135.00	-2.46
7.51	19630	0.59	140.00	-2.54
7.51	19630	0.54	145.00	-2.63
7.51	19630	0.50	150.00	-2.71

Table 3: Capacitor 1 data

Source of error	Type of error	Countermeasures
Capacitor leakage current	Systematic	The capacitor degrades and overtime it can lose its charge, even without a connected load.
Resistance measurement	Systematic	Multimeters are not very good at measuring resistances, which is why our calculated capacitance may differ from reality.
Reaction time	Random	Higher resistances cause slower dischrage and less human error.

Table 4: Estimated errors

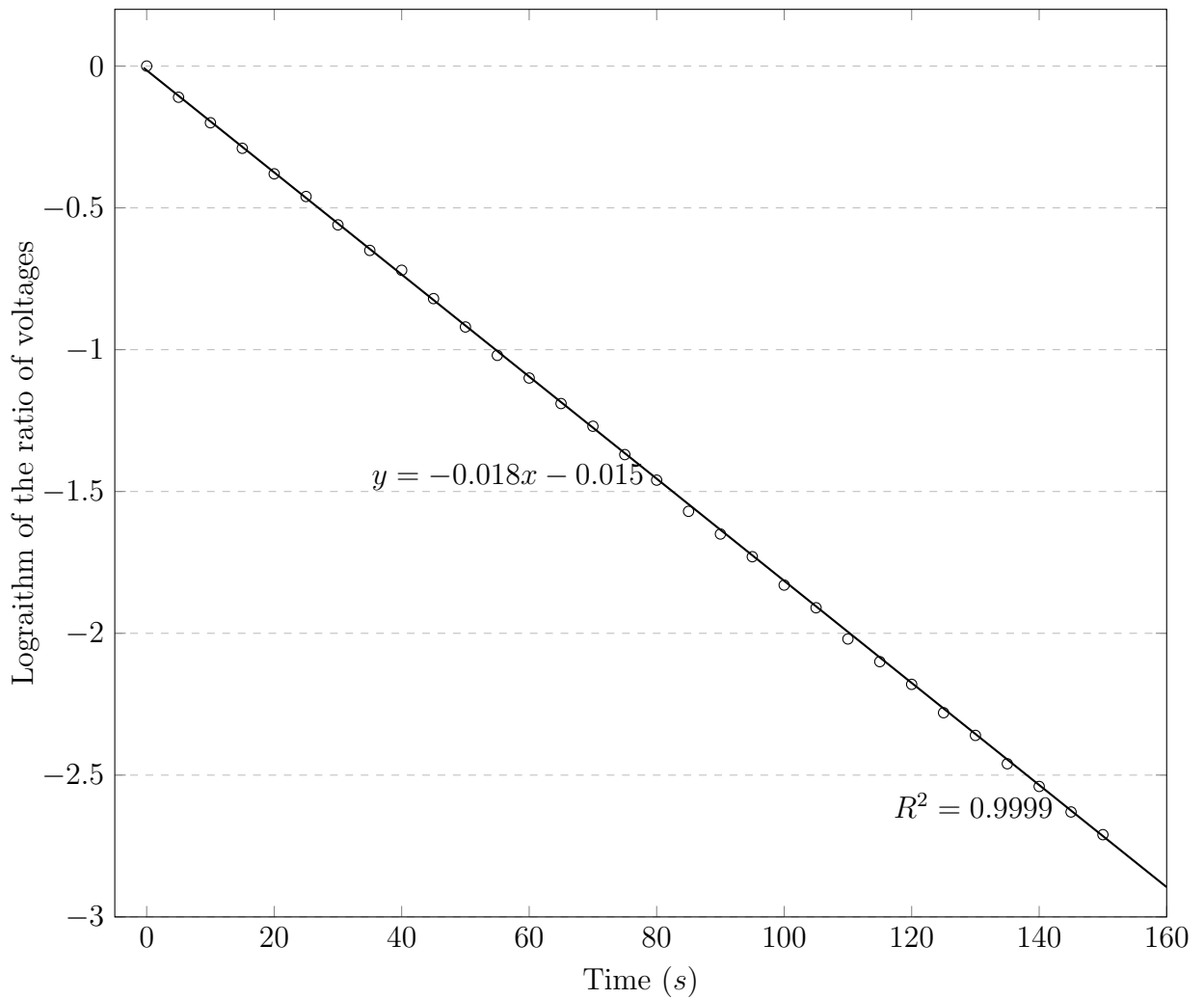


Figure 1: Plot of dependence of logarithm of ratio of voltages from time of the first capacitor

The above relation between time and voltage is confirmed and the capacitance is calculated $C_1 \approx$

$2820\mu F$. Another experiment was carried out with another capacitor, the formula is also confirmed and the capacitance is calculated $C_2 \approx 2670\mu F$, which will be used in the following experiments.

3 Two Parallel Capacitors

The same experiment was carried out, but the one capacitor was swapped with two capacitors in parallel. All the diagrams, error sources, tools/materials, procedures and calculations remain the same.

$V_{\text{all}} (V)$	$R_2 (\Omega)$	$V_R (V)$	$t (s)$	$\ln \frac{V_R}{V_{\text{all}}}$
7.51	19630	7.51	0.00	0.00
7.51	19630	7.15	5.00	-0.05
7.51	19630	6.80	10.00	-0.10
7.51	19630	6.47	15.00	-0.15
7.51	19630	6.17	20.00	-0.20
7.51	19630	5.88	25.00	-0.24
7.51	19630	5.59	30.00	-0.30
7.51	19630	5.35	35.00	-0.34
7.51	19630	5.09	40.00	-0.39
7.51	19630	4.85	45.00	-0.44
7.51	19630	4.64	50.00	-0.48
7.51	19630	4.43	55.00	-0.53
7.51	19630	4.20	60.00	-0.58
7.51	19630	4.01	65.00	-0.63
7.51	19630	3.82	70.00	-0.68
7.51	19630	3.65	75.00	-0.72
7.51	19630	3.48	80.00	-0.77
7.51	19630	3.33	85.00	-0.81
7.51	19630	3.17	90.00	-0.86
7.51	19630	3.03	95.00	-0.91
7.51	19630	2.89	100.00	-0.95
7.51	19630	2.75	105.00	-1.00
7.51	19630	2.63	110.00	-1.05
7.51	19630	2.40	115.00	-1.14
7.51	19630	2.27	120.00	-1.20
7.51	19630	2.27	125.00	-1.20
7.51	19630	2.07	130.00	-1.29
7.51	19630	1.97	135.00	-1.34
7.51	19630	1.88	140.00	-1.38
7.51	19630	1.80	145.00	-1.43
7.51	19630	1.72	150.00	-1.47

Table 5: Parallel capacitors data

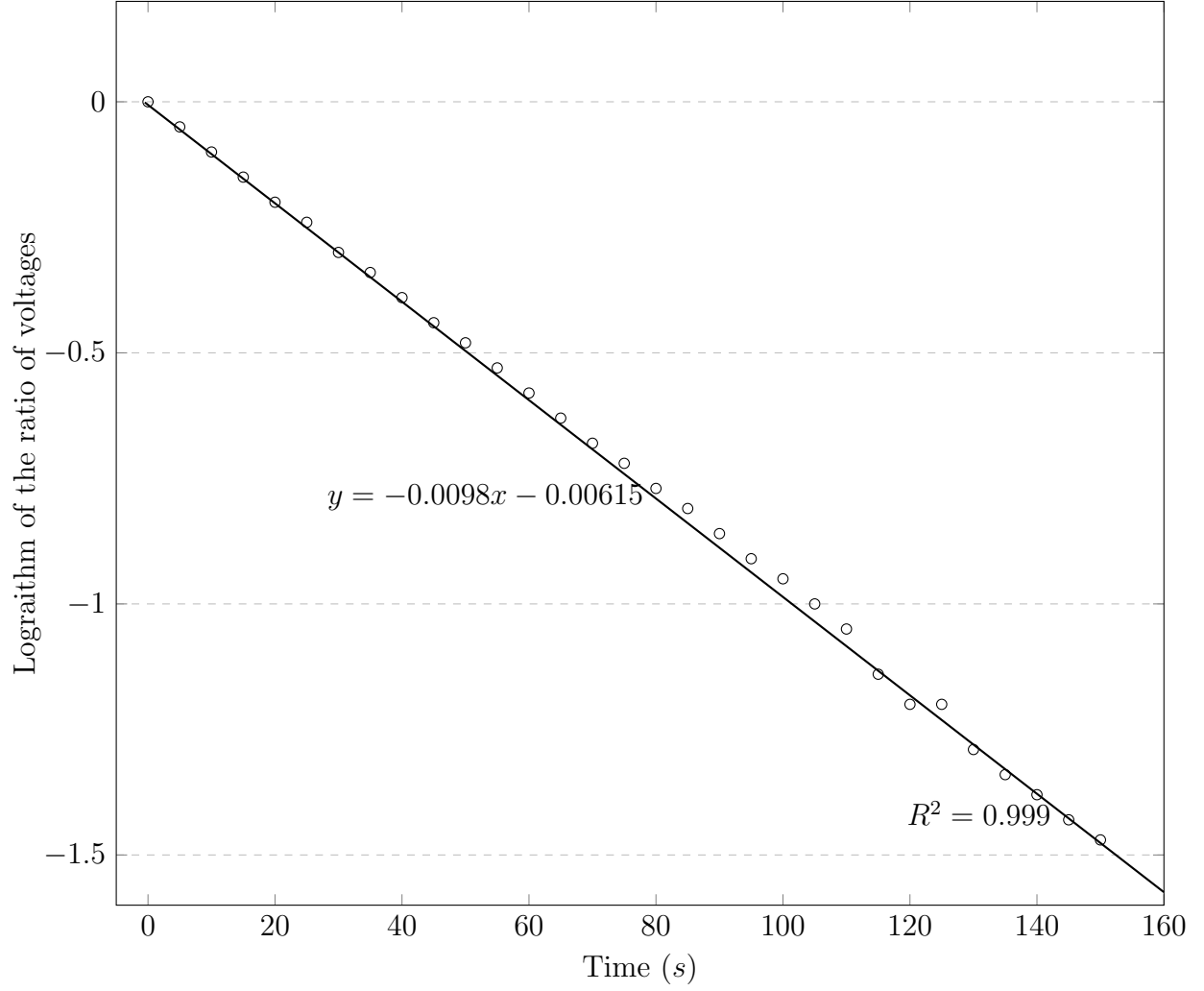


Figure 2: Plot of dependence of logarithm of ratio of voltages from time of two parallel capacitors

The calculated capacitance is $C \approx 5190\mu F$, and $C_1 + C_2 = 5490\mu F$, they are similar with a 5.5% error. The formula of parallel capacitors is confirmed.

4 Two Series Capacitors

The same experiment was carried out, but the one capacitor was swapped with two capacitors in series. All the diagrams, error sources, tools/materials, procedures and calculations remain the same.

$V_{\text{all}} (V)$	$R_2 (\Omega)$	$V_R (V)$	$t (s)$	$\ln \frac{V_R}{V_{\text{all}}}$
7.51	19630	7.51	0.00	0.00
7.51	19630	6.24	5.00	-0.19
7.51	19630	5.12	10.00	-0.38
7.51	19630	4.14	15.00	-0.60
7.51	19630	3.47	20.00	-0.77
7.51	19630	2.82	25.00	-0.98
7.51	19630	2.34	30.00	-1.17
7.51	19630	1.94	35.00	-1.35
7.51	19630	1.63	40.00	-1.53
7.51	19630	1.35	45.00	-1.72
7.51	19630	1.11	50.00	-1.91
7.51	19630	0.77	55.00	-2.28
7.51	19630	0.64	60.00	-2.46
7.51	19630	0.54	65.00	-2.63
7.51	19630	0.45	70.00	-2.81

Table 6: Series capacitors data

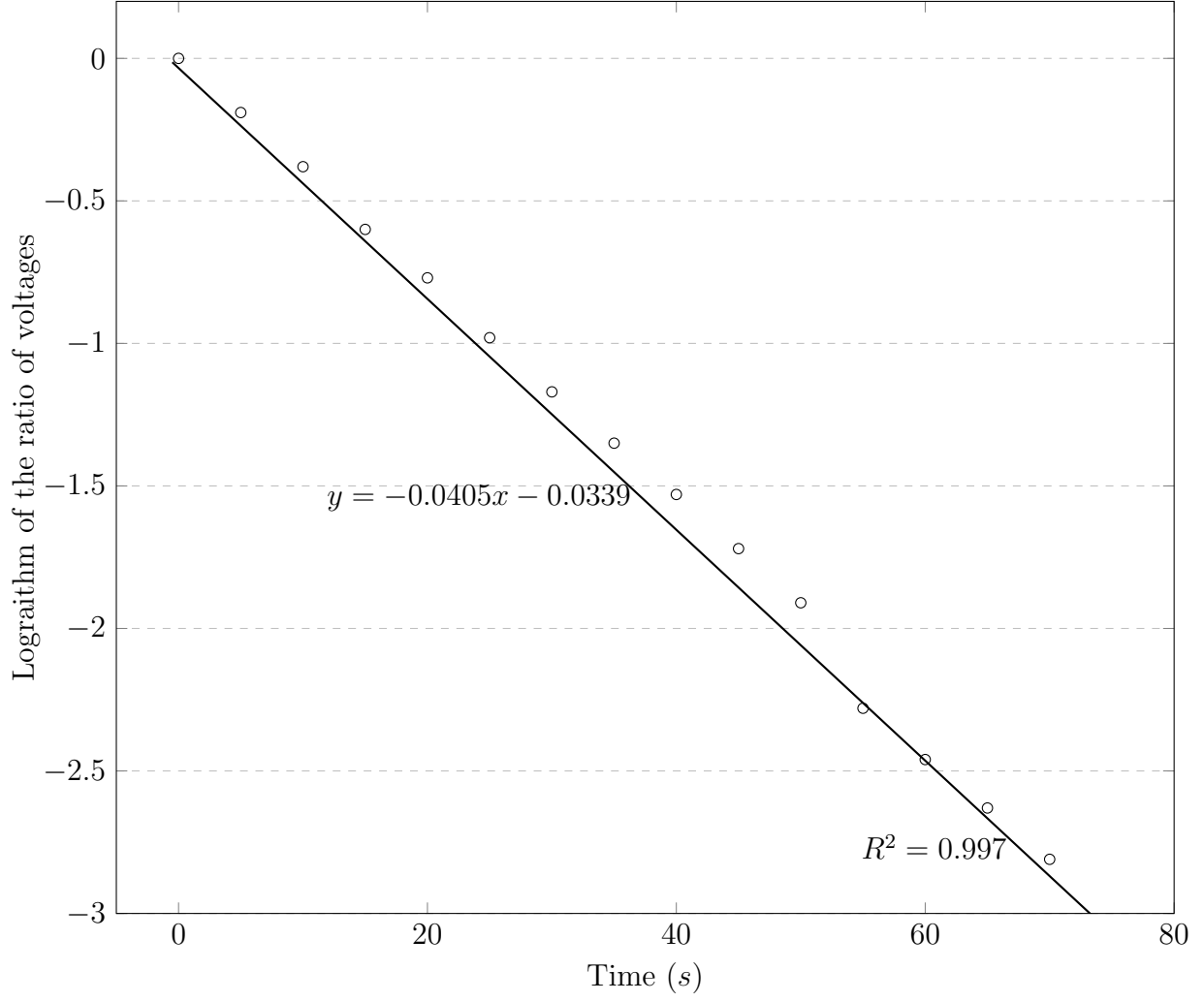


Figure 3: Plot of dependence of logarithm of ratio of voltages from time of two series capacitors

The calculated capacitance is $C \approx 1260\mu F$, and $\frac{C_1 C_2}{C_1 + C_2} = 1370\mu F$, they are similar with an 8% error. The formula of series capacitors is confirmed.