PHYSICS 281
EXPERIMENT 5
RCTime Constants

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OBJECT:

To study the RC circuits and the method of measuring the time constants. To learn the plotting and data analysis of the processes involving logarithmic functions.

APPARATUS:

Capacitor (about 24 µF), two resistors (about 1 MΩ and 1 kΩ),   DC power supply, double throw switch, computer and voltage sensor.

THEORY:

A useful device for storing charge and energy is the capacitor, which consists of a pair of parallel conducting sheets, closely spaced but insulated from each other. The magnitude of the charge on either conductor is proportional to the voltage across the two conductors. The ratio of the charge to the voltage is called the capacitance:

$$C = Q / V \qquad\qquad\qquad (1)$$

 Capacitors have many uses ranging from storage of energy and charge, electronic tuning, filtering of high frequencies, constructing delay lines, oscillation tanks, pulse shaping, voltage doubling. AC coupling and so on.

As shown in Figure 1, the capacitor C charged to a voltage V_0 will start to discharge through the resistor R as soon as the switch is turned on.
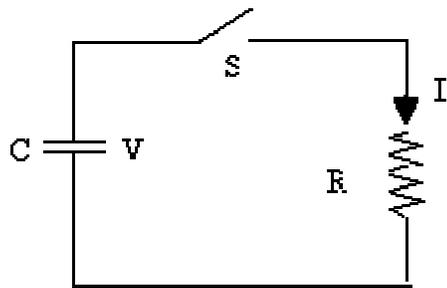

Figure 1

According to Kirchhoff's loop rule, the sum of the potential differences for a complete loop is zero:

$$V + I R = Q / C + I R = 0 \qquad (2)$$

Since $I = dQ/dt$, we have a differential equation of the first order:

$$(RC) \, dQ + Q \, dt = 0 \qquad (3)$$

with the initial condition that $Q_0 = C \, V_0$. The solution to Eq.(3) is

$$Q(t) = C \, V_0 \, \exp[- t / \tau] \qquad (4)$$

and

$$V(t) = Q(t) / C = V_0 \, \exp[- t / \tau] \qquad (5)$$

where $\tau = RC$ is called the time constant. It is the time for the voltage across the capacitor to reduce to $1/e$ (0.368) of its original value. After 3 time constants, only 5% of voltage is left. The voltage is practically zero after 10 time constants.

It can be shown in a like fashion that for a charging circuit of Fig. 2, the voltage across the capacitor is given by

$$V(t) = Q(t) / C = V_0 \, (1 - \exp[- t / \tau]) \qquad (6)$$
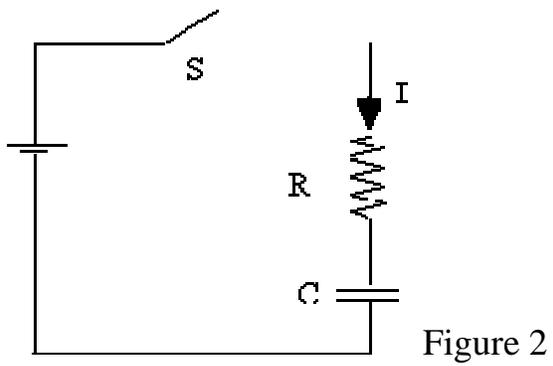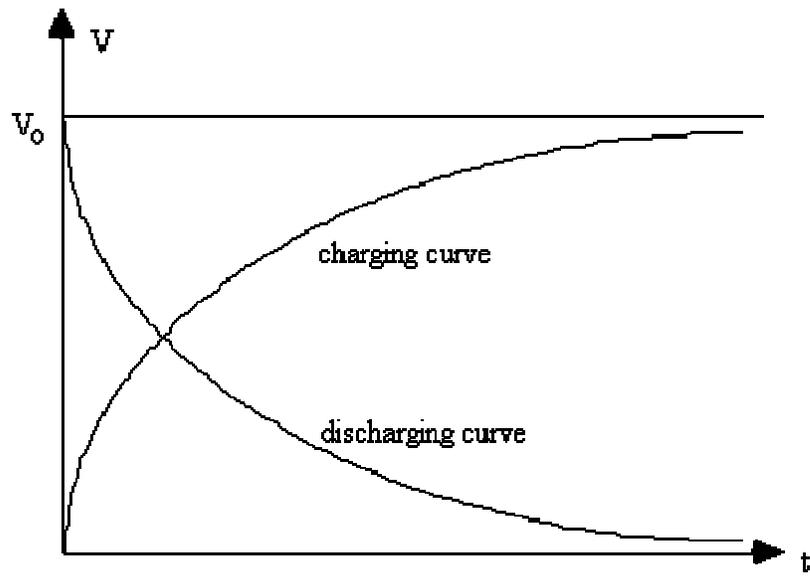
Figure 2

Fig. 3 shows the exponential curves of the discharging and the charging circuits.
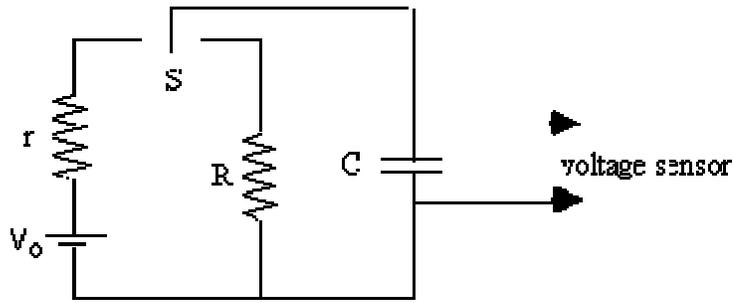

Figure 3

PROCEDURE:

1. Construct a circuit shown below.

Figure 4

2. Set up the computer system and open the appropriate program to run "RC Circuits". Set the voltage axis to 5 V and the time axis to 60 seconds. You can always change the range such that the exponential decay curve fills up the whole screen.

3. Turn on the power supply and set at about 4 V. Switch to the power supply to charge the capacitor. Since the charging resistor r has small resistance (about a few kΩ). It should take only a split of a second to charge up the capacitor to the full voltage of the power supply.

4. Then simultaneously switch the capacitor to the discharging resistor and click the "Start" or "collect" button to start collecting data. An exponential curve should show the remaining voltage across the capacitor. When the voltage is less than 10% or so, click "Stop" button.

5. Fit the curve to a natural exponential function of Equation (5). Find the decay constant τ from the results of the curve fitting. Calculate the resistance. The capacitance can be read from the capacitor.

6. Get a hard copy of the plot and the curve fitting data. Include it as a part of your data analysis.

7. The resistance obtained in step 5 is actually the combined resistance of the resistor R and the input impedance of the sampling circuit of the voltage sensor, which is usually quite high. You can measure the input impedance by measuring the RC constant. To do this, simply disconnect the resistor R and repeat steps 3 to 6. Since the R is not there, you need only to switch the capacitor to the power supply to charge up, then open the switch and click "Start" or "Collect".

DATA ANALYSIS:

1.How do you estimate the error in resistance ?