

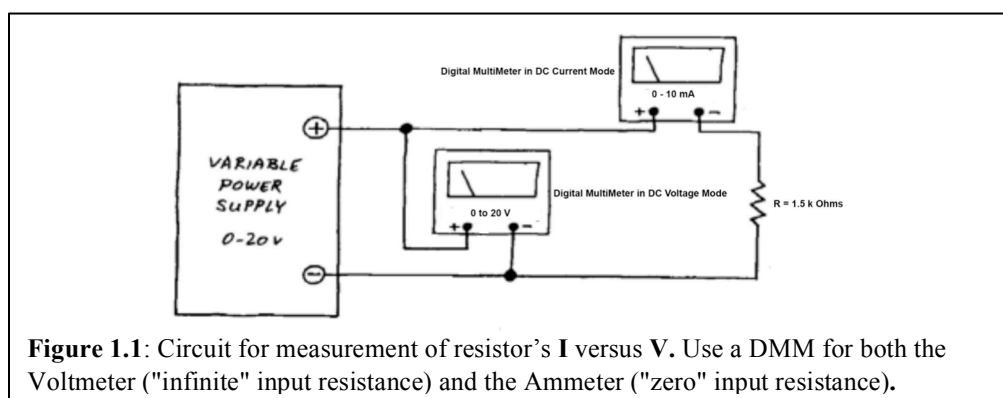
Physics 120 Lab 1: Instruments and DC Circuits

Welcome to the first laboratory exercise in Physics 120. Your equipment includes:

- *Digital oscilloscope w/USB output for SCREENSHOTS*
- *Function generator*
- *Audio oscillator*
- *Bench-top and hand-held digital multi-meters (use the bench-top unit for current measurements)*
- *Triple or quadruple power supply*
- *Resistance substitution box*
- *Breadboard, cables, and tools*

If you are stuck, or curious, please read the manuals! These are online at the course website (Neurophysics.ucsd.edu/physics_120a.php). The same website has the documentation for each active component (transistor, diode, op-amp, logic chip) that we use.

1-1. Ohm's Law



First, the pedestrian part of this exercise: Verify that the resistor obeys Ohm's law, by measuring V and I for a few different voltages.

The principal challenge here is simply to get used to the breadboard and the way to connect instruments to it. We do not expect you to find Ohm's Law surprising.

Check the parts manual to determine which holes are connected to which, how to connect voltages and signals from the outside world, *etc.*

This is also the right time to begin to establish some conventions that will help you keep your circuits intelligible. Try to build your circuit so that it looks like its circuit diagram:

- Let signal flow in from left, exit on right (in this case, the "signal" is just V ; the "output" is just I , read on the ammeter);
- Place *ground* on a horizontal breadboard *bus* strip *below* your circuit; place the positive supply on a similar bus *above* your circuit. When you reach circuits that include negative supply, place that on a bus strip *below* the ground bus. Logical layouts are easier to work with.
- Use **color coding** to help you follow your own wiring: use **black** for ground, **red** for the positive supply. Such color coding helps a little now, a lot later, when you begin to lay out more complicated *digital* circuits.

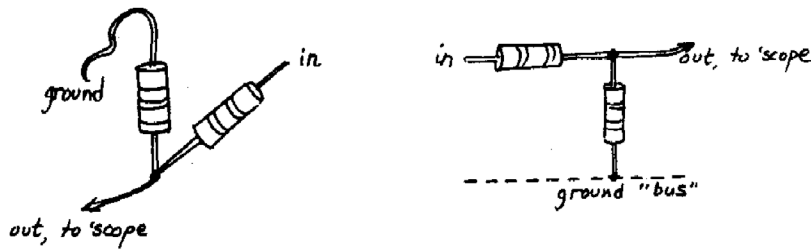


Figure 1.3: Bad and good breadboard layouts of a simple circuit.

Use the variable regulated DC supply, and the hookup shown in the first figure, above, Fig. 1.1. Note that voltages are measured *between* points in the circuit, while currents are measured *through* a part of a circuit. Therefore you usually have to break the circuit to measure a current.

Warning: Current measurements use a separate input than voltage measurements on the digital multimeter (DMM). Plus, the current input is fused. Use the low current input, the one marked "mA", and start at the highest setting on the dial, 1A or 100 mA depending on your meter, and work your way down to more sensitive settings. Be sure that you do NOT plug the Ammeter directly into the power supply - or pop goes the fuse!

Measure a few values of **V** and **I** for the 1.5 k Ω resistor. Next try a 1.0 k Ω resistor instead, and sketch the two curves that these resistors define on a plot of **I** versus **V**. You may be disinclined to draw these "curves," because you knew without doing this experiment what they would look like. Fair enough. But we encourage you to draw the plot in your report that do not obey Ohm's Law.

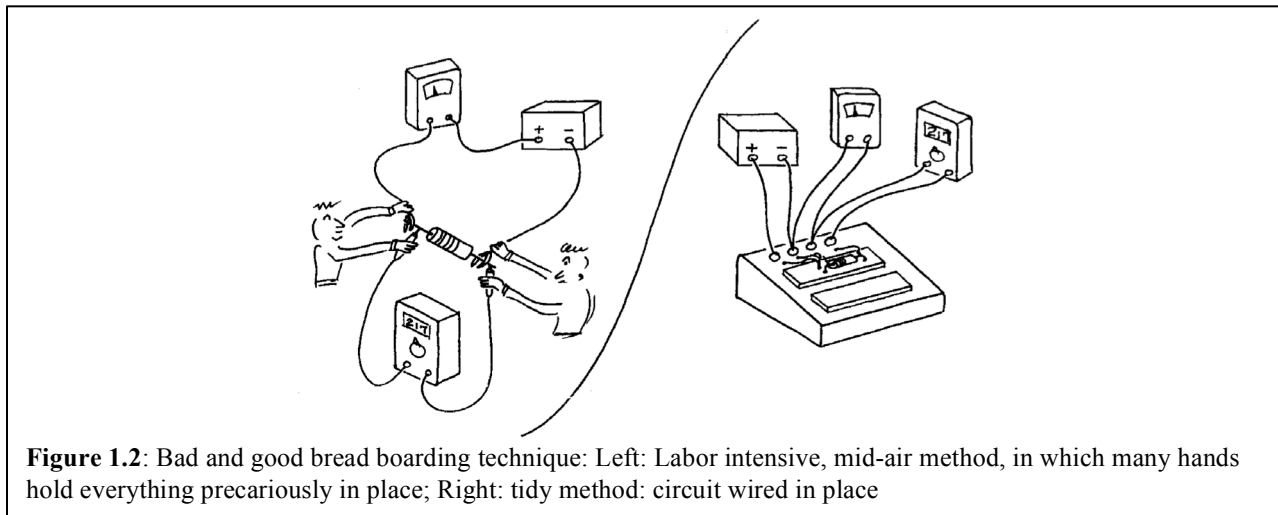


Figure 1.2: Bad and good bread boarding technique: Left: Labor intensive, mid-air method, in which many hands hold everything precariously in place; Right: tidy method: circuit wired in place

Build your circuit *on the breadboard*, not in the air. Novices often begin by suspending a resistor between the jaws of alligator clips that run to power supply and meters. Try to do better: plug the resistor into the plastic breadboard strip. Bring power supply voltages to the breadboard, first to the banana jacks and from there to the bus strips. Then use wires to bridge between supply voltages, ground, *etc.*, and components plugged into the breadboard. Figure 1.2 is a sketch of the poor way and the better way to build a circuit.

Two Nonlinear Devices: (*Ohm's Law Defied!*)

1-2. An incandescent lamp

Now perform the same measurement (**I** versus **V**) for a #47 lamp (yes, incandescent bulbs are now “illegal”). Use the 100 mA and 500 mA scales on your DMM. Do not exceed 6.3 Volts! Again you need only a few readings. Plot your results on the drawing you used to show the *resistor's* behavior. Get enough points to show how the lamp *diverges* from resistor-like performance.

What is the “resistance” of the lamp? Is this a reasonable question? If the lamp's filament is made of a material fundamentally like the material used in the resistors you tested earlier, what accounts for the funny shape of the lamp's **V** versus **I** curve?

1-3. The Diode

Here is another device that does not obey Ohm's law and does not even conduct in a symmetric fashion; the **diode**. (I don't expect you to understand how the diode works yet; I just want you to meet it, to get some perspective on Ohm's Law devices: to see that they constitute an important but *special* case).

We need to modify the test setup here, because you can't just apply a voltage across a diode without a big pop (!); as you did for the resistor and lamp above. You'll see why after you've measured the diode's **V** versus **I**. Do that by wiring up the circuit shown below.

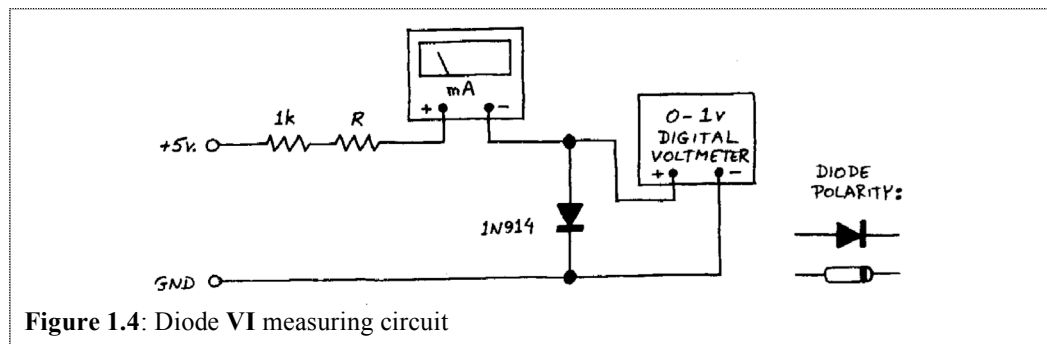


Figure 1.4: Diode VI measuring circuit

In this circuit you are applying a current, and noting the diode voltage that results; earlier, you applied a voltage and read resulting current. The 1 kΩ resistor limits the current to safe values. Vary **R** with a resistor substitution box and look at **I** versus **V**, sketching the plot in two forms: linear and “semi-log.” (\log_{10} **I** versus **V**).

First, get an impression of the shape of the linear plot; just four or five points should define the shape of the curve. Then draw the same points on a semi-log plot, which compresses one of the axes.

See what happens if you reverse the direction of the diode. Note the behavior.

How would you summarize the **V** versus **I** behavior of a diode?

Now explain what would happen if you were to put 5 V across the diode (**Don't try it!**). Look at a diode data sheet, if you're curious: see what the manufacturer thinks would happen. The data sheet won't say “boom” but that is what it will mean.

1-4. Function Generator

This device can generate periodic outputs of varying shape over a very broad range of frequencies - sine waves, triangular waves and square waves from about 0.3 Hz to 2 MHz for the device on hand, nearly a ten million fold range. The amplitude of the wave can be varied, and you can add a DC offset. There is also a **TRIGGER OUTPUT** that may be used to trigger the oscilloscope, as described next.

The function generator is an essential piece of equipment in the characterization and diagnosis of circuits. it is invariably used with an oscilloscope, described next.

1-5. Oscilloscope

We'll be using the oscilloscope ("scope") in virtually every laboratory class. Get familiar with the scope using the function generator as input. Start with a simple waveform, say a 1 KHz sine wave.

Play with the scope's sweep and trigger menus and controls. Specifically, try the following:

- The vertical scale switch. This controls "*volts/div*"; note that "*div*" for division refers to the centimeter marks, not to the tiny 0.2 cm marks;
- The horizontal scale selector: *time* per division.
- The trigger controls. Triggering is by far the subtlest part of scope operation. "Auto" is a great way to start, "Normal" on a stable waveform (like the input signal or better yet the **TRIGGER OUTPUT** signal described below) with judicious choice of "Level" is best.

Switch the function generator to square waves and use the scope to measure the "rise-time" of the square wave (defined as time to pass from 10% to 90% of its full amplitude). Include a **SCREENSHOT** of the rise to demonstrate this.

At first you may be inclined to despair, saying "Rise-time? The square wave rises instantaneously." The scope, properly triggered at a fast time-base, will show you this is not so.

What comes out of the function generator's **TRIGGER OUTPUT** connector? Look at this on one channel while you watch a triangle or square wave on the other scope channel. To see how this can be useful as a synchronization signal, try to trigger the scope on the peak of a sine wave *without* using the "internal" trigger; then notice how entirely easy it is to trigger so when you do use **TRIGGER OUTPUT** as the "external" trigger. (Triggering on a well-defined point in a waveform, such as peak or trough, is especially useful when you become interested in measuring a difference in *phase* between two waveforms; this you will do several times in the next lab.) Include a **SCREENSHOT** of the **TRIGGER OUTPUT** and a sinusoidal waveform, triggering on the **TRIGGER OUTPUT**.

Put an "offset" onto the signal and see what the **AC/DC** selector, found in the vertical menu, does.

Note on AC/DC selector on the oscilloscope

Common sense may seem to invite you to use the **AC**; after all, aren't these time-varying signals that you're looking at alternating current (in some sense)? *Eschew* this plausible error. The **AC** setting puts a capacitor in series with the scope input, and this can produce startling distortions of waveforms if you forget it is there; see what a 50 Hz square wave looks like an AC, if you need convincing. Furthermore, the AC setting washes away DC information, and you don't want to wash away information except when you choose to do so knowingly. Once in a while you *will* want to look at a little sine with its DC level stripped; but always you will want to know that this DC information has been made invisible. You might even put the same signal into two separate channels, one DC coupled out the other AC coupled to keep track of the DC and the little sine.

Set the function generator to some frequency in the middle of its range, then try to make an accurate frequency measurement with the scope; directly, you are obliged to measure *period*, of course, not frequency. You will do this operation hundreds of times during this course. Soon you will be good at it. In general, trust the scope period readings and not the function generator.

1-6. Voltage Divider

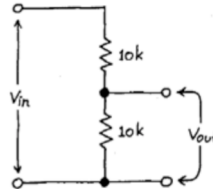


Figure 1.5: Voltage divider; V_{in} and V_{out} mark voltage levels

Construct the voltage divider shown above. Apply $V_{in} = 15$ Volts from the power supply. Measure the open circuit output voltage, $V_{Open_Circuit}$ ($V_{Open_Circuit} = V_{out}$ with no load).

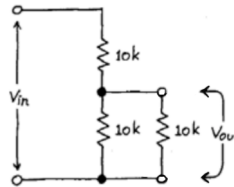


Figure 1.6: Voltage divider, as in Figure 1.5, with a load resistor

As a side exercise, attach a $10k \Omega$ load resistor to V_{out} , as shown above. Does V_{out} go up or down? Why?

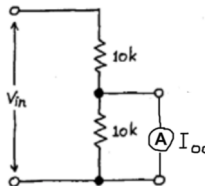


Figure 1.7: Voltage divider, as in Figure 1.5, with an Ammeter as a *short* across the 10K Ohm resistor.

Now measure the short circuit current, $I_{Short_Circuit}$. This means “short the output to ground, but make the current flow through your current meter” as shown above.

From the measurements of $I_{Short_Circuit}$ and $V_{Open_Circuit}$ you can calculate the Thevenin equivalent circuit. Do it!

Now replace the DC source with the output from the function generator. Start with a sine wave at 1 kHz with an output of ± 5 V for V_{in} . What is the output at V_{out} ? Do you expect the amplitude of the output to be frequency dependent? Test your ideas by measuring V_{out} as a function of frequency. This is best done using two channels on the oscilloscope, one displaying V_{out} and the other V_{in} . What happens at high frequencies, *i.e.*, at 1 MHz? Switch to a square wave. Does the waveform at the output make sense? Include a **SCREENSHOT** that demonstrates what happens at high frequency.

An oscilloscope probe is often used at high frequencies. This probe has high input resistance and low input capacitance. Use an oscilloscope probe to measure V_{out} at high frequencies rather than a clip lead. Remember to select the correct scale through the menu for the vertical scale. Does it make a difference? Why? Include a **SCREENSHOT** that demonstrates what happens at high frequency.