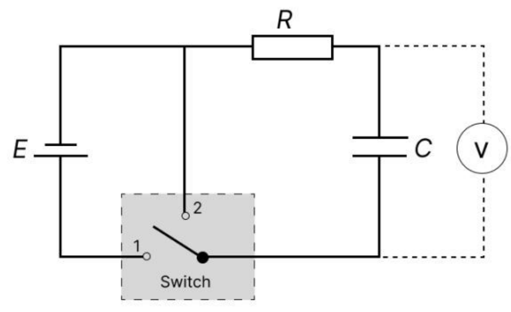
Charging and Discharging of a Capacitor

1.0 February 2024



Dr. Bouafia Saber | Faculty of Technology | University of M'sila

Table of contents

Objectives

Capacitors are crucial components in many electrical and electronic circuits. Their core functionality revolves around storing and releasing electrical energy. This process is often referred to as ‘charging’ and ‘discharging’.

Understanding this fundamental concept can provide a solid foundation for grasping more complex electronic concepts.

The objective of this experiment is to study the charging and discharging of a capacitor by measuring the potential difference (voltage) across the capacitor as a function of time.

I pre-requests

Objectives

Before students engage in practical work on the charging and discharging of a capacitor, it's important they have a foundational understanding of relevant concepts. Here are three pre-requests or prior knowledge requirements:

- Basic understanding of electricity and circuits: Students should be familiar with the fundamentals of electric circuits, including concepts such as voltage, current, resistance, and Ohm's law.
- Knowledge of capacitors: Students should have a basic understanding of capacitors, including their construction, capacitance, and behavior in circuits.
- Understanding of RC circuits: Students should comprehend the behavior of RC (resistor-capacitor) circuits, particularly in relation to charging and discharging processes.

II Concepts and preparation work

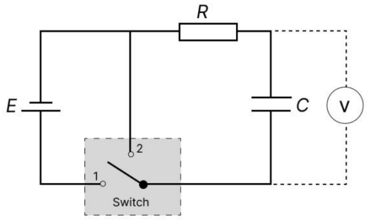
1. Charging a capacitor

1.1. Introduction

As given in the circuit of Figure 1, initially, the capacitor is discharged. We supply the circuit by turning the Switch to position 1.

The capacitor begins to charge. By applying Kirchhoff's law we found:

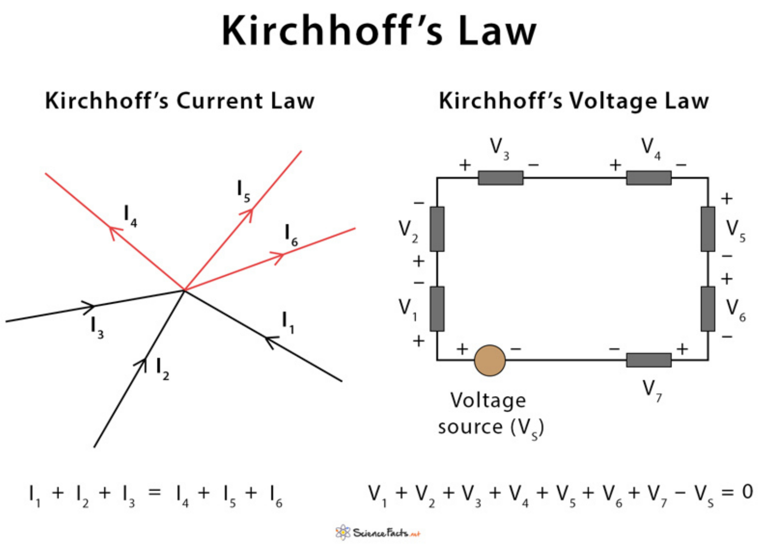
$$\sum_i U = 0 \implies E = Ri + \frac{1}{c}\int idt$$



1.2. Kirchhoff's law

Kirchhoff's law Az Definition

"The sum of the voltages in a circuit is zero"



1.3. Voltage across the capacitor

voltage across the capacitor

The charge "Q" of the capacitor is related to the potential difference by the following relation:

$$dQ = CdU_c$$

and the current *i* to the quantity of electricity (or charge) is given by the relation

$$i = \frac{dQ}{dt}$$

The first relationship can be written as a function of the output voltage “Uc" as follows

$$E = RC\frac{U_c}{dt} + U_c \Rightarrow \frac{R}{RC} = \frac{dU_c}{dt} + \frac{U_c}{RC}$$

Under the following initial conditions, t = 0; Uc = 0, the voltage across the capacitor is the solution to the above differential equation, and is written in the form:

$$U_c(t) = E(1 - e^{-t/RC})$$

and the current of the capacitor is

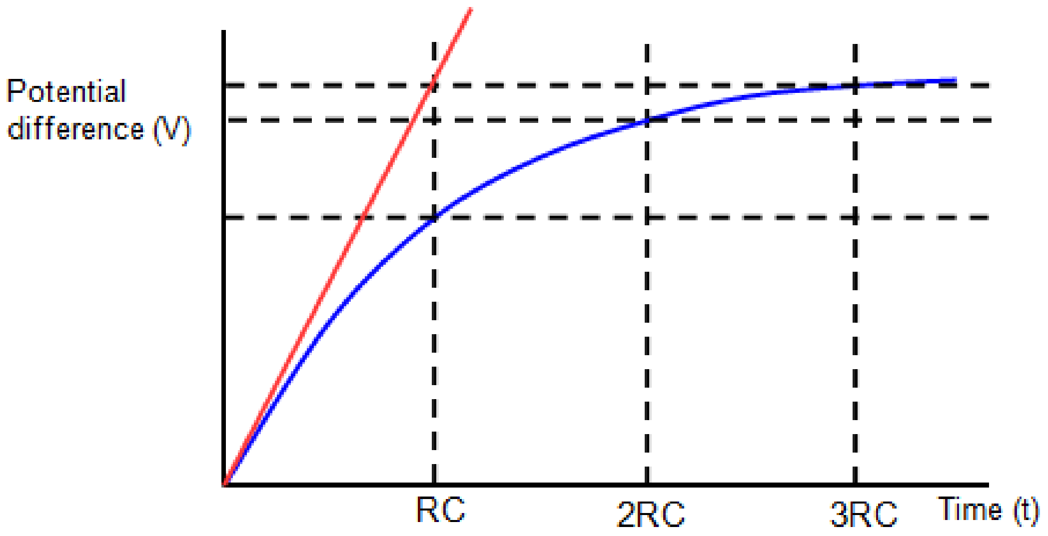
$$i(t) = \frac{E}{R}e^{-t/RC}$$

1.4. Curve of Uc = f(t)

Plot the curve of Uc = f(t)

Simulation

Plot the curve of Uc: = f(t) and the tangent to the curve for the coordinates of the origin during charging phase

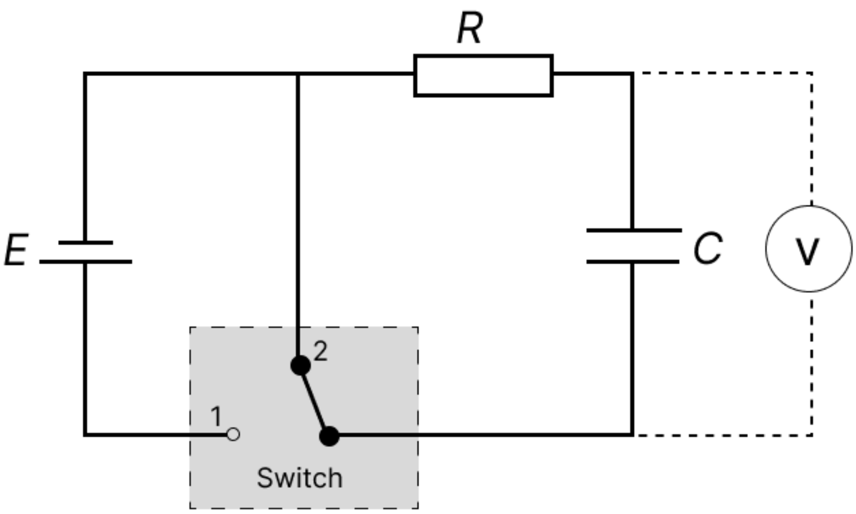


Uc =f(t) during charging phase

2. Discharging a capacitor

2.1. Introduction

The capacitor being charged, disconnects the voltage source by turning the Switch to position 2 to leave the discharge to take place through the resistance R.



Uc =f(t) during charging phase

2.2. Voltage across the capacitor

voltage across the capacitor

In the initial condition; (t = 0 ; Uc = E) that the voltage across the capacitor is the solution to the above differential equation (E = 0), and is written in the form:

$$U_c(t) = E.\, e^{-t(RC)}$$

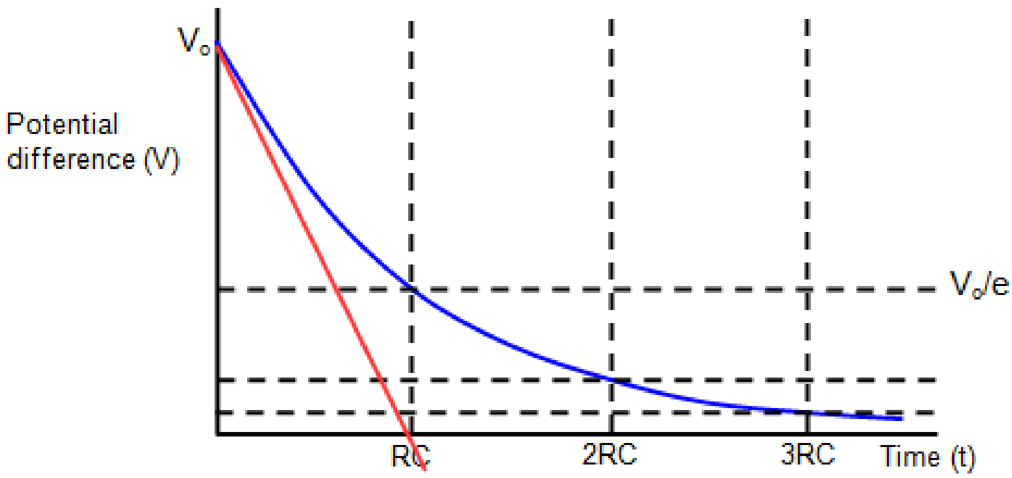
and the current of the capacitor is

$$i(t) = -\frac{E}{R} e^{-t/RC}$$

2.3. Curve of Uc = f(t)

Plot the curve of Uc = f(t) Simulation

Plot the curve of Uc: = f(t) and the tangent to the curve for the coordinates of the origin during discharging phase



Uc =f(t) during discharging phase

3. Additional resources

3.1. Learn more

To learn more about oscilloscopes you find here some videos explaining this device in depth :

(see Physics Core Practical: Capacitor Discharge[watch])
(see Capacitor charging and discharging[watch])

III Pracical work

1. Charging a capacitor

⚠ Warning

Before connecting the capacitor make sure it's discharged by short-circuiting it.

Perform the setup in Figure 1 and turn the switch to position 1. The resistance is equal to 3.8MΩ and a capacitor with a capacity of C=2μF

starts counting time with a stopwatch simultaneously with powering the circuits with a *DC* p.16 voltage source E=8V.

Note

Read the voltage of the capacitor terminal each 5 Seconds and record the values in the following table

$t(s)$	00	05	10	15	20	25	30	35	40	45	50	55
$U_c(V)$	0	1.35	2.1	2.92	3.8	4.50	5.01	5.40	5.85	6.1	6.1	6.1

1.1. Required work

a- On graph paper, plot the voltage Uc= f(t)

b- Determine the time constant, τ = RC; the abscissa of the point of intersection of this tangent with the limit voltage of the load

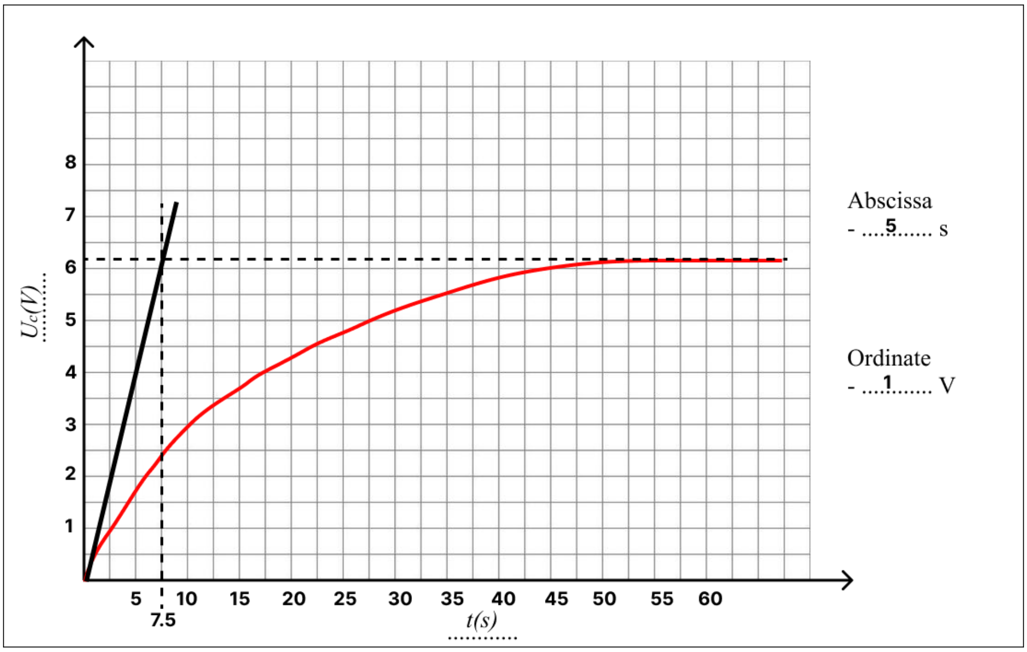
c- From the time constant ensure the value of C.

Method

Plot the tangent to the origin point and determine the time constant

Simulation

In this graph we found τ is 7.5s which is close to the calculated one τ = RC = 7.5s



2. Discharging a capacitor

⚠ Warning

Before connecting the capacitor make sure it's discharged by short-circuiting it.

To discharge the capacitor, disconnect the voltage source by turning the switch to position 2, and start counting time with a stopwatch simultaneously with disconnecting the voltage source. the capacitor discharges over time through the resistance R,

Note

Read the voltage of the capacitor terminal each 5 seconds and record the values in the following table.

$t(s)$	00	05	10	15	20	25	30	35	40	45	50
$U_c(V)$	0	3.85	2.92	2.00	1.52	1.12	0.62	0.28	0.1	0.02	0.02

2.1. Required work

a- On graph paper, plot the voltage Uc= f(t)

b- Determine the time constant, τ = RC; the abscissa of the point of intersection of this tangent with the limit voltage of the load

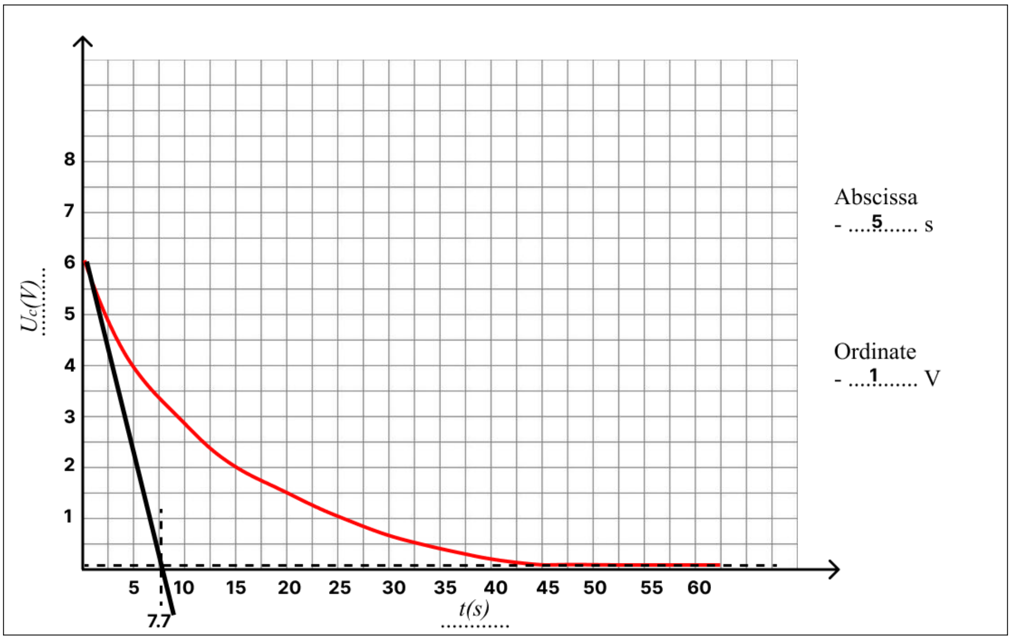
c- From the time constant ensure the value of C.

Method

Plot the tangent to the origin point and determine the time constant

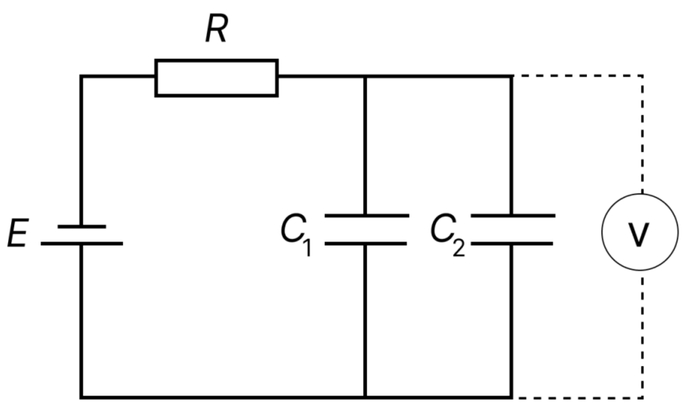
Simulation

In this graph we found τ is 7.5s which is close to the calculated one τ = RC = 7.2s



3. Combination of capacitors in parallel

Wire the circuit as shown in the following figure 2. for a resistance R = 3.8MΩ . and two capacitors of C1 =2 μF and C2=1 μF.



Note

Start counting the time using a stopwatch simultaneously when powering the circuit with a *DC* p.16 voltage source E =8V.

Read the voltage at the capacitor terminals every 05 seconds and record the values in the following table

t(s)	00	05	10	15	20	25	30	35	40	45	50	55
Uc(V)	0	1.5	2.7	3.3	3.7	4.25	4.8	5.20	5.62	6.02	6.10	6.10

Method

a- On graph paper, plot the voltage Uc= f(t)

b- Plot the tangent to the origin point and determine the time constant, τ = RC; the abscissa of the point of intersection of this tangent with the limit voltage of the load.

c- From the time constant ensure the value of C.

d- Compare this value to the equivalent one of two capacitors in parallel

3.1. Capacitors in parallel

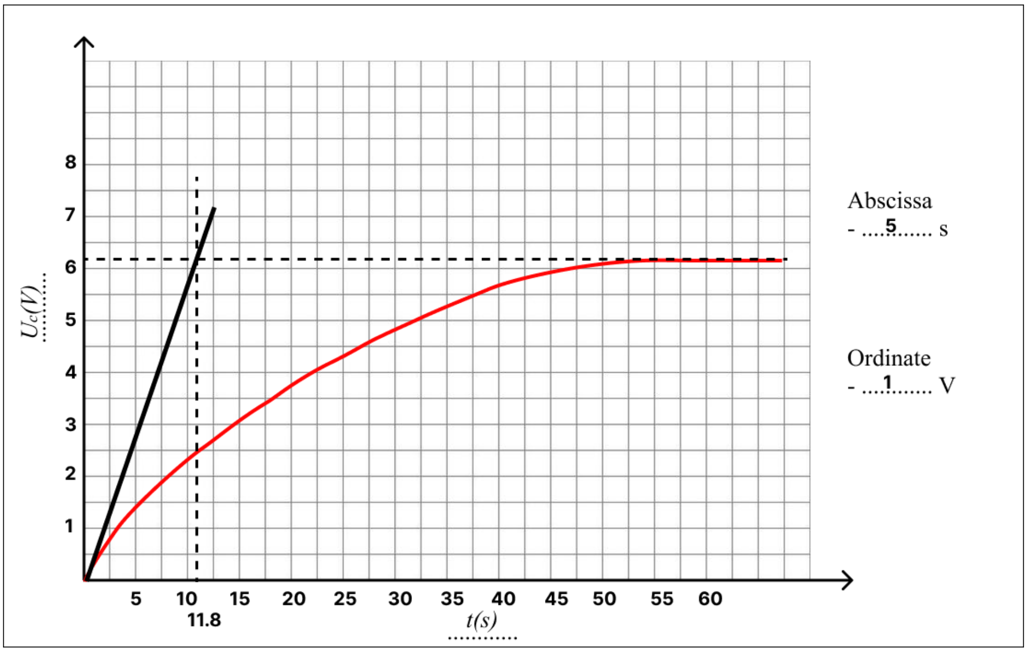
The equivalent one of two capacitors in parallel is given by

$$C_{eq} = C_1 + C_2$$

Compare this value to the equivalent one of two capacitors in parallel

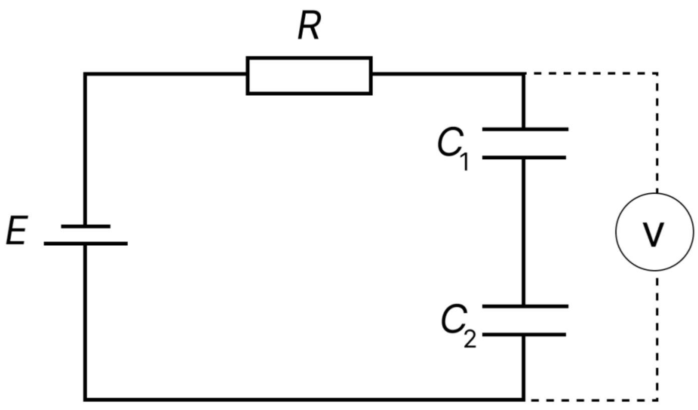
Extra

In this graph we found τ is 11.8s which is close to the calculated one τ = RC = 11.4s



4. Combination of capacitors in series

Wire the circuit as shown in the following figure. for a resistance R = 3.8MΩ . and two capacitors of C1 =6 μF and C2=3 μF



Note

Start counting the time using a stopwatch simultaneously when powering the circuit with a DC voltage source E =8V.

Read the voltage across the capacitor each 05 seconds and record the values in the following table

t(s)	00	05	10	15	20	25	30	35	40	45	50	55
Uc(V)	0	2.6	4.10	4.80	5.42	5.70	6.01	6.1	6.1	6.1	6.1	6.10

Method

a- On graph paper, plot the voltage Uc= f(t)

b- Plot the tangent to the origin point and determine the time constant, τ = RC; the abscissa of the point of intersection of this tangent with the load limit voltage

c- From the time constant ensure the value of C.

4.1. Capacitors in Series

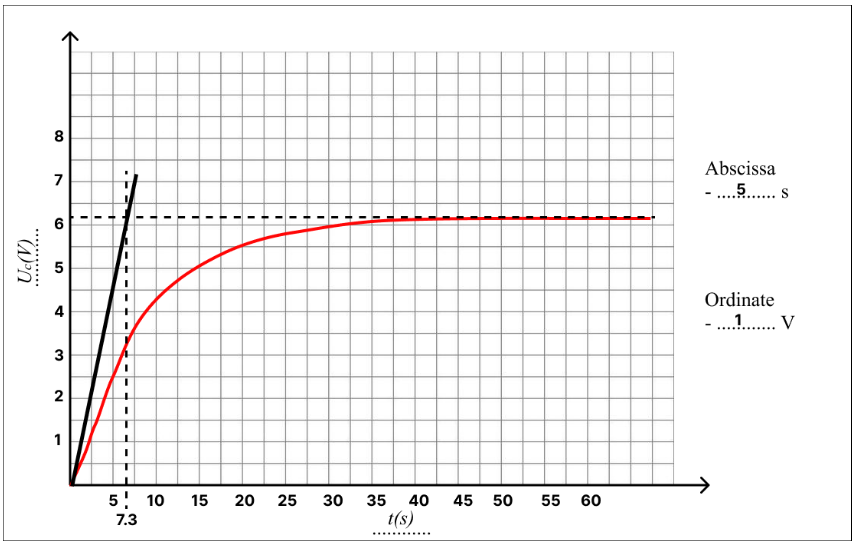
The equivalent one of two capacitors in Series is given by

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

Compare this value to the equivalent one of two capacitors in Series

⊕ Extra

In this graph we found τ is 11.8s which is close to the calculated one τ = RC = 11.4s



Conclusion

In this experiment, we study of charging and discharging of a capacitor by measuring the potential difference (voltage) across the capacitor as a function of time. we also measured the experimental time constant and used it to determine the experimental value of the capacitance of the capacitor. both on series and parallel combinations

Abbreviation

DC : Direct Current

References

[1] K.A. Navas Electronics Lab Manual.

[2] Xinru Li, Laboratory Manual For Basic Physics.