

# Physics 120 Lab 1 (2019) - Instruments and DC Circuits

Welcome to the first laboratory exercise in Physics 120. Your state-of-the-art equipment includes:

- Digital oscilloscope w/USB output for SCREENSHOTS.
- Two function generators; one with a synchronous pulse to serve as a trigger for the oscilloscope.
- Two bench-top digital multi-meters (use with care for current measurements).
- Triple or quadruple power supply that can be run as constant voltage or constant current sources.
- Resistance substitution box.
- Breadboard, power cables, signal cables, oscilloscope probes, and hand tools.

There is also a shared impedance meter by the parts supply bench to measure capacitance and inductance.

If you are stuck, or curious, about details of the equipment or the active components (transistors, diodes, op-amps, logic chips) that we use, then please read the manuals! These are online at the course website ([https://neurophysics.ucsd.edu/physics\\_120a.php](https://neurophysics.ucsd.edu/physics_120a.php)).

This handout contains general information of the correct use of equipment and the proper style of reporting data that is common to all of the laboratory exercises.

## 1-1. Common connections for the power supply

We wish to make a symmetric supply, i.e. one with a positive supply voltage (typically +15 V) and a negative supply voltage (typically -15 V) relative to ground. Connect two of the independent, floating supplies by ground the positive lead to make a negative supply and grounding the negative lead to make a positive supply. Add a third supply for digital devices, wired as

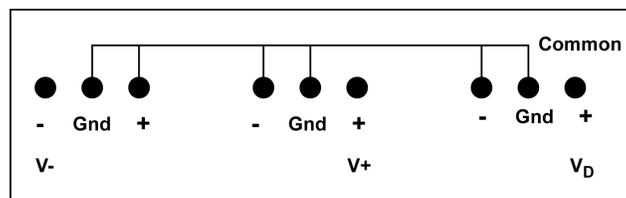
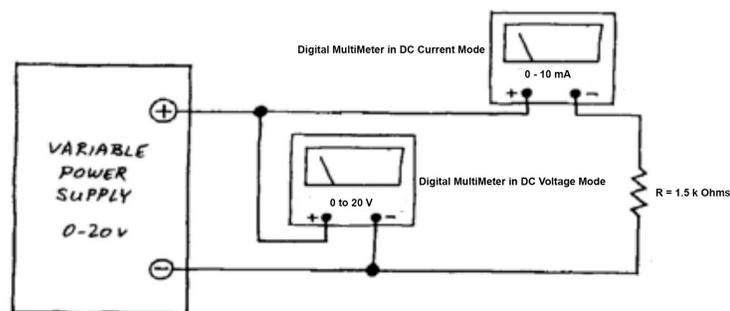


Figure 1.1

Why does this wiring scheme work? (2 pts).

## 1-2. Ohm's Law



**Figure 1.2:** Circuit for measurement of resistor's **I** versus **V**. Use a DMM for both the Voltmeter ("infinite" input resistance) and the Ammeter ("zero" input resistance). **Warning:** Current measurements use a separate input than voltage measurements on the 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, i.e., 500 mA, and work your way down to more sensitive settings. Never plug the Ammeter directly into the power supply - or pop goes the fuse.

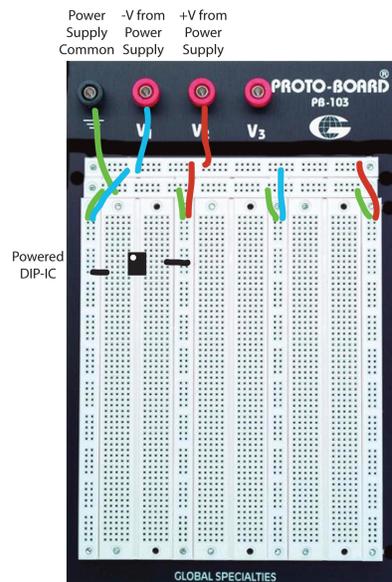
First, the pedestrian part of this exercise: Verify that the resistor obeys Ohm's law, by measuring  $V$  and  $I$  for a few different voltages and graphing  $I$  (Y-axis) versus  $V$  (X-axis).

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 in each row or column are connected to which, how to connect voltages and signals from the outside world, *etc.*

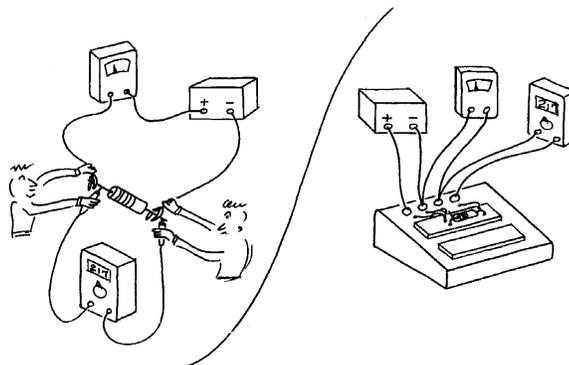
This is also the right time to begin to establish some conventions that will help you keep your "Proto-Board" circuits intelligible. Try to build your circuit so that it looks like its circuit diagram:

- Let signal flow in from left, exit on right (In the case of Figure 1.2, the "signal" is just  $V$ ; the "output" is just  $I$ , read using the multi-meter as an ammeter);
- Place the positive supply voltage ( $V_+$ ; typically +15 V), *ground* or common, and negative supply voltage ( $V_-$ ; typically +15 V) on a horizontal breadboard *bus* strip and use this to feed vertical breadboard bus strips. Check if jumpers are required along the bus. When you construct circuits that include a "digital" supply ( $V_D$ ; typically +5 V), place that voltage on a bus strips as well. Logical layouts are easier to work with and debug (Add snapshot, 1 pt).
- Use *color coding* to help you follow your own wiring: use *red* for the positive supply, *black* for ground, *green* for the negative supply, and *yellow* for the digital supply. Such color coding helps a little now, and a lot later, when you begin to lay out more complicated circuits.



Back to measuring resistance using a 1.5 k $\Omega$  resistor (Figure 1.2). Use the variable regulated DC supply, and the hookup shown in the Figure 1.3. 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.

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 1.3 is a sketch of the poor way and the better way to build a circuit.



**Figure 1.3:** Bad and good technique. Left: Labor intensive, mid-air method. Many hands hold everything precariously in place; Right: Tidy method. The circuit is wired in place using a Proto-Board.

Before we go on, this is a good time to recall some key concepts in measurement:

1. What is the internal resistance of an ideal voltmeter (1 pt)?
2. What is the internal resistance of an ideal ammeter (1 pt)?
3. What are the two different configurations to measure the voltage and current, noting that the set-up in Figure 1.2 is one such way (1 pt)? Briefly (a few sentences) discuss their relative accuracy (1 pt).

Measure a few values of  $V$  and  $I$  for the 1.5 k $\Omega$  resistor and plot your results; be sure to label your axis with the quantity and the units (2 pts). Next try a 1.0 k $\Omega$  resistor instead (2 pts). Think of this as a control run, as the next devices do not obey Ohm's Law. Finally, repeat the measurement of the 1.5 k $\Omega$  resistor with a different configuration to measure the voltage and current and compare with your previous result (2 pts).

### 1-3. An incandescent lamp (*Ohm's Law Defied!*)

Now perform the same measurement, i.e.,  $I$  versus  $V$ , for a #47 lamp. *Note: Incandescent bulbs are specialized sources, but they are an excellent device to demonstrate nonlinearity, i.e., non-Ohmic I-V curves.* Use the 500 mA ammeter scales on your DMM. Do not exceed 6.3 V, the maximum voltage for the lamp! Plot your results on the drawing you used to show the resistor's behavior (2 pts). Acquire enough points to show where and how the lamp *diverges* from resistor-like performance and, as a final reminder, remember to label your axes and the units (1 pt).

What is the "resistance" of the lamp (1 pt)? Is this a reasonable question (1 pt)? 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 pt)?

### 1-4. Function generator

This device can generate periodic outputs of varying shape over a very broad range of frequencies - sine waves, triangular waves, square waves, and pulses from about 0.3 Hz to 20 MHz, nearly a hundred 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 can 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 way to observe a slowly evolving signal on "Untriggered Roll". Yet always use "Normal" with a stable waveform, like the **TRIGGER OUTPUT** of the waveform generator, with the judicious choice of "Level".
- The use of **10-X OSCILLOSCOPE PROBES**. These act as a high impedance input to the oscilloscope and should be unfailingly used for all test measurements. Remember to set the input selector to 10-X.

### A warning on the AC/DC selector on the oscilloscope



Common sense may seem to invite you to use the *AC* setting; after all, aren't these time-varying signals that you are addressing? *Eschew* this plausible error. The *AC* setting puts a capacitor in series with the oscilloscope input. This will produce startling distortions of waveforms; see what a 50 Hz square wave looks like with AC coupling if you need convincing. Furthermore, the AC setting removes DC information and you don't want to lose 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 and the other AC coupled to observe the little sine.

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 (**1 pt**). At first you may be inclined to think "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** (**1 pt**).

### A note on SCREENSHOTS

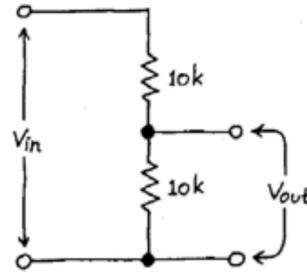
You will use these heavily throughout the class as a means to log and document your results. SCREENSHOTS are bit-mapped images that are readily inserted into a report. Make sure that:

1. The data fills the screen.
2. Input, output, and possibly auxiliary signals are present in one plot so that relative timing can be ascertained.
3. Unused channels are turning off for clarity.
4. Label the axes with names and units, and label the different channels, after you insert the SCREENSHOT in a report.

Put an "offset" onto the signal and see what the AC/DC selector, found in the vertical menu, does to the signal. Demonstrate this with a **SCREENSHOT** (**1 pt**).

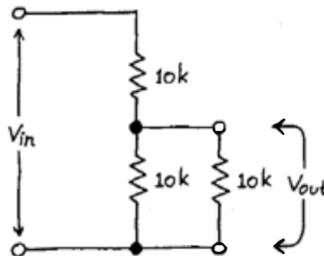
Set the function generator to some frequency in the middle of its range, then try to make an accurate frequency measurement with the scope; directly, you are obliged to measure *period*, of course, not frequency. You will do this operation hundreds of times during this course. In general, trust the scope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

## 1-6. Voltage divider - DC



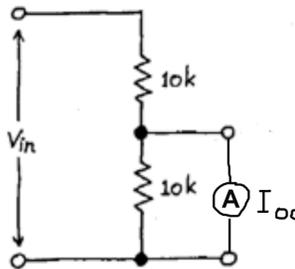
**Figure 1.4:** Voltage divider;  $V_{in}$  and  $V_{out}$  mark voltage levels.

Construct the voltage divider as shown in Figure 1.4. 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) (1 pt).



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

Now attach a  $10k \Omega$  load resistor to  $V_{out}$ , as shown in Figure 1.5. Does  $V_{out}$  go up or down (1 pt)? Why (1 pt)?

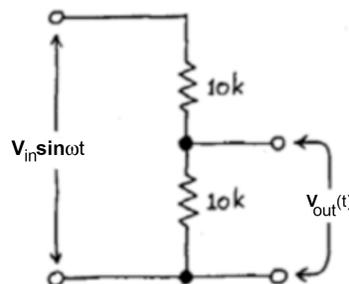


**Figure 1.6:** Voltage divider, as in Figure 1.4, with an Ammeter as a short across the 10K Ohm resistor

Now measure the short circuit current,  $I_{Short\_Circuit}$  (1 pt). This means “short the output to ground, but make the current flow through your current meter” as shown in Figure 1.6.

From the measurements of  $I_{Short\_Circuit}$  (Figure 1.6) and  $V_{Open\_Circuit}$  (Figure 1.5) calculate the Thevenin equivalent circuit (2 pts).

## 1-7. Voltage divider - AC



**Figure 1.7:** Voltage divider, as in Figure 1.4, but with an sinusoidal input.  $V_{in}(t)$  and  $V_{out}(t)$  denote waveforms.

Replace the DC source in Figure 1.4 with the output from the function generator (Figure 1.7). Start with a sine wave at 1 kHz with an output of  $\pm 5$  V for  $V_{in}(t)$ . Use an oscilloscope, with an oscilloscope probe, rather than the voltmeter, to measure the output.

What is the output at  $V_{out}(t)$ . (1 pt)? Do you expect the amplitude of the output to be frequency dependent (1 pt)? Test your ideas by measuring  $V_{out}(t)$  as a function of frequency. This is best done using two channels on the oscilloscope, one displaying  $V_{out}(t)$  and the other  $V_{in}(t)$ . What happens at high frequencies, *i.e.*, near or above 1 MHz; document with a **SCREENSHOT (1 pt)**?

Switch to a square wave. Try to go as high in frequency as you can. What happens to the waveform at the output, documented with a **SCREENSHOT (1 pt)**? Why (1 pt)?

Let's revisit the issue of the oscilloscope probe. This probe has high input resistance and low input capacitance. Measure  $V_{out}(t)$  at high frequencies with a sine wave input as above, but switch from an oscilloscope probe to a clip lead. *Note: remember to select the correct scale through the menu for the vertical scale.* Does it make a difference? Include a **SCREENSHOT (1 pt)**. Why (1 pt)?

**35 points total**