PHY132 Laboratory
DC Circuits
July 24, 31, 2008

[Based on an experiment developed by Milton From, Tony Key, Joe Vise, and Ruxandra M. Serbanescu]
Last revision: June 13, 2008 by Jason Harlow

Purposes

To give students experience in

1. planning and wiring simple circuits
2. using digital readout equipment
3. measuring currents and voltages associated with specific components in a DC circuit
4. combining resistors in series and parallel

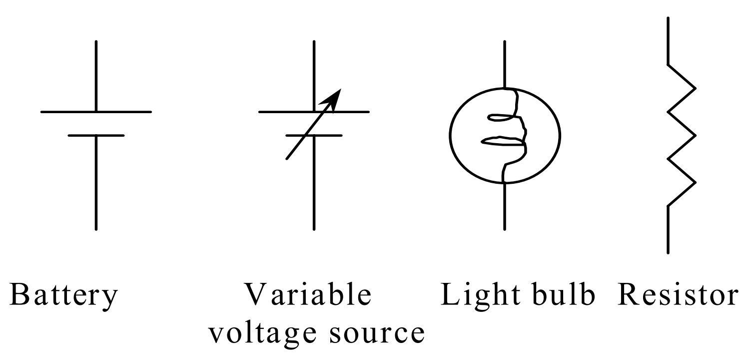
Background Information

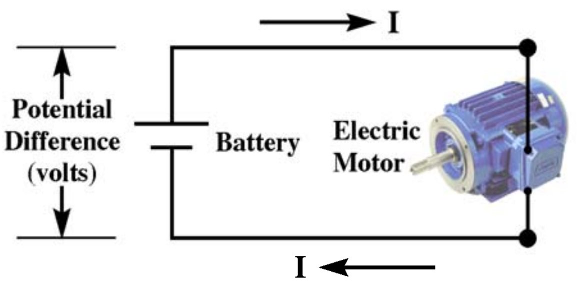
Charge carriers are charged particles (electrons), which are forced to move in electric circuits by applied electric forces. The force between two charges gives the value of an electron charge. The unit of electric charge is the Coulomb (C). 1 C = 6.2×10^{18} electron charges.

Current is the rate of flow of electric charge through a device or wire. The unit of current is the Ampere (A). 1 A = 1 Coulomb/1second

Voltage or **potential difference** is the difference in potential energy that 1 C of charge experiences when transferred between two points in the circuit that are being compared. The unit of voltage is the Volt (V). 1 V = 1 Joule/1 Coulomb

Symbols

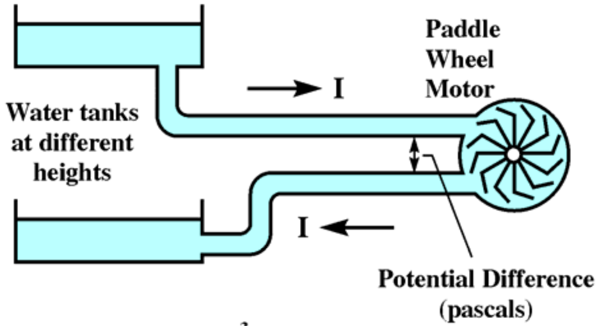




I **= current in coulomb/s (ampere)**

Note: the battery gets recharged prior to use by moving electrical charge from one battery terminal to the other.

Figure 1



I **= current in** $\mathbf{m^3/s}$

Note: the hydraulic energy source gets recharged prior to use when the water in the lower tank is transferred to the upper tank.

Figure 2

If a potential difference, *V*, is placed across the two ends of an electrical conductor, an electric current *I* will flow (Ohm's Law). To produce a steady flow of charge, you need a "charge pump", a device that, by doing work on charge carriers, maintains a potential difference between a pair of terminals.
The analogy with a hydraulic circuit is shown in **Figures 1 and 2**.
The potential difference *V* across the battery's terminals "pushes" charges which form the electric current *I*.
The difference in height of the two water tanks drives the water current *I* down through the pipes.
In both cases, the "pump" does work. The electric motor or the paddle wheel motor turn by using the energy from the "pump".

Ammeter: An ammeter measures the total current flowing in a wire. It has to be placed ***in series*** with that wire, i.e. the circuit connection to the wire must be cut and the ammeter placed in that cut. An ammeter must have two terminals, one for the current in and the other for the current out. An ammeter is designed to pass all the current in the wire into which it is inserted without providing barriers to the flow of that current. Thus ***an ammeter should never be placed across the terminals of the battery***, for such a connection would let the maximum current available from the battery to flow through the ammeter. **Please do not connect the ammeter ACROSS a voltage source. Only connect it in series with the wire where you want to measure the current.**

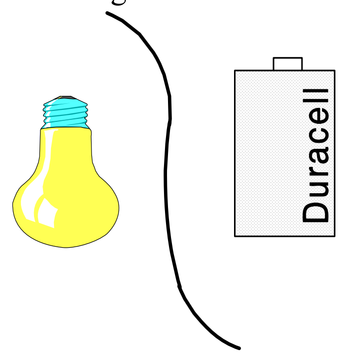
Voltmeter: A voltmeter, as it measures the potential difference between two different wires, has to be connected ***in parallel*** with (across) those two wires. Unlike the ammeter, the circuit connection to the wires must be attached without breaking into the circuit. Note that a voltmeter must have two terminals as it is measuring a potential difference. Note that there is not the danger of passing excessive current through the voltage terminals as there was for the current terminals.

Multimeter: A multimeter is an electronic measuring instrument that combines several functions in one unit. Depending on the dial setting, it can function as an **ammeter**, a **voltmeter**, or a resistance-measuring device (ohmmeter).

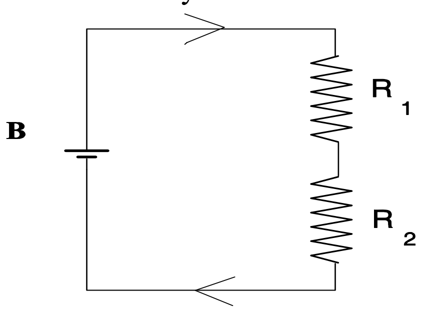
Preparatory questions

Please answer the following two questions on a separate piece of paper. EACH TEAM MEMBER MUST DO THIS SEPARATELY. They should be done as homework and then the answers taped or stapled into your team notebook as part of your write-up the DC Circuits experiment.

1. You are given a flashlight battery, one piece of flexible wire, and a flashlight bulb. Sketch two different circuits that you could use to light the bulb.

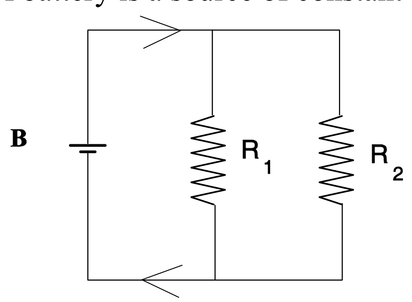


2. Which is a more accurate way of determining a resistor's resistance? a) Measuring it with a multimeter used as an ohmmeter or b) reading its color code.
3. A battery is a source of constant **voltage.** In the following circuit it is indicated by **B**.



The direction of the current is indicated by the arrows. The resistances have the values $\mathbf{R_1}$ = 500 **Ω** and $\mathbf{R_2}$ = 1,000 **Ω**. Which of the following statements is true?
a) The current passing through $\mathbf{R_1}$ is half of the current passing through $\mathbf{R_2}$.
b) The current passing through $\mathbf{R_1}$ is equal to the current passing through. $\mathbf{R_2}$.
c) The current passing through $\mathbf{R_1}$ is twice the current passing through $\mathbf{R_2}$.

4. A battery is a source of constant **voltage.** In the following circuit it is indicated by **B**.



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Equipment List

Item	Qty	Item	Qty
Light bulbs	3	Variable Voltage Source	1
DC battery	1	Box of unknown resistors	1
Digital multimeter	2	Assorted wires with banana connectors	several

Activity 1: Electric Circuits: Lamps in series, Lamps in parallel and Kirchhoff's rules.

You need a battery, light bulbs, multimeters, and wires. Of prime importance will be your systematic record of circuit diagrams and observations.

A. **Electric Circuits.** Use one bulb, the battery and a maximum of two wires. Note that the battery and the bulb each have two connections. Explore all of the ways to join the various connections to the battery and the bulb. Which ways make the bulb light? Which ways blow the breaker on the battery? Which ways do nothing? Does the order in which the ends of the battery are connected or the order in which you connect the ends of the bulb matter? Some examples of configurations you might try are shown in **Figure 3**.

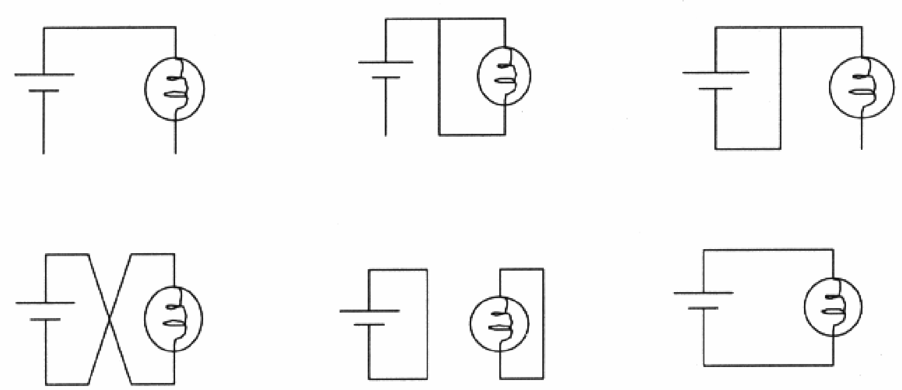

Figure 3

Write down all of your circuit diagrams, observations, and generalizations in your notebook. Can you extend your generalizations to the concepts of *complete circuit, open circuit,* and *short circuit?*

B. **Lamps in series.** The connection of two light bulbs *in series*, connected to the battery, is shown in **Figure 4**. From your observation of the brightness of the lamps, what can you conclude about the current through each lamp compared to the case of the successful circuit of **Figure 3**?

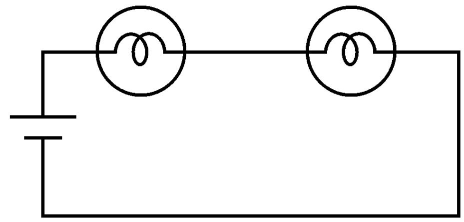

Figure 4

Note that more current through a lamp makes it shine more brightly. What can you say about the current through one lamp compared to that through the other in this configuration? With the circuit of Figure 4, try connecting a wire across the two terminals of one lamp. What happens? Can you explain? With the circuit of Figure 4, measure the current into and out of each lamp, using one of the meters as an ammeter. Use the 10 A ports of the instrument (10A HI and 10 A COM). With the circuit of Figure 4, measure the voltage across each of the lamps separately, using the other meter as a voltmeter. Also measure the voltage across the battery. What can you say about the way the voltage distributes itself across the identical lamps in series?

C. **Lamps in parallel.** Two bulbs in parallel, connected to the battery, are shown in Figure 5. From your observation of the brightness of the lamps, what can you conclude about the current through each lamp compared to the case of a single bulb and battery circuit? With the circuit of Figure 5, measure the current into and out of each lamp, and compare it to the current out of the battery. Do the measured values agree with your conclusion? With the circuit of Figure 5, measure the voltage across each of the lamps separately, using the other meter as a voltmeter. Also measure the voltage across the battery. What can you say about the way the voltage distributes itself across these lamps in parallel?

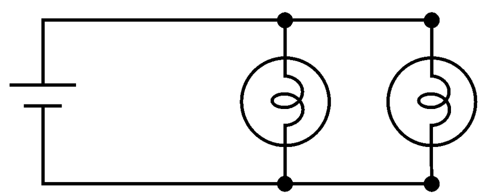

Figure 5

D. **Kirchhoff's rules.** These rules are obeyed by the voltages and currents in any electrical circuit, even those which involve devices like transistors and diodes.

First Kirchhoff's rule:

The sum of all the currents entering any node (branch point) in a circuit must equal the sum of all the currents leaving that node.

In the steady state, there is neither an accumulation nor a diminution of charge anywhere in the circuit. At a node the net amount of charge flowing in must equal the net amount flowing out (the principle of conservation of charge).

Second Kirchhoff's rule:

The algebraic sum of the potential differences around any closed loop in a circuit is zero.

If this sum were not zero, the principle of conservation of energy would not be obeyed.

As an example, consider **Figure 6.**

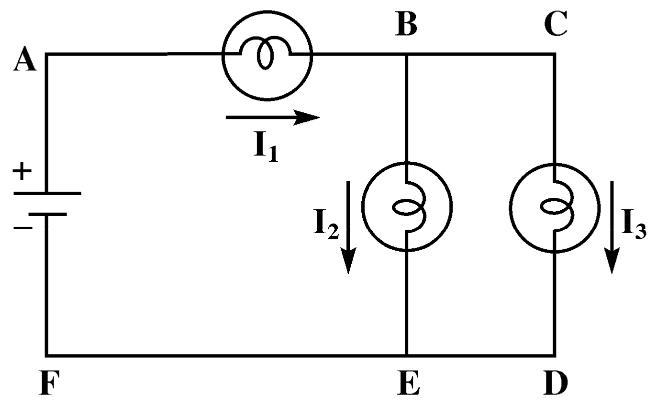

Figure 6

Looking at the branch points B or E, we see that rule 1 implies:

$$I_1 = I_2 + I_3 \qquad (1)$$

Looking at the loop ABEF we see that rule 2 implies:

$$V_{AB} + V_{BE} + V_{battery} = 0 \qquad (2)$$

Measure the currents I_1, I_2, and I_3 by inserting the ammeter in branches AB, BE, and CD. Check the validity of Kirchhoff's first rule (1).

Measure the voltages across each of the lamps and across the battery (from F to A). Check the validity of Kirchhoff's second rule (2).

Activity 2: Resistance and Ohm's Law

You need a variable power supply, a box with fixed resistors, multimeters, and wires. In this part you will have to obtain voltage and current data on **one** unknown resistor from the yellow resistor box and also on the **red light bulb** from the resistor box.

For many materials connected into electric circuits, the current *(I)* is simply proportional to the voltage difference *(V)* across that material. This proportionality is called Ohm's Law:

$$I = \frac{V}{R} \qquad (3)$$

The constant *R* is called the conductor's *resistance*, measured in **Ohms** (Ω) in the SI system of units (1Ω = 1 Volt/1 Ampere).

A *resistor* is simply a small piece of conductor which obeys Ohm's law and which has been designed to have a specific value for its resistance.

The purpose of this part of the experiment is to check if Ohm's law holds for ordinary resistors, by measuring the voltage *across* the resistor and the current *through* it.

A. **Ohm's Law for a Resistor**: The circuit consists of an unknown resistance (0.2 kΩ - 2 kΩ) from the resistor box, connected to the power supply, as shown in Figure 7a. In order to measure the current through this resistor, an ammeter has to be placed in the circuit, as shown in Figure 7b.

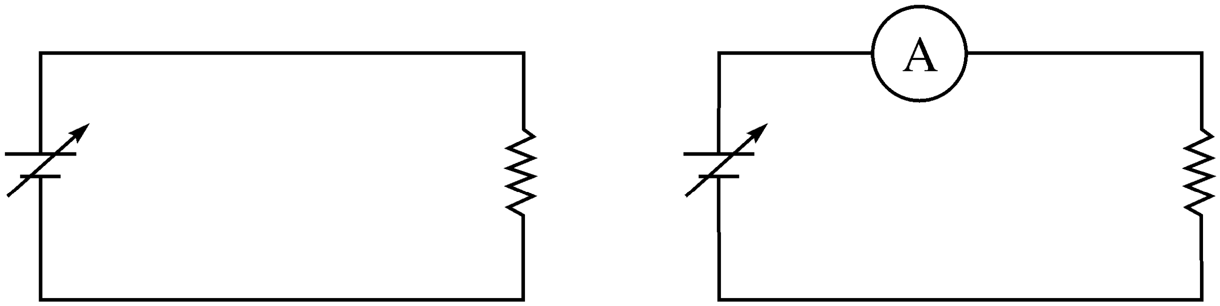

Figure 7a

Figure 7b

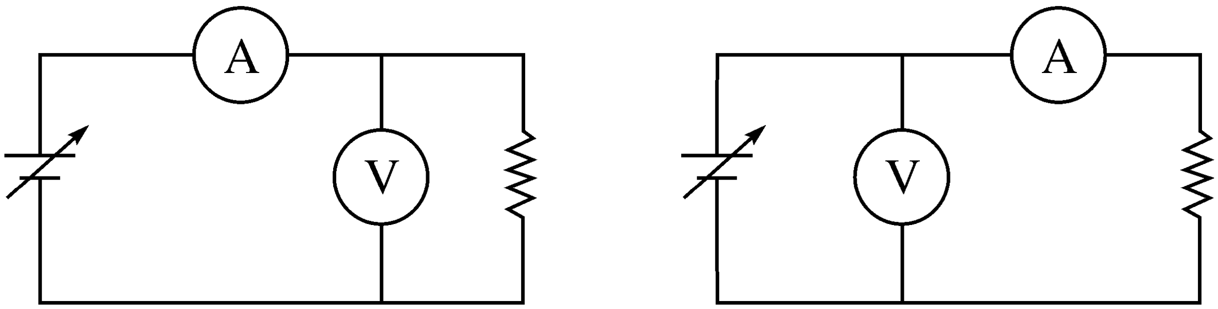

Figure 7c

Figure 7d

Note: Use the mA port of the ammeter. Also, note that the introduction of the ammeter changes the current through the resistor, since every measuring meter has some resistance of its own. What should be the resistance of an ammeter so that this change is as small as possible (large or small)?

We need to measure the voltage across the resistor. This can be done by including a voltmeter in the circuit, as shown in either Figure 7c or 7d. Note that, in both circuits, the voltmeter will allow some current to pass through it, thus changing the current that flows through the resistor. What should be the resistance of a voltmeter so that this change is as small as possible (large or small)?

Using either circuit, take several readings of V and I and plot your data.

Notes: The (random) reading errors on the multimeters follow the usual rules for digital instruments (about equal to half of the last digit) as long as all your readings remain on one scale. However for some multimeters, if you change scales during an experiment (as you almost certainly will) you may find that this error is an underestimate. In such cases the calibration error provided by the manufacturer should probably be used. See specs on Faraday: the first number, quoted as a % is the calibration error, the second is the random error.

Is Ohm's law verified? Compare the slope of your line with the resistor's nominal resistance (see Part C below). Which of the circuits (7c or 7d) is the best if the value of the resistor to be measured is very large (> 1 MΩ)?

B. Ohm's Law for a Light Bulb: Does the filament of a light bulb obey Ohm's law? Measure a few values of V and I and again plot your data to test your hypothesis. **Note: Use the red light bulb from the resistor box**. Include measurements in which the light bulb is glowing.

C. **Direct Measurement of the Resistance:** You can also use the lab multimeters to measure resistance directly, without taking separate *V* and *I* measurements. Use the resistance function to measure the equivalent resistance of a series and a parallel combination of two resistors**.**

Finally, if time permits, quickly measure and record the resistance of a few conductors around the lab such as your skin, a laboratory hookup wire, a drop of water, etc.

Note: To measure the potential difference $V_A - V_B$ between two points A and B, connect the *red* terminal of the voltmeter to A and the *black* terminal to B.

Don't forget to turn off the multimeters and please return the wires to their proper location !