3-2022

Experiment 2.06: Series RC dc-Circuit

Diego Castano

Victor Castro

I. EXPERIMENT 2.06: SERIES RC DC-CIRCUIT

A. Abstract

The voltage rise of a charging capacitor in an RC-circuit is monitored and the measurements are used to determine its capacitance.

B. Formulas

$$\Delta v_C(t) = \mathcal{E}\left(1 - e^{-t/\tau}\right) \tag{1}$$

$$i(t) = \frac{\mathcal{E}}{R} e^{-t/\tau} \tag{2}$$

$$\tau = RC \tag{3}$$

These are relevant during the charging process of a capacitor in series with a resistor.

C. Description and Background

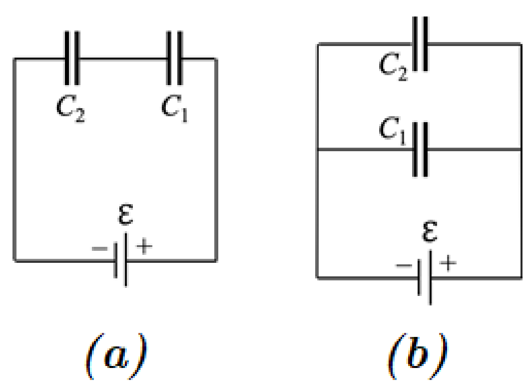

FIG. 1. (a) Capacitors in series and (b) parallel.

Capacitors are found in many electric circuits. Capacitors can be connected together in various ways. As with resistors, two common ways are in series, or in parallel (Fig. 1). Combining two capacitors in series have an equivalent capacitance of

$$\frac{1}{C_{\text{series eq.}}} = \frac{1}{C_1} + \frac{1}{C_2} \tag{4}$$

While two capacitors in parallel have an equivalent capacitance of

$$C_{\text{parallel eq.}} = C_1 + C_2 \tag{5}$$

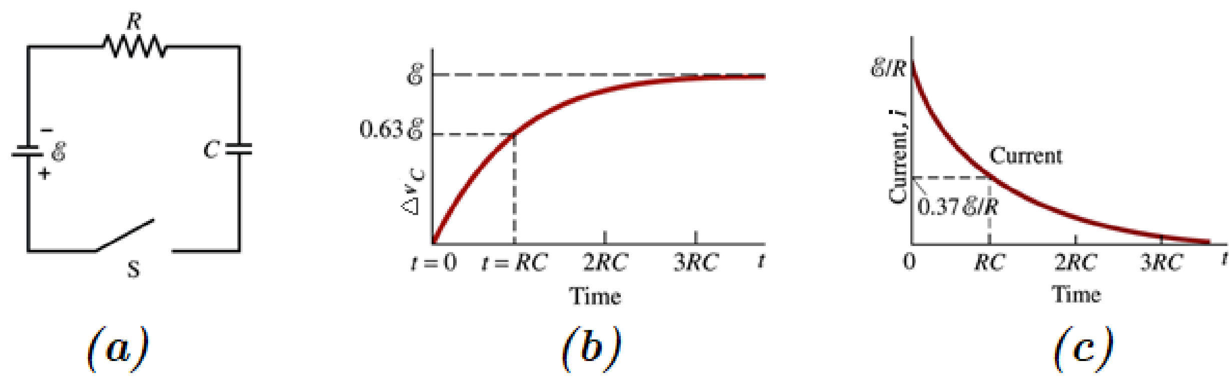

FIG. 2. (a) Simple RC-circuit. (b) The potential difference (Δv_C) increases with time until it reaches a value of $\mathcal{E}$. (c) The current decreases with time until it reaches a value of zero.

In RC circuits, we are not so interested in the final "steady state" voltage and charge on the capacitor, but rather in how these variables change with time. The RC circuit in Fig. 2a shows a capacitor (C) charged by a battery ($\mathcal{E}$) through a resistance (R). When the switch S is closed, the current immediately begins to flow through the circuit. As charge accumulates on the capacitor, the potential difference across it (Δv_C) increases (Fig. 2b), and the current is reduced (Fig. 2c) until eventually the voltage across the capacitor equals $\mathcal{E}$. At that point, there is then no potential difference across the resistor ($\Delta v_R = 0$), and no further current flows ($i = 0$). The mathematical form of this behavior is given by Eqs. (1) and (2). The paramenter, τ, is known as the time constant.

In this experiment, you will build the electric circuits in Fig. 3 and will measure the the voltage between points a and b. Finally, you will find the capacitance of each circuit and compare it to the theoretical value.

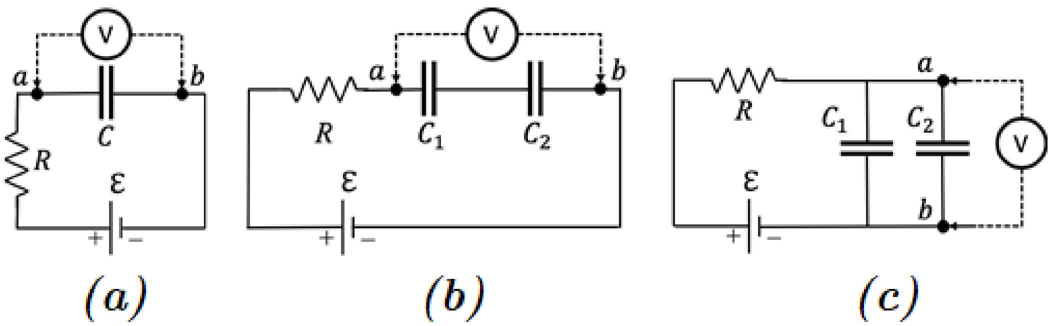

FIG. 3. Voltmeter placement in the case of (a) a single capacitor, (b) two capacitors in series, and (c) two capacitors in parallel.

D. Procedure

1. Measure and record the emf of the battery.

2. A large resistance resistor (*e.g.,* $100,000\ \Omega$) should be used in this experiment. Measure (with the ohmmeter) and record the resistance of the resistor. See Appendix I at the end of this document for important instructions on the use of multimeters.

3. Record the color equivalent reisitance of the resistor and printed capacitances of the capacitors.

4. Connect the battery, resistor, and a capacitor in series but do not complete the circuit until you are ready to monitor the voltage across the capacitor and the time.

5. Connect a voltmeter across the ends of the capacitor in the circuit. If there is a non-zero reading, then discharge the capacitor by contacting the ends of the capacitor with the ends of a patch cord.

6. Calculate the time of measurement (one time constant) based on the rated values of the resistor, R_*, and the capacitor being used, C_*.You can round this to the nearest whole number.

7. Complete the circuit and simultaneously start the timer.

8. When the calculated time is reached, record the voltage.

9. Open the circuit switch. Discharge the capacitor.

10. Repeat the procedure (steps 6-9) with a second capacitor.

11. Repeat the procedure (steps 6-9) with the two capacitors in series. Use Eq. (4) to calculate the equivalent capacitance in series.

12. Repeat the procedure (steps 6-9) with the two capacitors in parallel. Use Eq. (5) to calculate the equivalent capacitance in parallel.

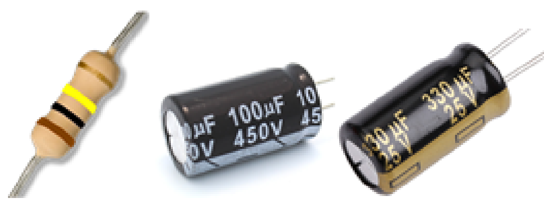

FIG. 4. The capacitors and resistors for this experiment.

1. Figures

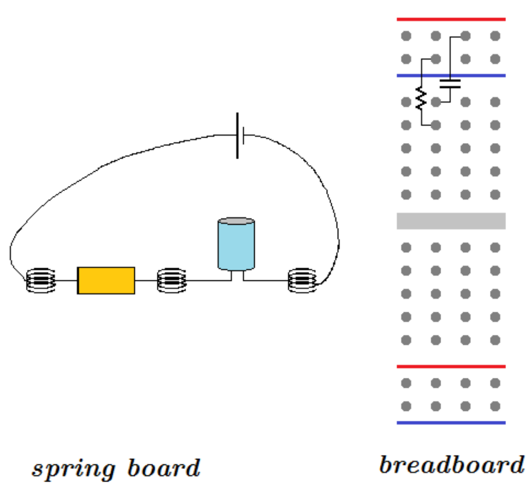

FIG. 5. Single capacitor.

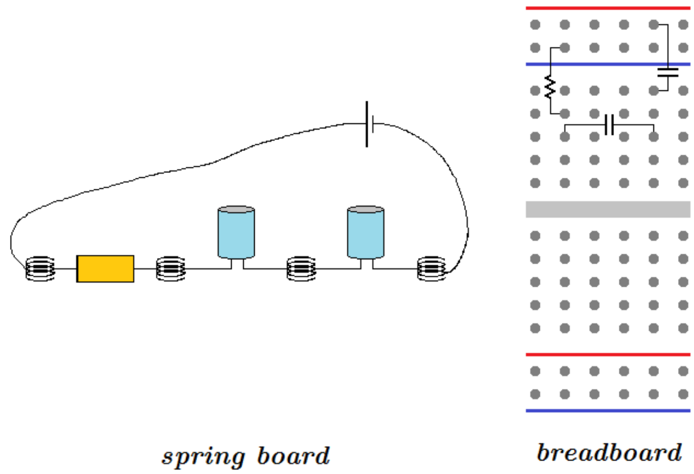

FIG. 6. Capacitors in series.

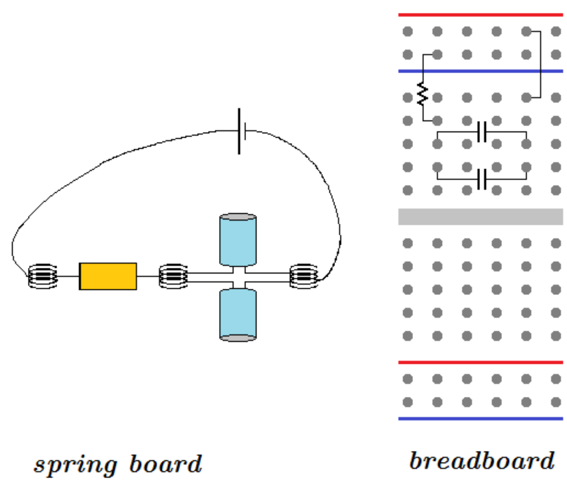

FIG. 7. Capacitors in parallel.

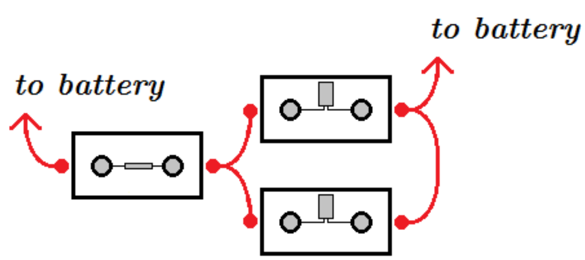

FIG. 8. Parallel capacitors with Di-Binding-Post Blocks

E. Measurements

emf, $\mathcal{E}$ [$Volt$]	
Ohmmeter measurement, R [Ω]	
resistance based on color, R_* [Ω]	

In the following table, C_* is the rated capacitance of the individual capacitor or calculated based on these.

	Capacitor 1	Capacitor 2	in Series	in Parallel
C_* [$\mu Farad$]				
$t_* = R_* C_*$ [sec]				
Trial 1: $\Delta v_C(t_*)$ [$Volt$]				
Trial 2: $\Delta v_C(t_*)$ [$Volt$]				
Trial 3: $\Delta v_C(t_*)$ [$Volt$]				

F. Instructions

1. Calculate the capacitance in each case and for all trials by solving for C using Eqs. (1) and (3).

2. Use the trial values to determine the average capacitance and standard error in each case

3. Calculate the percent diference between the experimental (average) capacitance and the rated value.

G. Calculations

	C_1 [$\mu Farad$]	C_2 [$\mu Farad$]	C_{series} [$\mu Farad$]	C_{parallel} [$\mu Farad$]
Trial 1				
Trial 2				
Trial 3				
$\bar{C}$ [μF]				
$\delta\bar{C}$ [μF]				
%-Diff				

II. APPENDIX I

A. Multimeters

Multimeters are versatile electronic devices that can be used to measure properties such as voltage, current, and resistance. Multimeters typically employ two leads, one of which is always plugged into a socket labelled COM for common. The second lead is plugged into the socket appropriate to the function desired and usually labelled V (Volts) for voltage, mA, μA, or 10A (Amps) for current (depending on the expected range), and Ω (Ohms) for resistance. There is also a dial that turns the multimeter on and must be turned to the appropriate setting. There is a toggle key that will switch from DC to AC mode and a toggle key that can switch the numerical range of measurements.

B. Voltmeters

Voltmeters are nonintrusive to a circuit. The leads are used to probe the voltage between two points in the circuit. When using a voltmeter to measure the voltage across a circuit element, attach the leads (alligator clips) to both ends of the element under consideration.

C. Ammeters

Ammeters, unlike voltmeters, are intrusive to a circuit in that they must be inserted into the circuit segment whose current is to be measured. The circuit segment must therefore be broken and the ammeter placed in series with the other segment elements.

When using the ammeter with the circuit spring board, lift one end of the resistor from the spring it is attached to and bridge the gap with the ammeter leads, *i.e.*, attach one lead to the spring and the other lead to the free end of the resistor.

When using the ammeter with the circuit breadboard, lift the end of the jumper wire depicted in the figures (*e.g.,* those in Experiments 2.02-2.04) by an open circle. Attach one lead to the free end of the jumper wire and the other lead to the exposed wire of the resistor on the same terminal strip (column in the figures).

The circuit should remain open until the ammeter is inserted. Once properly inserted, the ammeter is turned on. The circuit is then closed, and the current measurement taken.

Removal of the ammeter should proceed in reverse: The circuit is opened, then the ammeter is turned off and removed. *Failure to follow this procedure may result in damage to the ammeter.*

D. Ohmmeters

An ohmmeter measures the resistance of whatever is connected between its two leads. Consequently, it is important that only those elements (or arrangement), whose resistance is sought, be positioned between the leads. This may require separating the arrangement of elements from the rest of the circuit to make the proper ohmmeter measurement. Case (a) in the figure below depicts an example of a faulty ohmmeter measurement. The goal is to measure R_1, but this resistor is not the only element between the ohmmeter leads in case (a). The reading in case (a) would actually be $R_1\,(R_2 + R_3)\,/\,(R_1 + R_2 + R_3)$. In case (b) the resistor of interest is separated out and is the only element between the leads.

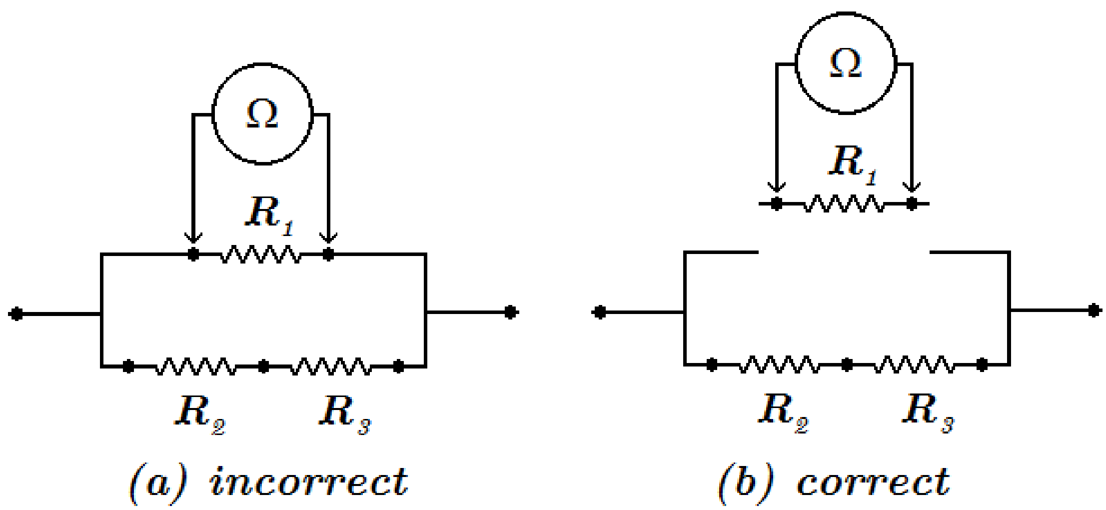

FIG. 9. Example of improper and proper use of ohmmeter.