Introduction:
This experiment is the first that deals with signals (voltages and currents) that change over time. In order to generate and analyze such signals, you will use two more pieces of equipment, the oscilloscope and the function generator. Read through chapter II of the introductory handout which contains a description of some of the main features of these instruments. This should be helpful in getting started.

In the experiment itself, you will use both one-time perturbations of a DC circuit (transients as induced by a switch) and continuously varying signals. At the end of the lab, you will be able to:

- Understand RC and RL circuits
- Measure the time dependent response of an RC circuit
- Measure time dependent signals on the oscilloscope
- Design an RC transient circuit with desired properties

Topics from lecture you need to be familiar with:
- Capacitors and inductors as energy storing circuit elements
- Transients in RC/RL circuits
- RC time constant
- Simple exponential functions, steady-state values

Pre-lab questions (hand in before lab starts):
1. In what form do capacitors/inductors store energy?
2. Why can a circuit with a capacitor and n (n>1) resistors be reduced to a circuit with a single capacitor C and a single resistor R?
3. How do you get a short/long time constant in an RC/RL circuit?
4. What circuit elements do capacitors/inductors resemble immediately after a circuit has been perturbed? Why?
Part 1: RC circuit basics

1. Basic RC circuit

a) Calculate the time constant $\tau$ of the circuit shown below. What inductor would you use to obtain the same $\tau$ in an RL circuit?

![Figure 1](image)

Build the circuit. CAUTION: Make sure you connect the capacitor correctly (polarity!)

b) Throw the switch to position 1 and use a watch to record the capacitor voltage $V_C$ as a function of time. Use the DMM to read off $V_C$. Then throw the switch to position 2 and record $V_C$ versus $t$ as the capacitor discharges. Designate the moment when you switch to position 2 as $t=0$ for this cycle. Repeat this measurement several times. Record your values in a table.

c) Take the average value of $V_C$ at your chosen times and plot $V_{C,ave}$ in volts versus time in seconds for both charging and discharging cycles. For the charging cycle the capacitor voltage is given by $V_C(t)=V_0e^{-t/\tau}$ and for the discharging cycle it is given by $V_C(t)=V_0(1-e^{-t/\tau})$. Determine the RC time constant $\tau$ of the circuit which is equal to the time after which the voltage has dropped to 37% of its original value (discharging cycle) or risen to 63% of its final value (charging cycle). A more accurate way to determine the time constant for the discharging cycle is to plot the same data on a semi log-scale, i.e. plot $\ln(V_{C,ave})$ (natural log) versus $t$ because we can rewrite the equation for the capacitor voltage as $\ln(V_C)=\ln(V_0)-t/\tau$. What type of curve do you obtain? Find $\tau$ from this curve. Can you find $t$ for the charging cycle in a similar way?

d) Compare your measured value for the time constant with your initial calculation. Discuss possible reasons for discrepancies.

e) One main reason for inaccuracies is the finite resistance of the DMM $R_D$. Your circuit actually looks more like this:

![Figure 2](image)
Calculate the time constant of this modified circuit? Can you determine the internal resistance of the DMM from your measured data?

f) In order to minimize the effect of $R_D$, do you have to increase or decrease $R$?

g) Try out different values for $R$ and $C$ and observe the effects on how fast the circuit charges or discharges. You do not have to plot your results, but describe qualitatively what you observe.

2. Transient response on the oscilloscope

a) Replace your circuit elements with $R=22\,\text{k}\Omega$ and $C=1\,\mu\text{F}$. Calculate the new time constant.

b) You will no longer be able to use a watch and need to use the oscilloscope instead. The scope replaces the DMM in your circuit. Is it better to use the x1 or the x10 probes? Why? (see part I.1. of the introductory handout)

c) Using the probes of your choice, replace the DMM with the scope. Use channel 1 across points A and B and channel 2 for $V_C$ in Fig. 1. Start with a sweep rate of 20 ms/div on the scope. Set the input coupling to DC and triggering to AUTO. Throw the switch back and forth and describe what you see on the scope.

d) Replace the circuit to the left of A and B with the function generator. Set the generator to a square wave with a period of $5\tau$. Set the scope’s trigger to channel 1 and the triggering slope to positive. Observe the signal voltage $V$ from the function generator on channel 1 and $V_C$ on channel 2. Determine the time constant from the scope image.

e) Increase the frequency of the square wave signal. Adjust the time scale on the scope such that you see 2-3 periods of the applied signal on the screen. Observe $V_C$ for each frequency and compare $V_C$ and $V$. What happens as the frequency increases? Why?

Part 2: Design of an RC circuit

In this part of the lab, you will design an RC circuit with a given time constant. Your design does not have to hit the target time constant exactly (even though that is possible), but the closer you get, the better.

a) Using one of your light bulbs (rating: 1.5V), a 10V DC source, a capacitor, and other resistors if necessary, design an RC circuit which has the following properties:

- With the switch closed, the power dissipation in the bulb is 30 mW. Assume a light bulb resistance of $R_L=30\Omega$.
- As the switch is opened, the lamp starts to dim with a time constant of $\tau=3s$.

**Hint**: These properties give you two conditions from which you can determine your required circuit element values C and R. Your circuit diagram should look somewhat like this:
b) Draw the circuit diagram for your design and explain your reasoning for the choice of circuit elements.

c) Build the circuit and verify it operates as desired. Specifically:
   - Determine the bulb power with the switch closed.
   - Measure the time constant by monitoring the capacitor voltage on the oscilloscope. Plot $V_C$ versus $t$.
   - Measure the time constant by monitoring the light bulb voltage $V_L$. Plot $V_L$ versus $t$.

d) What happens to the light bulb brightness immediately after the switch is opened? Explain.