  Graphical Analysis 24

Capacitors

The charge q on a capacitor’s plate is proportional to the potential difference V across the capacitor. We express this relationship with



where C is a proportionality constant known as the capacitance. The unit used for capacitance is the farad, F (1 farad = 1 coulomb/volt).

If a capacitor of capacitance C (in farads), initially charged to a potential V0 (in volts) is connected across a resistor R (in ohms), a time-dependent current will flow according to Ohm’s law. This situation is shown by the RC (resistor-capacitor) circuit below when the switch is connecting terminals 33 and 34.

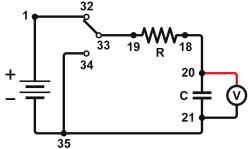


Figure 1

As the charge flows, the charge q on the capacitor is depleted, reducing the potential across the capacitor, which in turn reduces the current. This process creates an exponentially decreasing current, modeled by



The rate of the decrease is determined by the product RC, known as the time constant of the circuit. A large time constant means that the capacitor will discharge slowly.

objectives

* Experimentally determine the time constant of a resistor-capacitor circuit.
* Compare the time constant to the value predicted from the component values of the resistance and capacitance.
* Measure the potential across a capacitor as a function of time as it discharges.
* Fit an exponential function to the data. One of the fit parameters corresponds to an experimental time constant.

Materials

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct Voltage

connecting wires with clips

Vernier Circuit Board 2 with batteries or

   10 μF non-polarized capacitor

   100 kΩ and 47 kΩ resistors

   two C- or D-cell batteries with holder

   single-pole, double-throw switch

Preliminary questions

1. Consider a candy jar, initially with 1000 candies. You walk past it once each hour. Since you do not want anyone to notice that you are taking candy, each time you take only 10% of the candies remaining in the jar. Sketch a graph of the number of candies for a few hours.
2. How would the graph change if instead of removing 10% of the candies, you removed 20%? Sketch your new graph.

Procedure

1. Set up the equipment.
   1. Connect the circuit using the 10 μF capacitor and the 100 kΩ resistor, as shown in Figure 1. Note: The numbers in the figure refer to the numbered terminals on the Vernier Circuit Board.
   2. Record the values of your resistor and capacitor in your data table, as well as any tolerance values marked on them.
   3. Launch Graphical Analysis. Connect the Go Direct Voltage Probe to your Chromebook, computer, or mobile device.
   4. Connect the clip leads on the voltage probe across the capacitor. Note: Connect the red lead to the side of the capacitor connected to the resistor. Connect the black lead to the other side of the capacitor.
   5. Set Switch 1, SW1, located below the battery holder on the Vernier Circuit Board, to 3.0 V.
2. Monitor the input to determine the maximum voltage your battery produces.
   1. Set Switch 2, SW2, to charge the capacitor for 10 seconds (so the switch is closer to terminal 32).
   2. Watch the reading on the screen and record the maximum value reached. You will use this value in the next step.
3. Set up Graphical Analysis for triggering and data collection. In this mode you will not have to manually synchronize data collection and the capacitor discharge. Instead, Graphical Analysis will wait for the voltage to reach a certain level before collecting data.
   1. Click or tap Mode to open Data Collection Settings.
   2. Change Rate to 200 samples/s and End Collection to 4 s.
   3. Change Start Collection to start data collection on a triggering event rather than manually.
   4. Then, adjust the triggering settings so that data collection starts when voltage is decreasing. Enter a trigger level of 90% of the maximum voltage you observed in Step 2. This means that data collection will begin when voltage decreases across this trigger level.
   5. Use 0 as the number of points collected before data collection is triggered.
   6. Click or tap Done.
4. Collect data.
   1. Click or tap Collect to start data collection.
   2. Flip Switch 2 to discharge the capacitor.
   3. Graphical Analysis waits for the measured voltage to reach the trigger level before collecting data. After data collection is complete, a graph of voltage vs. time is displayed.
5. Fit the exponential function, y = a•exp(–cx) + b, to your data.
   1. Click or tap Graph Tools, , and choose Apply Curve Fit.
   2. Select Natural Exponent as the curve fit and click or tap Apply.
   3. Record the value of the fit parameters in your data table. Notice that the c used in the curve fit is not the same as the C representing capacitance. Compare the fit equation to the mathematical model for a capacitor discharge proposed in the introduction.



How is fit constant c related to the time constant of the circuit, which was defined in the introduction?

1. Export, print, or sketch the graph of voltage vs. time.
2. Replace the 100 kΩ resistor with a 47 kΩ resistor in the circuit and repeat Steps 2–6.

Data Table

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trial | Fit parameters | | | | Resistor | Capacitor | Time constant |
|  | a | b | c | 1/c | R (Ω) | C (F) | RC (s) |
| Discharge 1 |  |  |  |  |  |  |  |
| Discharge 2 |  |  |  |  |  |  |  |

Analysis

1. In the data table, calculate the time constant of the circuit used; that is, the product of resistance in ohms and capacitance in farads. Note: 1Ω•F = 1 s
2. Calculate and enter in the data table the inverse of the fit constant c for each trial. Now compare each of these values to the time constant of your circuit. How is the fit parameter a related to your experiment?
3. Resistors and capacitors are not marked with their exact values, but only approximate values with a tolerance. Determine the tolerance of the resistors and capacitors you are using. If there is a discrepancy between the two quantities compared in Question 2, can the tolerance values explain the difference?
4. What was the effect of reducing the resistance of the resistor on the way the capacitor discharged?

Extensions

1. What fraction of the initial potential remains after one time constant has passed? After two time constants? Three?
2. Instead of a resistor, use a small flashlight bulb. To light the bulb for a perceptible time, use a large capacitor (approximately 1 F). Collect data. Explain the shape of the graph.
3. Try different value resistors and capacitors and see how the capacitor discharge curves change.
4. Try two 10 μF capacitors in parallel. Predict what happens to the time constant. Repeat the discharge measurement and determine the time constant of the new circuit using a curve fit.
5. Try two 10 µF capacitors in series. Predict what will happen to the time constant. Repeat the discharge measurement and determine the time constant for the new circuit using a curve fit.
6. Make a plot of ln(V) vs. time for the capacitor discharge. What is the meaning of the slope of this plot? How is it related to the RC constant?