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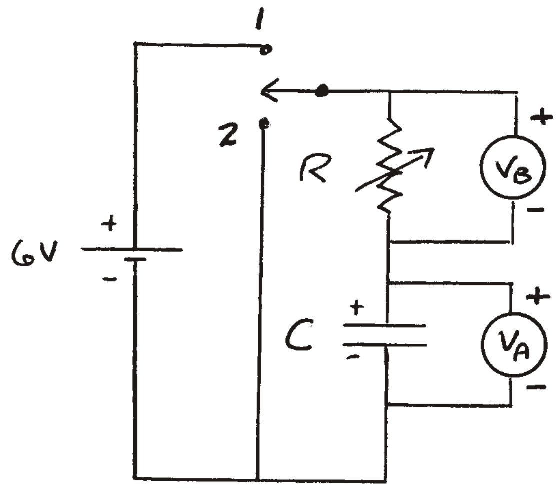
Experiment: Capacitor Charge and Discharge

Objective: To study the charging and discharging of capacitors in a RC circuit.

Part A: Charging and Discharging Curve

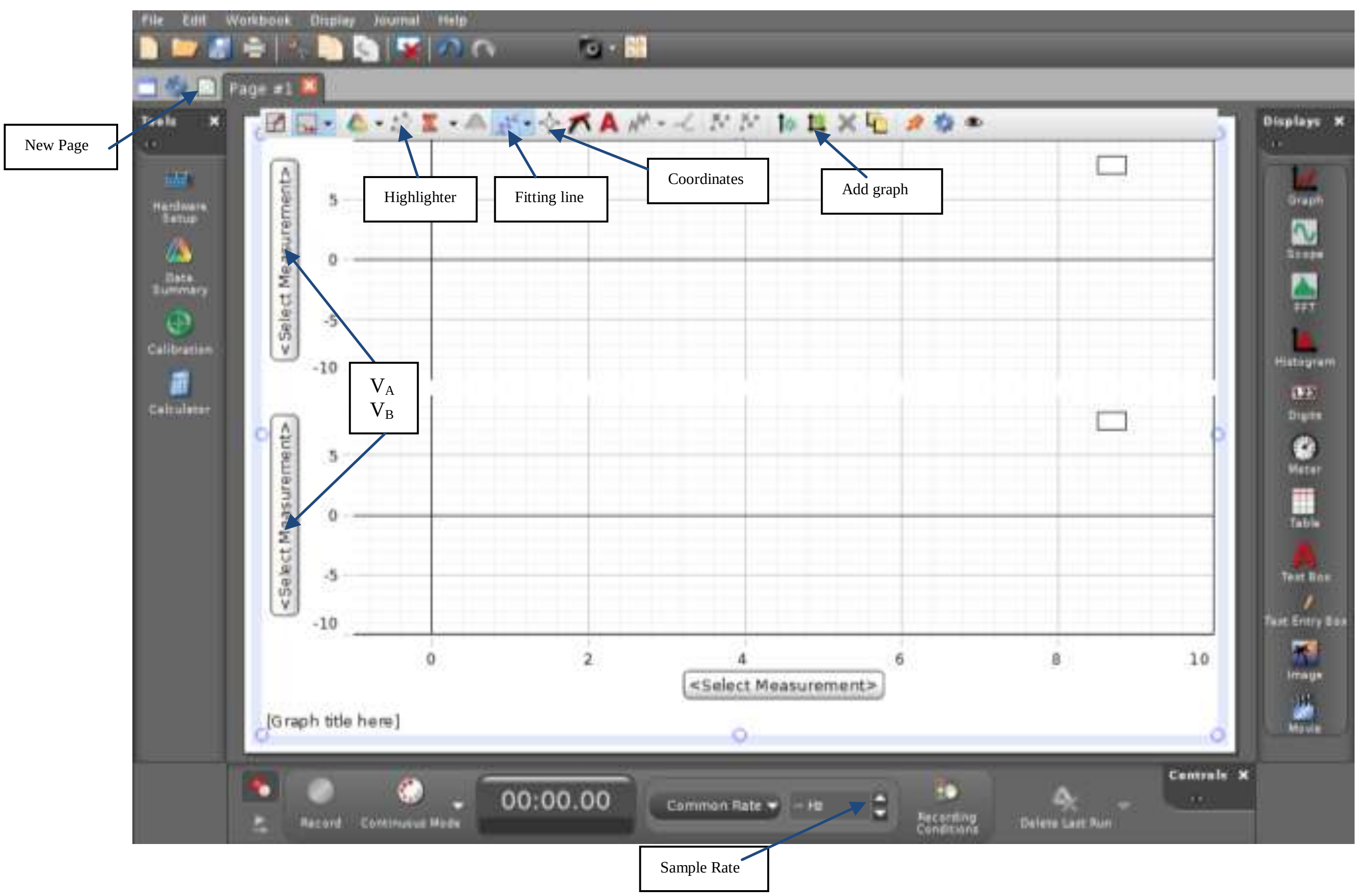
Procedure:

1) Connect the circuit as shown. ***C = 1000 μF*** and **R** is a decade resistance box set initially at ***1 kΩ*** . The single pole double throw switch allows you to change the connection from position 1 to position 2. In position 1, the ***6 -12 volt source (****battery or power supply****)*** charges the capacitor C through the resistor R. In position 2, the source is switched off the circuit and the capacitor discharges through the same resistor R. V_A is a voltage probe connected to input A and V_B is a probe connected to input B on the interface.



Important: *TURN ON THE INTERFACE BEFORE CONNECTING WIRES AND STARTING CAPSTONE SOFTWARE.*

2) Open the software "Pasco Capstone" on the desktop. Refer to the shown screenshot to find the tools needed for the following steps.



3) Fix the two connectors at outlets "A" and "B" of interface. Click on the blue icon "Hardware setup" to activate the two voltage sensors by selecting "Voltage Sensor" from the menu window. At the bottom of screen, change the sample rate from *20 Hz* to **100Hz(**or 200Hz**)** for each of them.

3) Open the **calculator** window. Define a function ***i* = V_B/1000,** click on ***accept*** or type on ***enter*** ; this will produce a set of data for "***i*** " variable i.e. the current in circuit (equal to $\mathbf{i_R} = V_R / 1000$).

4) Set up a window that *displays simultaneously three graphs as a function of time*, $\mathbf{V_C}$, $\mathbf{V_R}$ and ***i*** . Assign sensor $\mathbf{V_A}$ for " $\mathbf{V_C}$ " , sensor $\mathbf{V_B}$ for " $\mathbf{V_R}$ " and function ***i*** for " $\boldsymbol{i_R}$ " *graph*. To show graphs on the screen, double click "Graph". Then, click twice on "Add graph" to have three graphs in display. Click on "Select Measurement" and choose $\mathbf{V_A}$ for the first, $\mathbf{V_B}$ for the second and ***i*** for the third graph from the menu.

CHARGING and DISCHARGING C

5) Put the switch in position 2 and wait for a few seconds to make sure that capacitor is not charged. Next, click on **Record** to start collecting data. Immediately after that, put the switch to position 1. The voltage of capacitor will increase. After a while V_A reaches a value $\mathbf{V_{max}}$ and remains constant.

6) Then, turn the switch back to position 2, wait until V_A has returned to zero and click **on Stop**. The first graph, at top of screen , i.e. V_A or $V_C=V_C(t)$ should appear as shown below. Print the three graphs on the screen together and label their Oy axes as V_C, V_R , i_R.

7) Next, delete the window with three graphs and record another time ***only the graph V_A***.

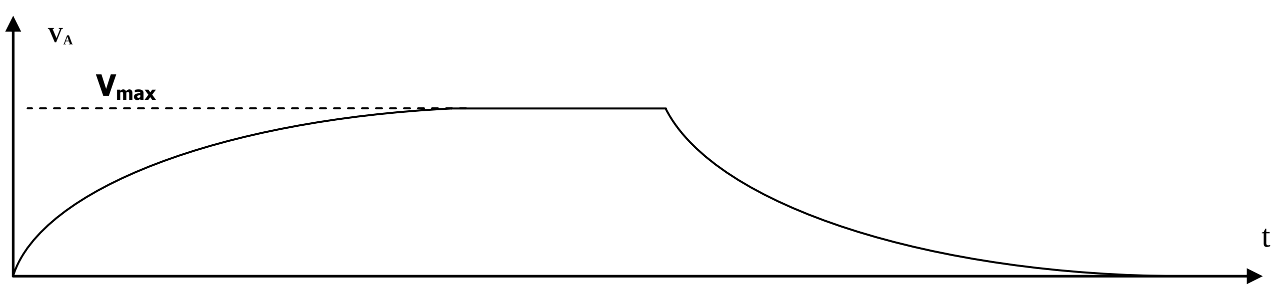


Figure 1

BASIC FORMULAS

During **charging** of **C** $\qquad \boldsymbol{V_C = V_{max}[1 - exp(-t/\tau)]}$ **and** $\boldsymbol{i_R = I_{max} exp(-t/\tau)}$

During **discharging** of **C** $\qquad \boldsymbol{V_C = V_{max} exp(-t/\tau)}$ **and** $\boldsymbol{i_R = -I_{max} exp(-t/\tau)}$

" - " shows that the current flows through resistor in opposite direction versus charging process.

$\tau = RC$ is the time constant of RC circuit and $T_{1/2} = 0.693 * \tau$

ANALYSIS

1) ***Measuring $T_{1/2}$ from recorded graph***

1.a Adjust the scales so that you are looking only at the first ***part of the graph*** V_A vs t (fig.1) where the ***capacitor is charging.*** Use the "**Coordinate** " tool to determine the maximum value (**V_O**) of voltage across the capacitor and then to get ***the time it takes*** for the voltage across the capacitor to increase

from ***0*** to **½ V_O**,
from ***½ V_O*** to ***3/4 V_O***
from ***3/4 V_O*** to ***7/8 V_O***.

1.b With same graph on screen (V_A vs t,) use the " ZOOM SELECT " or manually adjust the scales to display only the **part of the graph** where the capacitor ***is discharging*** *(decreasing part)*. Use the "**Coordinate** " tool to determine the time it takes for the voltage across the capacitor

to drop from **V_O** to **½ V_O** (this is called the half life $T_{½}$).
to drop from **½ V_O** to **V_O/4**
to drop from **V_O /4** to **V_O/8**

Also, record the time it takes to drop from **V_O** to **V_O** / e.
Write these times in a table on your data sheet.

N.B. It may happen that the exact value of voltage you are looking for is not recorded. In this case, you have to interpolate between two surrounding values that appear on graph to record the corresponding time. Otherwise, you may increase the recording rate and repeat the recording of the graph V_A=V_A(t). When you are done with all recordings, print the graph on screen and follow in part 1.c.

1.c Measuring the time constant from the discharging graph. Use the same graph of Va as in 1.b.
Click on the ***calculator***, write **y=** , click on function ***Ln(x)*** and get **y= *Ln(x).*** Follow inside the brackets ( ) by a right-click & input data & select **Va.** Then, click on ***accept*** to define the function ***y=Ln(Va).*** This way you will produce a set of data for **y**-variable. Open a new window containing the graph V=V_A(t) . Add downside another graph area, select **y** as a "measurement variable"; the graph **y=Ln(Va)** will appear. Next, click on the area of graph **y=Ln(Va),** then click on "**highlighter**" tool and select a *good straight part* of this graph inside the highlighter rectangle. Click on the ***Fitting function*** button on top of window, select "Linear" function ***mt+b;*** a box with ***m*** and ***b*** values will appear. *Note that it is very important to select the correct part of the data; otherwise, the computer will attempt to fit a straight line to the entire data set which may introduce errors*. When satisfied, print this graph with fitting line on it. Note the value of **the slope = m.** The **time constant** of RC circuit is ***τ = -1/slope***. Next, calculate the **half life** of the discharging curve from the time constant as ***$T_{1/2}$ =0 .693* τ.*** Compare this value to **$T_{1/2}$** measured directly (1.a & 1.b) on the graph.

Conclusions:

1) What is the relationship between the current in circuit and voltage of the capacitor ? (Think about how each of these is related to the charge on the capacitor " Q ") Do your graphs demonstrate this relationship? How?
2) Compare the maximum current I_{Max} to V_O / R. Is this what you expect?
3) Comment on all the time intervals measured in steps 1 and 2. Is the half-life for the discharging part of the curve the same as that for the charging part?
4) Does the discharging part of the graph V_A = V_A(t) follow an exponential decay? How do you know? Do the data start to deviate from the exponential decay at any point? Where?
5) Does the half-life calculated from the time constant τ at 1.c agree with the half-life measurements in steps 1 and 2 of the analysis?

Part B: Dependence of Time Constant on R and C

Measuring time constant τ *for different values of* ***R*** *but keeping* ***constant C =1000* µF**

1) Change the resistance of decade resistance box to ***300 Ω*** and collect a new set of data for charging and discharging the capacitor $\mathbf{V_A}$. Use the same method as at (1.c) for getting the slope of graph y=Ln(V_A) and calculating τ_{measured} . Otherwise, use "**Coordinate** " tool to measure the time constant τ_{measured} from the discharging part of the curve by finding ***the time*** it takes the voltage to drop from V_0 to V_0/e . Write the value τ_{measured} in a table#1 on your data sheet but **do not print the graph**.

2) Change the resistance in decade resistance box to **100 Ω** and repeat measurement of time constant " τ_{measured} " . Write it in table together with that measured at 1.b.

Table #1 C=1000µF

R	τ =RC	τ_{measured}
1kΩ		
300Ω		
100Ω		

Measuring time constant for different ***R*** *values with* ***C =100* µF**

3) Change the capacitance to **100 µF** and measure the time constants " τ_{measured} " for **R = 1 kΩ, 300Ω** and **100Ω**. Include the results in table#2.

Table#2 C=100µF

R	τ =RC	τ_{measured}
1kΩ		
300Ω		
100Ω		

Analysis and Conclusions:

Refer to your recorded graphs and verify if they fit to what you expect from theory.
Refer to collected numerical values and check if they fit to results of analytical relations (i.e. $\tau = RC$) to at least to two significant figures?