Lab 7: RC Series Circuits – Time Dependence

Experiment for Physics 226 Lab at CSUF

What You Need To Know:

The Physics

A capacitor is a device for storing charge. The capacitance *C* of a capacitor depends only on the geometry and material make up of the capacitor nothing else. The units of capacitance are the Farad. For a parallel plate capacitor with nothing between the plates we would have,

$$C = \frac{\varepsilon_o A}{d}$$

where *A* is the area of the plates and *d* is the separation of the plates.

The voltage across the capacitor is given as

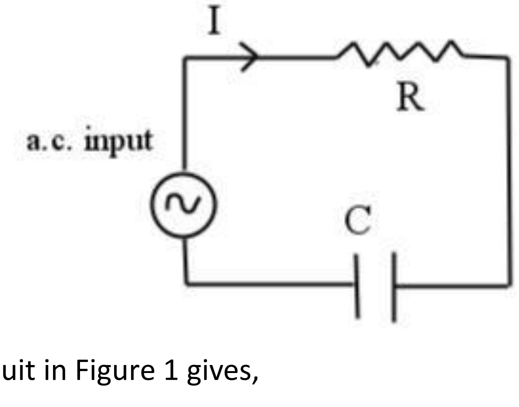
$$V_c(t) = \frac{q(t)}{C}$$

From this equation the voltage builds up over time when the current in the circuit is switched on, charge builds up on the plates until a maximum charge is reached when $V = \varepsilon$.

The maximum voltage across the capacitor is the amount supplied by the power source $\varepsilon = V_{battery}$.

Do not exceed the voltage rating of the capacitor. A given size of capacitor can only hold so much charge, then it fails *"catastrophically" by explosion*. ***A loud pop and acrid smoke***. Do not attempt this!

Figure 1 – Simple RC Circuit Diagram



The voltage loop law for the circuit in Figure 1 gives,

$$\varepsilon - IR - \frac{q}{C} = 0$$

Here the ac supply has voltage ε. In terms of the charge we may write,

$$C\varepsilon = RC\frac{dq}{dt} + q$$

We may solve this to find,

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

and from this we get,

$$I(t) = \frac{\varepsilon}{R}e^{-t/\tau}$$

The time constant is $\tau = RC$. Figure 2 shows the voltage on the capacitor and the voltage on the resistor as the capacitor is charging up.

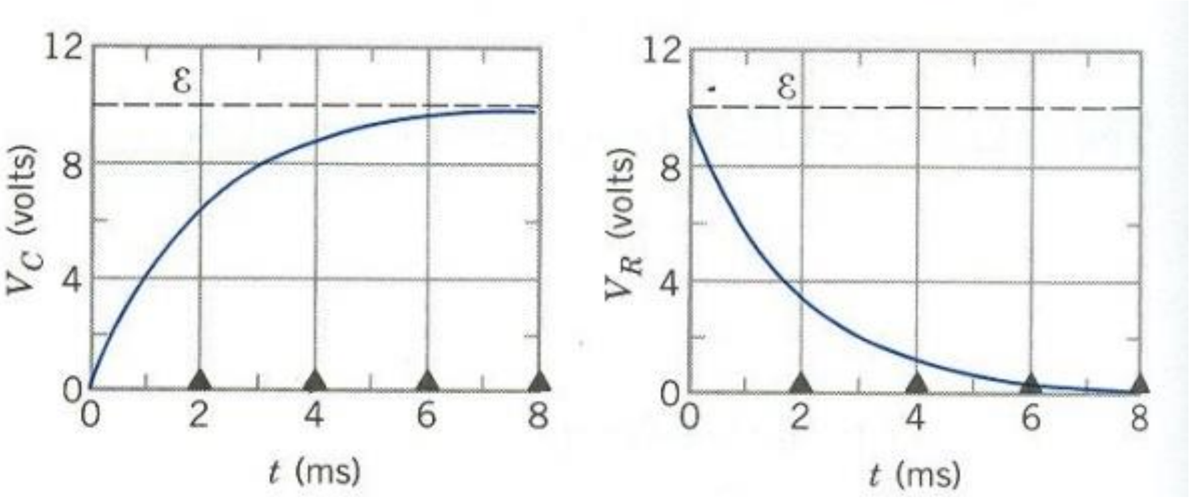


Figure 2 – Voltage of a Resistor and Capacitor During Charge.

You find $t_{1/2}$ from looking at the either the voltage gain across the capacitor or voltage drop over the resistor. When the voltage is half the max value measure $t_{1/2}$ from the time scale, using the relevant time/div. scaling on the scope. You can use $t_{1/2}$to find the time constant τ_c .When the capacitor is discharging the equation for $V_c(t)$ decreases to zero looks like,

$$V_c\,(t) = \varepsilon e^{-t/\tau}$$

Note that when $t = t_{1/2}$ then $V_c = \varepsilon/2$.

We can solve this to find the time constant τ_c . Measuring the $t_{1/2}$ value allows us to write,

$$t_{1/2} = \tau_c\, ln\, 2$$

where ln 2 = 0.693. Note that $\tau_c > t_{1/2}$.

What You Need To Do:

RC circuits make excellent timing circuits since the capacitor charges and discharges at a set rate. You can imagine switching a motor to go forward and then backward for a time when it hits a relay switch and charges up an RC circuit… robotics application, or a light made to switch on and off with the charge discharge cycle like a strobe. You will be making a strobe light with a simple LED later on. First we need to make sure you have understood the theory so you can apply it in the experiments.

This lab has the following parts:

1. You will be completing a simple RC calculation given sample data.
2. You will be hooking up an RC circuit and viewing the voltage vs. time across the capacitor on the CH 1 of the oscilloscope.
3. ~~You will be making a simple LED flashing circuit (basic strobe)~~ (Temporarily Discontinued while a safer setup is worked on)
4. Additional Exercises on RC Circuit behavior

Part 1 – RC Calculation with Given Data

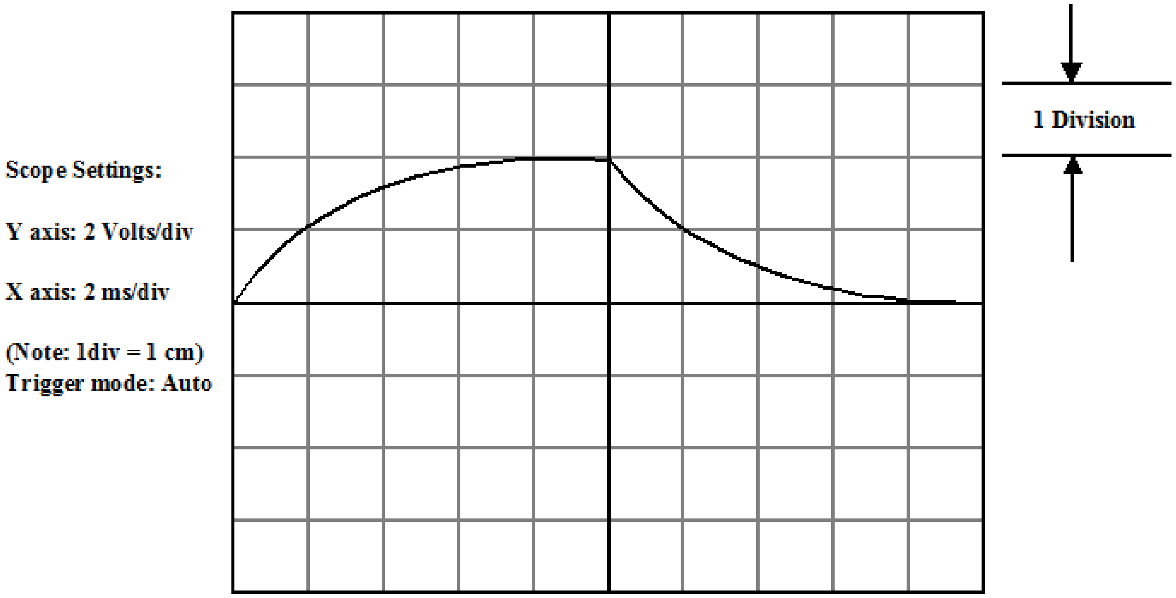


Figure 3 – Sample Oscilloscope Waveform Data

Consider the oscilloscope display in Figure 3. This shows the voltage across a capacitor in an RC circuit. The left part of the curve corresponds to charging, the right half to discharging the capacitor. The resistor is 2 kΩ.

A) From the trace determine the value of the Capacitance C.

B) What is the time constant for the circuit τ? ***HINT: First find*** $t_{1/2}$ ***from the given display.***

C) What is the voltage across the battery terminals?

Part 2 - Oscilloscope Observation of RC Signal

Here we will show the capacitor voltage vs. time on the scope CH 2. We will also show the square wave from the generator on the same scope on CH 1. Figure 4 has a simple circuit diagram for the set up. Use the resistance box for R.

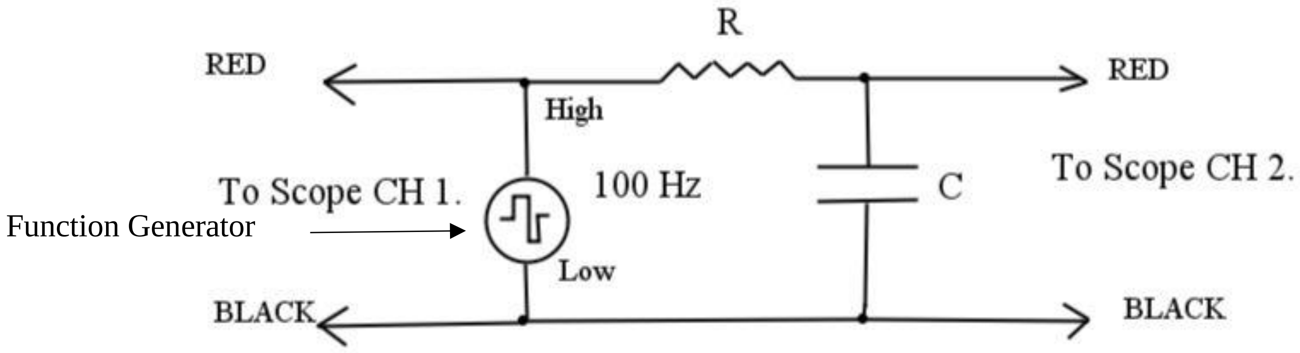


Figure 4 – Circuit Diagram for RC Circuit.

A) Use Figure 4 to setup the required basic RC Circuit.

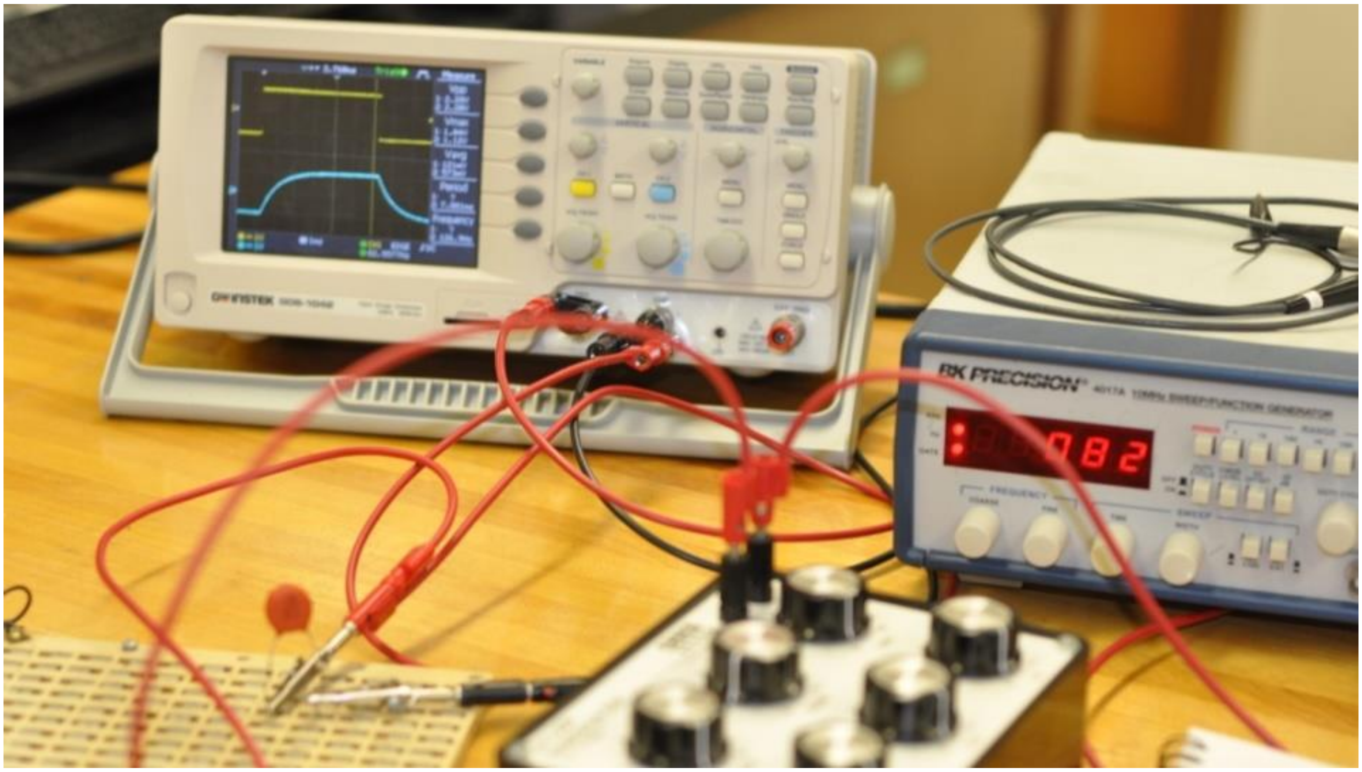


Figure 5

Note: CH 1 and CH 2 of the scope have a common ground. It is not necessary to runs leads to both ground (black) terminals.

B) Adjust the oscilloscope and signal to get a full view of the waveform.

   a. If the square wave form is too fast the capacitor will start to discharge before it reaches its maximum voltage which should be the generator voltage, 2 volts. Adjust the time/div setting and the horizontal scale can be adjusted left and right to get a good reading of the scale if needed.

   b. You may need to adjust the frequency of the generator so you see a full charge charging cycle. You may find 80 Hz better than 100Hz as in Figure 6. This will give you a nice full image on the screen. They both work.

Using 80 Hz signal **Using 100 Hz signal**

Figure 6- 80Hz vs 100Hz signal

C) Fill in Table 1

   a. Use the same method as part 1 to find $t_{1/2}$.

   b. Calculate τ_C from the expected values of R and C.

   c. Calculate τ_C from the measured value of $t_{1/2}$.

Table 1 – Part 2 Data

R (kΩ)	**C** (µF)	**$t_{1/2}$** (µs)	**τ_C = *RC*** (µs)	**$\tau_C = t_{1/2} /0.693$**
10	0.05			
20	0.05			
30	0.05			
40	0.05			

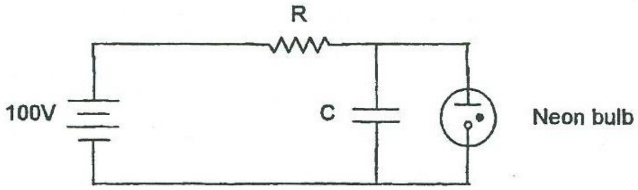
~~Part 3 – Building a Relaxing Oscillator (flashing LED)~~

SKIP TO PART 4

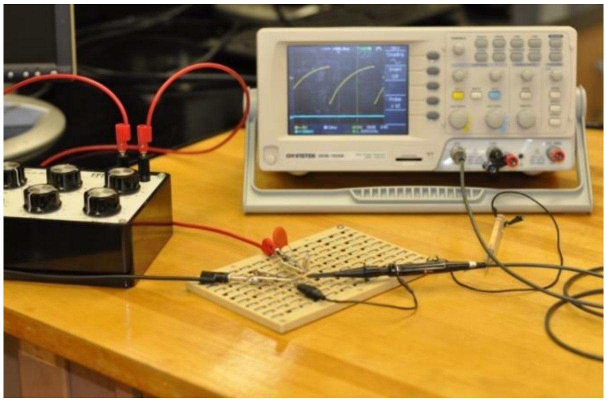
When the circuit is closed the battery charges up the capacitor… until you get to about 80 volts. The neon bulb breaks down at 80 volts and shorts out the circuit. When the voltage reaches about 80 volt, (the breakdown potential V_b) the neon bulb shorts out the capacitor which means that the battery current flows through the bulb (which now conducts like a wire) and bypasses the capacitor. The capacitor then discharges through the neon bulb. When the discharge passes through the bulb the neon gas emits a flash of light. The capacitor does not discharge completely since the neon bulb ceases to conduct before this can happen. The capacitor will reach a minimum voltage V_m known as the maintenance potential. After this process the battery charges the capacitor again until you reach 80 volts and the cycle repeats itself.

WARNING high voltage (~90 Volt) in use from the wall, you will be shocked if you are not careful !

Construct the circuit below. Use a decade resistance box, a 0.05 µF capacitor and a neon bulb.

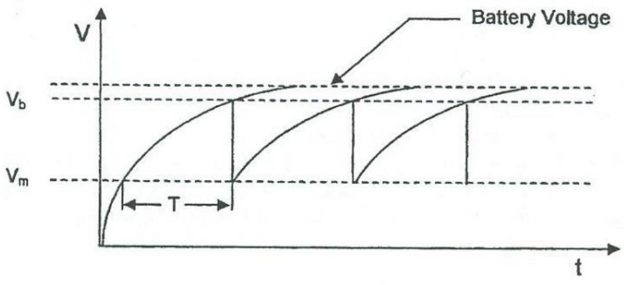


Simple circuit diagram for the basic strobe



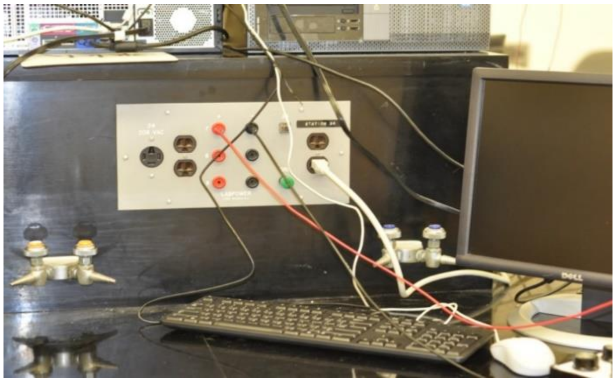
You can use the same springs for the capacitor and neon bulb. That will put them in parallel. Use the large handle probe as positive and the clip as negative. **Make sure both scope AND probe are set to 10x mode.**

Breakdown voltage and the maintenance voltage draw out. The diagram below shows the cycle of charging and discharging of the capacitor and hence the flashing of the LED.



Waveform of a neon bulb relaxation oscillator

On the oscilloscope make sure the AC GND DC switch is switched to AC, this is because the ac component may be small compared with the dc offset and you want to see the ac part $(V_b - V_m)$. The scope is not designed to measure large voltages… so set the probe 10x switch on. Read as ten times. This is under CH 1 and menu option 4th button down. (Most probes have a switch, for normal use 1x and 10x to attenuate 10 times.) Make sure you are using 10x mode on the probe as well as the scope, this will attenuate the voltage by a factor of 10. So, for example, if you are using 80 volts would read 8 volt on the scope. Set the time/div to 10ms (5 ms for higher resistance). Use the 5volt/div setting for CH 1. Connect CH 1 using the probe and BNC clip… you will need to remove the banana plug adapter to do this.



This photo shows the wall voltage supply. This will be set to between 80 - 90 volts

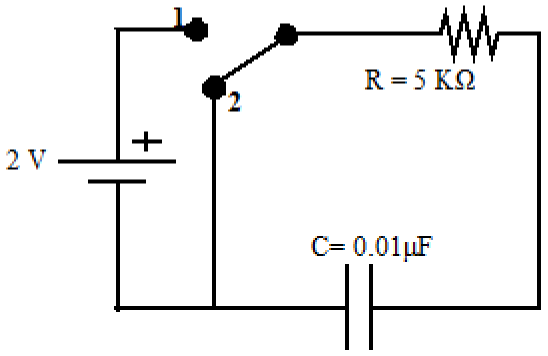
This is the probe set to 10x and a close up of the bulb and capacitor in parallel.

Fill in the table below using your 0.05µF capacitor.

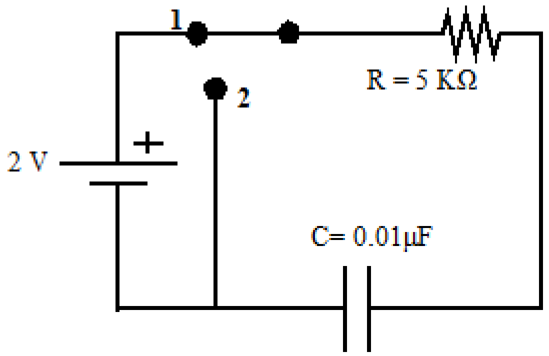
R (MΩ)	**C** (µF)	**τ** (sec)	**Period T** (sec)	**T/τ**
1.0	0.05			
0.8	0.05			
0.75	0.05			
0.55	0.05			

Part 4: RC Circuit Exercises

Consider the circuit below which is shown both in the discharging and the charging state. The values of the components are: R = 5kΩ, C= 0.01 μF and V = 2 Volts.



Series RC circuit with the switch in the discharging position

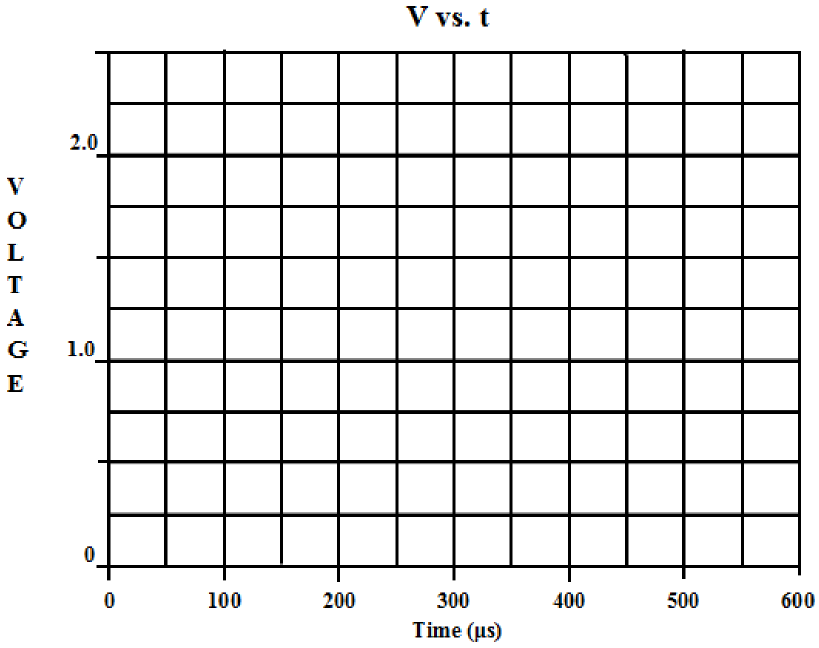


Series RC circuit with the switch in the charging position

1. Suppose the switch has been left in position 2 for a long period of time so that the capacitor had become fully discharged. Assume the switch is thrown from position 2 to position 1 at t = 0.

    a. What is the time constant for this circuit?

    b. Plot accurately the potential difference across the capacitor, V_c, as a function of time.



c. What is the value of the maximum current that will flow in the circuit? At what time does this maximum occur?

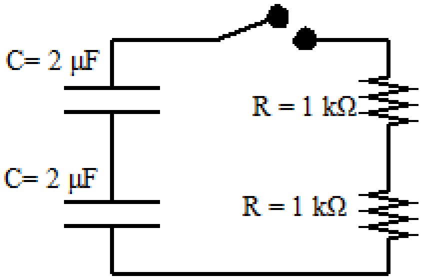
d. What is the value of the maximum charge on the capacitor? At what time does the maximum occur?

e. Determine the times at which the current in the circuit and the charge on the capacitor each have reached one half their maximum values.

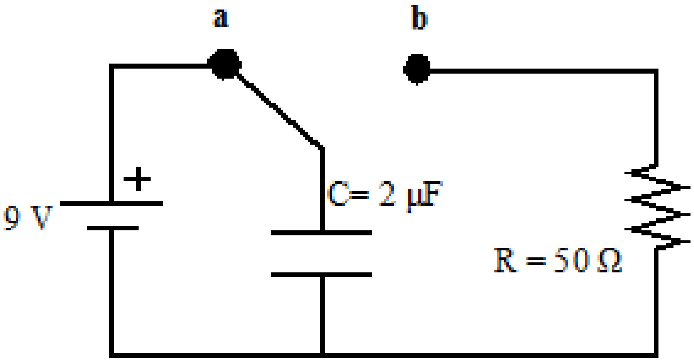
2. Derive, showing all the steps, the equation relating τ and $t_{1/2}$, i.e. $\tau = \frac{t_{1/2}}{ln\,2}$.

3. Show that the product of RC has units of seconds (s).

4. What is the time constant for the discharge of the capacitors given in the figure here?



5. The switch in the figure below has been in position **a** for a long time. It is changed to position **b** at t = 0 s. What are the charge Q on the capacitor and the current I through the resistor …



   a. Immediately after the switch is closed?

   b. At, t = 50μs?

   c. At, t = 200μs?

Rev 2023