REV0[1]; February 12, 2007

Physics 15b: Lab 1, Simple Circuit Elements

Due Friday, Feb. 23, 2007, by 12 noon in front of Science Center 301

This lab is to be done at the Science Center, not in your dorm

You can do later labs in your dorm, but the first two we will do in Science Center 305, to make sure that you have quick access to help from a lab T.F. Your section, for this first lab, will run either Thursday, Feb. 15 or Thursday Feb. 22. Please consult the lab website to see your date and hour:
http://www.people.fas.harvard.edu/ thayes/15b/

In the early labs, most of your questions are likely to concern *error analysis*. When students *fail* the early labs, it's nearly always because they don't take this part of the task seriously, or just misunderstand what's requested. If you're puzzled, please ask your lab T.F. for help.

Please make a start on the lab at home. . .

Our lab TA's tell us that no one finished, last spring, if they had not done a little preliminary work in the dorm, before coming in to lab. You needn't do a lot, but enough so that when you're in lab you can make efficient use of the TA's availability.

Notebooks Returned:

We expect to be able to return your notebooks to you (placing them on the table outside SC301) by *Saturday, 6 p.m.*.

1 Purposes

- To begin to analyze and take account of the effect of uncertainties in data measurement
- To learn how to solder.
- To use the resistor color code and the ohmmeter.
- To measure the current-voltage characteristics of a resistor and in an incandescent bulb.

2 Background

Please read Purcell Chapter 4.1 - 4.3, and 4.7 - 4.11 on circuit elements

2.1 Soldering

The theory of soldering is that the solder melts and forms a conducting bridge between two conductors. The solder **wets** the surface of the conductor (this wetting is very important). In practice, it is most

[1]Revisions: make labs in-house (9/05); add note 'use measured AA voltages, not nominal (p. 6) (10/04).

conservative to "tin" each conductor separately, so that it is obvious that it has been wet by the solder. If the solder spreads over the surface, it has been wetted. If the solder balls up like a water droplet on waxed paper, you have failed. All solder used for electronic wiring has a *rosin* core, which is a mixture of chemicals that melts with the solder and is designed to clean surfaces and facilitate wetting. This rosin core *flux* works well on copper, tin, and some steels. It will not work on aluminum, stainless steel, nor on nichrome resistance wire. If you try to tin these they will not wet. (These metals can be wet using acid flux but we will not use acid flux in 15b).

For wetting to take place the piece must be above the melting temperature of the solder. If a molten blob is merely deposited on a piece that is too cold, and a joint finally made, the electrical conductivity of this **cold solder joint** is likely to be unreliable, and intermittently bad. This may cause great frustration and may be hard to trace if the joint is part of a complex circuit. In order to tin, bring the iron in contact with the piece and then melt some solder into the area where they are touching. This provides good thermal conductivity from the hot iron to the piece and also provides flux for cleaning. As you work, the iron will tend to accumulate excess solder; this you can remove by wiping the iron against your dampened sponge. When you turn on your iron, also dampen your sponge and have it ready. The round plastic dish holds the sponge.

There will be a demonstration video on soldering, so you can see the process in class. There will also be demonstrations on soldering during the next few help-labs, so go to one of those if you have never soldered before.

2.2 Breadboard

The white plastic "breadboard" strip that you've glimpsed in class allows you to build temporary circuits without soldering. More important to us, the breadboard lets you build temporary circuits *tidily*: it offers an alternative to laying components on the table and linking them with alligator-clips and wires. The on-the-table layout method gets messy and confusing. The breadboard lets you make circuits that are compact and easily "read" –by you or by someone (like one of us lab teachers) who's looking over your shoulder.

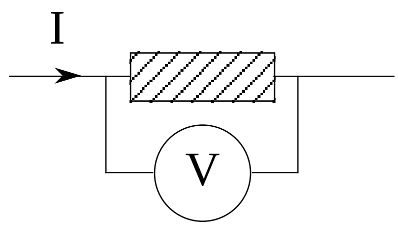
You should try to lay out the circuit so that it resembles its schematic: if the circuit "input" comes in from the left, say, and goes to a voltage divider to ground, place the parts that way on your breadboard. Use the long horizontal strips to define *ground* and *power-supply* (I like to use the next-to-bottom row for ground, leaving the lowest strip available for a negative supply: *below* ground; I'd use the top strip for the positive supply.) Beware the nasty detail that the horizontal strips are interrupted at their center. You should join the two sections of each horizontal strip with a short wire "jumper", to protect yourself from surprise later, when you've forgotten that the strips are not continuous.

2.3 The resistor color code

Resistor values are given in units of ohms, whose meaning is discussed below. The value is encoded by three colored stripes on composition resistors such as those you have. A fourth band is used to indicate the manufacturing "carbon tolerance", i.e., the accuracy you can expect. Sometimes there is a fifth band to indicate some special characteristic, such as failure rate. A color code chart appears at the end of this experiment.

2.4 I-V characteristics, "ohmic" and "non-ohmic" circuit elements

The behavior of an electric circuit component with two terminals in a circuit with a steady current can be characterized by the relationship of the current through it (I) to the potential difference across it (V):



For an ohmic device, a resistor, this relationship is very simple, and given by Ohm's law:

$$V = I\,R$$

where R is a constant called the resistance. Its units are ohms (current is in amperes and voltage in volts). These SI units are the only ones used in electrical engineering today.

Many important circuit elements are not *ohmic*; that is, they show I-V relationships that are not linear. A silicon *diode* is such a device, as you will confirm in Experiment 3; so is an *incandescent lamp*–though it presents a curious case: the *filament* is ohmic if you hold its temperature constant (we usually assume we'll hold the temperature constant, when we classify devices)–but the filament's temperature varies so widely that the *lamp* is not ohmic. Such devices cannot be specified by a constant resistance R. A modified concept of resistance does hold for such devices: a relation between I and V that is understood to apply only locally; this is called the "dynamic resistance" of the device. A silicon diode cannot be characterized by a "resistance;" but it may show a dynamic resistance of a few tens of ohms at a milliamp. You notice that one is obliged to add the "... milliamp" to make the statement valid.

But don't let the refinement "dynamic resistance" obscure the main point: only ohmic devices–*resistors*, in these laboratory experiments–can be specified by a constant R.

3 Procedure

3.1 Notebook

This experiment is the first for which you need to keep a real notebook record. To repeat the standards you should meet:

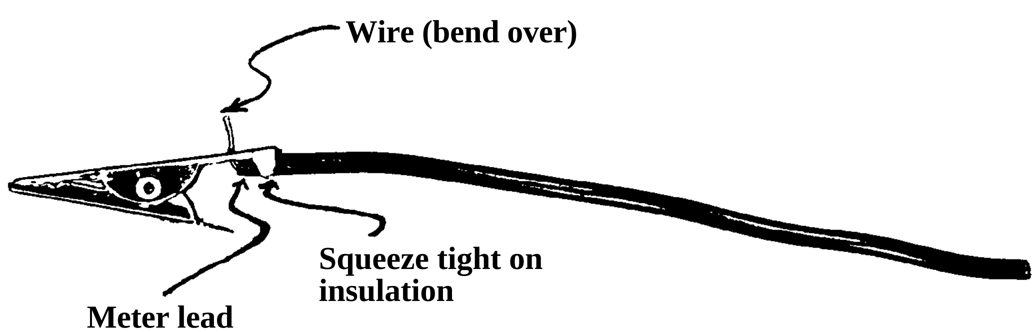
- The notebook should be a record *written as you work*, which can be brief but *needs to be intelligible to your T.F.*, and to yourself at some later date. Each part of an experiment ought to be labeled with a heading when you start it. DO NOT take notes on scrap paper and then copy them over neatly into the lab book. If you feel your initial scribbles are illegible, leave them in, but also write up a neater summary at the end. As the semester progresses, you will get better at taking neat notes "on the fly".

- There should be **a schematic diagram of every circuit you use**, and enough information to define what procedures you followed and what voltages, currents, or other data were recorded.
- Error bars

  Include these on your graphs whenever your error (or "uncertainty") is substantial on the scale of the graph. You'll find an example–with both x and y uncertain, as will be usual in our labs–on p. 9 of the handout, "Introductory Error Analysis" (fig. 5).
- Where a graph will help in data interpretation, or analysis (such as an I-V curve in this experiment), it should be *drawn immediately after* data is collected, or even as the data is obtained. Graphs should be large enough to be meaningful; at least one half sheet of paper. Raw data should be written in a clear and neat table. There is no need for extra sheets of graph or data paper in this course; the quadrille-ruled notebook pages will do very well.
- Write down your bright ideas, questions, and interpretations as you go. Try to estimate the precision of measurements when they are to verify or contradict some theory. Otherwise a rigorous interpretation cannot be made.
- Record at the end of an experiment the approximate time you spent on it. If you have problems, they need to be documented, and your strategies to overcome them noted.

3.2 Preparation

The probes which the meter comes with are not convenient for laboratory use because they must be held in place with your hands, leaving no hands to make adjustments or measurements. Installing alligator clips leads in place of the probes lets you clip the meter into the circuit and still have both hands free for adjustments and measurements. Two small steel alligator clips, with rubber insulators are in your plastic box. Cut off the probes **(the longer ends)**; then put the red and black insulators over the meter leads, facing toward the ends; and then strip the leads about 1/4 in. Your wire strippers work by putting a wire in the notch and closing them so they cut the insulation but not the wire. There is a movable screw which you can set to limit how far the jaws close. Set it to strip the probe wires, and then remove about 1/4 inch of insulation at the end of each wire. The stranded wire is easier to deal with if you twist it after stripping. Clip the alligator clip to the edge of your notebook to hold it, and solder a meter lead to it, as shown below:



It will be easier if you don't tin the wire until it is threaded through the hole and bent back over the clip. When you are finished, check your soldering by connecting the leads together and measuring the resistance on the "1 ohm" scale. The meter should be easily set to zero, and should stay there when you pull on your solder joints.

3. Resistance Measurement. We'd like you to determine how close the *measured* value of your resistors comes to the *nominal* value.

First, find resistors with the nominal values listed below, by reading the color code. Then, measure the actual resistance of a few of these parts (we're trying to spare you the tedium of too much measuring!):

2.7Ω: measure *one*

360Ω: measure *one*

2.4kΩ: measure all 3

240kΩ: measure *one*

1.2MΩ: measure *one*

Record your readings, including a measure of the deviation of the measured value from the nominal (that is, simply the difference from nominal value, as a percentage of nominal). Note, along with your result, the meter *scale* that you used.

The uncertainty of your decision concerning where the meter pointer lies (perhaps ± half a "tick"?)[2] conspires with the limited accuracy of the meter (let's call it ±5%, though Radio Shack claims it's a little better: ±3% [3]), so as to render some of your readings pretty rough. Don't bother to compute the uncertainty of each R reading; instead, please *note the formula* you would use if you did want to estimate the uncertainty, and apply it to *one* R (*resistance*) uncertainty; we don't want to put you through repetitious toil!.

Remember to set the meter to *zero* each time you change the resistance *scale*: clip the leads together and adjust the "zero-adjust" knob. The *zero* setting is likely to change each time you change scales; you must re-*zero* each time.

4 More soldering

You need to do some more preparation in order to measure I-V curves, and for use later throughout the course.

4 leads on battery pack

[2] Here's an answer to a good question a student asked recently, concerning the meaning of this form of "uncertainty." The student said, "All I can say is that I think I'm right, to the nearest tenth of a milliamp." Does that sort of diffidence fit the statistical model that the *error analysis* handout relies on? We think it does. One can fit this diffidence to the model, a little informally, if we say that "I think I'm right..." means "I think that if I recorded 1000 visual readings of this needle deflection, I'd be within 0.1 mA for most of them" (or "the standard deviation of my 1000 readings would be 0.1 mA").

[3] And what does Radio Shack mean by "±3%"? If they are being very careful, then they mean "If you tested lots of our meters, the standard deviation of their readings from the true value would be 3%."

The 4-cell AA holder presents you with two wires, from the most negative and most positive ends of the stack of cells. If you use only these two wires, you have, a 6V battery. (The wire used in these leads, is *stranded*, incidentally. Often that quality makes the wire useless for breadboarding: it won't insert in the breadboard's holes. The battery leads, however, are *tinned* for your breadboarding pleasure. You should be able to get them into the breadboard's openings.) We would like you to provide yourself with three more *taps* from this stack of four cells, so that you can pick off 1, 2, 3 or 4 cell voltages.

The voltages are roughly 1.6V per cell, for an alkaline cell—but we would like you to *measure* the voltage at each successive tap, and then use those measured voltages in your experiments!

All you need do, now, is to solder three more leads to the battery- holder, at the appropriate points. Those points are the coil springs at the 1/4, 1/2, and 3/4 points in the holder.

• Before soldering, strip about 1/2" of insulation from the end of a piece of "hookup" wire (22 gauge, solid: any color is fine–except red or black, the color of the battery-pack end leads);

• "tin" the exposed end of wire;

• loop that end of wire completely around the wire of the battery-holder's spring coil; that loop will effect mechanical connection and relieve the solder joint of strain if you tug on the wire. The solder then can handle just the electrical task, which is the one at which it excels.

When you store your battery pack, you should make sure that no two leads can touch or "short" together. You may want to slip a piece of scrap insulation over the exposed end, during storage. Covering with tape is a sure protection, though a little harder to undo.

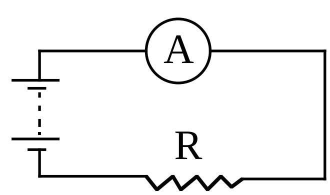
You can have your solder roll lying on the bench, supporting a piece of solder for you, and can then use both hands to tin the wire (do not use your lips to hold the solder).

2 leads on small light bulb

Next, attach 2 wires to the two terminals of the small light bulb. One terminal is at the bottom and is already tinned. The other is the brass-colored metal cylinder which holds the glass - it needs tinning wherever you plan to attach the wire.

4.1 I-V curve of a resistor

You should verify that a resistor is indeed an ohmic device. This is a circuit you can use:



The meter is labeled A for amperes, and is used to measure the current through R. You can Assume the meter is accurate to about 5%, plus any reading uncertainty. By using clip leads to connect batteries in series you can easily add their potential differences, obtaining five values from 0 to roughly-6 volts. *Note*, again, that we want you to use measured voltages at the several taps of your stack of cells—not the nominal battery voltages.

As you know, a truly ohmic device must have the same resistance to current flowing in either direction. How can we most easily test for this behavior?

Assume the 250 milliampere is the proper scale for your measurement. You need to choose the most appropriate resistor from your choice of ten values. Think about how to do this, and make your choice, before reading further. Record your value of R (*resistance*) and how you chose it.

Here is our procedure:

- From the maximum battery voltage and Ohm's law, calculate the value of R for which this voltage would give the maximum current of 250 milliamperes. To do the experiment, pick a resistor whose value is greater or equal to this, but the one that is closest, to give the largest (and most accurate) meter readings.
- Measure the I-V curve over the full range of battery voltages (O and four other voltages) and for both current directions through the resistor.
    - Reminder on measuring V and I in "both directions"
        * How not to do it: Some students, in past terms (when students were not quite so clever as you are) have tried to measure V and I in both positive and negative directions by reversing the polarity of every element: battery, meter, resistor. Do you see what's wrong with that method?!
        * How to do it: instead, you want to reverse only the orientation of the resistor:

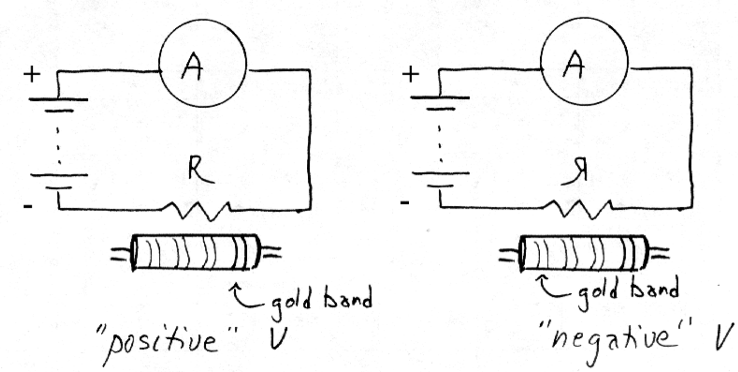


Figure 1: Measuring resistor's response to both polarities of applied voltage

Plot I vs. V for the data, using plus and minus V and I for the two current directions (It is highly conventional to use the vertical, or "y" axis for I, and the horizontal, or "x" axis for V). Include error bars to show your estimate of uncertainty for each reading.

Is there a reasonable straight line fit? Should it go through the point (0,0)? What value of R does the slope of your best straight line give? How does it compare with that given by the color code and the ohmmeter?

Aha! There is a systematic error because the ammeter is not ideal. If it were, there would be no voltage drop across the meter. In fact, it has an ohmic resistance. Hence the voltage drop across it is proportional to the current through it. Assume (not quite correctly, it turns out) that the meter is designed so that on both current scales, a full-scale current reading corresponds to a voltage drop of 250 mV. (We'll use this assumption, though it's not quite correct: In fact, the drop varies pretty widely, from meter to meter. If you are ambitious, you can ask for help detuning your meter's peculiar full-scale drop.) On the 250 milliampere scale, the meter resistance would be 1 ohm.

Thus, the voltage across your resistor was the battery voltage minus the voltage across the meter, and therefore less than we have assumed.

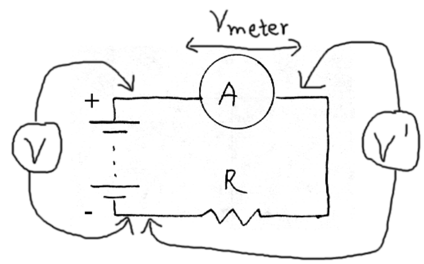


Figure 2: Ammeter introduces systematic voltage error

The true voltage across the resistor is V', in the figure above, rather than the battery voltage, V. Which way does this voltage error push your plot of I vs V? Your readings of current can easily be used to calculate the voltage across the meter, for each measurement, and thus to make a corrected estimate of the voltage that interests you, voltage across the resistor. Correct the voltage data by subtracting the *calculated* meter voltage drop. Then plot the new I-V curve (you can add these new points to the earlier graph) to get a better value of R. Compare with the nominal value.

Note: The 50 microampere scale has a double label on the meter. What is the meter resistance on this scale? Because of the ohmic voltage drop across the ammeter on this setting, it can also be used to measure voltages between 0 and 250mV.

4.2 I-V curve of your flashlight bulb.

Proceed as in the preceding experiment, with the small flashlight bulb in place of the resistor, correcting for the voltage across the meter from the start. Is the bulb an ohmic resistor? Does its I-V relationship depend on the current direction?

Resistor Value Chart

The colored bands on a composition resistor specify numbers according to the chart below. The two mnemonics (which read from top to bottom) may help you learn them. One of the end bands is almost always gold or silver. That is the fourth band, so you should start reading from the other end. The first two bands specify the significant figures of the value, and the third is a power of ten multiplier. The fourth band is the *tolerance* or accuracy of the resistor, with gold being ±5% and silver ±10%. Note that gold and silver can also be used as multipliers, and their values are -1 and -2, respectively.

Examples:

Red=2	Green=5	Brown=1	Gold=5%	= 25. $*10^1$ ±5%	= 250 Ω ±5%
Blue=6	Grey=8	Yellow=4	Silver=10%	= 68. $*10^4$ ±10%	= 680 KΩ ±10%
Brown=1	Black=0	Gold=-1	Gold=5%	= 10.$*10^{-1}$ ±5%	= 1.0Ω ±5%

Note that there is no decimal point between the first two numbers

Value	Color	Mnemonic1	Mnemonic 2
0	Black	Black	Black
1	Brown	Bart	Brown
2	Red	Rides	rainbow
3	Orange	Over	“
4	Yellow	Your	“
5	Green	Grave	“
6	Blue	Blasting	“
7	Violet	Violent	“
8	Grey	Guns	Grey
9	White	Wildly.	White
-1 or 5%	Gold	Go	Gold
-2 or 10%	Silver	Shoot!	Silver

(End lb1_feb07b.texFebruary 12, 2007)