Experiment 201-3

Discharge of a Capacitor

Introduction

A simple capacitor is made of two parallel plates separated from one another by an insulating material so that no current can flow between them. The electrolytic capacitors used in this experiment are rather more complicated in their construction. Electrolytic capacitors[1] are often made with two aluminum foils, one of which is insulated with an aluminum oxide coating. The foils are separated by a paper spacer soaked in an electrolyte, and the foil-paper-foil sandwich is then rolled and fitted into a can with electrodes attached at the ends.

In a circuit like the one shown in Figure 3.1a, the potential difference applied by the power supply when the switch is closed induces a charge separation on the capacitor plates. Electrons on the plate connected to the positive terminal flow towards the power supply, and electrons flow from the negative terminal of the power supply to the other plate. Since the induced current cannot flow across the gap, a charge difference between the plates develops, resulting in a potential difference across them. The build up of charge and potential on the capacitor continues until the potential across the capacitor is equal to the emf of the battery. The charge on the capacitor remains even if the switch is then opened.

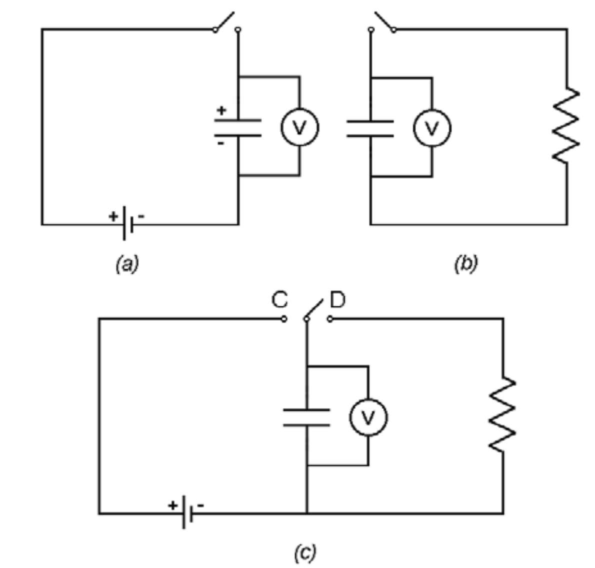

Figure 3.1 Capacitor Circuits

A capacitor may be discharged by connecting it to a resistor, as shown in Figure 3.1b. When the switch is closed, electrons flow from the negative plate of the capacitor, through the resistor to the positive plate, where they neutralize the positive charge. This process continues until the charge is completely neutralized and the capacitor is totally discharged.

The circuit shown in Figure 3.1c is a combination of the two circuits 3.1a and 3.1b. When the switch is closed in the “C” position, the battery charges the capacitor; in the “D” position, the capacitor discharges through the resistor.

Theory: It is difficult to measure the charge Q on the capacitor directly, but the voltage V across the capacitor can easily be measured with a voltmeter. The charge and voltage are related by the equation

$$Q = CV \tag{3.1}$$

[1] See, for example http://electrochem.cwru.edu/ed/encycl/art-c04-electr-cap.htm

where the constant C is called the *capacitance*. The capacitance depends upon the physical characteristics of the capacitor. The unit of charge is the *coulomb* and the unit of capacitance is the *farad*. From Equation (3.1) it can be seen that a farad (F) is one coulomb (C) per volt.

When a capacitor discharges through a resistor, both the charge and the voltage on it decrease with time. The equation relating the voltage V across a capacitor to time t is given by

$$V = V_0 \, \mathrm{e}^{kt} \tag{3.2}$$

where V_o is the initial voltage across the capacitor, e is the base of natural logarithms, and k is a negatively valued constant. The *time constant* τ of the circuit is given by

$$\tau = \left| k^{-1} \right| \tag{3.3}$$

in units of seconds. Consequently, Equation (3.2) can be written as

$$V = V_0 \, \mathrm{e}^{-t/\tau} \tag{3.4}$$

The time constant of a circuit is related to the size of the capacitor and the size of the resistor through which it is being discharged.

Purpose

The primary objective of the experiment is to determine the equations that give the voltage across a capacitor as a function of time as it discharges through different resistors. From them, the general equation showing how the discharge depends on the capacitance and the resistance will be derived. A secondary objective is to use the general equation to determine the value of a very high resistance by discharging a capacitor through it.

Procedure

Preliminary Measurements: Record the nominal capacitance written on the side of the capacitor. (The letters MF or mFd stand for microfarad; 1 μF = 10^{-6} farad). Often the nominal value is not especially accurate; the manufacturer's tolerances[2] can be larger than $\pm$ 20%. Following the instructions for the capacitance meter on the side bench, directly measure the capacitance.

Circuit Setup and Measurements: Set up the circuit shown in Figure 3.1c, using the largest of the six resistors provided. Record the value of the resistor used in the circuit.

Charge the capacitor with the switch in position **C**. Then flip the switch to position **D** to start the capacitor discharging through the resistor. Record the voltage V across the capacitor and the corresponding time for eight to ten regular time intervals, starting at t = 0. Plan your time intervals such that the voltage decreases to roughly one quarter of its original value by your final reading.

Repeat this procedure for each of the five remaining resistors on the board. The time intervals will have to be different for some of the resistors to ensure that you get enough points for the graph, but use constant intervals for each individual one.

[2] Radiotron Designer's Handbook, 4th edition, ed. F. Langford-Smith, RCA, 1953.

Experimental Equations Relating Voltage and Time: Plot a graph of the natural log of the voltage (ln *V*), versus time on semi-log graph paper. Find the slope and intercept of the resulting straight line and use these values to write an equation relating voltage and time in exponential form. If you don't know how to use semi-log graph paper, read the relevant parts of Chapter 5. Also, use the slope value in Equation (3.3) to determine the time constant τ of the circuit.

As noted in the final paragraph of the theory, the time constant is related to the capacitance and resistance in the circuit. Once this relationship is established we can use it to fulfill one of our primary objectives, i.e., to express the equation relating V and t in general terms using R and C instead of the specific numerical constants found above.

Use your results to plot a graph of the time constant versus resistance on linear paper. You should obtain a straight line that passes through the origin of the graph. Find the slope of the line. It should be equal to either some simple multiple or some simple fraction (i.e. C, $2C$, $3C$......or $1/C$, $1/2C$, $1/3C$....) of the capacitance in the circuit. Write the equation relating the time constant τ to the capacitance C and the resistance R and then rewrite Equation (3.4) using the symbols C and R in place of τ.

High Resistance: An electrostatic voltmeter is located on the side bench. It has an essentially infinite internal resistance, so it can be used to measure the voltage drop across large resistances. An 82 ± 2% pF (1 pF = 10^{-12} F) capacitor and a very high resistance (in the form of a pencil line on a paper card) are wired in parallel across the terminals of the voltmeter.

With the switch in the open position, charge the capacitor up to a voltage somewhat over 300 volts. This can be done by briskly stroking the charging rod with the piece of animal fur provided, and then by drawing the rod across the positive wire of the capacitor. You may have to repeat this several times until sufficient charge is transferred to the capacitor to exceed the required 300 volt potential.

Close the switch and time (in seconds) how long it takes for the voltage to decrease from 300 volts to 150 volts. It's not critical that these particular values be used, any two widely spaced values will do (e.g., 280 and 120 volts). Use these data in the general equation relating voltage and time to calculate the value of the very high resistance.

Some Points for Discussion

The voltmeter used to measure the voltage across the capacitor in the first part of the experiment has an internal resistance of 10 MΩ. Does this have a significant effect on the rate of discharge? Explain.

What happens to the charge on the capacitor when the switch is in the neutral position, neither in position "C" or "D"?

The slope of the time constant versus resistance graph has units of seconds per ohm. Can you show that this is equal to a farad?

References

1. Halliday, D., Resnick, R., & Krane, K. S., *Physics, Volume 2, 5th edition, Chapter 31, pp. 713–716*