

PHYSICS 171

UNIVERSITY PHYSICS LAB II

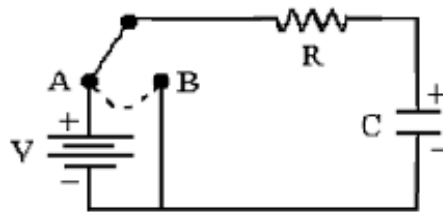
Experiment 6

Transient Response of An RC Circuit

Equipment: Function Generator, Dual Trace Oscilloscope

Supplies: .002 Microfarad, 0.1 Microfarad capacitors; 1 Kilohm, 10 Kilohm, 100 Kilohm resistors.

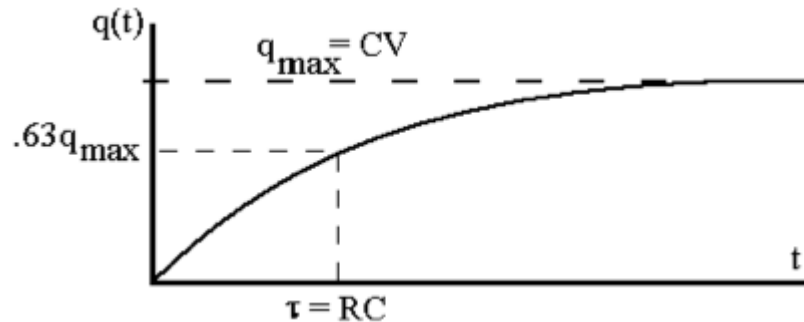
In the circuit below a switch is used to apply a D.C. voltage V to a resistance R and capacitance C in series.



While the switch is at A the capacitor charges up according to the equation (Kirchhoff's voltage law):

$$V = q/C + iR = q/C + R \frac{dq}{dt}$$

The solution of this equation is $q(t) = CV (1 - e^{-t/RC})$, and graph of charge as a function of time is shown below.

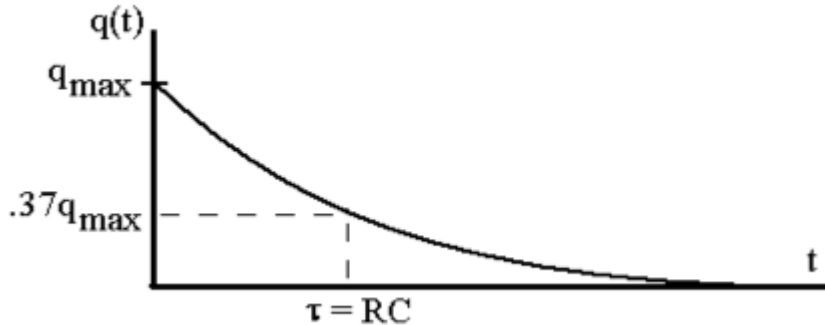


The charge on the capacitor starts out at zero and approaches a maximum value CV . The time constant $\tau = RC$ is the time required for the capacitor to change to $\approx 63\%$ of its maximum value.

When the switch is thrown over to B, the voltage source V is out of the circuit and the capacitor discharges according to the equation (Kirchhoff's voltage law):

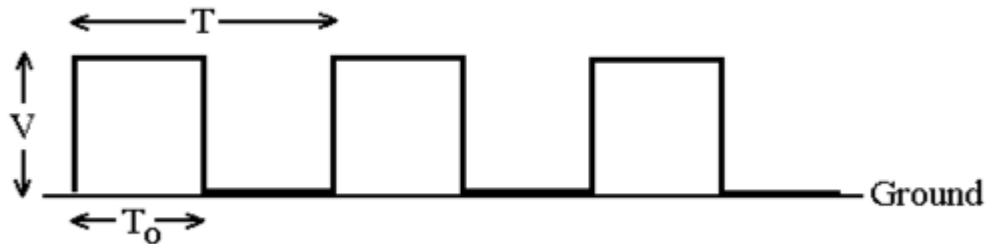
$$0 = q/C + iR = q/C + R \frac{dq}{dt}$$

If the capacitor is fully charged ($q = CV$) when the switch is thrown, the solution of this equation is $q(t) = CV e^{-t/RC}$, and graph of the discharge process as a function of time is shown below. The graphical representation of the discharging process is



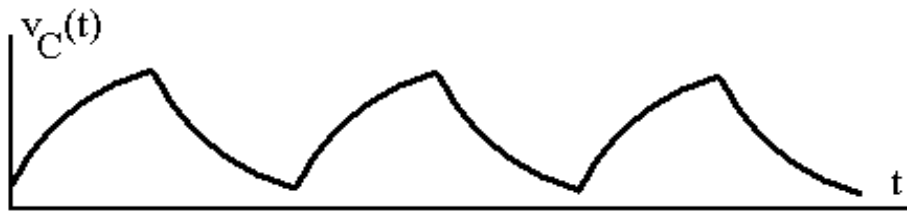
The time required for the charge to drop to 37% of its maximum value is again taken to be the time constant RC .

We can mimic the effect of the switch can by using the function generator to produce a square wave that has the positive voltage V for a time T_0 and then is zero for time T_0 , as shown below.



The period of the square wave is $T = 2T_0$. Note that it has a positive D.C. offset of $V/2$ so that it does not go below ground.

If T_0 is larger than the time constant RC the capacitor will have time to charge and discharge. The voltage $V_C(t) = q(t)/C$ across the capacitor will then have the characteristic exponential charging and discharging shapes:

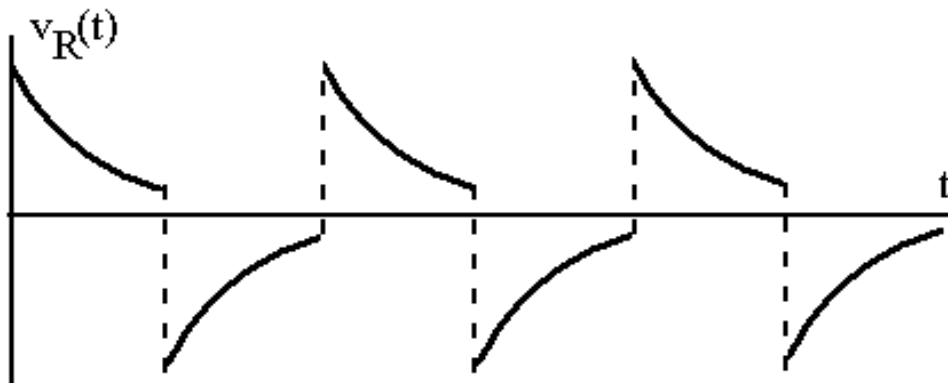


The current during charging and discharging can be found by examining the rate at which charge changes with time.

Charging: $i(t) = \Delta q/\Delta t = + (V/R) e^{-t/RC}$

Discharging: $i(t) = \Delta q/\Delta t = - (V/R) e^{-t/RC}$

The signs of these two equations are opposite because the current flows clockwise during the charging process and counter clockwise when the capacitor discharges. From these two relations we can determine the voltage across the resistor using Ohm's Law, $v(t) = i(t)R$. The voltage across the resistor as a function of time is plotted below.



If T_0 is not long enough (compared with the RC time constant) to allow complete charging and discharging of the capacitor, then the curves for $V_C(t)$ and $V_R(t)$ will have shapes that do not show exponential behavior as clearly as those drawn above.

Procedure - Experiment 6

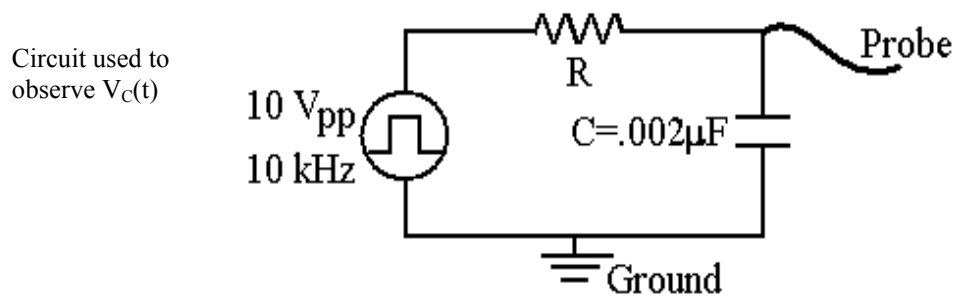
1. Adjust the function generator output to give a 10 V(pp) square wave. Use a +5 volt D.C. offset so that the square wave does not go below ground. Adjust the frequency to 10 kHz.

Record on the data sheet the square wave width, period, and amplitude.

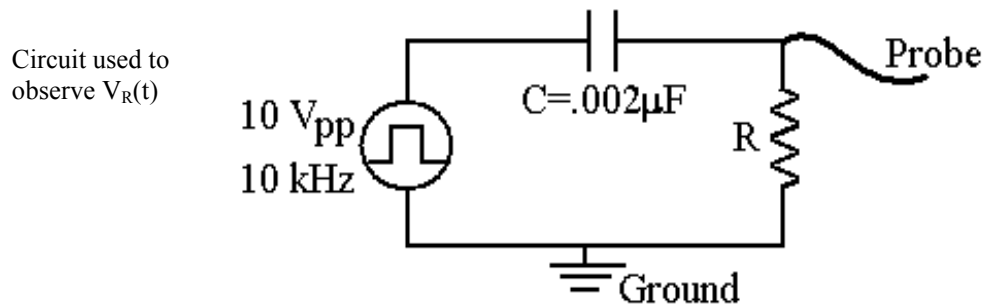
2. Apply the square wave to an RC circuit (shown below) with $C = .002\mu\text{F}$ and R equal to each of the values shown on the data sheet graphs (10 K Ω , 1 K Ω , 100 K Ω).

Observe the voltage across the capacitor with the oscilloscope and sketch the signal for the three R values.

Be sure that the grounds of the oscilloscope probes are connected to the function generator ground.

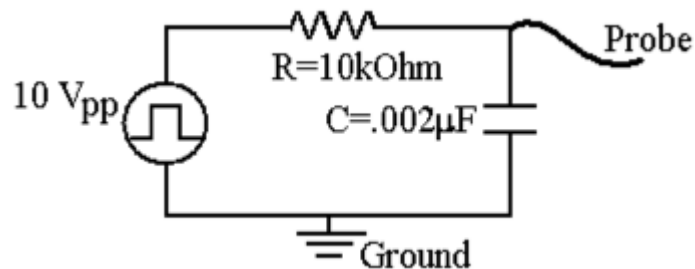


3. Interchange R and C (as shown in the circuit below) so that the voltage across R can be observed and proper ground connections can still be made.



Observe the voltage across the resistor with the oscilloscope and sketch the signal for the three R values.

4. This experimental set-up may also be used to check the values of capacitors. First use the digital ohmmeter to measure the resistance of the 10 k Ω (nominal value) resistor, then apply the square wave to the RC circuit shown below using a capacitor with a nominal value of 0.002 μ F.



Observe the voltage across the capacitor with the oscilloscope. In order to make an accurate measurement it will be necessary to first vary the frequency of the square wave so that the capacitor becomes just completely charged in time T_0 . Then adjust the time scale on the oscilloscope (sec/div) so that this charging pulse is displayed over a major portion of the screen. Record this oscilloscope setting.

Now sketch the pulse on your data sheet. Make sure you label the units on the horizontal axis.

The time constant is defined as the time required for the capacitor to charge to 63% of its maximum value. Measure this time constant directly off of the scope.

Now using the values you have just found for the resistance and time constant, use $\tau = RC$ to calculate the capacitance of this capacitor.

5. Repeat procedure 4 using a capacitor with a nominal value of 0.1 μ F.

Data Sheet - Experiment 6

Name

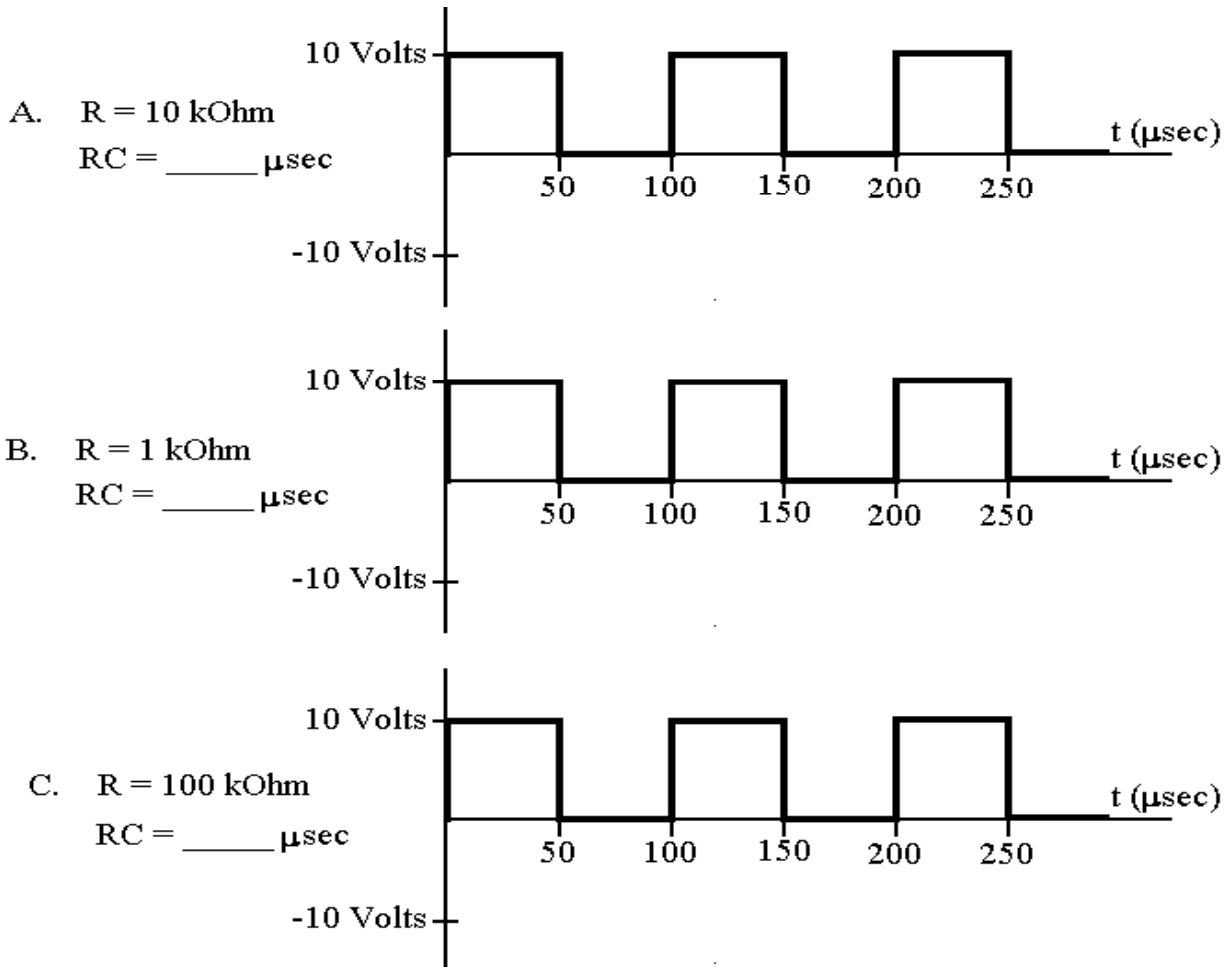
Section #

1. Square wave width $T_0 = \underline{\hspace{2cm}} \mu\text{sec}$

Square wave period $T = \underline{\hspace{2cm}} \mu\text{sec}$

Square wave amplitude $V_{pp} =$

2. Calculate the time constants corresponding to the three different resistors. Below are three plots showing the applied square wave potential over one period. For each case plot the voltage measured across the capacitor (use a solid line) and the voltage measured across the resistor (use a dashed line). Please put the correct scale on the axes.



What relationship between the applied voltage and $V_C(t)$ and $V_R(t)$ do these plots suggest?

4. Measuring Capacitance

R = _____ k Ω

Nominal value of C = 0.002 μ F

Function generator frequency = _____ Hz

Time scale on the oscilloscope = _____ sec/div



Measured time constant = _____ sec

Measured C = _____ μ F

Nominal value of C = 0.1 μ F

Function generator frequency = _____ Hz

Time scale on the oscilloscope = _____ sec/div



Measured time constant = _____ sec

Measured C = _____ μ F