Experiment 3: RC Circuits **Date: 22.03.2004**

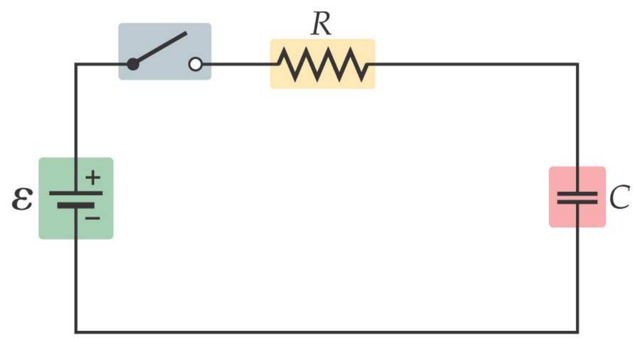
OBJECTIVE: 1. To investigate variation of the voltage across a capacitor as it charges up.

2. To determine the capacitive time constant.

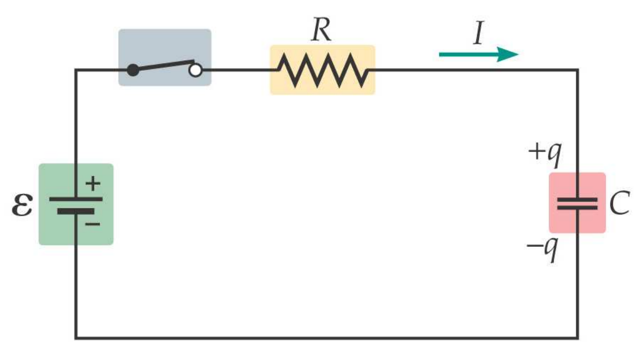
THEORY:

RC CIRCUIT

An RC circuit is a circuit consisting of a resistor and a capacitor connected in series to a cell or battery as shown in a. When switch S is closed as shown in b current will start to flow through the circuit. Electrons from the negative terminal of the battery will accumulate on the lower plate of the capacitor. This process is called charging a capacitor through a resistance



(a) $t < 0$



(b) $t > 0$

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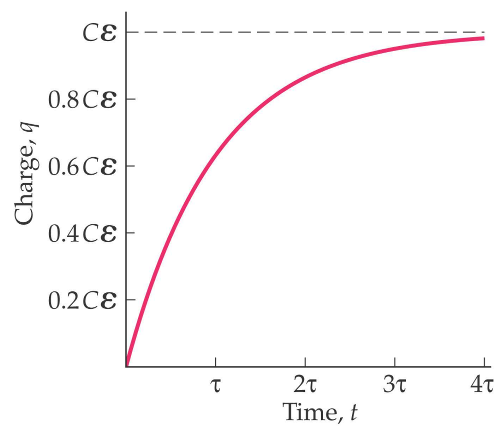
Electrons from the upper plate of the capacitor will flow into the positive terminal, leaving a positive charge on the upper plate. As charge accumulates on the capacitor, the potential difference across it increases, and the current is reduced until the voltage across the capacitor equals the voltage of the battery. No more current will flow. The diagram below shows the evolution with time of the voltage across a charging capacitor. The charging is an exponential function of time. The voltage across the capacitor is therefore given by the exponential relation

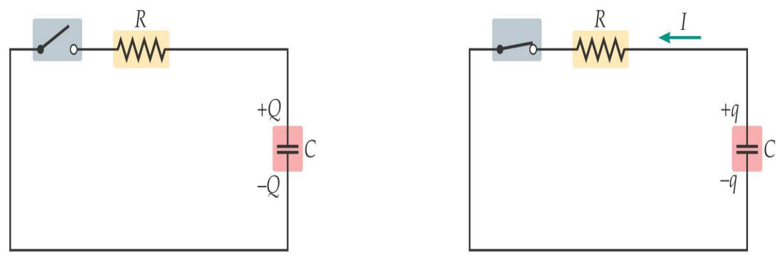
$$V = \quad (1 - e^{-t/RC})$$

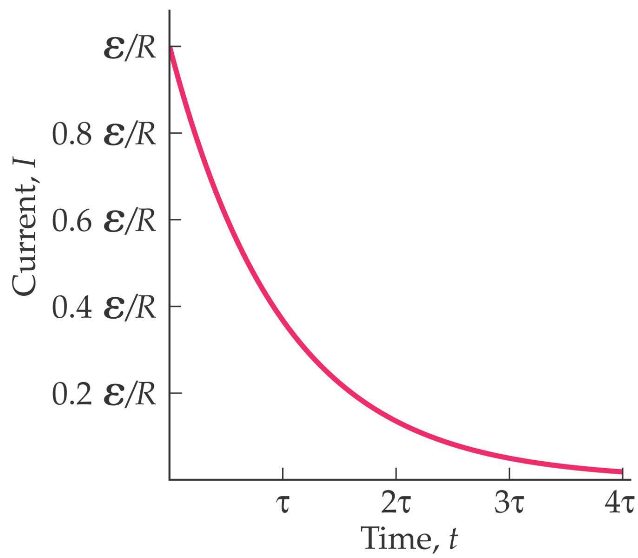


When switch S is closed as shown in (b) , current will start to flow through the circuit. Electrons from the negative plate of the capacitor will flow to the +ve plate and neutralize the positive charges on the lower plate of the capacitor. This process is called discharging a capacitor through a resistance.

The charges flow from the –ve to the +ve plate until the capacitor is fully discharged. The voltage across the capacitor decreases with time as shown in the graph and given by

$$V = V_0 \, e^{-t/RC}$$





When a DC voltage source is connected across an uncharged capacitor, the rate at which the capacitor charges up decreases as time passes. At first, the capacitor is easy to charge because there is very little charge on the plates. But as charge accumulates on the plates, the voltage source must "do more work" to move additional charges onto the plates because the plates already have charge of the same sign on them. As a result, the capacitor charges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully charged. The charge on the plates at any time is given by:

$$\mathbf{q} = \mathbf{q}_o\left(1 - e^{-t/\tau}\right)$$

where $\mathbf{q_o}$ is the maximum charge on the plates and τ is the capacitive time constant (τ = RC, where R is resistance and C is capacitance). NOTE: The stated value of a capacitor may vary by as much as ±20% from the actual value. Taking the extreme limits, notice that when t = 0, q = 0 which means there is not any charge on the plates initially. Also notice that when t goes to infinity, q goes to q_o which means it takes an infinite amount of time to completely charge the capacitor.

The time it takes to charge the capacitor to half full is called the half-life and is related to the capacitive time constant in the following way:

$$t_{1/2} = \tau \ln 2$$

In this activity the charge on the capacitor will be measured indirectly by measuring the voltage across the capacitor since these two values are proportional to each other: q = CV.

APPARATUS:

1. Computer and Science workshop interface.
2. Voltage sensor.
3. AC/DC Electronics Lab Board, 100Ω resistor, 330 μF capacitors, wire leads.
4. Banana plug patch cords.
5. Power Amplifier.

Procedure

1. A 100-ohm (Ω) resistor (brown, black, brown) is placed in the pair of component springs nearest to the top banana jack at the lower right corner of the AC/DC Electronics Lab Board.
2. A 330 microfarad (μF) capacitor is connected between the component spring on the left end of the 100-Ω resistor and the component spring closest to the bottom banana jack.

3. An alligator clips is put on the Voltage Sensor banana plugs. The alligator clips are connected to the wires at both ends of the 330 μF capacitor.

4. A banana plug patch cords is connected from the 'OUTPUT' ports of the interface to the banana jacks on the AC/DC Electronics Lab Board.

DATA REOCRDING

1. The process of measuring the data is started. The Signal Generator output automatically starts when data recording begins.

2. Data recording continues for four seconds and stop automatically.

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Result

DATA

Beginning time = 2.370 s

Time to 2.00 V = 3.955 s

Time to half-max ($t_{1/2}$) = 0.0255 s

$\mathbf{t}_{1/2} = \tau \ln 2$ = 0.693 RC is used to calculate the capacitance (C) of the capacitor. Thus we have:

Capacitance = 3.68×10^{-4} Farad

Calculation

$\mathbf{t_{1/2} = 0.0255\ s}$

Resistance = 100Ω

By substituting the value in the equation $t_{1/2} = \tau \ln 2 = 0.693\ RC$ we have:

$$0.0255 = 0.693(100)\ C$$

$$0.0255 = 69.3\ C$$

$$C = \frac{0.0255}{69.3}$$

$$= \underline{3.68 \times 10^{-4}}$$

The percentage of errors can be calculated by substituting the value from the equation

$$\text{Percentage of errors} = \frac{|\text{theory value} - \text{experiment value}|}{\text{Theoretical value}} \times 100\%$$

$$= \frac{|0.00033 - 0.000368|}{0.00033} \times 100\%$$

$$= \underline{0.115\ \%}$$

Discussion

Through the experiment, we are able to calculate the value of the capacitor which is recoded in the unit SI Farad (F). The capacitance is calculated by using the formulae

$\mathbf{t}_{1/2} = \tau \ln 2$ whereby $\mathbf{t}_{1/2}$ is the time it takes to charge the capacitor to half full. In this activity the charge on the capacitor is measured indirectly by measuring the voltage across the capacitor since these two values are proportional to each other: $q = CV$.

Note that there is a little percentage of errors in the experimental value when compare to the theoretical value. This might have been due to random errors. In this experiment, errors can be made in many ways for instance the data is not calculated properly, the wires are not connected properly or even when the value are not calculated accurately. Thus to overcome this, the wires has to be make sure that it is connected properly and the data is calculated to three significant figure to increase the accuracy of the value itself.

Conclusion

The capacitance can be calculated from the equation $\mathbf{t}_{1/2} = \tau \ln 2$.