

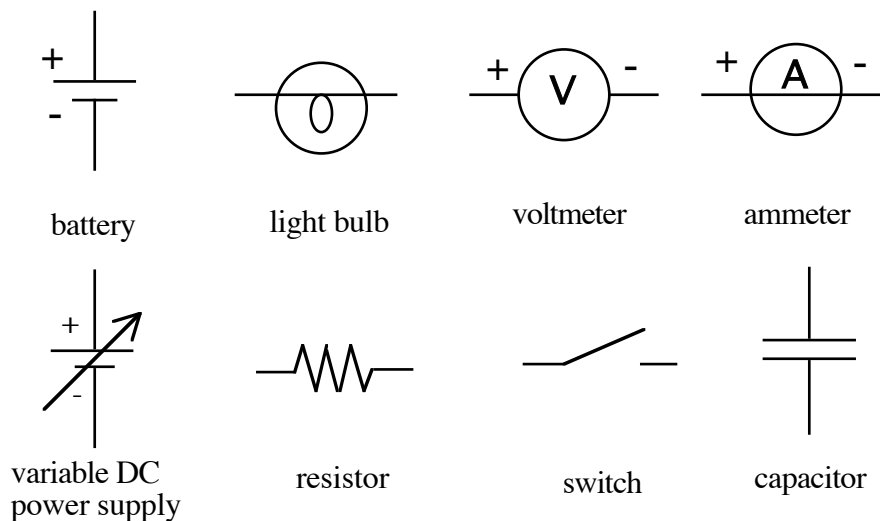
## SIMPLE CIRCUITS

- Objectives:**
- To help you learn how to think about circuits, both in using conventional symbols on paper and in wiring up actual hardware.
  - To understand something about how voltmeters and ammeters differ in construction and operating principles.
  - To investigate the dynamical properties of RC circuits (opt.)

- To Do Before Lab:**
- Read this lab
  - Read Giancoli 25-1 – 25-4, 26-1, 26-2, 26-4 (opt.) (You may have read these before...)
  - Two resistors,  $R_1$  and  $R_2$ , are connected in series. Find the total resistance and uncertainty. Repeat this for resistors in parallel.

**Apparatus:** #14 and #40 light bulbs in sockets, 6 V battery, Keithley digital multimeter (DMM), hand-held DMM, knife edge switch, variable DC power supply, steel wool, resistors, LabPro, capacitor.

The following circuit symbols are used throughout this handout.



### Introduction

**Power sources and loads:** The world's most elementary circuit is shown in Figure 1. The battery (EMF, power supply, charge pump—there are many synonyms) converts energy from some source in such a way as to maintain a constant difference of potential (or voltage) of magnitude  $\mathcal{E}$  between its terminals.

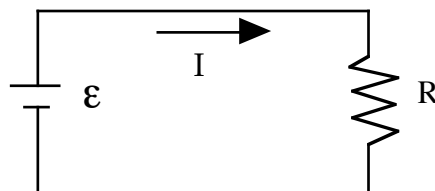


Figure 1. World's simplest circuit

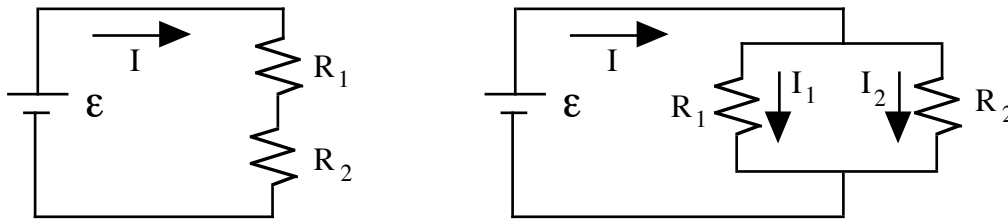
This action drives a current  $I$  through the **load resistor**  $R_1$  which consumes the electrical energy by converting it into heat. Ohm's law says that the voltage across the resistor  $\Delta V$  is proportional to the current through it.

$$\Delta V = IR_1 \quad (1)$$

Indeed, this is the definition of the resistance  $R$ . Assuming no resistance in the connecting wires, the conservative nature of electrostatic fields requires that the voltages across battery and resistor be the same. Thus,

$$\mathcal{E} = \Delta V = IR_1 \quad (2)$$

**Series and parallel.** (The following is also in your text, Ch 26-2) To make things a little more interesting, let's add a second resistor. There are two ways to do this, shown in Fig. 2.



(a) series resistors

(b) parallel resistors

Figure 2. Elementary circuits with series and parallel resistors.

The two circuits of Fig. 2 behave just like the elementary circuit of Fig. 1 if we replace the series, or parallel, combination of resistors by the **equivalent** single resistances

$$R_{equiv}(series) = R_1 + R_2 \quad (3)$$

$$\frac{1}{R_{equiv}(parallel)} = \frac{1}{R_1} + \frac{1}{R_2} \quad (4)$$

The extension to more than two resistors is straightforward.

**Explanation:** In the **series** circuit, there is only one current  $I$ , because there is no place where the current can branch and, if it were not the same all the way around the loop, charge would build up continuously at some point. Furthermore, in the series circuit, the two resistor voltages add to give a total  $\Delta V$ , which is maintained at the value  $\mathcal{E}$  by the battery. That is,

$$\mathcal{E} = \Delta V_1 + \Delta V_2 = IR_1 + IR_2 = I(R_1 + R_2). \quad (5)$$

Comparison with equation 2, shows that equation 3 is established.

In the **parallel** circuit the battery current  $I$  divides into two portions,  $I_1$  and  $I_2$ , to pass through the two resistors, and then recombines to be pumped through the battery again. In order for charge not to accumulate at the two junction points, it follows that

$$I = I_1 + I_2. \quad (6)$$

For the parallel circuit, each resistor is connected directly to the battery, so  $\Delta V_1 = \Delta V_2 = \mathcal{E}$ . Then we have

$$I = I_1 + I_2 = (\mathcal{E} / R_1) + (\mathcal{E} / R_2) = \mathcal{E}(1 / R_1 + 1 / R_2). \quad (7)$$

One more manipulation and equation 4 is established.

To summarize, in a series circuit the current is the same in all of the resistors. However, the voltage drop across each varies in direct proportion to the resistance. In a parallel circuit the voltage across each branch is the same, but the current in a branch is inversely proportional to the resistance of that branch.

**Important:** If we want to measure the voltage common to battery and resistor, we connect a **voltmeter** in **parallel**, as shown in Fig. 3(a). If we want to measure the current, we connect an **ammeter** in **series**, as shown in Fig. 3(b). If we want to measure both at the same time, things get a little tricky—we'll come back to that.

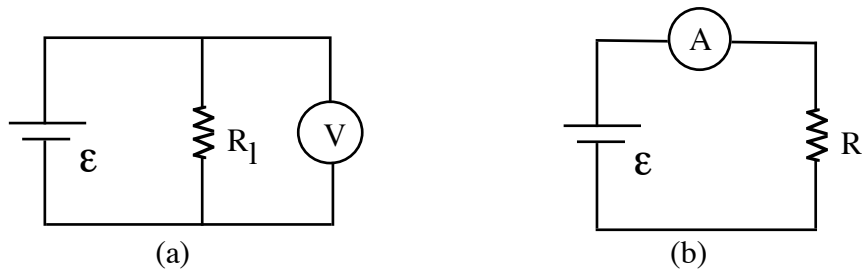


Fig. 3. Meter connections to measure (a) voltage or (b) current.

Keep in mind that a voltmeter measures the potential difference between two points by touching the "leads" to two places in the circuit. A **positive** reading occurs when the (+) **red** lead is touching a point which is at a **higher potential** than the point where the (- or common) black lead is touching. Most circuits refer to one end (usually the - terminal) of the battery/supply as ground or common. All stated voltage levels are measured with respect to ground. Note that a voltmeter should have a very *large* resistance so that it does not significantly affect the circuit.

To measure current at some location in the circuit one must "break" the circuit there and insert the meter "inside" the circuit. A positive current flows into the (+) red lead, through the meter, and out the (-) lead back into the circuit. Note that an ammeter should have a very *small* resistance so that it does not significantly affect the circuit. Beware that you must be very careful **not** to place the ammeter in parallel with a power source. This will provide a very low resistance path for the current. According to Ohm's law the current will become huge and will end up destroying the meter, supply and portions of the circuit.

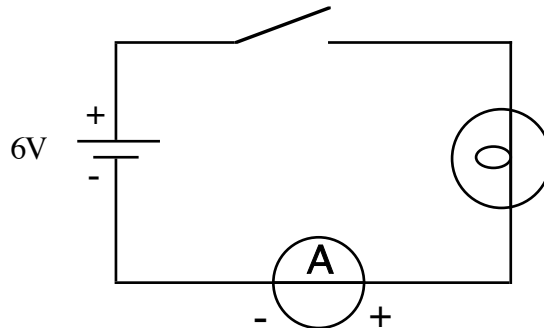
## Procedure:

### **Part 0:**

(1) Connect the battery and the small lamp with the *cylindrical* bulb so that the bulb lights up. Hooray! In your lab notebook draw your working circuit and the other configurations you may have tried. Why did these not work?

### **Part I:**

(1) Connect the circuit shown below. Use the lamp with the cylindrical bulb.



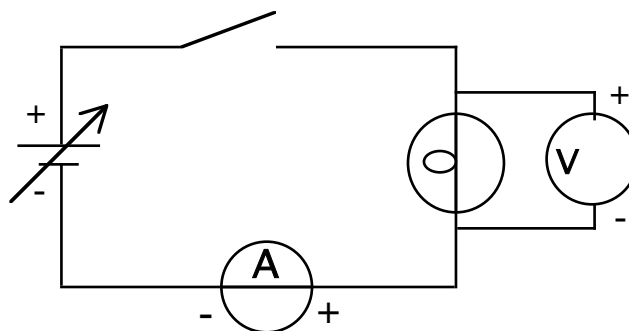
(2) Measure the current with the switch open and with the switch closed.

(3) Measure the voltage produced by the battery with the switch open and with the switch closed. Can you explain what you observe?

(4) Investigate what happens when you change the order of the components. For example, place the ammeter between the switch and the light bulb. Try other possible variations. Does anything change?

### **Part II:**

(1) Replace the battery with the variable power supply and connect the voltmeter to measure the potential difference across the light bulb, as shown below.



(2) Investigate the relationship between the current through the light bulb and the voltage across the light bulb. Do not use the meters on the front of the power supply; they are not very accurate. Do not exceed 6 V or you may burn out the light bulb. Make a graph of your data. What do you think is responsible for the shape of this graph? Be as specific as possible.

(3) Replace the light bulb in the circuit with one of the resistors and repeat the investigation of current versus voltage. Add your data to your graph for the light bulb.

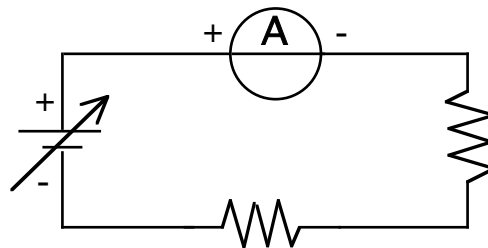
**Caution:** too much current will cause the resistor to overheat. If the resistor gets hot to the touch your current is too high.

### Part III:

(1) Measure the individual resistances of the two resistors with your digital multimeter in the  $\Omega$  (ohms) mode.

(2) Predict the equivalent resistance of  $R_1$  and  $R_2$  in series and parallel.

(3) Connect the *series* circuit shown below. Adjust the variable power supply so that it produces a voltage of 3.0 V. Measure the voltage across each resistor, the total voltage across the resistor network, and current through the circuit. Determine the equivalent resistance of the two resistors in series and compare to your prediction. What do you notice about the individual voltages and the total voltage?

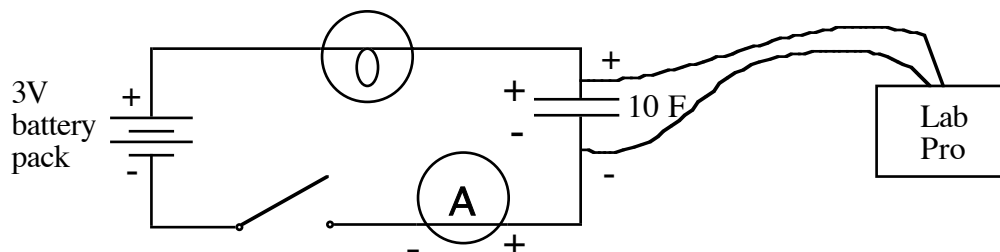


(4) Parallel circuit: Repeat Step 3 for the two resistors connected in parallel. Also measure the current through each resistor. Determine the equivalent resistance of the two resistors in parallel and compare to your prediction.

(5) Make a circuit with a thread of steel wool connected in series with a light bulb. Add another bulb in parallel with the first light bulb. Add another and another .... What happens? Why? What do we normally call the devices that function as the steel wool did in this circuit?

### Part IV:

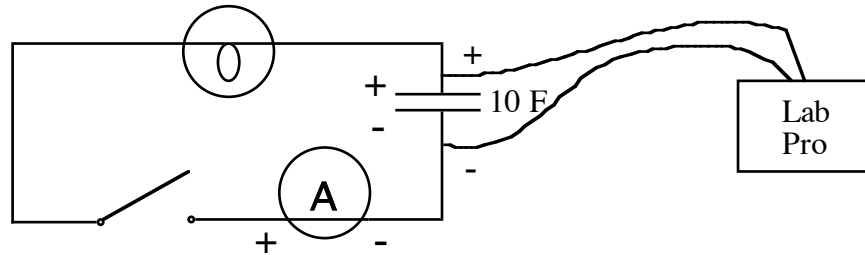
(1) Connect the circuit shown below, using the light bulb with the *spherical* bulb. Be sure to connect the positive and negative sides of the capacitor and LabPro as shown.



Open the LoggerPro program called *RC circuit*. RC stands for resistor and capacitor. In your RC circuit the light bulb is the resistor. Its advantage over a regular resistor is that you can see when current is flowing through it. The LoggerPro program measures voltage every 0.1 s for 300 s.

(2) With the switch open, start collecting data. If the voltage recorded is not zero, discharge the capacitor by connecting a wire from the positive to the negative terminal. Once the voltage reads zero, start collecting data again, and after a few seconds, close the switch. Observe the light bulb and the ammeter. Record your observations. Can you explain the shape of the voltage vs. time graph?

(3) Open the switch, remove the battery pack from the circuit, and reverse the connections to the ammeter. Your circuit should look like the one below.



What will the curve look like this time? Draw the prediction in your lab notebook.

(4) Start the RC circuit program and then close the switch. Does the result match your prediction? Why or why not?

#### Part V:

(1) Make a series circuit consisting of the variable power supply, a  $0.1\text{M}\Omega$  resistor, and the ammeter. Set the voltage of the power supply to about 15V and measure the current through the resistor. Measure the voltage across the resistor with the DMM. What happens to the current reading when you make the voltage measurement? Why? Why didn't we have to worry about this effect in the earlier experiments? Can you think of a way that you can *simultaneously* measure the current through the resistor and the voltage across the resistor without introducing an error into either measurement?

