<u>First:</u> demonstrate the charging of a capacitor with the provided 1 Fahrad capacitor. Charge the capacitor with the provided 9 volt battery. Once it is charged, use the charged capacitor to switch on a little LED-lamp. With a little bit of luck you can have the LED lamp illuminate for more than a minute. We use an LED-lamp as it is very efficient and only requires a small current. You might need to switch off the light in the room. Emphasize that a capacitor can be used to store charge or store energy, that is released later. Large capacitors are nowadays used in electric cars next to the batteries. So capacitors can store energy, just like rechargeable batteries. Capacitors however can release their energy much faster. Also capacitors can be charged and recharged more than a million times without loosing its properties. Rechargeable batteries loose most of their power after 1000 charge-discharge cycles.

Capacitors are also used in memory chips to store information. Such memory is called DRAM and can be found in every personal computer.

<u>Second discuss our water model:</u> Consider that a large water reservoir is connected via a narrow tube to a large test tube. On the left side of the tube is a valve that is closed. Assume that the test tube on the right is empty. If one opens the valve, water will flow in the test tube. Because of this the water level in the test tube rises. The flow of water through the tube will stop when the water level in the test tube is the same as the water level in the large water reservoir. We say that the test tube is full. We assume that the water reservoir is much, much larger than the test tube, so the water level in the water reservoir can be considered to be constant.

Note that when the tube between the water reservoir and the test tube is shorter and has a larger diameter, the filling of the test tube will go faster. Also when the test tube is smaller the filling of the test tube will be faster.
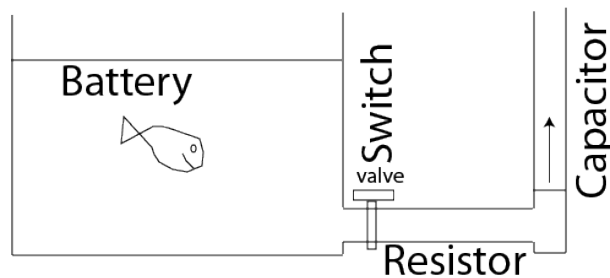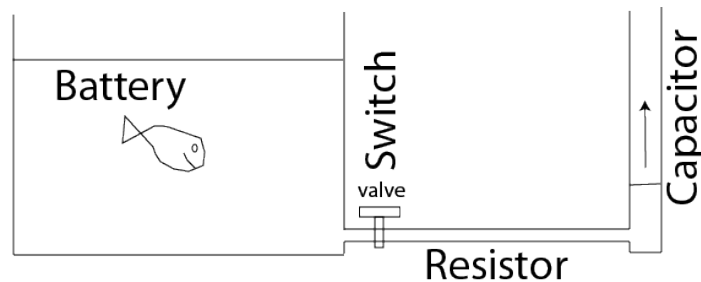
Third: now introduce the RC circuit: This water model is equivalent with the RC circuit shown below. Assume that initially the capacitor is not charged and that the switch is flipped up at t=0. So from t=0 the battery will start to charge the capacitor. Positive charge moves from the positive pole of the battery to the top plate of the capacitor. So the top plate of the capacitor will become positively charged. Positive charges flow also from the bottom plate of the capacitor but now to the negative pole of the battery. As the bottom plate was neutral before we flipped the switch and loses positive charge, it becomes negatively charged. Since charge moves from the positive pole of the battery to the top plate, we have a current going through the resistor.
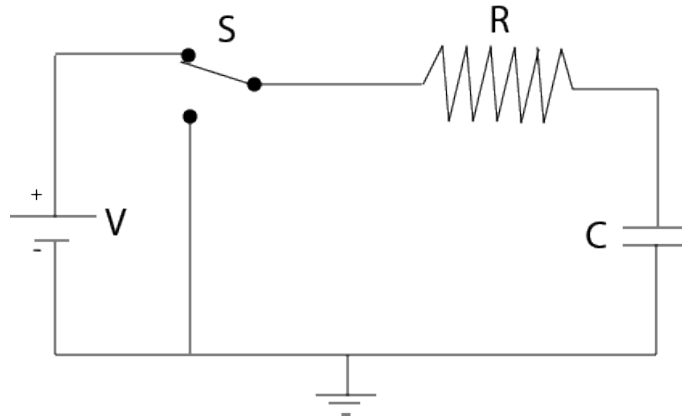
As more and more charge will accumulate on the capacitor, the electric potential difference across its terminals increases, $Q=CV_c$. Once the capacitor is completely charged the charge transport will stop. So there will no longer be a current going through R. Since i=0 through the resistor, there is not electric potential difference across the resistor and the voltage across the capacitor will be equal to the battery voltage. The smaller the resistor, the faster the capacitor will be fully charged. Also the smaller the capacitor, the faster the capacitor will be charged.

Once the capacitor is fully charged, I could flip the switch S down. The battery is now disconnected from the circuit. Positive charge on the top plate of the capacitor can now travel through the resistor to the bottom plate. We call this process the discharging process of the capacitor. Again if the resistor is small, this discharging process happens quickly. For a large resistance values, it might take a while before the capacitor is completely discharged. Using the equation of the resistor, V=iR, and the equation of the capacitor, Q=CV, It is now possible to calculate how the charge on the capacitor plates decreases as a function of the time. I redrew the circuit below.
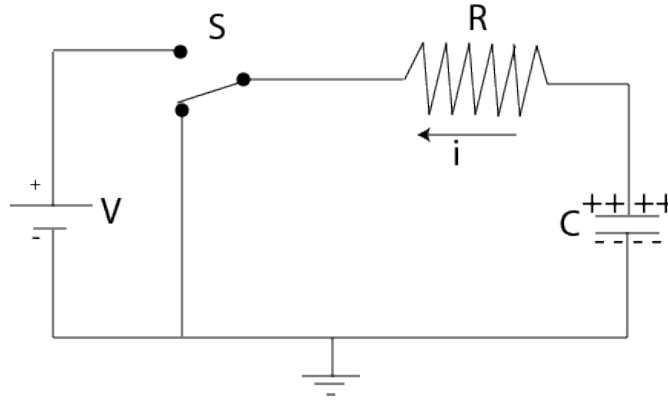
<u>Fourth: Do the math:</u> Now let us do Kirchhoff's voltage law on the mesh. Going counter clockwise gives us first the voltage across the capacitor which depends on the charge in the capacitor, so Q/C. Then we go through the resistor in the direction of the current, so that is a voltage drop, so –iR. Note that i is the discharge current, or the rate with which the charge on the capacitor decreases, so i=-dQ/dt :

$$\frac{Q}{C} - iR = 0 \Leftrightarrow \frac{Q}{C} + \frac{dQ}{dt}R = 0 \Leftrightarrow \frac{Q}{C} = -\frac{dQ}{dt}R \Leftrightarrow \frac{dQ}{dt} = -\frac{Q}{RC}$$

(1)

This is a new type of equation for us. It contains and parameter Q and its derivative towards the time, so Q and dQ/dt. We call this a differential equation. You will learn to solve differential equations in differential equation. This one is not too difficult for us though. We are looking for a function Q(t) whose derivative is equal to the function itself times a constant. For which function does the function and its derivative look the same?

The derivative of an exponential function is again a exponential so the following function is a good choice:

$$Q(t) = Ae^{\alpha t}$$

Plugging this trial solution in differential equation (1) gives:

$$\alpha Ae^{\alpha t} = -\frac{Ae^{-\alpha t}}{RC}$$

Dividing both sides by A and the exponential terms gives:

$$\alpha = -\frac{1}{RC}$$

Or in other words the discharging of the capacitor can be described by the following equation:

$$Q(t) = Ae^{-\frac{t}{RC}} = Q_o e^{-\frac{t}{RC}}$$

Where Q_o is the initial charge on the capacitor. This is an exponentially decaying function. See fig. 27.16b. Note that for t=RC the charge on the capacitor will be reduced to 37% of Q_o. For t=5RC the charge on the plates will be reduced to 0.6% of Q_o.