Lab 1: Voltage, Current, and Resistors

Note: This first lab has a number (maybe *too large* a number) of little experiments. Don't worry if you are unable to complete all of them today.

1 Multimeters: Resistance

(a) The color code chart for resistors is available on your bench. You probably won't memorize the whole code, but you should remember the meaning of the third (multiplier) band: brown resistors are in the 100 Ω range, red resistors are in the kΩ range, orange in the 10 kΩ range, and yellow in the 100 kΩ range. Typical resistors are rated for 1/4 W (= 0.25 W = 250 mW).

What is the smallest 1/4 W resistor that can safely drop 5 V, and what is its color code?

Using $P = VI = V^2/R$, and plugging in $V = 5$ V and $P = 0.25\,\mathrm{W}$, we find $R = 100\,\Omega$. That's $10 \times 10^1\,\Omega$, whose corresponding color code is Brown (1), Black (0), Brown (1).

(b) Read the three loose resistors on the sticky note on your bench by color and write down their values. For each resistor, which is rated for 250 mW, what is the maximum voltage you can place across it before it will get dangerously hot?

Color code	Resistance Value	Power rating	Max safe voltage
Yellow, Violet, Black	47 Ω	250 mW	$\sqrt{0.25\,\mathrm{W} \cdot 47\,\Omega} = 3.4\,\mathrm{V}$
(depends on setup)		250 mW	
		250 mW	

(c) Using a multimeter, measure the resistance values (you will have to attach appropriate leads).

Do they agree with the nominal values within ±5%?

Hopefully!

(d) How does the multimeter measure resistance? (Hint: note that the leads are connected the same way as for a voltage measurement.)

It injects a known current, measures the voltage, and calculates $R = \frac{V}{I}$.

Under what conditions will this measurement fail?

It will not work if any other currents are flowing in the circuit, which means that you can never measure resistance in a live circuit.

Also, if the resistor is in a circuit, the current injected by the multimeter will not all flow through the resistor of interest if other paths are available! So you must always disconnect resistors before measuring them.

(e) Switch to the continuity-check mode of the multimeter by moving the dial to the diode symbol. This is an arrow with a bar at the end.

Use the continuity-check mode to draw a diagram of the connections inside the breadboard (use the separate empty strip for this). Which rows and columns are connected? Check your diagram with the lab staff.

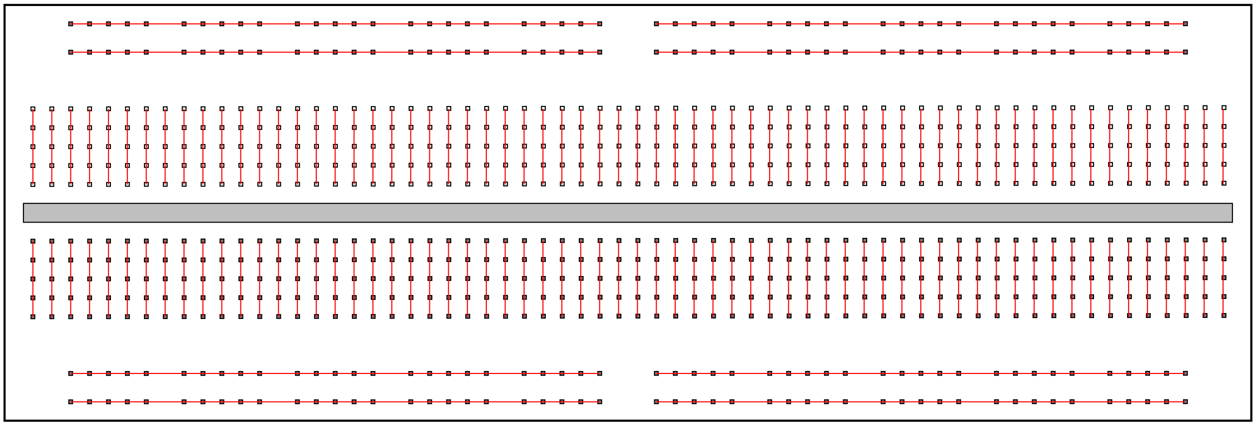


Figure 1: Draw the internal connections on this empty "solderless breadboard."

The four rows of connected holes along the long edges are called the "power rails" because they are often used for distributing power (such as $+5\,\mathrm{V}$) and ground to the circuit. Note that they have a break at the middle of the breadboard; forgetting to connect the rails in the middle is a common mistake in breadboarding!

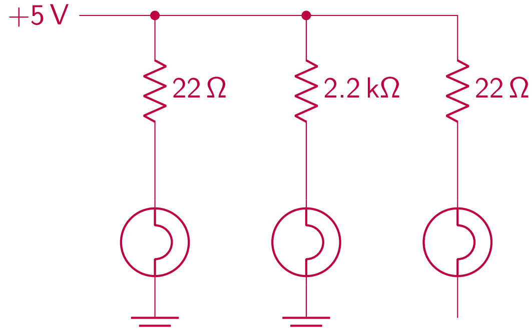
2 Reading Circuits

(a) Determine why two of the light bulbs do not light when the protoboard is switched on. You can use the multimeter, but make your investigation non-destructive (i.e., don't disconnect the circuit).

Bulb 2: The resistor is 100 times larger; not enough current flows to heat and light the bulb.

Bulb 3: The bulb is not connected to ground; the circuit is not complete so no current flows.

(b) Draw a full diagram of the circuit including what you have learned, then check it with one of the lab staff.



3 Multimeters: Current

(a) Explain why an ideal current meter has no resistance, while an ideal voltage meter has infinite resistance.

Current is measured *through* a device. In order for the measurement to not affect the circuit, the ammeter, which goes in *series*, should approximate a wire with no resistance. Voltage, on the other hand, is measured *across* a device. To not disturb the circuit, a voltmeter, which is placed in *parallel*, should approximate an open circuit (infinite resistance).

(b) Use a second DMM to measure the resistance of a DMM when set on its 2 mA (2000 μA) dc current range.

What would the voltage drop across the DMM be, if a "full-scale" current (i.e., 2 mA) were flowing through it? (this is known as the "voltage burden.")

For the μA mode, the internal resistance is about 100 Ω. You may have noticed that while you were measuring resistance with one DMM, the other DMM read a current of around 300 μA — this is the current discussed in question 1(d)! The voltage burden if 2 mA is flowing would be $V = IR =$ 200 mV or 0.2 V, which is not negligible in a lot of circuits!

(c) Hypothetically — *DON'T TRY IT!!* — What would happen if the DMM, set to measure current, were connected from +5 V to ground?

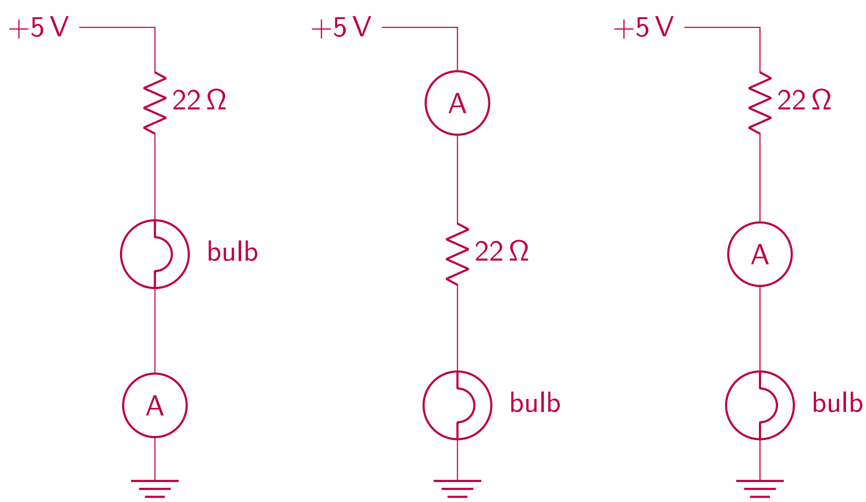
In the μA mode, the current flowing would be $I = V/R = 50$ mA, which is a fair bit of current but not going to blow the fuse. However, the DMM's mA mode has only 2 Ω of internal resistance. In this mode, placing 5 V across the leads would cause 2.5 A to flow! Or rather, the current would start to rise, and the 400 mA fuse inside the DMM would blow.

(d) Remove bulb 1 from the circuit, measure its resistance with the DMM, then predict the current through it when the circuit is powered. Reconnect bulb 1.

Depending on the bulb, the resistance is likely on the order of ohms. Thus, the current would be mostly limited by the 22 Ω resistor, and the predicted current will be around 200 mA.

(e) Draw how you will connect the multimeter as a current meter to measure the current through bulb 1, then check this with the lab staff before proceeding to make the measurement.

The ammeter goes in *series* with the bulb. The placement along that branch of the circuit (above the resistor, between the resistor and the bulb, below the bulb) doesn't matter, as all elements in series must have the same current flowing by Kirchhoff's Laws.

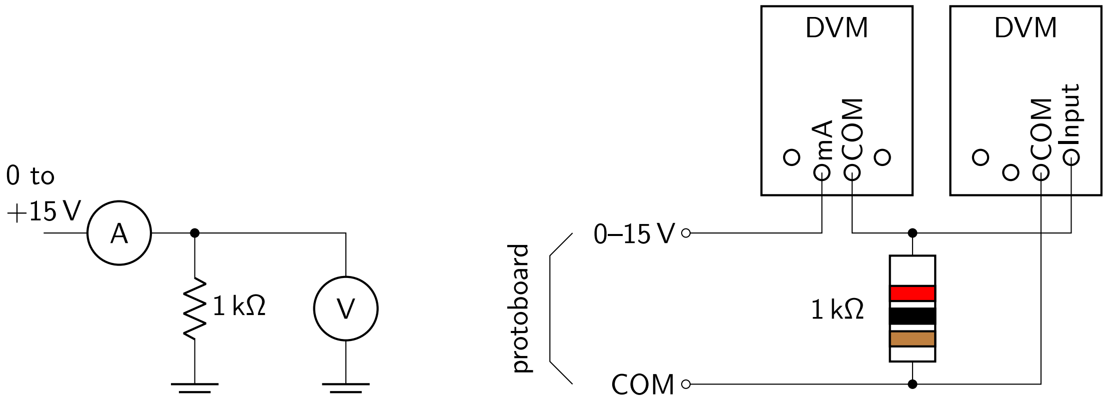


(f) Measure the current through bulb 1. Did your measurement match your prediction? Why or why not?

The current will be lower than predicted, because the bulb's resistance increases as it heats up.

4 Ohm's Law

(a) Rig up the circuit shown in Figure 2, using a pair of DMMs so that you can measure both voltage and current at the same time. Then, using the variable positive supply voltage (yellow wired, top rail) to drive the circuit, plot a set of measurements of current versus voltage on the handy graph paper of Figure 3.



A. (schematic) B. (pictorial)

Figure 2: Simple circuit to learn about voltage, current, multimeters, and Ohm's law.

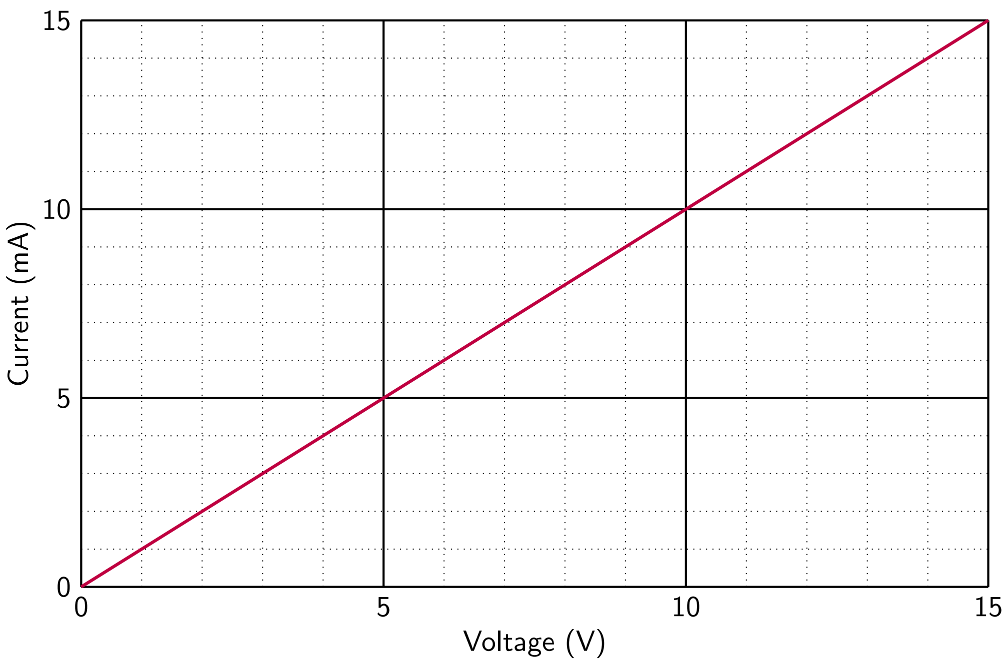


Figure 3: Graph paper for 1 kΩ resistor measurements.

(b) What would be wrong if you put the current meter on the low side of the resistor, as in Figure 4 below?

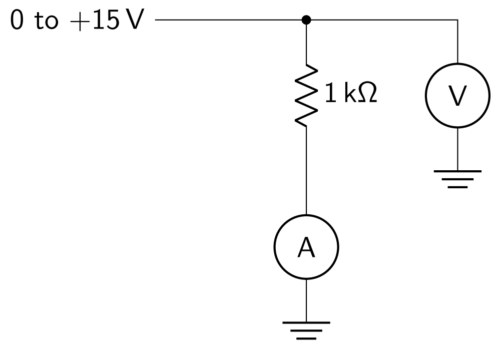


Figure 4: What's wrong with this innocent variation on the circuit of Fig. 2?

If the meters are ideal, it's not a problem. But we know that the ammeter has internal resistance (we measured it!). In the configuration of Figure 4, the voltmeter measures the voltage across 1 kΩ + (ammeter's internal resistance), when we in fact want to measure only the voltage across the 1 kΩ. So, we would measure a voltage that is slightly too large.

5 A Nonlinear Device: Light Bulb

The light bulb in measurement 3 behaved "non-Ohmic," and here we'll explore this a bit more.

(a) Rig up a 10 kΩ pot (potentiometer) as shown in Figure 5A.

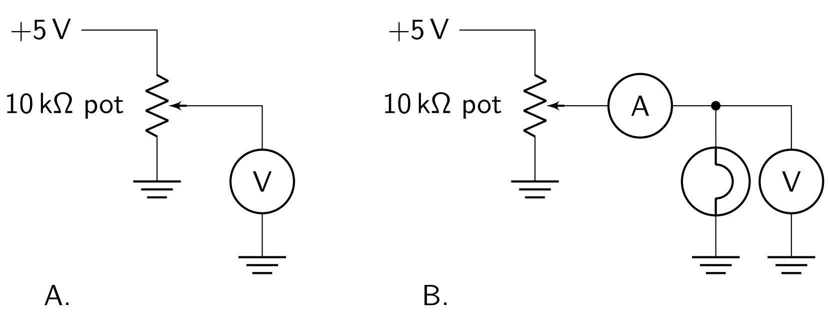


Figure 5: A. Potentiometer ("pot") used as variable voltage divider. B. Circuit to investigate I vs V of a small incandescent bulb.

Be careful not to connect the center wire to either +5 V or to ground! Explain why not.

If, for example, the center wire is connected to ground (as shown below), turning the pot all the way in one direction would make the +5 V connected directly to ground. This is a "short circuit, and a LOT of current will flow. The correct circuit in Figure 5A ensures that there is always 100 Ω between +5 V and ground.

(b) Turn the power on, and satisfy yourself that it lets you create a voltage between 0 and 5 V.

(c) Now rig up the circuit of Figure 5B, and plot a set of measurements of current versus voltage on the custom graph paper of Figure 6.

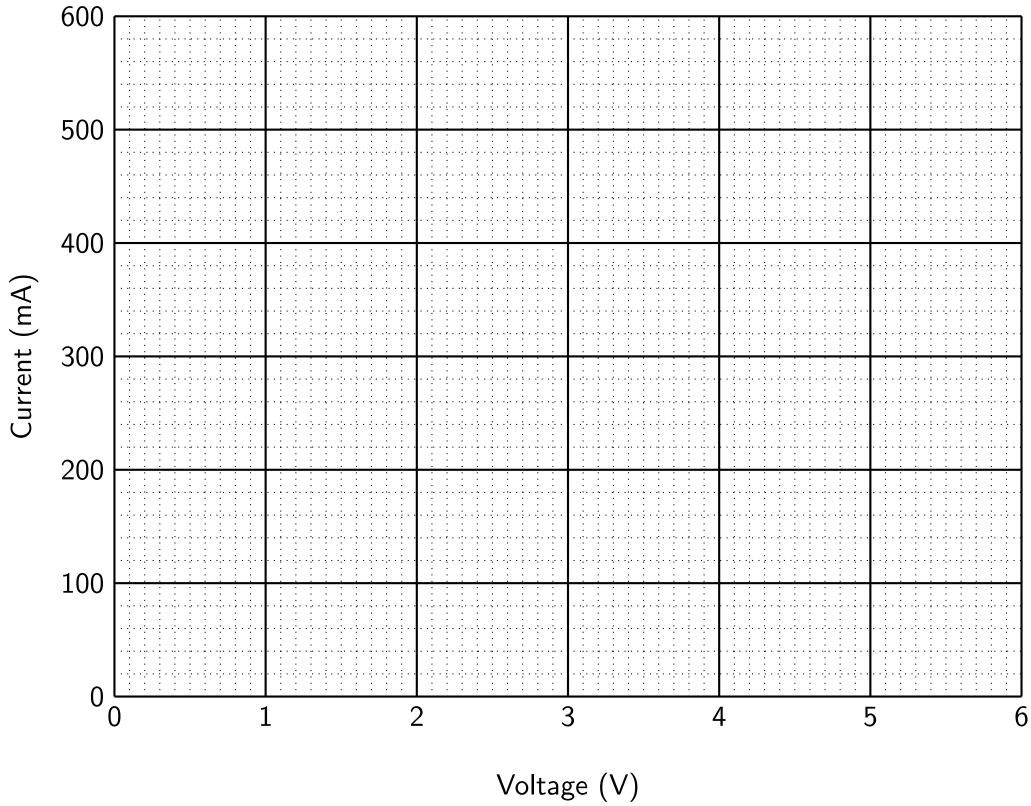


Figure 6: Graph paper for 5 V bulb I vs V measurements.

6 Time Permitting: An Important Nonlinear Device: The Diode

We don't use light bulbs much anymore (LEDs have taken over the job of making light), but we *do* use a 2-terminal device called a *diode*. The ideal diode is an electronic "one-way valve" — it conducts in one direction, but not the other way around. Now that you've got a low-voltage I vs V tester working, let's see what a diode does.

(a) Replace the bulb in your Figure 5B with a diode, and (important!) add a $100\,\Omega$ resistor in series; thus the circuit of Figure 7.

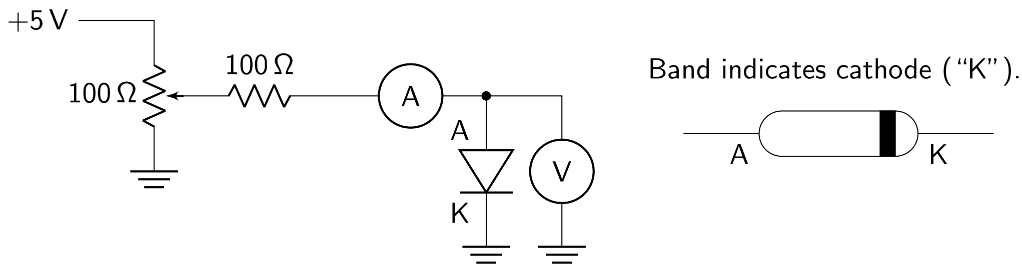


Figure 7: Circuit to investigate I vs V of a diode.

(b) Before you turn on the juice, explain why the resistor is needed, and check with lab staff.

The diode conducts current in one direction, acting like a wire. Thus, when I turn the pot all the way up, I could have a short circuit between 5 V and ground unless I include the $100\,\Omega$ current-limiting resistor.

(c) Now power the circuit and plot I vs V on the custom graph paper of Figure 8.

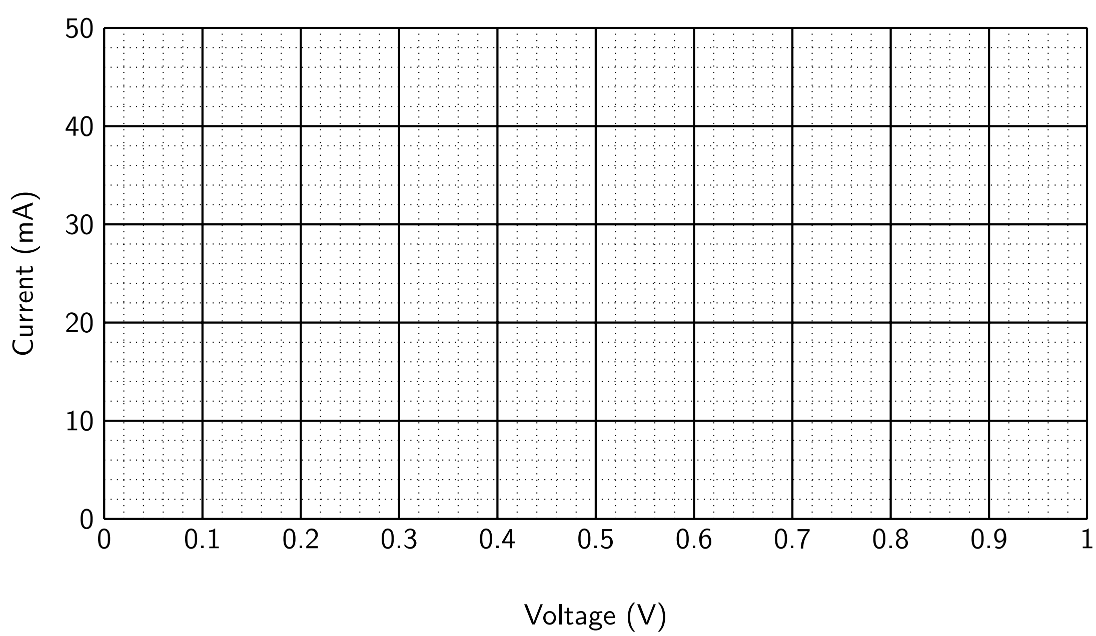


Figure 8: Graph paper for diode I vs V measurements.

(d) In the region 0 V to 0.4 V, does the diode behave like a very small or a very large resistor? What about in the region 0.6 V–0.8 V?

0 V to 0.4 V: like a very large resistor. 0.6 V–0.8 V: Like a very tiny resistor.

(e) Now reverse the diode and observe I vs V.

Negligible current flows in the reverse direction.