Lab IV - Capacitors: Charging and Discharging

Introduction

In your lecture class, you have discussed the process of placing charge on conductors and the disposition of that charge after it is placed there. Here in lab, we have measured the field and potential distribution of several different conductor shapes and positions. Now we will consider the effect of placing two conductors near one another and charging them equally.

If one conductor is connected to the positive pole of a battery, and another is connected to the other pole (the negative or ground pole), each will acquire a charge equal in magnitude and opposite in sign. There will then be a potential difference between the two conductors, roughly equal to the potential difference at the poles of the battery. Such a configuration is referred to as a capacitor. Its function is to store charge and the associated potential difference (and electrical potential energy). (The memory storage of a computer stores the “bits” of information as voltages on capacitors – you have to wait for the flash on a camera to store up energy in a capacitor before you can take a flash picture). In the course of the lab, you will charge a number of capacitors using a power supply, and then observe the process of discharging.

Discharging

Recall that to charge a conductor requires energy: adding more charge to a conductor already partially charged requires that the opposing force be overcome. Once a conductor is charged up, the charge on it wishes to leave because of the repulsive force it feels from all the other charges. The presence of the battery prevents any leakage of charge, but if the battery is disconnected, you will observe that the voltage will slowly drop, signifying that the charge is leaking off (why does one imply the other?). It seems reasonable that the rate at which the charge leaks off will be proportional to the voltage of the capacitor. That is:

\[ \frac{dq}{dt} \sim -V \]  

(1)

where the minus sign signifies that the amount of uncompensated charge on the conductor is decreasing. We know that the potential to which a conductor is raised is proportional to the charge placed on it (right?), so we can write:

\[ \frac{dq}{dt} \sim -q \]  

(2)

or, equivalently:

\[ \frac{dV}{dt} \sim -V \]  

(3)

Since we can more easily measure the voltage, we will use Eq. (3), and rewrite it as:

\[ \frac{dV}{dt} = -V / \tau \]  

(4)

where \( \tau \) is a constant of proportionality which has units of time. If these assumptions are correct, we can integrate Eq. (4) and get:
\[ V = V_0 \exp[-t/\tau] \quad (5) \]

where we have recognized that the initial voltage, \( V_0 \), occurs at \( t=0 \). That is, if our assumptions are correct, the voltage on the capacitor should decay exponentially. We will test these assumptions by testing the conclusion: i.e., does the voltage decay exponentially? Furthermore, we will vary the time constant, \( \tau \), by varying the capacitors used (and the manner in which we connect them), and attempt to draw some conclusions about the dependence of the time constant on the capacitance.

**Task 1 - Charging and discharging a single capacitor**

Wire a single capacitor as shown in the figure so that it can be charged by the power supply and the voltage simultaneously read. Disconnect the power supply and observe the decrease in voltage with time. Quantify this decrease by measuring the voltage at a series of times after disconnecting the power supply (i.e., measure \( V(t) \)). You should measure \( V(t) \) several times in order to A) obtain a consistent set of data, or B) evaluate the range of values for your data (i.e., measure the error bars). Plot \( V(t) \) (with error bars, if any) as a function of time in such a way that you can evaluate whether or not the decay is exponential. To the extent that it is, evaluate and record the time constant, \( \tau \), along with its error bars.

**Task 2 – Charging and discharging a single capacitor**

Repeat task 1) for the other capacitor.

**Task 3) Capacitors in Parallel**

Wire the capacitors in parallel as shown in the figure, and obtain a value for the time constant.

**Task 4) Capacitors in Series**

Wire the capacitors in series as shown in the figure, and obtain a value for the time constant.

**Conclusions**

Prepare a report which includes the data you measured (\( V(t) \) plots and the time constants obtained), and attempt to correlate any differences in \( \tau \) with the differences in the capacitors and the way they were wired (series or parallel). Keep in mind that your ability to correlate differences in the time constants will depend on the error bars associated with those time constants. Determine the sound of one hand clapping.
Figure 1 - Single capacitor wired up and ready to go

Figure 2 - Capacitors in Parallel

Figure 3 - Capacitors in Series