

Topics: RC Circuits

Related Reading:

Course Notes (Liao et al.): Chapter 7
Serway and Jewett: Chapter 26
Giancoli: Chapter 24

Experiments: (4) RC Circuits

Topic Introduction

Today we will continue our discussion of circuits, and see what happens when we include capacitors.

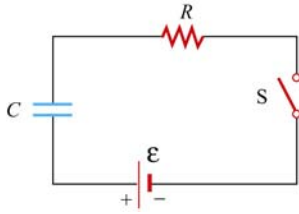
Circuits

Remember that the fundamental new concept when discussing circuits is that, as opposed to when we were discussing electrostatics, charges are now allowed to flow. The amount of flow is referred to as the current. A circuit can be considered to consist of two types of objects: nodes and branches. The current is constant through any branch, because it has nowhere else to go. Charges can't sit down and take a break – there is always another charge behind them pushing them along. At nodes, however, charges have a choice. However the sum of the currents entering a node is equal to the sum of the currents exiting a node – all charges come from somewhere and go somewhere.

In the last class we talked about batteries, which can lift the potentials of charges (like a ski lift carrying them from the bottom to the top of a mountain), and resistors, which reduce the potential of charges traveling through them.

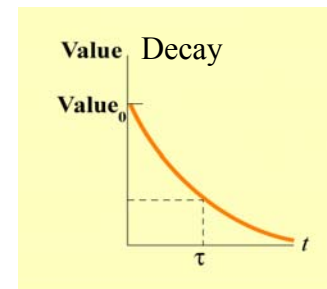
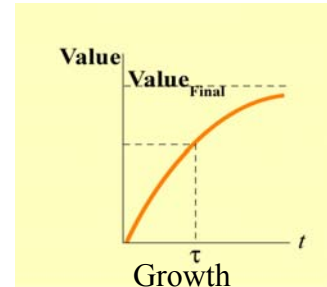
When we first discussed capacitors, we stressed their ability to store charge, because the charges on one plate have no way of getting to the other plate. They perform this same role in circuits. There is no current *through* a capacitor – all the charges entering one plate of a capacitor simply end up getting stopped there. *However*, at the same time that those charges flow in, an equal number of charges flow off of the other plate, maintaining the current in the branch. This is important: the current is the **same** on either side of the capacitor, there just isn't any current inside the capacitor.

A capacitor is fundamentally different in this way from a resistor and battery. As more current flows to the capacitor, more charge builds up on its plates, and it becomes more and more difficult to charge it (the potential difference across it increases). Eventually, when the potential across the capacitor becomes equal to the potential driving the current (say, from a battery), the current stops. Thus putting a capacitor in a circuit introduces a time-dependence to the current flow.



A simple RC circuit (a circuit with a battery, resistor, capacitor and switch) is shown at the top of the next page. When the switch is closed, current will flow in the circuit, but as time goes on this current will decrease. We can write down the differential equation for current flow by writing down Kirchoff's loop rules, recalling that $|\Delta V| = Q/C$ for a capacitor and that the charge Q on the capacitor is related to current flowing in the circuit by $I = \pm dQ/dt$, where the sign depends on whether the current is flowing into the positively charged plate (+) or the negatively charged plate (-). We won't do this here, but the solution to this differential equation shows that the current decreases exponentially from its initial value while the potential on the capacitor grows exponentially to its final value. In fact, in RC circuits any value that you could ask about (potential drop across the resistor, across the capacitor, ...) either grows or decays exponentially. The rate at which this change happens is dictated by the "time constant" τ , which for this simple circuit is given by $\tau = RC$.

Once the current stops what can happen? We have now charged the capacitor, and the energy and charge stored is ready to escape. If we short out the battery (by replacing it with a wire, for example) the charge will flow right back off (in the opposite direction it flowed on) with the potential on the capacitor now decaying exponentially (along with the current) until all the charge has left and the capacitor is discharged. If the resistor is very small so that the time constant is small, this discharge can be very fast and – like the demo a couple weeks ago – explosive.



Important Equations

Exponential Decay: $Value = Value_{initial} e^{-t/\tau}$

Exponential Increase: $Value = Value_{final} (1 - e^{-t/\tau})$

Simple RC Time Constant: $\tau = RC$

Experiment 4: RC Circuits

Preparation: Read lab write-up.

This lab will allow you to explore the phenomena described above in a real circuit that you build with resistors and capacitors. You will gain experience with measuring potential (a voltmeter needs to be in *parallel* with the element we are measuring the potential drop *across*) and current (an ammeter needs to be in *series* with the element we are measuring the current *through*). You will also learn how to measure time constants (think about this before class please) and see how changing circuit elements can change the time constant.