Physics Department | EXP. TEN
Kuwait University | Course 127

February, 2001

RC-Circuit

Objective

- To study the charging and discharging of a capacitor.
- To determine the capacitance of an unknown capacitor.

Theory

Charging

Consider a single loop circuit as shown in Fig. 1. By closing the switch, *S*, a current, *i*, is setup in the loop. Applying the loop theorem, we get

$$\varepsilon - iR - \frac{Q}{C} = 0\,, \tag{1}$$

where, ε is the electromotive force, *R* is the resistor, *Q* is the charge of the capacitor, and *C* is the capacitance. Substituting *dQ/dt* for the current *i*, gives

$$\varepsilon - \frac{dQ}{dt}R - \frac{Q}{C} = 0\,. \tag{2}$$

Rearranging the terms, Eq.(2) becomes

$$\frac{dQ}{dt} = \frac{\varepsilon}{R} - \frac{Q}{RC}\,. \tag{3}$$

The solution of Eq.(3) is given as

$$Q = C\varepsilon(1 - e^{-t/RC})\,, \tag{4}$$

which, determines the charge on the capacitor at a given time, *t*.

Since the voltage across the capacitor, V_c, is given as

$$V_c = \frac{Q}{C}, \tag{5}$$

dividing Eq.(4) by *C* yields

$$V_c = \varepsilon(1 - e^{-t/RC})\,. \tag{6}$$

At a specific value of time, $\tau = RC$ (called the time constant of the RC circuit),

$$V_c = \varepsilon(1 - e^{-1})\,, \tag{7}$$

or, $$V_c=0.63\varepsilon \ . \tag{8}$$

Therefore, by plotting V_c versus t, the time constant, τ, can be determined, and hence, the value of C, if R is known.

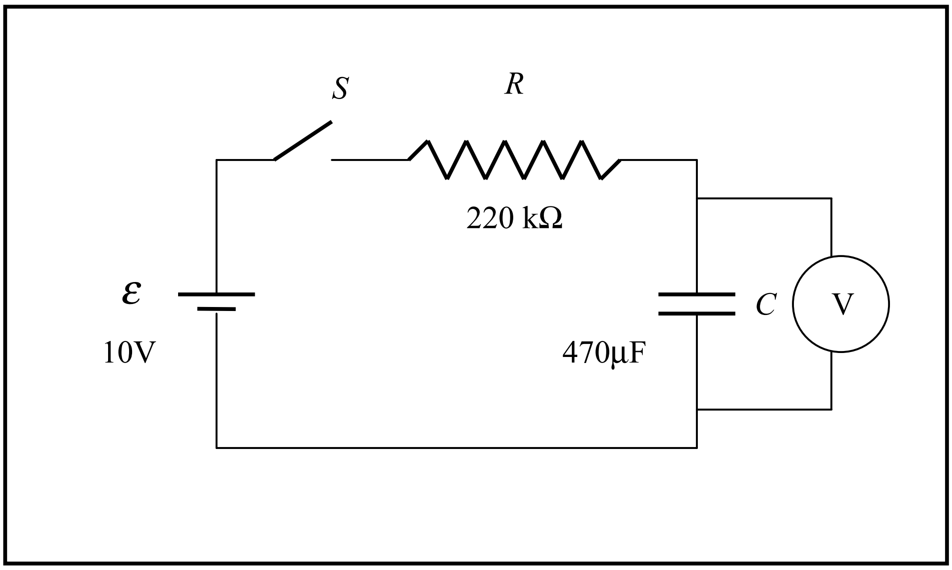

Figure 1: Charging circuit

Discharging

For the discharging process, consider the circuit shown in Fig. 2. When the switch, S, is closed, the capacitor is charged up to a value of $Q=C\varepsilon$. As the switch is opened, the electromotive force is disconnected from the circuit, and the capacitor starts to discharge through the resistor.

Following the same procedure as for the charging analysis, the differential equation that characterizes the discharging process, is given as

$$-\frac{dQ}{dt}R-\frac{Q}{C}=0\,. \tag{9}$$

The solution to Eq.(9) is given as

$$Q=C\varepsilon e^{-t/RC}\,. \tag{10}$$

Equation (10), determines the charge on the capacitor at a given time t.

The voltage across the capacitor, V_c, is derived to be

$$V_c=\varepsilon e^{-t/RC}\ . \tag{11}$$

At $\tau = RC$,

$$V_c = \varepsilon e^{-1}, \qquad (12)$$

or,

$$V_c = 0.37\varepsilon . \qquad (13)$$

Therefore, by plotting V_c versus t, the time constant, τ, can be determined, and hence, the value of C, if R is known.

Using Eq.(11), we can write

$$\ln V_c = \ln \varepsilon - \frac{t}{RC} \ . \qquad (14)$$

Equation (14) represents a straight line, where the y-intercept represents $\ln\varepsilon$ is, and the slope represents $-1/RC$.

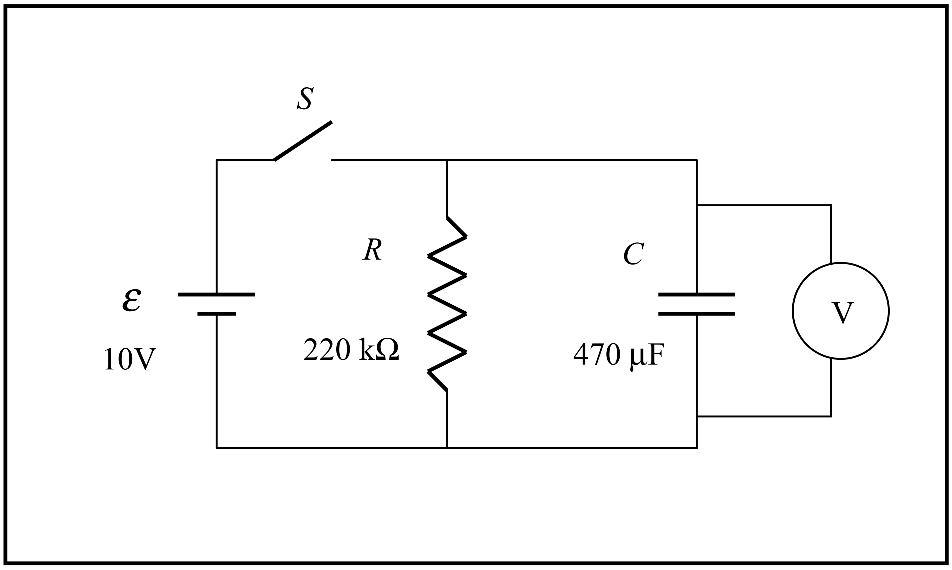

Figure 2: discharging circuit

Equipment

- Electronic design experimenter (Heathkit).
- 220 KΩ resistor.
- 470 μF capacitor.
- Voltmeter.
- Stopwatch.

Procedure

Part 1: (*charging*)

1. Connect the circuit as shown in Fig. 1 (make sure that the lead of the capacitor at the arrow head side, is connected to the ground).
2. Turn on the power supply. Set the output of the power supply to 10 V.
3. Short out the capacitor, temporarily, by connecting a wire parallel to it (so that the capacitor is completely discharged).
4. Close the switch, *S*, and reset the stopwatch.
5. Simultaneously, remove the shorting wire, and start the stopwatch.
6. The capacitor will start charging up, and the voltage across the capacitor, V_c, will increase correspondingly.
7. Corresponding to integer values of V_c , from (1-8) V by 1 V increments, stop the stopwatch, temporarily, record the time, *t*, in Table I under t_1 heading, and restart the stopwatch.
8. Stop the stopwatch.
9. Repeat steps 3-8. Record the measured time under t_2.
10. Calculate the average time, t_{avg}.
11. Plot a graph for V_c versus t_{avg}, from which, determine τ, and calculate *C*.

Part 2: (*discharging*)

1. Connect the circuit as shown in Fig. 2 (make sure that the lead of the capacitor at the arrow head side, is connected to the ground).
2. Turn on the power supply, and set the voltage to10 V.
3. Close the switch, *S*. This will cause the capacitor to charge up immediately.
4. Start the stopwatch and open the switch, *S*, simultaneously.
5. The capacitor will start discharging through the resistor, *R*, and the voltage across the capacitor, V_c, will decrease correspondingly.
6. Corresponding to integer values of V_c, according to Table II, stop the stopwatch, temporarily, record the time, *t*, in Table II under t_1 heading, and restart the stopwatch
7. Stop the stopwatch.
8. Repeat steps 3-7. Record the measured time under t_2.
9. Calculate the average time, t_{avg}.
10. Determine $\ln V_c$ for all the values, using a calculator.

11. Plot V_c versus t_{avg} on the same graph of part one, from which, determine τ, and calculate C.
12. Plot another graph for $\ln V_c$ versus t_{avg}, from which, determine ε and C.
13. Calculate the average value of C, using the values obtained from parts one & two.

Table I: (*charging*)

V_c (V)	t_1 (sec)	t_2 (sec)	t_{avg} (sec)
0			
1			
2			
3			
4			
5			
6			
7			
8			

Table II: (*discharging*)

V_c (V)	t_1 (sec)	t_2 (sec)	t_{avg} (sec)	$\ln V_c$
10				
9				
8				
7				
6				
5				
4				
3				
2				

Questions

1. Why is it recommended to short out the capacitor before starting the charging process?
2. If you use larger value for *R*, would that increase the charging time, or decrease it? What about using larger *C*?
3. Using Eq.(10), derive the formula that gives the value of the current, *i*, at any time.
4. Compare the average value of *C*, with the printed one. If they differ, explain the reason.