Performance:
Report:

Total:

Physics 212-3

Simple Circuits

NAME: ______________________________ ☐

STUDENT ID ______________________________ ☐

LAB PARTNER(S): ______________________________ ☐

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Check the box next to the name of the person to whose report your group's data will be attached.

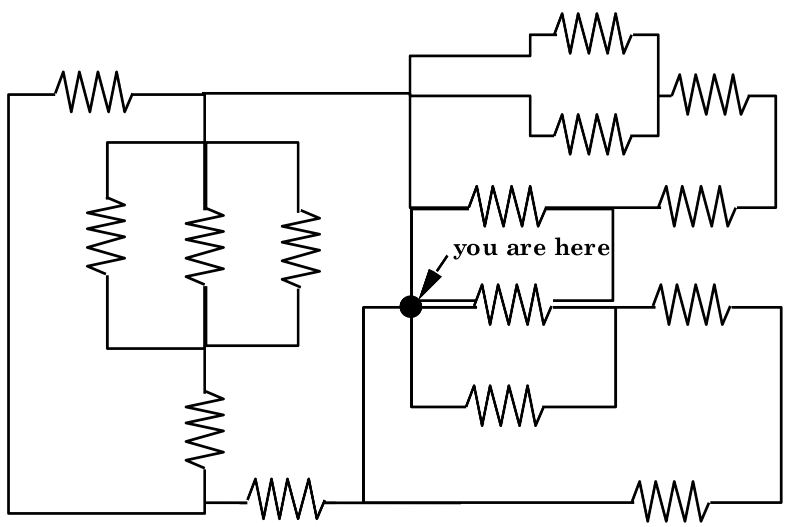
LAB SECTION: ________________________

INSTRACTOR: ________________________

DATE: ________________________

TABLE: ________________________

(YOU WILL BE TAKEN 3 POINTS IF TABLE IS VACANT.)



Physics Lab 212-3

Equipment List
Sparklink Air interface
Current-Voltage probes
DC Power Supply
Digital Multimeter (DMM)
Circuit board
2 Toggle switches mounted on dual banana plugs
One light bulb mounted on dual banana plug
5 resistors, mounted on dual banana plugs
Two 100 microfarad (μF) capacitors mounted on dual banana plugs
1 Ω resistor and 1 MΩ resistor
1 microampere

Computer File List
Capstone file "212-03 Capacitor Charge"

Physics Lab 212-3

Simple Circuits

Investigation 1: Current and Resistance

To find out
- How combinations of resistors can be reduced to an effective equivalent resistance.

Preview
- Build complex networks of resistors and explore their equivalent resistance.

Note: take care not to short-circuit the DC power supply!

Activity 1 Measuring Resistance

You will use a Digital Multimeter (DMM) as an Ohmmeter to make the measurements in this activity.

To make wiring easier, you can design circuit on the circuit board illustration in figure 1. This circuit board could be used on building circuit by standard "banana plug" hardware. **Note, the black line on the *circuit* board indicates the connection between holes, if no black line, then no connection between them.** All connections are to be made on the top side of the board. These are just holes into which you can insert the ends of banana plugs.

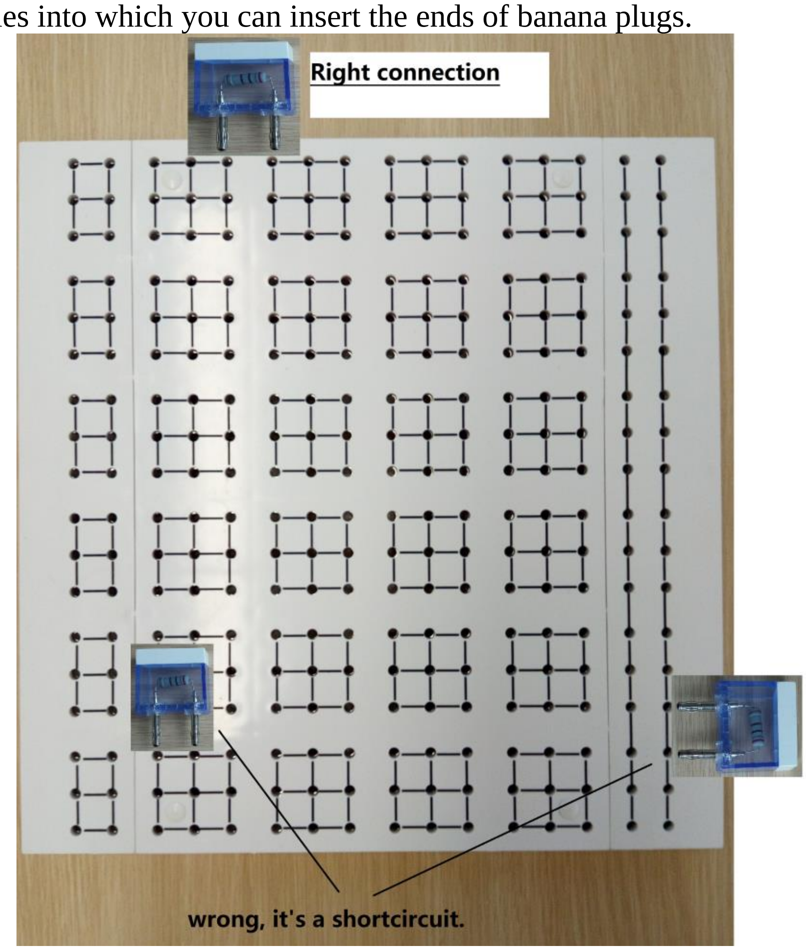


Figure 1. An example of connection.

Important Tip: You will find it *much* easier to construct your circuits if you build them *first* without any measuring devices in place. Add in your current meter or voltage probes *after* you have wired the circuit. It is easy to become confused if you add in too many elements right from the start!

To draw circuits like those you see in textbooks you need to use a few standard symbols. Table 1 is designed to help you make the translations between both real objects (batteries, bulbs, switches) and their standard symbols. Further, the circuit components we have available may have yet a third look. Have a look and find some of the stuff *in* Table 1 and *on* the table in front of you.

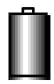
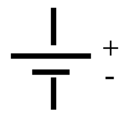
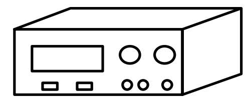
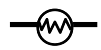
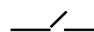
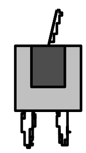
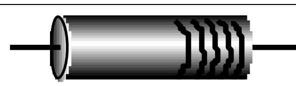
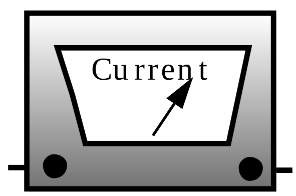
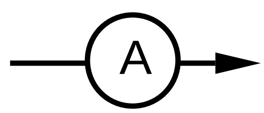
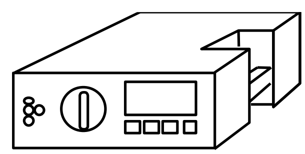
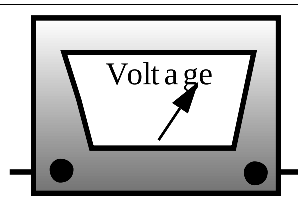
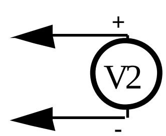
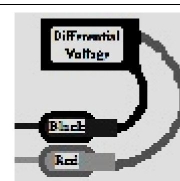
ITEM	Generic Look	Standard Symbol	Our look
Battery or power supply			
Bulb			
Switch			
Resistor			
Current Meter			
Voltage Probe			
Connectors			

Table 1. Non-periodic table of the elements

1. Gather materials. You will need:

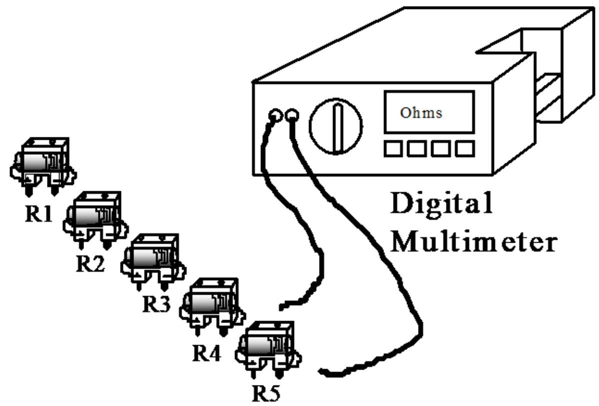


Figure 2. Equipment for Activity 1

2. Measure your reference set of resistors.
   • Use the DMM in Ohm (Ω) mode and record the resistance values in Table 2. (Ignore the label on the resistor and choose any 5 resistors.)

Name	Measured R [Ω]
R1	
R2	
R3	
R4	
R5	

Table 2. Resistance values

Ohm's Law gives the relation between the voltage across a circuit element and the current through that element for any given voltage. This expression defines the quantity called "resistance" (R).

$$V = IR \qquad \text{(Eq. 1)}$$

Q1 Given Ohm's Law in Equation 1, can you speculate how the digital multimeter determines a value for resistance?

____

____

____

This can have important consequences. **You should be careful if you hook an ohmmeter to a sensitive circuit (such as a computer chip); <u>the current from the ohmmeter might damage the circuit.</u>**

Sometimes a two-terminal portion of a circuit consists solely of a network of resistors. You can simplify that part of the circuit by computing an *equivalent resistance* of the network using the laws for series and parallel equivalent resistance.

An easy way to interpret and remember the series and parallel equivalence rules is to use the following simple relation: for cylindrical ohmic conductors, resistance is proportional to the length l and inversely proportional to the cross-sectional area A. Specifically,

$$R = \rho \frac{l}{A} \qquad \text{(Eq. 2)}$$

where ρ the resistivity, is a constant characteristic of the material.

3. Start out easy.
    - Pick any three of your resistors and connect them in series, as shown in the margin. You can do this on the *circuit* board if you wish.

Theory Calculation

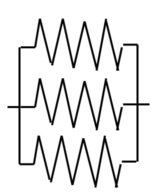
What is the equivalent resistance of these three resistors connected in series?

Resistor R___ = ___________ [Ω] Note: using measured value, same below.
Resistor R___ = ___________ [Ω]
Resistor R___ = ___________ [Ω]

R_{series} = ____________ [Ω]

4. Measure it.
    - Use your DMM to measure the resistance from one end of the network to the other (**here you may need a banana-plug wire**).

Measured R_{series} = ____________ [Ω]



5. A bit harder now.
    - Pick any three resistors from your set and assemble them in parallel, as shown in the margin (←).

Theory Calculation

What is the equivalent resistance of these three resistors connected in parallel?

Resistor R___ = ___________ [Ω] Note: using measured value, same below.

Resistor R___ = ___________ [Ω]

Resistor R___ = ___________ [Ω]

$R_{parallel}$ = ____________ [Ω]

6. Measure it.
   - Use your DMM to measure the resistance from one end of the network to the other.

Measured $R_{parallel}$ =____________ [Ω]

Q2 How closely do your predictions for adding resistors in series and in parallel agree with your measurements? Give absolute and percentage differences for both cases.

____

____

The resistivity equation (Eq. 2) actually allows us to *derive* the rules for adding resistors in series ($R = R_1 + R_2$) and in parallel ($1/R = 1/R_1 + 1/R_2$)! The next two questions indicate how this derivation is accomplished.

Q3 When connecting identical resistors in series, what are you effectively changing in the resistivity equation (Eq. 2)?

____

____

____

Q4 When connecting identical resistors in parallel, what are you effectively changing in the resistivity equation (Eq. 2)?

____

____

____

A challenging exercise is presented in Figure 3. Try to work on your own to analyze its equivalent resistance. Your first step should be to copy the actual resistance values directly onto the diagram. Then try to break down the problem into simpler parts.

After each team member has had a few minutes to work, compare notes.

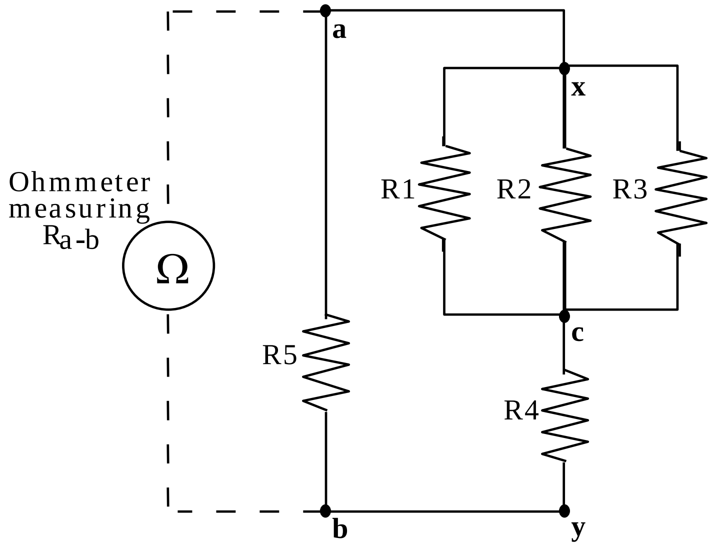


Figure 3. Compound resistor network

Theory Calculation

From your knowledge of the rules for series and parallel resistor equivalents, compute the equivalent resistance for the network shown in Figure 3 from point **a** to point **b**. Show your work.

$R_{a\text{-}b}$ = ____________ [Ω]

7. Build and test your circuit.
   - Clear off your *circuit* board and construct the circuit in Figure 3.
   - Now use the DMM in resistance mode to determine the resistance between the two points of your circuit, marked **a** and **b**.
   - Record your result:

   Measured $R_{a\text{-}b}$ = ____________ [Ω]

8. How well does your result compare with your calculation? If they do not agree well, go back and check your calculation and the construction of your circuit – build and test parts of the circuit, for example between **x** and **c (use the banana-plug wire to connect with DMM)**.

Prediction **Without modifying the circuit** in Figure 3, what would the resistance be if you had connected your DMM probes at points **x** and **y**?

____

____

$R_{x\text{-}y}$ = __________ [Ω]

9. Test your prediction.

Measured $R_{x\text{-}y}$ = __________ [Ω]

Q5 Does your prediction agree with your measurement between points **x** and **y**?

____

____

Q6 Why is the resistance between points **a** and **b** the same as that between points **x** and **y**? Does this fact depend on the particular values of R_1, ...R_5?

____

____

____

____

____

Activity 2 Nonlinear Resistance

In this class we always treat resistors as completely “linear” devices (i.e., if you double the applied voltage, the current will also exactly double). Real devices can display nonlinearities, which are sometimes useful, sometimes troublesome. A simple example is a light bulb (which aside from this activity we will pretend is a linear device). In this activity, you will use the microampere meter as a current meter to measure the current through a light bulb at different applied voltages. You will then use the measured current to calculate the bulb’s resistance at different applied voltages. Note that to measure the current flowing through a particular component of a circuit with this type of current meter, you must wire it into the circuit in series with the component. The current actually flows through the current meter (it becomes part of the circuit), but the current meter has low enough resistance that it will not appreciably alter the current levels for the circuits in this lab.

1. **Change the measuring range of the microampere meter to milliampere.**

   Make sure not to overload the microampere meter.

   Normally the resistance of a light bulb is about tens of Ohm, while the applied voltage in the circuit is 2-7 V, so the current in the circuit is about dozens of mA, which exceeds the range of microampere meter.

   - Pick the 1 MΩ resistor and connect it with the microampere meter **in series**. Apply 5 V in this circuit use the DC power supply.
   - Measure the voltage applied to the microampere meter using the DMM. V=________.
   - Read the current value in the circuit from the microampere meter. Current I = _____ μA. Then you could get the resistance of the microampere meter: r = V/I = ____________.
   - Clear off the circuit. To make a milliampere meter, you should choose the resistor Rs (recommendation: 1 Ω) and connect it with the microampere meter **in parallel**. Now the range of new-built milliampere meter is: 100 μA *(r+Rs)/Rs = ______________A. Note: it's better to use the real measured resistance of Rs.

2. Now it's time to start. Clear off your *circuit* board and build a circuit that will light the lamp as shown in Figure 4. **Attention: the ampere meter now is composed of the microampere meter and the 1 Ω resistor in parallel.**

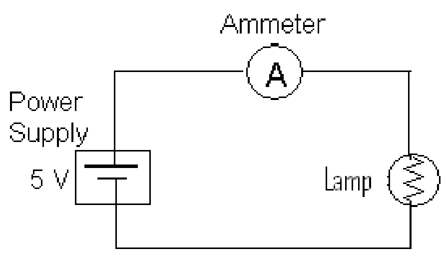
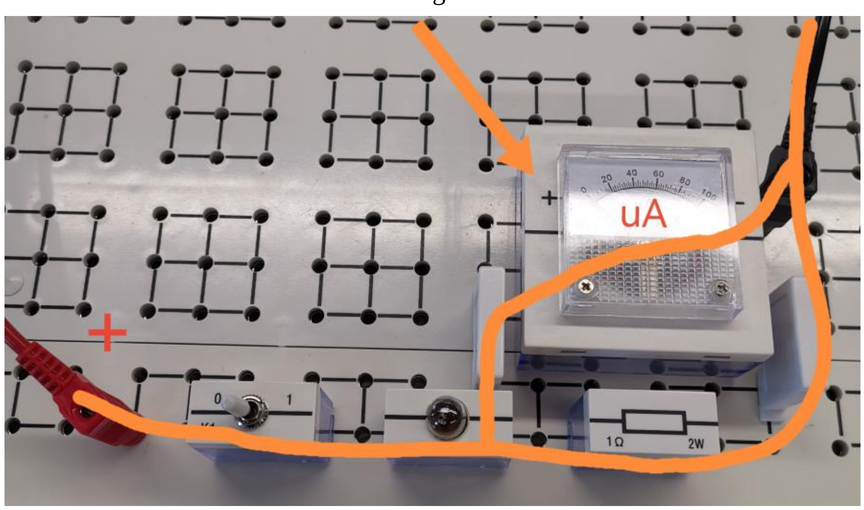


Figure 4.



Real circuit of figure 4.

Note: if you are not sure your circuit is right, ask instructor for help. If you damage the 1 Ω resistor, 40 points will be taken off.

An easy and safe way to check your circuit: set the power supply to 2 V. Then apply it to the circuit. If the bulb and ampere meter work well, then the circuit is ok.

- Turn on the DC power supply. **<u>Carefully</u>** adjust the voltage to 5V. **It will be better to insert a switch into the circuit, then you could control when to apply voltage by switching.**
- Turn the function select knob on the DMM to the DC setting to measure DC voltage applied to the light bulb. The lamp should light. If not, check your connections. If necessary, ask your instructor for help.

3. Record the current here: I (V = 5.0 volts): ______________A (think how?)

4. From the voltage and the current, calculate the resistance of the lamp.
   R_{lamp} (V_{lamp} = ______ volts) = ________________ Ω

5. Now change the input voltage to 2.5 volts and measure the current again.
   I (V_{lamp} = ______volts): ______________ A

6. Finally, calculate the new resistance of the lamp.
   R_{lamp} (V_{lamp} = ______volts) = _____________ Ω

Q7 What do you conclude about the resistance of the lamp? Does it increase, decrease, or stay the same as more power is dissipated in the resistive wire that glows?

____
____
____
____

Note that the change of resistance with temperature of some materials is the basis of all digital thermometers.

Investigation 2: Exploring Simple *RC* circuits

To find out

- The charging characteristics of a single capacitor in a simple *RC* circuit
- How to fit the charging behavior to a mathematical form
- The characteristics of capacitors assembled in parallel

Preview

- Using the *Capstone* software, examine the dynamics of charging or discharging a capacitor
- Fit the charging and discharging graphs to a mathematical formula
- Explore how the *RC* time constant changes by varying the capacitance in the circuit

Activity 3 Charging a Capacitor

So far all of your circuits have contained devices whose response to current did not change over time (neglecting the slight time it took the bulb to reach an equilibrium temperature in the previous activity). Now you will build circuits in which currents and voltages *depend on the elapsed time* after a switch is opened or closed. To capture the voltage change over time, you will use the *Capstone* software for a data interface (sparklink Air) in conjunction with two voltage probes (see Table 1).

If you connected a simple resistor to a battery and closed a switch to permit current to flow, you would find that the voltage across the resistor appears almost instantaneously equal to that across the battery. The current is derived from Equation 1, $V = IR$.

What would happen if we added a capacitor to the circuit, as shown in Figure 5?

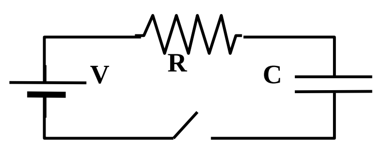


Figure 5. A simple *RC* circuit

A capacitor is a device that stores electrical charge. Initially, current will flow into the capacitor and the capacitor begins to "fill up" with charge. More precisely, positive charge will start to accumulate on the top plate (with an equal amount of negative charge on the bottom plate). This slows down the initial flow of current into the capacitor and thus through the whole circuit. After a long time, the capacitor is fully charged, and the flow of current in this circuit stops completely. The charge stored by the capacitor is given by

$$Q = CV \qquad \text{(Eq. 3)}$$

Thus the amount of charge stored Q depends on the value of the capacitance C and on the voltage V of the battery.

Q8 After a long time, what is the voltage across the resistor and why?

____

____

You can see the dynamics of this current flow in one of two methods. A straightforward way would be to put a current meter directly in the circuit. An equivalent method is to examine the voltage across the resistor. Using Ohm's Law, the latter method yields the current. You will use the second method here.

1. Gather materials. You will need:
   - The *circuit* board
   - Two 100 microfarad (μF) capacitors (one for this Activity, two for the next)
   - The voltage-current probe.
   - Switch mounted on dual banana plugs
   - The resistor with resistance 510 or 470 Ω.

2. Set up the measuring equipment.
   - Insert the voltage-current probe into the data interface box.
   - Properly set the Capstone file. You need a V-t graph.

   Note: the measurable range is -10 V to 10 V and -1 A to 1 A.

3. Set up the power supply.
   - As in Activity 2, adjust the DC Power Supply to 5.0 Volts.

4. Set up the supply and circuit.
   - Draw the circuit in Figure 6 on the circuit board illustration below.
   - Note: leave the discharging switch (S2) in the off (open) position generally. This switch will be closed only to reset your experiment. Switch S2 acts to discharge the capacitor.

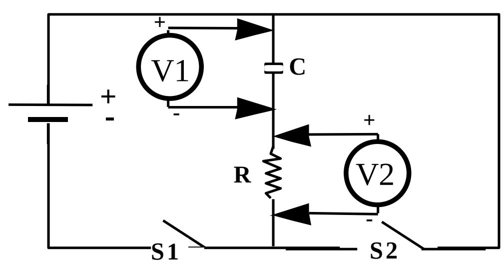
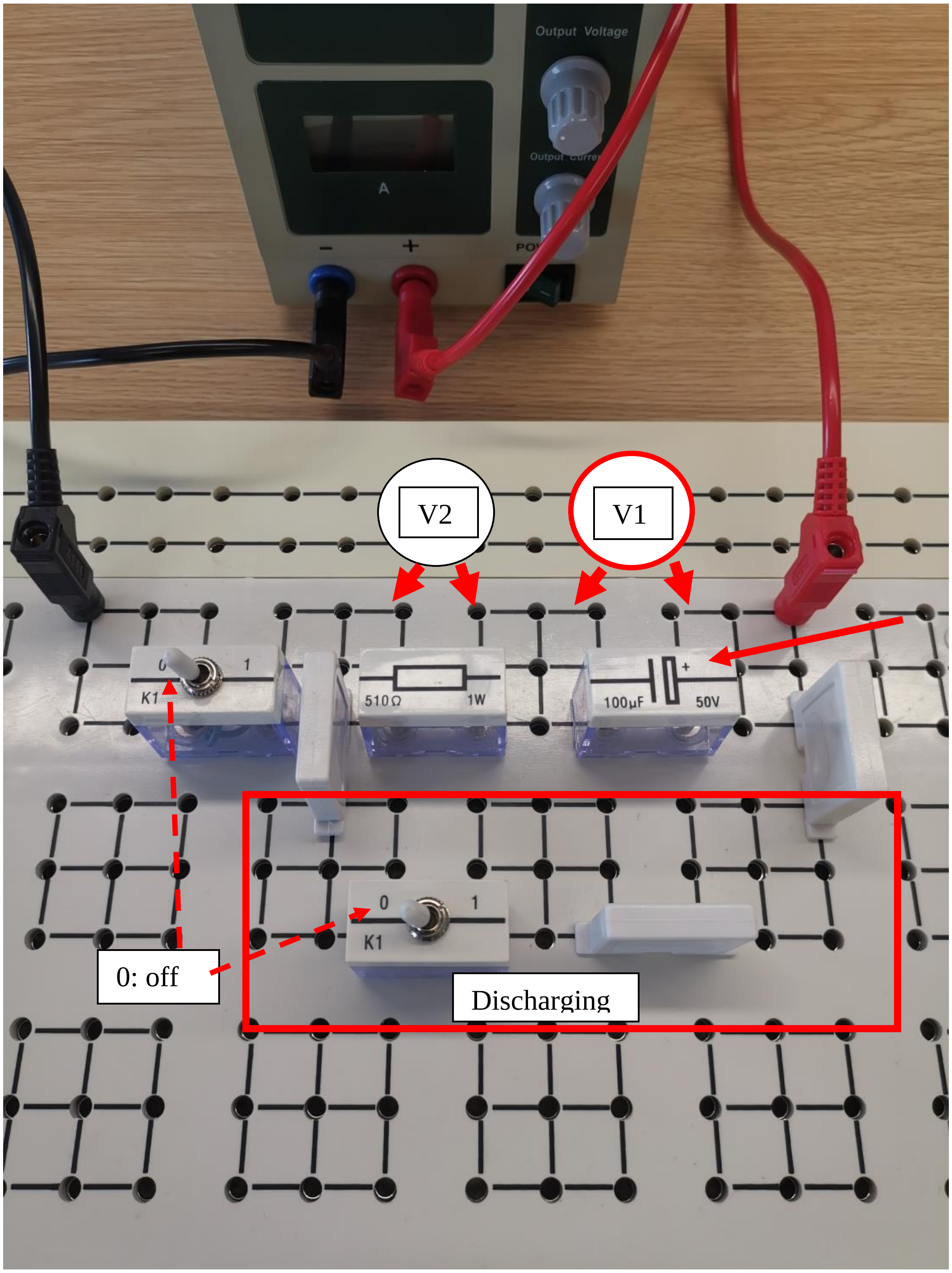


Figure 6. Simple resistor-capacitor circuit



Real circuit

Prediction	What is the voltage (V1) across the capacitor before you turn on (close) the charging switch (S1)? ____ What is the voltage (V1) across the capacitor immediately after you turn on (close) the charging switch (S1)? ____ What will be the voltage (V1) across the capacitor a long time after the charging switch (S1) has been turned on (closed)? ____ Sketch the expected V1 behavior.

Prediction	What will be the voltage (V2) across the resistor before you turn on (close) the charging switch (S1)? ____ What will be the voltage (V2) across the resistor when you turn on (close) the charging switch (S1)? ____ What will be the voltage (V2) across the resistor a long time after the charging switch (S1) has been turned on (closed)? ____ Sketch the expected V2 behavior.

Theory Calculation

Since you know the value of *R* from the earlier part of this lab and the value for *C* from step 1, calculate the time constant *RC* and its inverse, 1/*RC*.

RC_{calc} = __________ [seconds]

$1/RC_{calc}$ = __________ [seconds^{-1}]

The key changes in the voltages in this experiment happen in less than 1 second. Thus the Capacitor file that you have open is configured to take data for only .5 seconds. The data recording will begin (*trigger*) when V1 rises above .05 V after you press the **Record** button.

5. Take some data.

i. Charging:

a. Press **Record.**
b. Keep discharging switch (S2) open/off (choose '0').
c. Turn on (close) the charging switch (S1). The graph should appear.

- If data is not taken after two tries, contact your instructor to check the circuit.

Note: if you redo the charging without doing discharging, then the voltage reading will be wrong.

ii. Discharging:

iii. *a*. Turn off (open) the charging switch (S1).
iv. *b*. Press **Record.**
v. *c*. Turn on (close) the discharging switch (S2) to discharge the capacitor. The graph should appear.

Q9 How do your graph predictions compare with your actual results? Sketch the shape of your measured graphs on top of your predictions using a different color pen or pencil and label both curves appropriately.

____

____

You can analyze the curves and determine the value of *RC* from the curves. Do this by having the computer draw a curve with the proper exponential form and vary the parameters until it closely matches the curves you generated. This is called *curve fitting*.

6. Fit your capacitor voltage (V1) data.
   - Choose the proper data range to fit (the curve part).

Question: When you choose the data range, do you need data points of part 1 in figure 7? Why? What about part 2 and why?

____

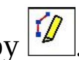
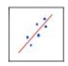
____

____

Question: Do you always need the special point in figure 7? Under what conditions must you not choose it?

____

____

- After choosing the data range which need be fitted by . Click once on the curve fitting button  on the toolbar to choose a proper function: $y = A*\left(1-\exp(-\frac{1}{RC}(t)\right)+B$. If you cannot find a default formula, you may use the "user defined: f(x)" to define a new function. After that there will be a 'curve fit editor' button on the left side of the software interface. Click it to define your own function and set the initial values of parameters.
- If the parameters' results are bad, use a new set of initial guesses and update fit. Initial guesses should be near the results.

Note: sometimes you lock one parameter, but the fitting results show it's not locked, then you need click the Fitting results box, the editor will renew.

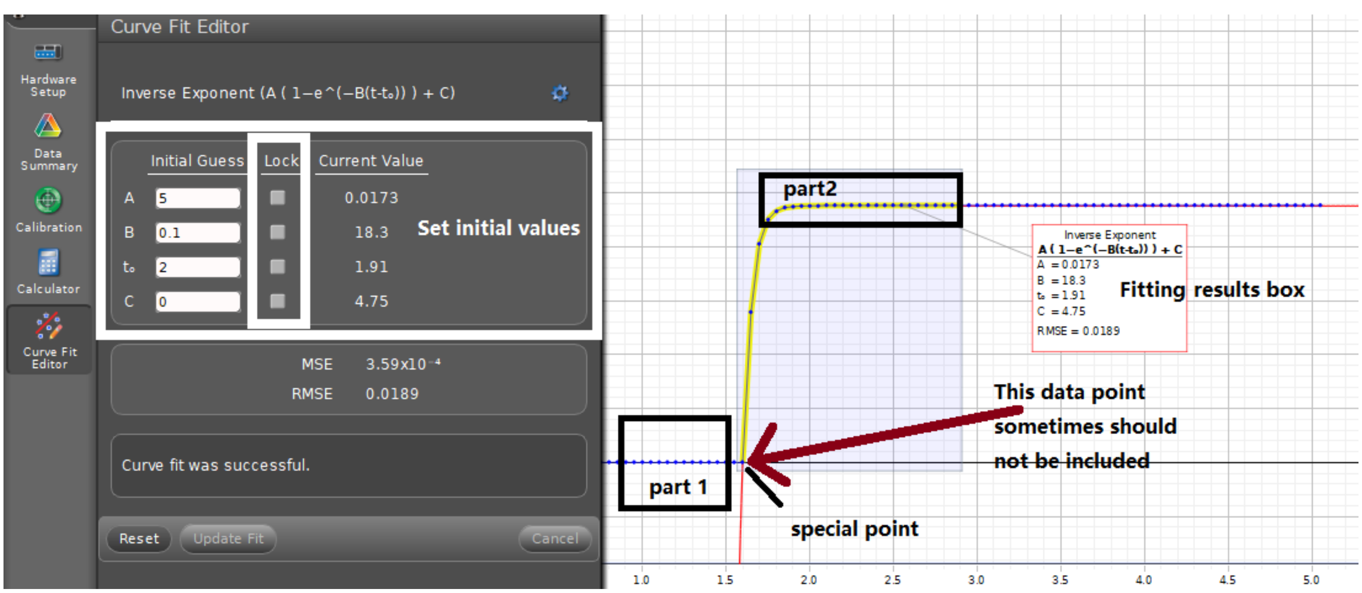


Figure 7. Fitting to a 1-Exp curve

- If the fit looks good, print it / send it in WeChat group.
- Record the fitting formula below (note: replace the **A**, **B**, and/or **C** of the equation with the actual numbers the software calculates).

  ____

Record your t_0 value. Why is t_0 around this value.

____

- Keep the program running as is for the next activity.

7. Determine 1/*RC* and *RC* from the capacitor voltage (V1) data.
   - The formula you recorded should have the form:

$$y = A * \left(1 - \exp(-\frac{1}{RC}(t)\right) + B ,$$ (experimentally, replace t wit (t-t_0), think the reason.)

   - Determine the value of 1/*RC* and *RC* that produced the V1 data and record them here:

     $1/RC_{V1}$ = ________ [s^{-1}] RC_{V1} =____________ [s]

Q10 After one time constant (= *RC*), how much has the voltage increased compared to its initial value in your measurement?

____

____

Q11 What two values did you get for 1/*RC* from the theory calculation and from the voltage V1 graph fit? What values did you get for *RC*?

$1/RC_{calc}$ = ____________ [s^{-1}] RC_{calc} = ____________ [s]

$1/RC_{V1}$ = ____________ [s^{-1}] RC_{V1} =____________ [s]

Q12 The nominal value of the capacitance of the capacitor is 100μF, but all of our capacitors actually have been measured to each have capacitance within 5% of 100 μF. They could be as low as 95 μF and as high as 105 μF. Calculate and record $RC_{calc\ max}$ and $RC_{calc\ min}$ for these extreme values. Does your measured RC_{V1} fall within these values?

____

____

____

Activity 4 Equivalent Capacitance

Since the capacitance of a simple parallel plate capacitor increases if you increase the area of the plates, can you guess what happens when you put two such capacitors in parallel in a circuit? Let us find out.

1. Set up the parallel circuit.
   - Place **two** capacitors in parallel as in the circuit in Figure 8. (Note that just plugging the two capacitors in on top of each other puts them in parallel.)

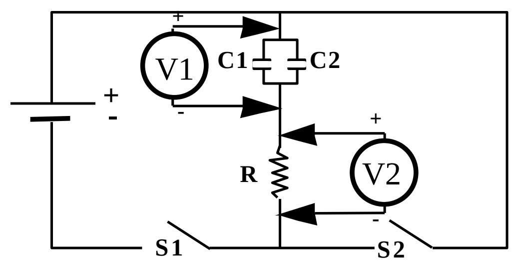


Figure 8. Capacitors in parallel

Prediction	What will happen to the V1 and V2 graphs for this circuit? What will happen to the time constant *RC*? ____ ____ ____

2. Take data as before.
   - Turn off (open) the charging switch (S1).
   - Turn on (close) the discharging switch (S2) for about 5 seconds to discharge the capacitors.
   - Turn off the discharging switch (S2).
   - Click on **Record** and turn on (close) the charging switch (S1).
   - If all is well, you should get a good data curve and then fit it.

3. Print your results or send graph in WeChat group.

Q13 Use the curve fitting program to actually *measure* the new time constant, and record that, as well as the ratio of that to the time constant measured with a single capacitor. How well does the ratio match your prediction?

____

____

Q14 Is more, less, or the same amount of energy stored in this circuit after charging as in the circuit with only one capacitor? How do you know?

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____

____

Time permitting, repeat this measurement with the two capacitors in series.

Q15 What is the time constant for the two capacitors in series?

____________________ seconds

How does it compare with the time constant for a single capacitor?

____

____

____

CLEAN UP CHECKLIST

- ☐ Quit all computer programs and do not save any data. Turn off all the equipment except the computer.
- ☐ Make your setup look neat for the next group.
- ☐ Collect all printouts, annotate them, and attach them to the lab report of the designated member of your group.
- ☐ Staple everything together, make sure you have answered all the questions and done all the activities, make sure the first page is completed with lab partners' names and check boxes. Hand in your work before leaving the laboratory.