Inroduction to DC Measurements

Kevin "Yama" Keyser[1, a)]
University of Missouri-Kansas City

In Laboratory 1, we are introduced to the usages of the Digital Multimeter (DMM), and how to apply it when measuring resistance, voltage, and current across a circuit. We also learn the trace diagram for the Elenco breadboard (which the general idea can be applied to other solderless breadboards).

I. BACKGROUND

On a personal note, there was already a lot of familiarity with using DMMs, and solderless breadboards before this lab. We will be applying Kirchhoff's laws for voltage and current for some of the circuit we set up. One note to make is the sensitivity of the measuring equipment. The only DMM that has a mA option, doesn't seem to work for the lower readings. The fuse may be blown out on the DMM.

II. PROCEDURE

The procedures for Laboratory 1 is very straight forward, so the Laboratory 1 sheet will be attached at the end of this write up.

III. PRESENTATION OF DATA

A. 1-1: Resistance Measurements

Resistance Values vs Measure Values		
Resistor	DMM	DMM while Held
10	9.9	9.9
105	105.1	105.1
1k	0.983k	0.982k
10k	9.82k	9.74k
100k	99.2k	81.9k
1M	0.968M	0.390M
10M	10.29M	0.390M

Resistance When Heated			
Type	Listed Value	DMM	DMM (heated)
Carbon	10k	9.83k	9.65k
Metal Film	11k	10.95k	10.99k

B. 1-2: Introduction to the breadboard frame

No tabular data. Will discuss experimental results in the Discussion section.

C. 1-3: DC Voltage Measurement

V Listing	V Actual	Breadboard Reading
+5V	5.045V	5.045V
+12V	11.85V	11.85V
-12V	-12.11	-12.11

D. 1-4: Current Measurement

Current Across Resistor	
Voltage	Current
8.45V	0.009A
10.76V	0.011A

E. 1-5: Meter Resistance

Multimeter Resistance (Amps)	
Without 10Ω	With 10Ω
.026A	.025A

F. 1-6: Voltage Divider

No tabular data. Will discuss experimental results in the Discussion section.

G. 1-7: Resistors in Parallel

No tabular data. Will discuss experimental results in the Discussion section.

H. 1-8: Complex Circuits

No tabular data. Will discuss experimental results in the Discussion section.

a) Electronic mail: kk8r8@mail.umck.edu

I. 1-9: Charging a Capacitor

Voltage Drop Across Capacitor	
Time (s)	Voltage (mV)
0	1010
5	920
10	830
15	765
20	700
25	635
30	584
35	535
40	485

IV. DISCUSSION

A. 1-1: Resistance measurements

The resistors measured all fell within the tolerance listed each resistor (except the 968kΩ resistor. Their stamps suggest a ±5% tolerance. There will always be errors from the factory, and a decline in resistance over time. The body resistance does seem to go down, the harder you press on the material/wire. This is easier to see with bigger valued resistors (1MΩ and 10MΩ). This leads us to believe that the DMM uses current to measure resistance, since current will take the path of least resistance, which would make the body's resistance lower than those of the higher valued resistors.

After heating 2 different resistors, there was an interesting effect. The carbon resistor's resistance went down, where the thin metal film one went up. This might make sense when taking into account that conductivity goes down for conductors. Since metals are conductors, the thin metal film's conductivity will go down, making its resistance actually go up.

B. 1-2: Introduction to the Breadboard Frame

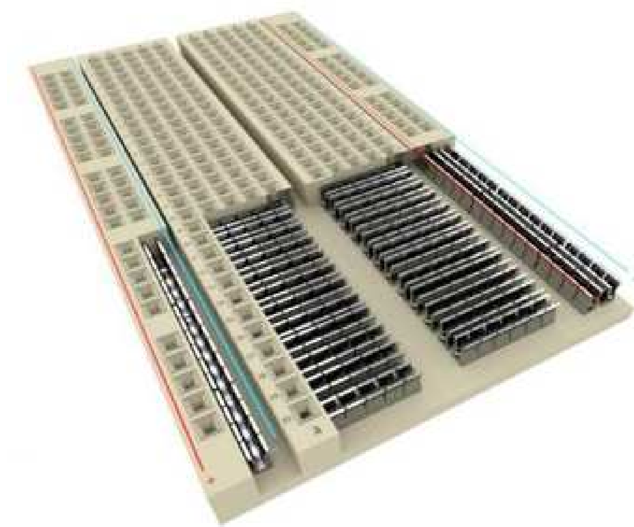

FIG. 1. Open view of a breadboard.

There is not much to say here that the image can't convey. You have rows of solderless connectors, which are separated by a divider. Running along the sides of these connectors are voltage/ground rails. They're all just rows of metal that make it easier to prototype your connections. The resistance across the terminals/tie in points were virtually zero.

C. 1-3: DC Voltage Measurement

This experiment, similar to the previous, was to show which points connected together, and to show the virtually zero resistance of these connections. The voltage in always equaled the voltage out. We would need a much more sensitive measuring device to see any change.

D. 1-4: Current Measurements

There is one key thing to realize here: when using the DMM as an Ammeter, the current has to flow through the DMM. If you connect the DMM to the positive and negative (or positive and ground), you will short the circuit. This is due to the low internal resistance of the DMM, and back to the first experiment, we know that current will want to travel through the path of least resistance (as will all things that flow). This is what is meant by a short. We will see in the next experiment, just how low the internal resistance of the DMM is.

The current does follow Ohm's law, but we don't know how exact. Our instruments are not sensitive enough to get a precise measure on it. The power supply will have its own internal resistance as well. This is why when doing calculations, when ignoring this, we call the battery an "‘ideal"’ battery. In real life, nothing is ideal, but we can pretend that for really low values, that they have a negligible effect.

E. 1-5: Meter Resistance

The first parts of this experiment uses the ideas behind Kirchhoff's Voltage Law. We see that the voltage across the 1MΩ resistor is the same as the voltage supplied. This is because the voltage supplied, minus all the voltage drops across each resister, should equal zero. Or mathematically:

$$V_s - V_1 - V_2 - \cdots - V_n = 0$$

Where 1, 2, . . . , n are resistors in series in the circuit.

When we measure before the resistor, with respect to ground, we get or full voltage reading, but measuring after the resistor, we get zero. This is because since there is only one resistor in the circuit (ignoring the internal resistance of our power supply), all of the voltage drop will be across that resistor.

Following that, we then have a circuit that is in parallel, and we find an addition to Kirchhoff's Voltage Law. The law applies to each loop in a circuit. Meaning, if resistors are placed in parallel, they should all experience the same voltage drop across each one. Said more mathematically:

$$V_s = V_1 = V_2 = \cdots = V_n$$

Similarly, where 1, 2, . . . , n are the resistors in parallel in the circuit.

Then the final circuit, applying Kirchhoff's laws, should give us the internal resistance of the DMM. We made a small change here, and used a 200Ω resistor for our resistor from the power supply instead of a 1kΩ resistor, to make it easier to measure the differences. As expected, our value without the 10Ω resistor is 26mA. Though our input is 5V (actually 5.045V) and our resistor is 200Ω, there is a tolerance rating, so the calculation of Ohm's law is still within the bounds. Now, with the 10Ω resistor in parallel, we get a reading of 25mA. Qualitatively put, this means that our DMM in Amp mode has an incredibly low resistance, if majority of the current in the circuit is still flowing through the DMM. It also means that our resistance is so low, that the equivalent resistance of the two resistors combined (see next subsection for formula) gives us almost the same total resistance in the circuit. Quantitatively, this means the DMM in Amp mode has an internal resistance of $\leq 1\Omega$.

F. 1-6, 7, 8: Series, Parallel, and a combination

As stated above, we were unable to get accurate readings in the mA and below range, due to the only DMM in the lab that has an accuracy in the mA not seeming to work (most likely, the fuse on that side has been blown out).

What we can deduce for the law of resistors from Kirchhoff's Voltage Law and our measurements goes as follows. We saw that in a series circuit, the current across all resistors stayed the same, but the voltage across all resistors is not. If we take the voltage across each resistor, and divide that by the resistor's value, we get the current. So for a circuit in series, we have

$$I_t = I_1 = \cdots = I_n$$

Further, because the total voltage drop across each should equal the voltage of our power supply, then the total voltage divided by the total resistance, equals our current. Looking at these values, we see that when resistors are in series, we get the formula

$$R_T = R_1 + R_2 + \cdots + R_n$$

Moving along to parallel circuits, doing the same analysis of voltage, and current, and applying Kirchhoff's Current Law, we get the following formula for total/effective resistance for resistors in parallel

$$R_T = [\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}]^{-1}$$

G. 1-9: Charging a Capacitor

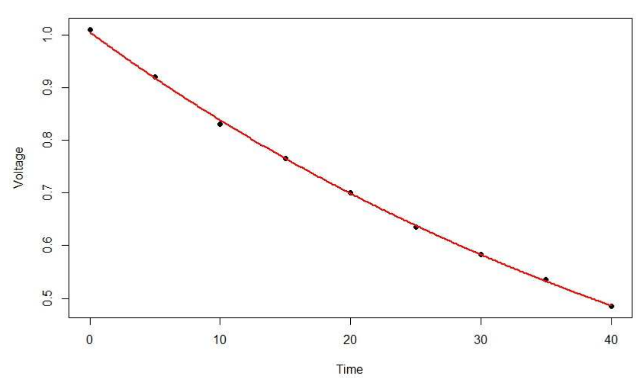

FIG. 2. Fitting our data to an exponential curve in R.

Looking at the fit above, with an R-squared value of 0.9996, we can see that our values do follow an exponential decay, with most of the error being due to the limits of the human brain and eye being able to read constantly falling values on a DMM (still, an R-squared value of 0.9996 is pretty amazing).

V. CONCLUSION

Though we were limited on the accuracy of the devices we had available to us, the overall idea of the application of Kirchhoff's laws, and deriving them from what we observed in our experiments was key. We were able to also figure out how to derive equivalent resistance in a series and parallel circuit just from our observations. Though we had the benefit of hindsight, and years of progress, the key points do not change. Unlike other fields, where many of the rules are agreed upon, or chosen (I'm looking at you, Axiom of Choice), the models that we come up with in Physics rely completely on understanding, and measuring what happens in nature. It is not up to us to make the rules. It is up to scientists (and specifically here, physicists) to observer nature, and understand its rules. Being able to pull insight from the smallest of interactions, and building upon those intuitions is how we continue to find progress (though, yes, luck doesn't hurt).