PHYS143

Physics for Engineers

Lab Report - 3

28th Jan, 2023

Instructor

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Experiment 1

Purpose:

To study the behavior of the time dependent potential difference across a capacitor in a simple RC series circuit.

Hypothesis:

As the capacitor charges, the voltage progressively rises over time. The rate at which the capacitor is charged or discharged is indicated by RC, which is the result of resistance and capacitance.

Materials:

- Power supply
- One 1000μF capacitor
- Resistance box
- Multimeter
- 4 crocodile-banana cables
- Stopwatch

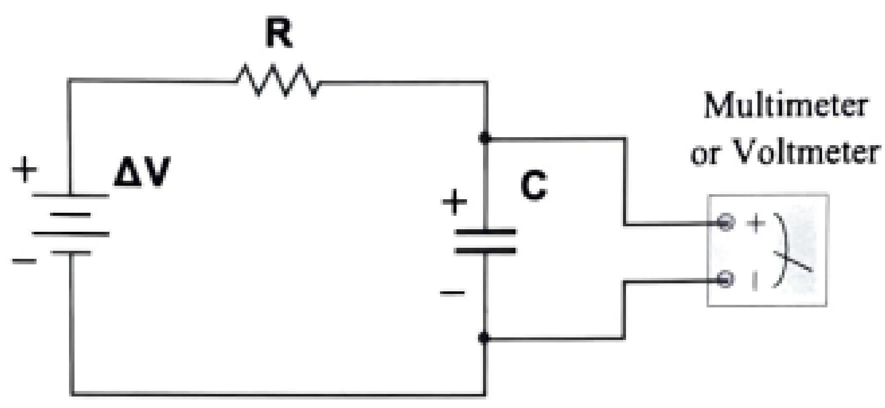


Fig. 1: Experiment 1 circuit diagram

Procedure:

1. Use a 12 kΩ resistor (practical value was 11.85kΩ) , a 1000μF capacitor and set the resistance box to 1200Ω. Time constant for this combination was found to be 11.85s.
2. Set the DC voltage power supply to 5V and measure the voltage using a multimeter. Applied voltage recorded is 5.05V.
3. Ensure the capacitor is discharged. If not discharged, connect both ends of the capacitor using a cable and wait 5 seconds.
4. Follow the diagram and connect the components to form the circuit. Make sure the power supply is turned off when doing so. Ensure the capacitor's longer side is connected to the positive output to prevent any mishaps.
5. Turn on the power supply and look on the multimeter for the value of Vc(voltage across the capacitor), and measure the time that Vc takes to reach 1V using a stopwatch.

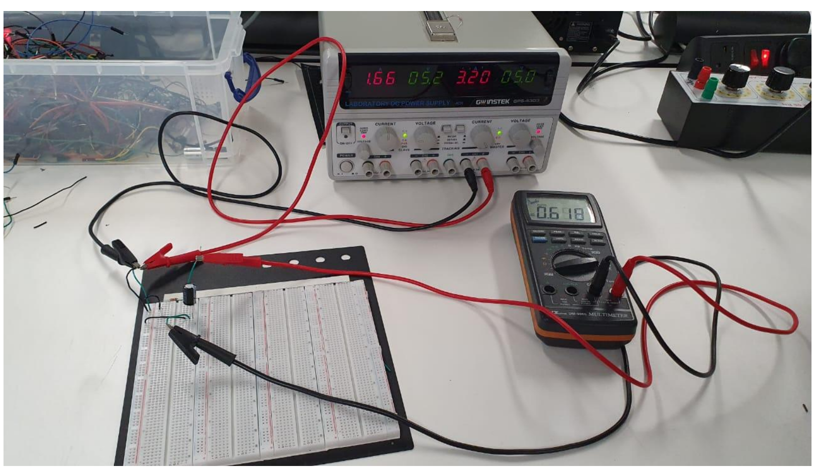


Fig. 2: Experiment 1 setup

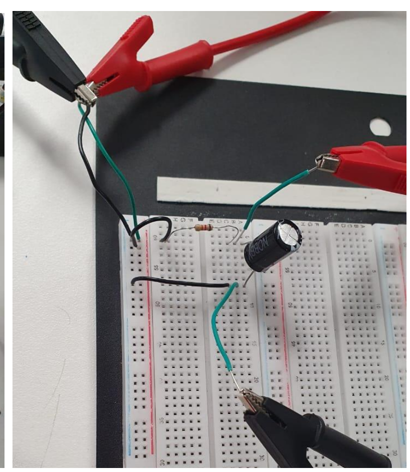


Fig. 3: Experiment 1 circuit

Data and Observations

Measured Values:

Resistance = 11.85 kΩ

DC Voltage = 5.05 V

Calculated Values:

Time Constant = RC = 11.85 kΩ x 1000μF = 11.85 s

Voltage Across Capacitor, V_C (V)	Time (s)
1	4.09
1.5	4.98
2	6.75
2.5	9.15
3	12.16
3.5	15.29
4	21.04
4.5	30.74

Table 1: Measured time for each value of V_C

Graphs

By plotting the values obtained in the table, the following graph was produced.

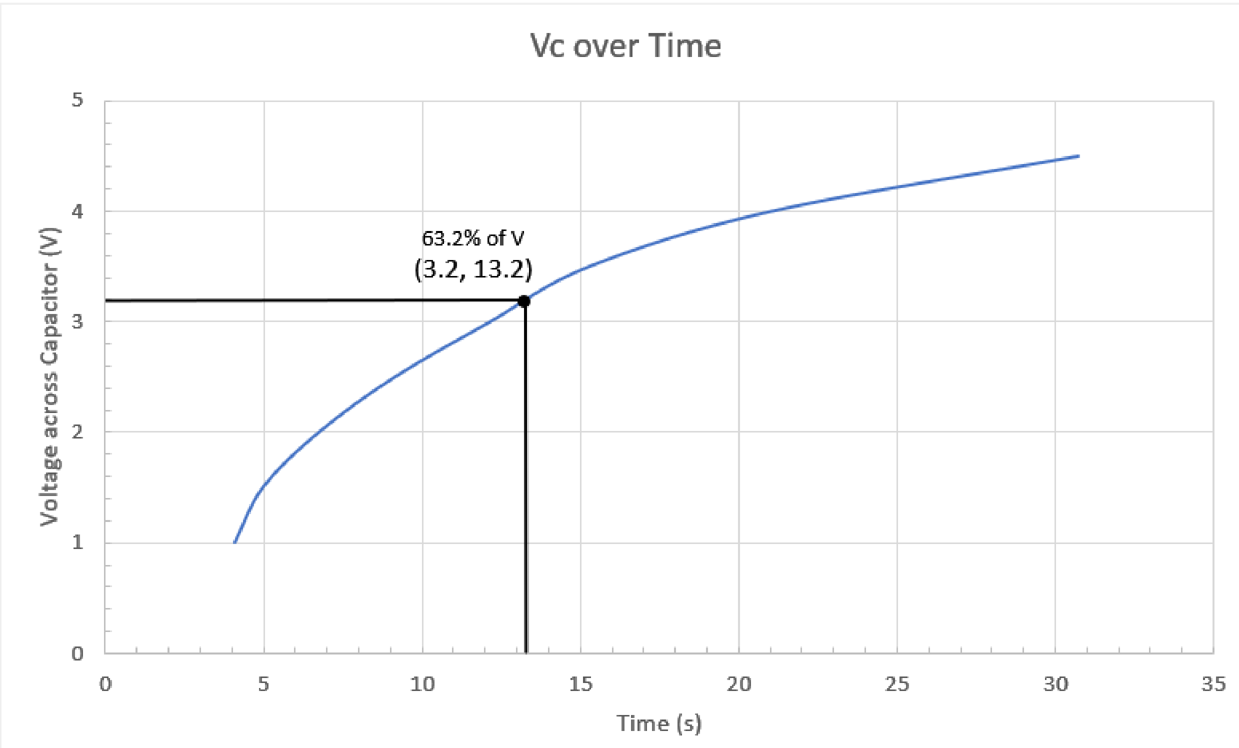


Fig. 4: Graph of V_C over Time

The time constant τ is the time taken for a capacitor to charge 63.2% times the supply voltage.

Therefore, voltage at 63.2%: $\frac{63.2}{100} \times 5.05 = 3.2V$

From the graph we can find the time period (τ) at 3.2V to get 13.2s. To get the capacitance, we can use the formula:

$$\tau = RC, \; C = \frac{\tau}{R}$$

$$C = \frac{13.2s}{11.85\ k\Omega} = 1110\mu F$$

The value of capacitance obtained is close to the given value of 1000µF

The same can be accomplished using a natural log function of $(1 - (\frac{VC}{V}))$ and plotting it against time to produce the following graph

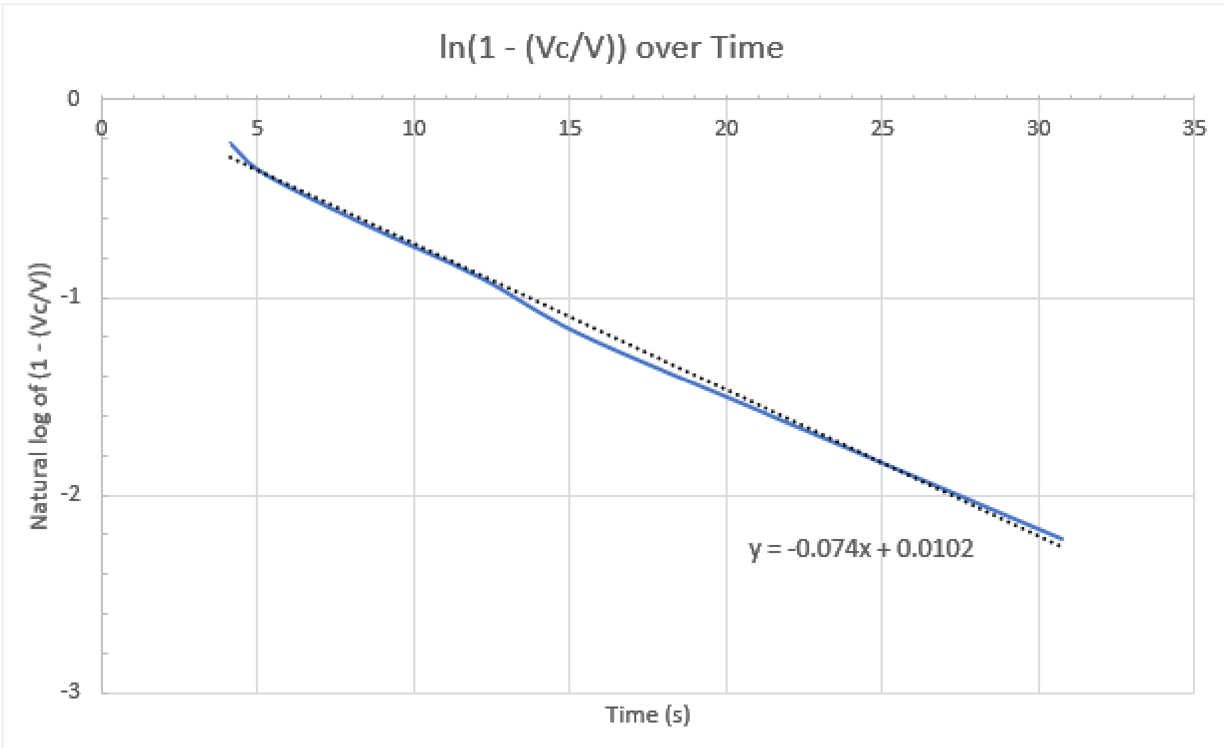


Fig. 5: Graph of $(1 - (\frac{VC}{V}))$ over Time

From the equation of the line, slope = -0.074. And the following equation,

$$Vc = V(1 - e^{\frac{-t}{RC}})$$

Can be rearranged as

$$-\frac{1}{RC} = \frac{ln(1-\frac{Vc}{V})}{t} = slope$$

Therefore, to find capacitance

$$C = -\frac{1}{slope \times R}$$

$$C = \frac{-1}{-0.074 \times 11.85\ k\Omega} = 1140\mu F$$

This value is very close to the previously obtained value of 1110µF

Conclusion

In conclusion, the purpose of the lab is to investigate how the voltage across a capacitor changes over time in a basic circuit that consists of a resistor and a capacitor connected in series. We learnt at the lectures about capacitors and the formulas concerning charging and discharging so this links to what we are studying. The procedure was a bit complicated but we were able to do it. We placed resistors then used the DC power then discharged the capacitor. Some problems that faced us during the experiment were finding the right cables in the lab. Our results made sense since we understood the whole procedure and finished the first group. We learnt how to use voltages over time across capacitors when charging and discharging. If we would face this experiment again we would want to be more accurate with the cables and where to place them on the breadboard since they did not work the first time.

Experiment 2

Purpose:

To compare the two methods for measuring resistance using an ammeter and a voltmeter, as well as how to connect an ammeter and a voltmeter in a circuit.

Hypothesis:

Given that the voltmeter and resistance R are in a parallel circuit, it is believed that the current determined by the ammeter will be divided between both. Therefore, the relevant formula may be used to determine the unknown resistance.

Materials:

- Power supply
- One resistor of a value 10 Ohms
- Resistance box
- Ammeter and Voltmeter
- 6 crocodile-banana cables

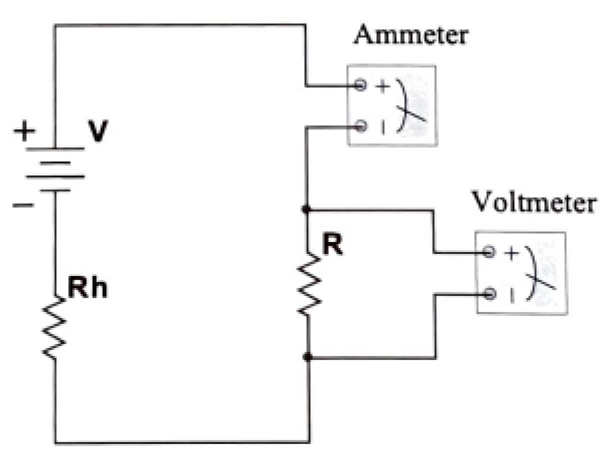


Fig. 6: Experiment 2 circuit diagram

Procedure:

1. Setup the circuit as shown in the diagram.

2. Activate the circuit and take three different readings of the ammeter and the voltmeter corresponding to the different resistance box settings.

3. Record the resistance of the voltmeter for the scale setting used in the acquisition of the data.

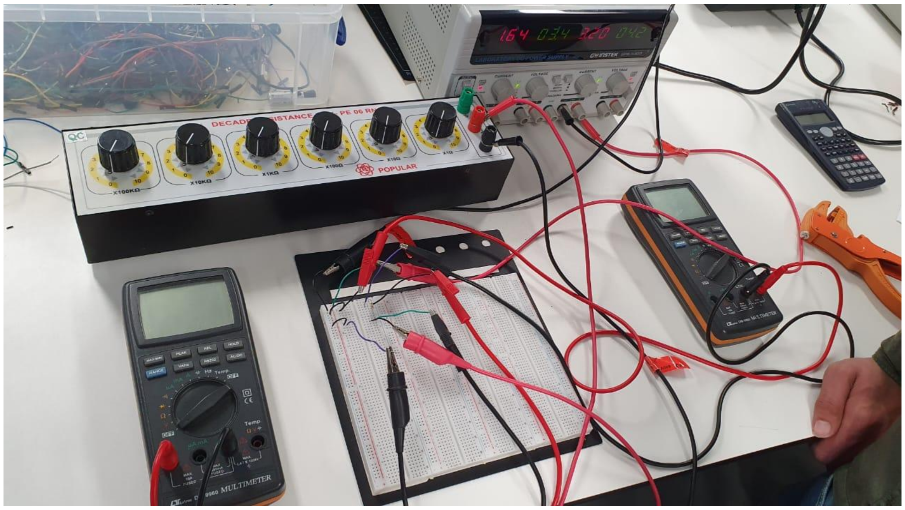


Fig. 7: Experiment 2 setup

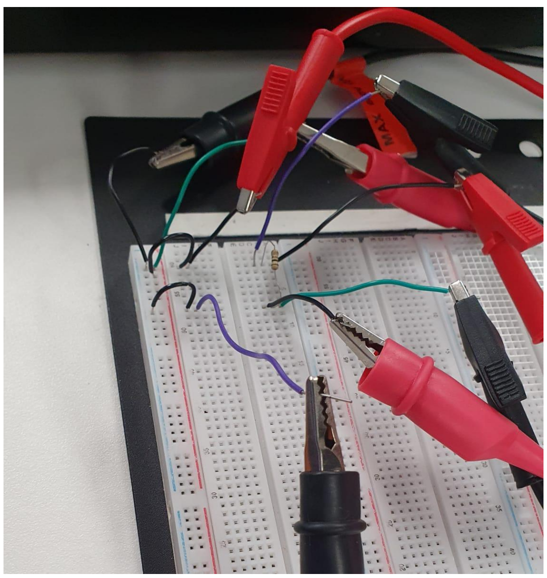


Fig. 8: Experiment 2 circuit

Data and Observations

For this experiment the resistance of the voltmeter itself is taken into account to give a more accurate measurement of the resistance.

$I = 0.05$ A and $V = 4.67$ V

$I_R = 0.047$ A

$I_V = I - I_R = 0.002$ A

$I_V = \frac{V}{Rv} \Rightarrow R_V = \frac{V}{Iv} = 2335\ \Omega$

Rheostat Setting	Voltage (V)	Current (A)	Resistance (Ω)
200	1.628	0.01626	104.609
400	0.985	0.00984	104.585
600	0.706	0.00705	104.629

Table 2: Measured voltage and current for each rheostat setting

Resistance is calculated using the following formula

$$R = \frac{I}{I_R} = \frac{V}{I - I_V} = \frac{V}{I - {}^{V}/_{R_V}}$$

Average Resistance = 104.6 Ω

Percentage Error = 4.6 %

Analysis Questions

1. What does it mean that a capacitor is discharged?

When a capacitor is "discharged," it means that the voltage across the capacitor terminals is decreasing. This can occur when a circuit is designed such that the capacitor is connected in series with a resistor and a voltage source.

2. When a capacitor is *charged* through a resistor by a constant voltage source, what are the voltages across the capacitor and a resistor?

When a capacitor is charged through a resistor by a constant voltage source, the voltage across the capacitor and resistor will vary over time. Initially, when the circuit is first connected, the voltage across the capacitor will be zero, and the full voltage of the constant voltage source will be across the resistor. As the capacitor charges, the voltage across it will increase and the voltage across the resistor will decrease. Eventually, the voltage across the capacitor will reach the same value as the voltage of the constant voltage source, and the voltage across the resistor will be zero.

3. When a capacitor is *discharged* through a resistor by a constant voltage source, what are the voltages across the capacitor and a resistor?

When a capacitor is discharged through a resistor by a constant voltage source, the voltage across the capacitor will decrease exponentially over time, while the voltage across the resistor will remain constant. The voltage across the capacitor will approach the voltage of the constant voltage source asymptotically as the time approaches infinity.

Conclusion

In conclusion, the purpose of this experiment is to examine the difference between utilizing an ammeter and a voltmeter to determine resistance, and to learn the proper way to connect each instrument in an electrical circuit. The work we did in the lab refers to the theory we understood and practiced in the lectures. Regarding experiment two the procedure was setting up the circuit then activating it and note three different readings then finally recording the resistance of the voltmeter for the scale setting used in the acquisition of the data. We did not face any problems in the second experiment because the tutor was assisting us constantly. Our results were fine since we directly read and noted it from the meters. We learned about resistors and how to connect them in series and parallel. If we were to repeat this lab in the future we would be set and ready for it because we had almost everything right.

Appendix

Lab Experiment: RC circuits and electrical meters

	1	2	3	4
Family Name:	Sharif	AHMED	AbaseEldin	
First Name:	Hiba	SYED	Ahmed	
Student Number:	7860742	7782640	7684125	

Objectives:

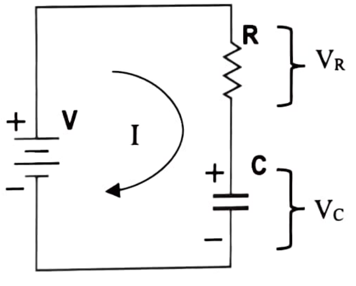
Part 1: Study the behavior of the time dependent potential difference across a capacitor in a simple RC series circuit.

Part 2: Learn two ways to measuring resistance with an ammeter and a voltmeter and explain how they differ and how to connect ammeter and a voltmeter in a circuit.

Part 1: Charging a Capacitor

Equipment:

- Power supply
- One large capacitor (about 2500μF), Resistance box
- Multimeter
- 4 banana cables
- Stopwatch (online)

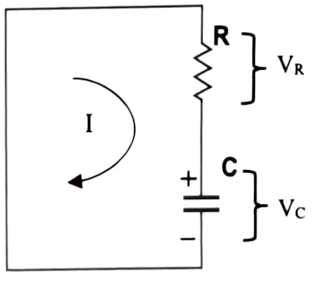


When a capacitor is charged through a resistor by a constant voltage source, the voltages across the capacitor and resistor change exponentially with time. That is,

$$V_C = V\left(1 - e^{-\frac{t}{RC}}\right)$$

$$V_R = Ve^{-\frac{t}{RC}}$$

Where V is the applied voltage.



Likewise, when a capacitor is discharged through a resistor, the voltage are given by

$$V_C = V_0e^{-\frac{t}{RC}}$$

$$V_R = -V_0e^{-\frac{t}{RC}}$$

Where V_0 is the initial voltage across the capacitor.

The rate at which the capacitor charges or discharges can be characterized by the time constant RC. When **charging,** RC is the time that it takes for the capacitor voltage to increase from zero voltage to 0.632 times the charging voltage, since at t=RC

$$V_C = V(1 - e^{-1}) = V_C = V(1 - 0.368) = 0.632V$$

Similarly, when **discharging,** RC is the time for the voltage to fall to 0.368 times its initial value, since at t=RC

$$V_C = V_0 e^{-1} = 0.368V_0 \qquad \text{i.e, 36.8\% of the original value}$$

Procedure:

1. Set the resistance of the resistance box to ~~5000~~ 1200 Ω. Check its actual value with the multimeter. If you read a bad value (~MΩ) change the resistance. Try in the range 4000 to 7000 Ω.

   R= 11.85 kΩ

   For the lab you will use the above resistor and a capacitor with a capacitance of the order ~~2500~~ 1000 μF. What is the time constant for this RC combination?

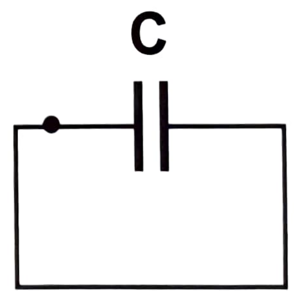
   τ= 11.85 sec

2. Before starting check the DC voltage of the power supply – it should be set at 5V. Measure the voltage using the multimeter. Record the applied voltage.

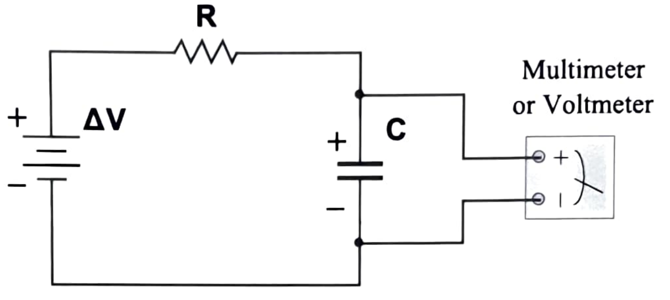
   V= 5.05 V

3. First we need to make sure the capacitor is discharged.
   Question:
   What does it mean that a capacitor is discharged?

   To discharge it, simply connect both ends of the capacitor using one cable as shown in the picture below (and wait about 5 seconds):



4. **Turn off** the power supply and build the circuit. Take a close look at the circuit diagram below. It is important that you connect the negative output of the DC power supply to the end of the capacitor that has a minus sign "-" on it (the shorter side of the capacitor) and the positive output of the DC power supply to the resistor and then the resistor to the end of the capacitor that has a plus sign "+" on it (the longer side of the capacitor). If you do not connect the components accordingly to the right polarity, the capacitor might blow up and be dangerous (if you're not sure, ask the instructor to check). Set the multimeter to measure DC voltage and connect it as show in the diagram below:



5. **Take the measurement:**
Open a stopwatch at: http://tools.arantius.com/stopwatch. Turn on the power supply (which should be kept at 5V), look on the multimeter for the value of V_C, the voltage across the capacitor and measure the time that V_C takes to reach 1V. Then discharge again the capacitor (step 3) and repeat to measure the time to charge to 1.5V, 2V … 4.5V.

Voltage Across the Capacitor, V_C (V)	Time (s)
1	4.09s
1.5	4.98s
2	6.75s
2.5	9.15
3	12.16
3.5	15.29
4	21.04
4.5	30.74

Time x axis
V_c y axis

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6. **PLOT 1:** Using Excel, plot V_C as a function of time. Determine *RC* by finding the time at which the voltage has increased to 63.2% of the power supply value. Assume that you do not know the capacitance and calculate it from the measured resistance R and the time constant you just determined.

C=________________μF

7. **PLOT 2:** Now plot this same data in semi-log format. Plot the natural log of $\left(1-\frac{V_C}{V}\right)$ on the vertical axis and the time on horizontal axis: $y=\ln\left(1-\frac{V_C}{V}\right)$ and x=t. Draw a single "best fit" straight line through your data and determine *RC* from this line. What capacitance does it correspond to?

C=________________μF

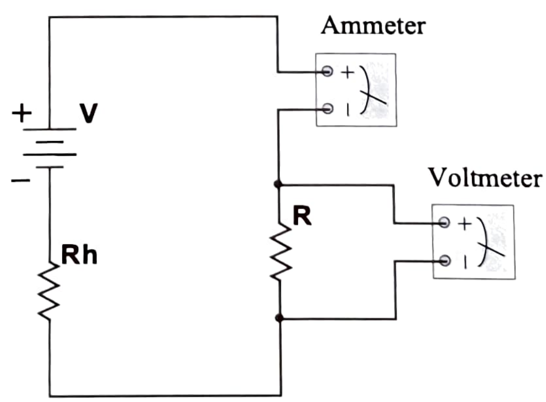
How does this compare with the value given on the capacitor?

Part 2: Ammeter – Voltmeter Methods

Equipment:

- Power supply
- One resistor of a value 10 Ohms
- Resistance box or Rheostat
- Ammeter and Voltmeter
- 6 banana cables

We will use the circuit below to measure the resistance using this method.



In this circuit, the current measured by the ammeter divides between the resistance R and the voltmeter in parallel. The voltmeter is a high resistance instrument and draws little current as long as the voltmeter resistance R_V is much greater than R. Thus,

$$R = {}^{V}/_{I} \quad if \quad R_V > R$$

For a more accurate measurement, the resistance of the voltmeter must be taken into account. The current drawn by the voltmeter is

$$I_V = {}^{V}/_{R_V}$$

and the total current measured by the ammeter is

$I = 0.05$

$$I = I_R + I_V$$

$I_R = 0.047$

The true current through the resistance is

$$I_R = I - I_V$$

$I_V = 0.002$

And from Ohm's Law

$$R = \frac{I}{I_R} = \frac{V}{I - I_V} = \frac{V}{I - {}^{V}/_{R_V}}$$

$R_V = \frac{4.67}{0.002} = 2334.5$

1. Setup the first circuit, where R is the unknown resistance and R_h is the rheostat (variable resistance). Do not connect the power supply until the professor has checked it. (Use the 10 ohm resistor on the circuit board for R).

2. Familiarize yourself with the ammeter and voltmeter. There are three scale connections with the black binding post common for the three scales. It is good practice to start with the highest scale to prevent damaging the instrument. The scale setting may be changed to a lower scale after the general magnitude the measurement is known.
   Attention should also be given to the proper connection of the meters. Connect + to + and – to –.

   Do not connect the power supply until the professor has checked it.
3. The current in the circuit is changed by varying the rheostat resistance R_h. This is done by sliding the rider to a new position. Activate the circuit and take three different readings of the ammeter and the voltmeter corresponding to the different rheostat settings. Be sure to use one scale setting for the three data points. Record the data in Data Table 2. Deactivate the circuit.

4. Record the resistance of the voltmeter for the scale setting used in the acquisition of the data.

Table 2:

R= 100 Ohms R_V= 2335 Ohms

	Rheostat Setting	V (Volts)	I (Ampere)	R (ohms)
1	200	1.628	0.01626	~~1.629~~ 104.609
2	400	0.985	0.00984	104.585
3	600	0.706	0.00705	104.629

Average R= 104.6

% error= 4.6

$$\frac{1.628}{0.01626 - \frac{1.628}{2335}} =$$

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Family Name:____________________

First Name:____________________

Student Number:________________________

PRE-LAB TEST

Experiment 2 – RC Circuits

1. When a capacitor is **charged** through a resistor by a constant voltage source, what is the voltages across the capacitor and a resistor?

2. When a capacitor is **discharged** through a resistor by a constant voltage source, what is the voltages across the capacitor and a resistor?