EXPERIMENT 5

RC Circuits

Purpose:

- To determine the speed of charge / discharge of a capacitor in a RC circuit.
- To establish a connection with the lumped element values and charging/discharging time.
- To provide an understanding of "time constant" concept of charging and discharging circuits.

This information will be gained by measuring the current passing through the charging and discharging RC circuits and by analyzing how the current changes according to time.

Instruments for the Experiment:

- Electricity laboratory set
- Capacitors
- Connection cable
- Resistors
- AVOmeter

Theoretical Information:

In the circuit shown in the Figure 5-1, the current does not flow when S is switched off and the capacitor is empty. The condition that the capacitor is empty at t = 0 (the load at the beginning of each plate of the capacitor is zero) is expressed mathematically as follows;

$$q(0) = 0 \tag{5.1}$$

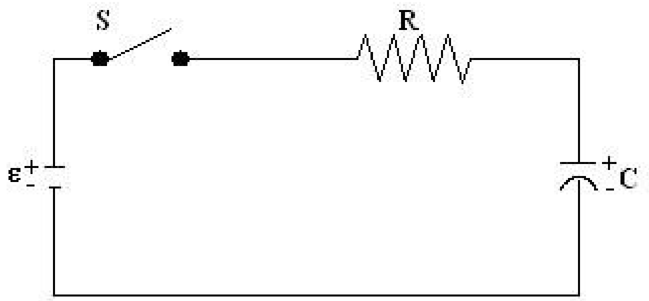

Figure 5.1 RC circuit

If the switch S is turned on at t = 0, the circuit is completed and a current, I, is transmitted. This current starts to load the capacitor C. During the loading, the electric charges are carried from one plate of the capacitor to the second plate. The load transfer from one plate to the other is provided through the resistor, switch and power supply until the capacitor is fully loaded. When the load on the capacitor's plates reaches its maximum, the current in the circuit becomes zero. When the current in the circuit is zero, it is called the equilibrium state of the RC circuit. Thus, at the end of the loading process one of the plates has $-q_0$ and the other has $+ q_0$ charge.

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The potential difference between the ends of the capacitor V_C is not immediately equal to the open circuit voltage ε at the output of the power supply. According to Kirchhoff's voltage law, at any time t;

$$V_C(t) + V_R(t) = \varepsilon \tag{5.2}$$

where $V_C(t)$ and $V_R(t)$ are potential differences between the ends of the capacitor and resistor, at any time t, respectively. By using the definition of a capacitor:

$$V_C(t) = \frac{q(t)}{C} \tag{5.3}$$

From Ohm's Law:

$$V_R(t) = I(t)R \tag{5.4}$$

$$\Rightarrow \frac{q(t)}{C} + I(t)R = \varepsilon \tag{5.5}$$

If the initial (t = 0) condition (specified in Eq. (5.1)) is used here, the current I_0 value at t = 0;

$$I_0 = \frac{\varepsilon}{R} \tag{5.6}$$

The potential drop at t = 0 occurs entirely between the ends of the resistance. When the capacitor is loaded to the maximum q_0 after a certain time, the load flow stops, i.e. the current passing through the circuit becomes zero (I = 0). Using this condition in Eq. (5.5), the maximum load on any plate of the capacitor is:

$$q_0 = C\varepsilon \tag{5.7}$$

$$I(t) = \frac{dq}{dt} \tag{5.8}$$

If both sides of Eq. (5.5) is taken the derivative with respect to time,

$$\frac{dI(t)}{dt} + \frac{I(t)}{RC} = 0 \tag{5.9}$$

$$\frac{dI(t)}{I(t)} = -\frac{dt}{RC} \tag{5.10}$$

$$\int_{I_0}^{I} \frac{dI(t)}{I(t)} = -\frac{1}{RC}\int_0^t dt$$

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$$\Rightarrow I(t) = \frac{\varepsilon}{R} e^{-t/RC} \quad (5.11)$$

As can be seen, the current passing through the circuit decreases exponentially during the load of the capacitor.

Charge of the capacitor at any t instant is from eq. (5.5) and (5.8):

$$\frac{dq}{dt} + \frac{q}{RC} = \frac{\varepsilon}{R} \quad (5.12)$$

Solution for q(0)=0 condition:

$$q(t) = C\varepsilon(1 - e^{-t/RC}) \quad (5.13)$$

$$\tau = RC \quad (5.14)$$

RC multiplication is in the dimension of time (the exponential expression must be dimensionless), and it is known as the time constant of the RC circuit. This τ constant defines how fast or slow the process of changing the current in the circuit and the charging of the capacitor occurs as seen from Eq. (5.11). The current flow through the RC circuit at t= τ;

$$I(\tau_C) = I_0 e^{-1} \approx 0.37 I_0 \quad (5.15)$$

where I_o is initial current value.

Similarly, the initially empty capacitor was loaded on each plate with equal magnitude of charges $q(\tau_C)$ and - $q(\tau_C)$ after t = τ seconds from the start of charging;

$$q(\tau_C) = C\varepsilon(1 - e^{-1}) \approx 0.63 C\varepsilon \quad (5.16)$$

If the resistor R in Figure 5-1 was zero, the charge q in the capacitor would immediately get the value Cε as soon as the S switch was closed. R resistance prevents the capacitor from being loaded suddenly. During the loading of the capacitor, the current passing through the circuit and the change of the load on the plate of the capacitor according to time are shown in Figures 5-2 (a) and (b), respectively.

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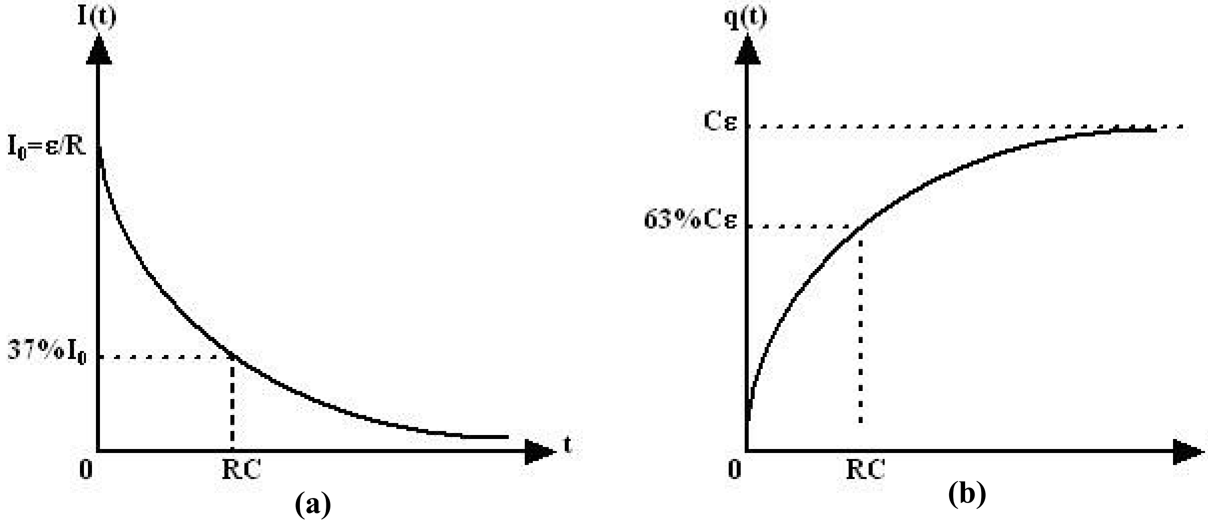

Figure 5.2 Variation of **a)** current and **b)** charge with time during charging process in the RC circuit.

Figure 5-3 shows an RC discharge circuit consisting of resistor R, capacitor C and switch S. When the switch is open, there is a potential difference between the ends of the capacitor with the charge q_0, and since I = 0, the potential difference at the ends of the resistance is zero. If the switch is turned off at t = 0, the capacitor starts to discharge over the resistor. At any time, the current is I (t) in the circuit and the charge on the capacitor is q(t). From Kirchhoff's second law, the sum of the potential difference at the ends of the capacitor and resistor is zero.

$$\mathbf{V_C(t) + V_R(t)} = 0 \tag{5.17}$$

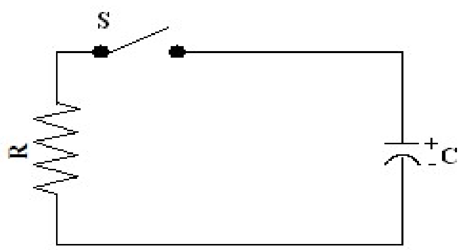

Figure 5.3 RC Discharge circuit

If similar operation steps are followed in case the capacitor is loaded, the load of the capacitor is,

$$\boldsymbol{q(t) = q_0 e^{-t/RC}} \tag{5.18}$$

$$\Rightarrow \quad I(t) = \frac{dq}{dt} = -\frac{q_0}{RC} e^{-t/RC} = -I_0 e^{-t/RC} \tag{5.19}$$

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Here $I_0 = \frac{q_0}{RC}$ is value of the current at t=0 and the minus sign indicates that the direction of the I(t) is opposite to the direction given by Eq. (5.11) in the process of loading the capacitor. During the discharge of the capacitor, the change in the current flowing through the circuit and the time load on the capacitor plates is shown graphically in Figure 5.4 (a) and (b).

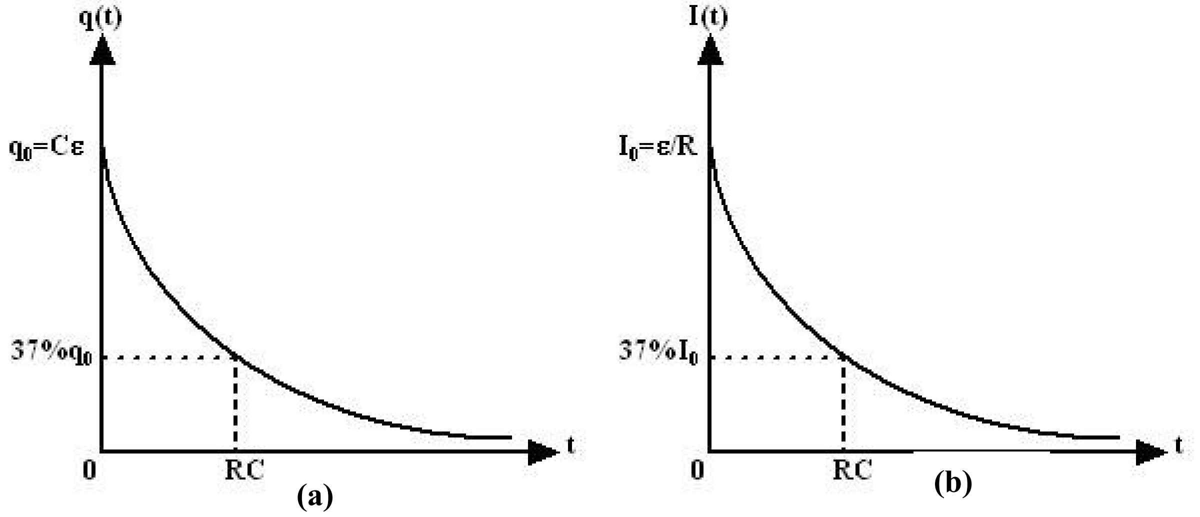

Figure 5.4 Change of **a)** charge and **b)** current with time during discharging process in the RC circuit.

It is seen that the load and current on the capacitor decreases exponentially with the speed indicated by the time constant.

Additional information:

Parallel connected two capacitors for equivalent capacitance: $C_{eq} = C_1 + C_2$

Serial connected two capacitors for equivalent capacitance: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$

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DATE :

GROUP ID :

Student ID	Name Surname	Signature

Experiment Expectation	

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CALCULATIONS AND RESULTS:

1. Make the circuit shown in Figure 5-5. If the capacitor you are using is a polar capacitor, please note that the positive terminal must be connected to the positive end of the power supply and the negative terminal to the negative end of the power supply. Set the voltage at the output of the power supply to 5 volts by holding the S switch in the neutral state.

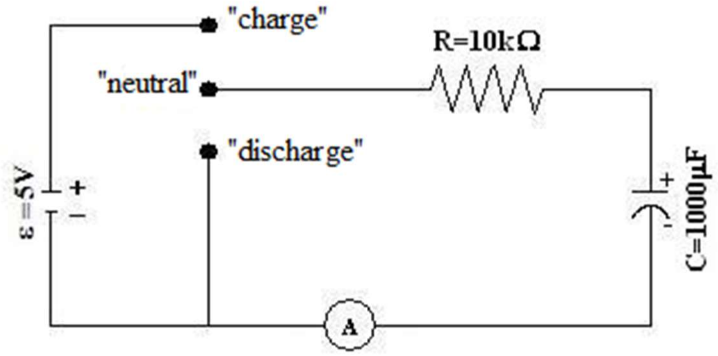

Figure 5.5 RC circuit

2. Make sure that the capacitor load is zero and turn switch S to the “charging” position. At the same time, start the chronometer and record the current you have read every 2 seconds with an ammeter and write to the table below.

Table 5.1 Current measured during the loading of capacitor.

t(s)	I (mA)	t(s)	I (mA)	t(s)	I (mA)
0		38		76	
2		40		78	
4		42		80	
6		44		82	
8		46		84	
10		48		86	
12		50		88	
14		52		90	
16		54		92	
18		56		94	
20		58		96	
22		60		98	
24		62		100	
26		64		102	
28		66		104	
30		68		106	
32		70		108	
34		72		110	
36		74		112	

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3. After the capacitor has been fully loaded (there is no current passing through the load circuit), turn the S switch to the "discharging" position. At the same time, start the stopwatch and record the current data you read every 2 seconds from ammeter to Table 5.2.

Table 5.2 Current data measured during capacitor discharging

t(s)	I (mA)	t(s)	I (mA)	t(s)	I (mA)
0		38		76	
2		40		78	
4		42		80	
6		44		82	
8		46		84	
10		48		86	
12		50		88	
14		52		90	
16		54		92	
18		56		94	
20		58		96	
22		60		98	
24		62		100	
26		64		102	
28		66		104	
30		68		106	
32		70		108	
34		72		110	
36		74		112	

4. Plot the graph of current versus time for "Charge" and "Discharge" using Table 5.1 and 5.2.
5. Use the graphs you plot to determine the time constant taken for the current to decrease to 37% of the initial value and show it on the graph. Theoretically calculate the time constant (τ) and compare them with the values you find using the graphs for charge and discharge.

	τ (s)
Experimental value for charging circuit	
Experimental value for discharging circuit	
Theoretical value	

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6. Calculate the quantity of charge stored in the capacitor:

q(t)	
q(t→∞)	

7. Repeat steps 1, 2 and 4 for the circuit in Figure 5-6 in which R=20 kΩ and note the data.

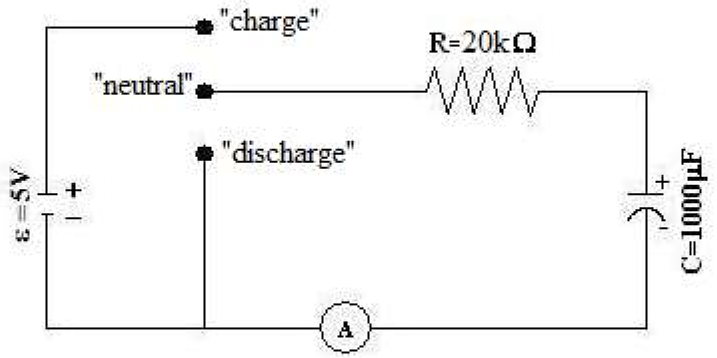

Figure 5.6 RC circuit with different resistor

Table 5.3 Current data measured during capacitor **loading**

t(s)	I (mA)	t(s)	I (mA)	t(s)	I (mA)	t(s)	I (mA)
0		38		76		114	
2		40		78		116	
4		42		80		118	
6		44		82		120	
8		46		84		122	
10		48		86		124	
12		50		88		126	
14		52		90		128	
16		54		92		130	
18		56		94		132	
20		58		96		134	
22		60		98		136	
24		62		100		138	
26		64		102		140	
28		66		104		142	
30		68		106		144	
32		70		108		146	
34		72		110		148	
36		74		112		150	

8. Make the following calculations using the loading data and note the results.

τ (s) (Experimental value for charging circuit)	
τ (s) (Theoretical value)	
q(t)	
q(t→∞)	

9. Repeat steps 1,3 and 4 for the circuit in Figure 5.7 and note the data.

Table 5.4 Current data measured during capacitor **discharging**

t(s)	I (mA)	t(s)	I (mA)	t(s)	I (mA)	t(s)	I (mA)
0		38		76		114	
2		40		78		116	
4		42		80		118	
6		44		82		120	
8		46		84		122	
10		48		86		124	
12		50		88		126	
14		52		90		128	
16		54		92		130	
18		56		94		132	
20		58		96		134	
22		60		98		136	
24		62		100		138	
26		64		102		140	
28		66		104		142	
30		68		106		144	
32		70		108		146	
34		72		110		148	
36		74		112		150	

10. Make the following calculations using the loading data and note the results.

τ (s) (Experimental value for discharging circuit)	
τ (s) (Theoretical value)	
q(t→∞)	

DISCUSSION AND COMMENTS:

1) Discuss how the change of resistance varies the time constant and how it varies the charging or discharging time.

2) Discuss how the change of capacitance varies the time constant and how it varies the charging or discharging time.