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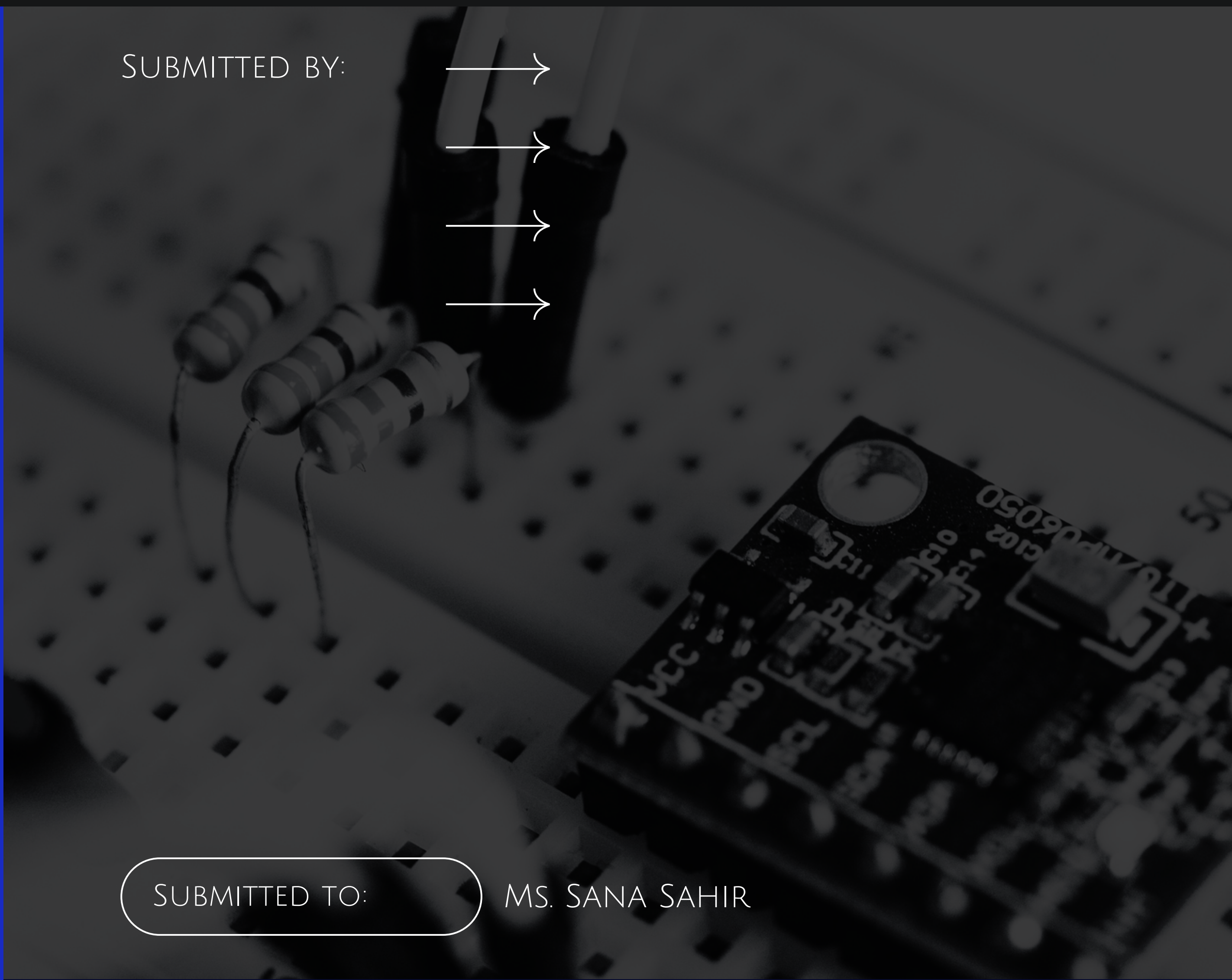
Winter 2024

experiment 4

Equivalent Resistance

University of Wollongong in Dubai



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PHYS143
Physics for Engineers

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Purpose
To experimentally determine equivalent resistance and compare theoretical and experimental results.

Hypothesis Statement
It is expected that the experimental values of the total resistance will be similar to the theoretical values of the equivalent resistance.

Materials
- Power supply
- 5 resistors of varying resistances
- Multimeter / Ammeter
- 4 banana cables
- Bread Board
- Wires

Procedure
1. Select known resistances R_1 to R_5.
2. Find R_{eq} using formulas for resistances in parallel and series.
3. Implement the following circuit to determine R_{eq} by applying a DC voltage source across points A and B.

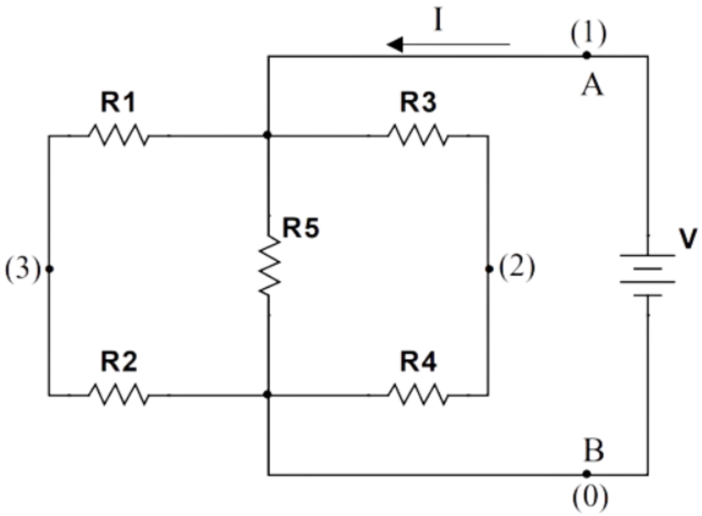

Figure 1: Circuit to be implemented.

4. Calculate $R_{eq} = {V_{AB}}/{I}$ (use ammeter to measure the current *I*)

Data & Calculations

V_{AB} (V)	R_1 (Ω)	R_2 (Ω)	R_3 (Ω)	R_4 (Ω)	R_5 (Ω)	R_{eq} (theoretical) (Ω)	R_{eq} (experimental) (Ω)	Relative Error (%)
10	100	270	150	220	10000	181.6397	178.9	1.508

R_{series} $R_1 + R_2 = 100 + 270 = 370\ \Omega$

$R_3 + R_4 = 150 + 220 = 370\ \Omega$

$R_{parallel} = \frac{1}{370} + \frac{1}{370} + \frac{1}{10000} = 181.6397\ \Omega$

Relative Error = $\frac{R_{theoretical} - R_{experimental}}{R_{theoretical}} \times 100 = \frac{181.6397 - 178.9}{181.6397} \times 100 = 1.508\%$

Observations

R_1 and R_2 are connected in series, and the same can be said about R_3 and R_4. The equivalent resistances of R_1 and R_2, R_3 and R_4, and R_5 are parallel to each other. The experimental equivalent resistance is close to the calculated value for equivalent resistance, with a low margin of error of 1.5%.

This close alignment between the experimental and theoretical values suggests a high degree of precision in both the experimental setup and the calculations performed.

Conclusion

1. **What was the purpose of this lab?**

To experimentally determine equivalent resistance and compare theoretical and experimental results.

2. **How does the lab we performed relate to what we are studying in class?**

With the experiment requiring us to set up a circuit with resistors both in parallel and series, we get to apply the ratio formulas of resistors learnt in class, where in series the sum of resistors is the equivalent resistance whereas in parallel connections the sum of reciprocals of resistance of an individual resistor is the total reciprocal resistance of the system. All of this is in-line with what is taught in class.

3. **Give a brief recap of the procedure used.**

Select resistances R_1 to R_5, apply formulas for parallel and series resistances to find R_{eq}, implement the circuit with a DC source across A and B, and calculate R_{eq} using $R_{eq} = {}^{V_{AB}}/_{I}$, measuring current I with an ammeter.

4. **What problems did you have during the lab? Did you have to modify your procedure?**

A problem we faced during the lab was the burning out of resistor R_5, which was heating up rapidly and releasing smoke. To avoid this, we chose a high R_5 value so that it would not burn out.

5. **Do your results make sense? What are the sources of error?**

The experimental results closely match the theoretical calculations. Some sources of error include improper connections of materials used, the resistors not being the exact advertised value, and human error

6. **What did you learn from this lab?**

We learnt about series and parallel circuits, and how resistors connected in series versus parallel can affect the overall resistance of the circuit and in segments of the circuit.

7. **If you were to repeat this lab in the future, how would you modify or improve the procedure?**

If this lab was to be repeated, special care would be taken to ensure that readings were accurate. In addition, resistances with higher values would be used to ensure that they do not burn out.

Purpose

To determine current flowing through a resistor using Kirchoff's Current Law and Kirchoff's Junction Law.

Hypothesis Statement

The experimental values of the current across the resistors will be similar to the theoretical values of the current across the resistors using Kirchoff's Laws.

Materials

- Power supply
- 5 resistors of varying resistances
- Multimeter / Ammeter
- 4 banana cables
- Bread Board
- Wires

Procedure

1. Implement the circuit shown in Figure 2.

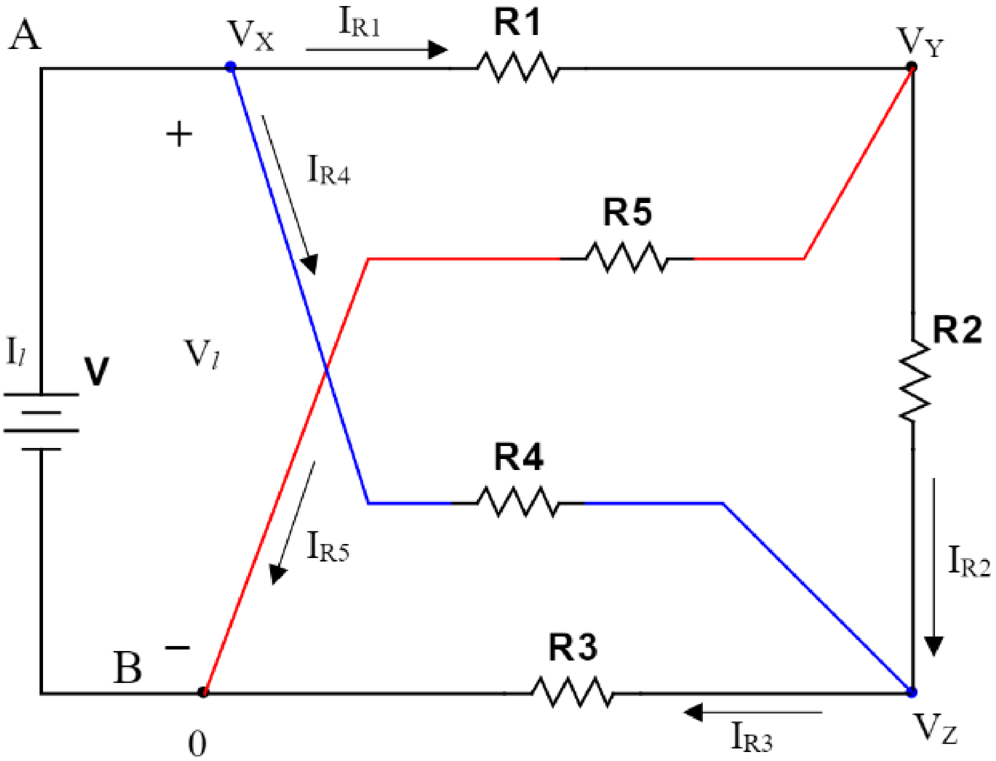

Figure 2: Circuit to be implemented.

2. Apply a voltage source across AB and measure the current *I* and the currents through each resistance I_{R1} to I_{R5}.
3. Note equations for the currents using Kirchoff's Junction Rule and Kirchoff's Loop Rule and solve for different values of *I*.
4. Compare theoretical and experimental values of *I*.

Data & Calculations

Circuit Input Data		Measured Currents (mA)		Calculated Currents (mA)	Relative Error (%)
R_1	100 Ω	**I_{R1}**	10.52	10.87	3.22
R_2	270 Ω	**I_{R2}**	9.66	9.97	3.11
R_3	150 Ω	**I_{R3}**	39.92	41.47	3.74
R_4	120 Ω	**I_{R4}**	30.26	31.50	3.94
R_5	10000 Ω	**I_{R5}**	0.86	0.89	3.37
$V_A - V_B$	10 V	**I_L**	40.78	42.37	3.75

Kirchoff's Junction Rule

$I_L = I_{R1} + I_{R4}$

$I_{R1} = I_{R5} + I_{R2}$

$I_{R3} = I_{R2} + I_{R4}$

Kirchoff's Loop Rule

$-10 + 100(I_{R1}) + 270(I_{R2}) + 150(I_{R3}) = 0$

$100(I_{R1}) + 270(I_{R2}) - 120(I_{R4}) = 0$

$270(I_{R2}) + 150(I_{R3}) - 10000(I_{R5}) = 0$

To solve the above equations, we obtain the following matrix

$Ax = B$

$$\begin{bmatrix} 1 & -1 & 0 & 0 & -1 & 0 \\ 0 & 1 & -1 & 0 & 0 & -1 \\ 0 & 0 & -1 & 1 & -1 & 0 \\ 0 & 100 & 270 & 150 & 0 & 0 \\ 0 & 100 & 270 & 0 & -120 & 0 \\ 0 & 0 & 270 & 150 & 0 & -10000 \end{bmatrix} \cdot \begin{bmatrix} I \\ I_{R1} \\ I_{R2} \\ I_{R3} \\ I_{R4} \\ I_{R5} \end{bmatrix} \times 10^{-3} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ -10 \\ 0 \\ 0 \end{bmatrix} \times 10^{-3}$$

Solving the matrix, we get

$$\begin{bmatrix} I \\ I_{R1} \\ I_{R2} \\ I_{R3} \\ I_{R4} \\ I_{R5} \end{bmatrix} = \begin{bmatrix} 42.37 \\ 10.87 \\ 9.97 \\ 41.47 \\ 31.50 \\ 0.89 \end{bmatrix} mA$$

Relative Error = $\frac{I_{theoretical} - I_{experimental}}{I_{theoretical}} \times 100 = \frac{42.37 - 40.78}{42.37} \times 100 = 3.75\%$

Observations

In analyzing this circuit, we confirm the validity of Kirchhoff's Current Law and Kirchhoff's Junction Law, which govern the flow and conservation of current within the system. Additionally, upon comparing the theoretical and experimental values of the current, we note a relative error of approximately 3.75%. Such a deviation could potentially stem from various sources, including inaccuracies in measurement instruments like an improperly calibrated multimeter, computational errors in calculating theoretical currents, or external factors such as environmental conditions impacting the circuit's behavior. It's essential to consider these potential sources of error when interpreting experimental results and refining experimental methodologies for future investigations.

Conclusion

1. What was the purpose of this lab?

To determine current flowing through a resistor using Kirchoff's Current Law and Kirchoff's Junction Law.

2. How does the lab we performed relate to what we are studying in class?

This experiment allows us to truly understand how Kirchoff's Current Law and Kirchoff's Junction Law work in a real-life circuit to give us current in certain segments of the circuit.

3. Give a brief recap of the procedure used.

Implement the circuit in the Figure, measure currents I and I_{R1} to I_{R5}, derive current and voltage equations using Kirchoff's rules, and compare theoretical and experimental values of I.

4. What problems did you have during the lab? Did you have to modify your procedure?

Connecting such a complex circuit in a small area on the breadboard was not easy. Wires were used to extend the circuit and make it bigger to ensure visibility of all the components.

5. Do your results make sense? What are the sources of error?

The results make sense. The sources of error could include loose wires, improper connections of the circuit and human error such as reading incorrect values from the multimeter.

6. What did you learn from this lab?

We learnt about the real-life applications of Kirchoff's Laws and how it can be used to calculate current in specific portions of interest in a circuit.

7. If you were to repeat this lab in the future, how would you modify or improve the procedure?

If this lab was to be repeated, special care would be taken to ensure that readings were accurate.

Purpose
Determine the time constant of the RC circuit using a large resistor value.

Hypothesis Statement
Voltage across the capacitor increases as voltage across the resistor decreases with respect to time.

Materials
- Power supply
- Resistor
- Multimeter
- Banana cables
- Bread Board
- Wires
- Capacitor

Procedure
1. Implement the following circuit.

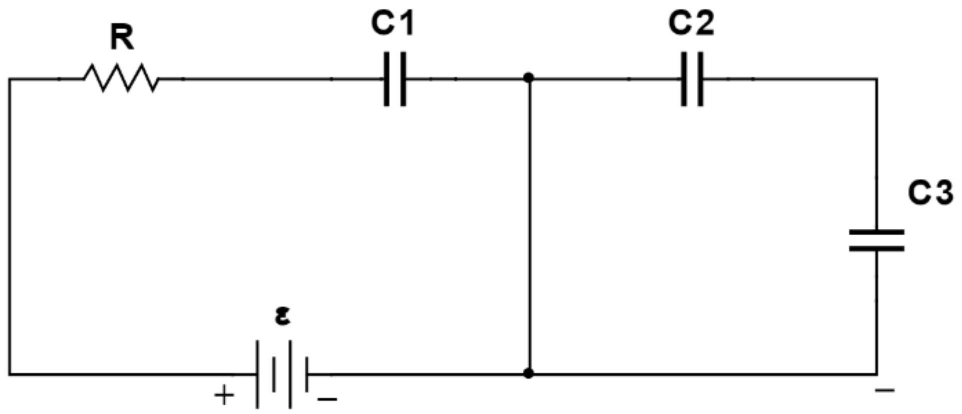

Figure 3: Circuit to be implemented.

2. Select RC values to maximize the circuit's time constant.
3. Measure voltage across each capacitor both experimentally and theoretically.

Data, Calculations & Graphs

V = 5 V, R = 22 kΩ, C = 1000 μF, τ = RC = 22 s

Time (s)		Experimental Voltage across C_1 (V)	Theoretical Voltage across C_1 (V)
0.2 RC	4.4	0.81	0.91
0.4 RC	8.8	1.46	1.65
0.6 RC	13.2	2.13	2.25
0.8 RC	17.6	2.64	2.75
1.0 RC	22	3.02	3.16
1.2 RC	26.4	3.33	3.49
1.4 RC	30.8	3.53	3.74
1.6 RC	35.2	3.74	3.99
1.8 RC	39.6	3.98	4.22
2.0 RC	44	4.22	4.32

To obtain an approximate time constant from the experimental data, we use the formula $V_c = V\left(1 - e^{-\frac{t}{RC}}\right)$

This equation can be rearranged to:

$\frac{V-V_c}{V} = e^{-\frac{t}{RC}}$

$\ln\left(\frac{V-V_c}{V}\right) = -\frac{t}{RC}$

$\ln\left(\frac{V}{V-V_c}\right) = \frac{1}{\tau}t$

Comparing with $y = mx$

$y = \ln\left(\frac{V}{V-V_c}\right), m = \frac{1}{\tau}, x = t$

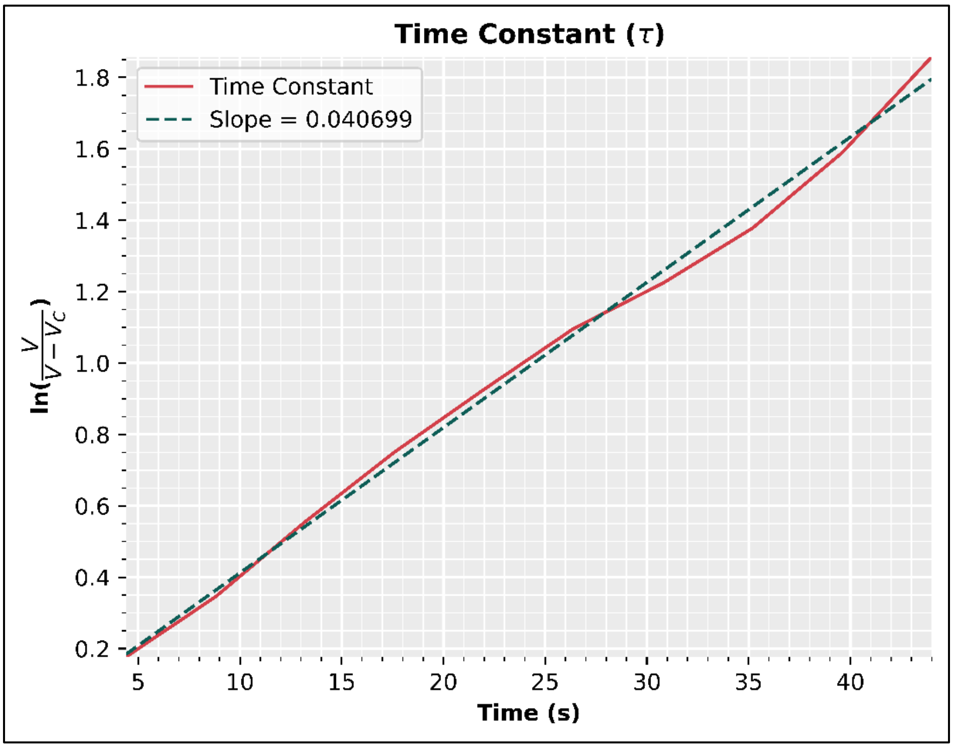

Figure 4: Time Constant τ.

From the equation of the graph, $\frac{1}{\tau} = 0.040699$. To find τ we rearrange the equation to obtain

$$\tau = \frac{1}{0.040699} = 24.57s$$

Observations

As time progresses, the voltage across the capacitor gradually rises until it approaches, and eventually reaches, the input voltage of the circuit. This observed behavior indicates that the capacitor is indeed undergoing a process of charging within this particular configuration. Consequently, our initial hypothesis regarding the charging of the capacitor is further validated by these findings.

Conclusion

1. **What was the purpose of this lab?**

Determine the time constant of the RC circuit using a large resistor value.

2. **How does the lab we performed relate to what we are studying in class?**

In class we learnt that in an RC Circuit when the switch closes, current will flow into the capacitor. As the voltage on the capacitor rises, the difference in voltage between the capacitor and the battery decreases, so the capacitor charging current closes off. As the voltage across the capacitor reaches the voltage of the battery, the capacitor's rate of charging slows down. This is in line with what was performed in the lab experiment.

3. **Give a brief recap of the procedure used.**

Implement the circuit as shown in the figure, select RC values to maximize the circuit's time constant and measure the voltage across the capacitor.

4. **What problems did you have during the lab? Did you have to modify your procedure?**

We faced no issues during the lab. We modified our procedure by having 1 equivalent resistance in the circuit instead of having three individual capacitors.

5. **Do your results make sense? What are the sources of error?**

Our results make sense as the time constant obtained experimentally is close to the value of the theoretical time constant. This means that the circuit was implemented successfully. Some sources of error could include human error in measuring voltage at the time intervals and inaccuracies in the devices such as the multimeter.

6. **What did you learn from this lab?**

We learnt about the time constant of a RC circuit, and how much time it takes to charge up a capacitor. We also learnt that a capacitor reached approximately 63.2% of its capacity in one time constant.

7. **If you were to repeat this lab in the future, how would you modify or improve the procedure?**

If this lab were to be repeated in the future, we would try to minimize any sources of error.

Purpose
To charge a capacitor using the charge of another capacitor.

Hypothesis Statement
The voltage across each capacitor and its charges should be equal in magnitude. C_1 will charge using the energy stored in C_2.

Materials
- Power supply
- 2 capacitors
- Multimeter / Ammeter
- 4 banana cables
- Bread Board
- Wires

Procedure
1. Implement the circuit shown in Figure 5.

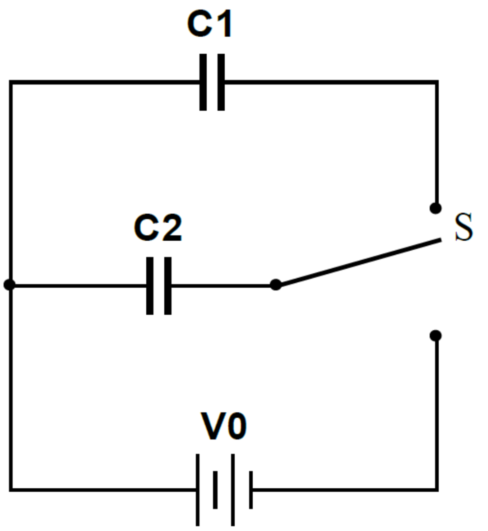

Figure 5: Circuit to be implemented.

2. Set the switch to charge C_2.
3. After a long time, flip the switch to charge C_1 from C_2.
4. After a long time, measure the voltage across C_1 and measure the charges of each capacitor.
5. Compare experimental measurements with theoretical calculations.

Data
$C_1 = C_2 = 1000\mu F$, $V = 3V$

$Q = CV = 3 \times 1000 \times 10^{-6} = 3$ mC

$$V_{C1} = \frac{Q}{C_1 + C_2} = \frac{3\times10^{-6}}{2\times10^{-6}} = 1.5\ V$$

Since the capacitances are the same, they will also have the same voltage. Hence, $V_{C1} = V_{C2} = 1.5$ V

Theoretical Charge

$Q = Q_1 + Q_2$

$Q = V_1C_1 + V_2C_2$

$Q = (1.5 \times 1000 \times 10^{-6}) + (1.5 \times 1000 \times 10^{-6})$

$Q = 3$ mC

Experimental Charge

$Q = Q_1 + Q_2$

$Q = V_1C_1 + V_2C_2$

$Q = (1.69 \times 1000 \times 10^{-6}) + (1.73 \times 1000 \times 10^{-6})$

$Q = 3.42$ mC

Observations

In this experiment, it can be observed that when a capacitor is charged, it can charge up another capacitor completely without the use of an external power source.

The experimental charge in the circuit is close to the result of the theoretical calculations, which implies that the circuit is correct.

Conclusion

1. **What was the purpose of this lab?**

To see and observe the charging of an uncharged capacitor using the charge of another capacitor.

2. **How does the lab we performed relate to what we are studying in class?**

The lab closely relates to the concepts taught in the lecture. The theoretical knowledge of how capacitors charge, store and discharge current is visible in this lab experiment.

3. **Give a brief recap of the procedure used.**

Implement the circuit from Figure, charge C_2 initially, then switch to charge C_1 after a while, finally compare measured values with theoretical predictions.

4. **What problems did you have during the lab? Did you have to modify your procedure?**

No, we did not face any difficulties in this lab. No, we did not have to modify our procedure.

5. **Do your results make sense? What are the sources of error?**

Our results make sense as they are in line with the theoretical calculations made. Some sources of error include variations in power supply voltage and imperfections in capacitors, affecting their capacitance value.

6. **What did you learn from this lab?**

From this lab, we learnt that a capacitor, when charged, can charge another capacitor without the need for an external power source such as a power supply or a battery.

7. **If you were to repeat this lab in the future, how would you modify or improve the procedure?**

If the lab were to be repeated, we would ensure that the capacitors are connected properly. We would also ensure that the capacitor is fully charged before discharging it.