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THE MEASUREMENT OF RESISTANCE OF UNKNOWN WIRES USING THE WHEATSTONE BRIDGE

Abstract:

Using Ohm's law, the resistance of a meter wire is calculated. Using the same wire, a Wheatstone bridge is constructed with a standard resistance panel to calculate the resistance of 5 unknown wires. The resistivities of the unknown wires are calculated and compared to literature values of wires of the same material and the results are found to be similar: $\rho(\mathrm{Cu}) = 1.7 \times 10^{-8}\Omega\mathrm{m}$ where our value agrees within two standard deviations $(1.65 \pm 0.62) \times 10^{-8}\Omega\mathrm{m}$.

Introduction:

In this lab, we will apply ohm's law to find the resistance of a wire. We will use this wire to calculate the resistance and other properties of 5 coils. We cannot simply use a digital multimeter for this lab because such instrumentation is incapable of measuring resistance for such conductive materials as copper.

A Wheatstone apparatus consists of a galvanometer and 4 resistors, two of known resistance R1 and R2, one of well-defined variable resistance Rs, and one of unknown resistance Rx. The two known resistors in our apparatus turn out to be a bisection of the same meter wire whose resistance was calculated. Due to the mathematics of the Wheatstone bridge, only the ratio R1 to R2 is required, not absolute resistance. So, due to constant resistance density in the wire, the ratio of lengths of the wire bisections is sufficient. Rs is simply a resistor box that allows us to create any resistance between 0.1Ω and 1111.0Ω in 0.1Ω increments. Rx is a coil of wire with known material, length and thickness.

Ohms law you know the drill.

$$R = V/I$$

Wheatstone diagram with labeled resistors here lol.

When making a measurement with the bridge, we want the current across the bridge to be zero. When this is the case the voltage across R1 and Rx are equal, and the voltage across R2 and Rs are equal. This allows equate the ratios of resistance:

$$\frac{R1}{R2} = \frac{Rx}{Rs}$$

Resistance of a wire is increased when the length of the wire increases. When the cross-sectional area of the wire decreases the resistance increases. This allows us to create a new measurement which normalizes both variables: resistivity defined as resistance times area over length.

$$\rho = \frac{\mathrm{RA}}{\mathrm{L}}$$

Theses values are tabulated for specific metals and allows us to compare to literature values.

Experimental Procedure:

The resistance of a meter wire is determined by measuring the voltage across the wire and measuring the current through the circuit. The power supply is adjusted so that the ammeter measures five values between 0 and 80 mA. At each current, the voltage is measured and a plot of voltage over current is generated. The slope is calculated and recorded with uncertainty as the resistance of the meter wire. Next the thickness of the wire is measured at five different points using a micrometer. The values are averaged to obtain the diameter of the meter wire. The resistivity can be calculated now.

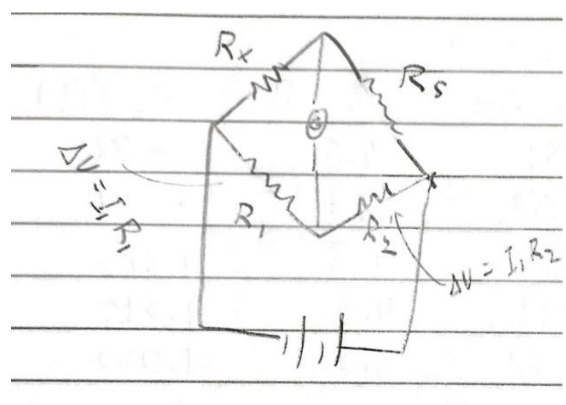
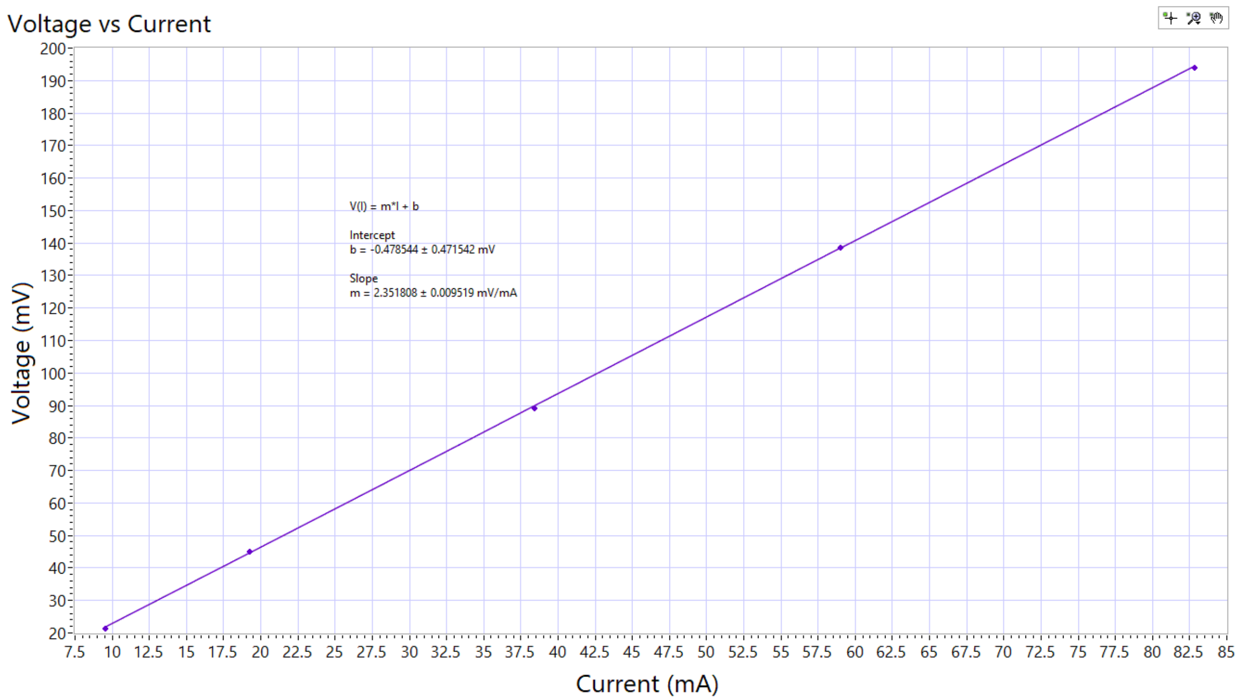


FIGURE 1: WHEATSTONE BRIDGE DIAGRAM

In the second half of the experiment, the Wheatstone bridge is connected according to figure 1. The entire length of the wire is R1 and R2, the node between the two is a contactor that you can move around that is connected to the galvanometer. Select some Rs around .3 Ohms, move the system voltage to around .3V and move the contactor around to try and make I=0. The most accurate measurements are made when the contactor is close to the middle position so incrementally increase Rs by .1 Ohms until you can place the contactor near the middle while minimizing the magnitude of the galvanometer. Now increase the voltage to 1.5V to get a more accurate measurement of current and flick the contactor by tiny amounts to truly zero in. Now Measure the length of the wire to the left of the contactor as L1 and to the right as L2, note Rs and move to the next coil.

Results and Data:

FIGURE 2: PLOT OF VOLTAGE OVER CURRENT FOR THE METER WIRE.



The slope of this graph is the average value for V/I which is resistance by Ohm's law. Our value for the resistance of the meter wire is calculated to be (2.352+-0.009)Ωm.

The calculation of our meter wire was done using student-t distribution. Using the formulas

$$\boldsymbol{s^2 = \frac{1}{n-1}\sum(x_i - \overline{x})^2}$$

for variance s of a set x with n elements and for critical value t:

$$\boldsymbol{\overline{x} \pm \frac{ts}{\sqrt{n}}}$$

With 95% confidence interval and 4 degrees of freedom the critical value of a two tailed distribution is 2.776. Therefore, for our data:

diameter (mm)
0.5023
0.5025
0.5026
0.2016
0.5026

$$\overline{x} = (0.5023 \pm 0.0005)mm$$
$$s = 0.000421$$

So our 95% confidence interval is $(0.5023 \pm 0.0005)mm$

This gives the area of the wire

$$\pi r^2 = 3.141593\left(\frac{(0.5023 \pm 0.0005)\text{mm}(1\text{m}/1000\text{mm})}{2}\right)^2 = (1.982 \pm 0.004) \times 10^{-6}\ \text{m}^2$$

Using our equation for resistivity we can also calculate:

$$\rho = \frac{\text{RA}}{\text{L}} = \frac{(2.352 \pm 0.009)\Omega(1.982 \pm 0.004) \times 10^{-6}\ \text{m}^2}{1.00 \pm 0.01\text{m}} = (4.66 \pm 0.07) \times 10^{-6}\Omega\text{m}$$

For the second half of the experiment, the data L1, L2 and Rs was collected. The ratio is there for ease of calculation of Rx. We can calculate Rx for example:

$$\text{R}_\text{x} = \text{R}_\text{s}\frac{\text{L}_1}{\text{L}_2} = 0.5\Omega * 1.064 = 0.5320\Omega$$

Coil No.	L1 (cm)	L2 (cm)	L1/L2	Rs (Ω)	Rx (Ω)
1	51.55	48.45	1.064	0.5	0.5320
2	49.50	50.50	0.9802	1.9	1.862
3	57.20	42.80	1.336	1.0	1.336
4	49.20	50.15	0.9940	4.2	4.175
5	49.55	50.45	0.9822	9.5	9.330

To eliminate any discrepancy due to uneven resistance density on the wire: R1 and R2 are flipped:

Coil No.	L1 (cm)	L2 (cm)	L1/L2	Rs (Ω)	Rx (Ω)
1	55.00	45.60	0.818	0.5	0.4091
2	49.55	50.45	1.0180	2.0	2.036
3	49.38	50.62	1.025	1.2	1.230
4	49.20	50.80	1.0320	4.2	4.336
5	50.90	49.10	0.9646	9.5	9.164

For our last trial we have:

Coil No.	L1 (cm)	L2 (cm)	L1/L2	Rs (Ω)	Rx (Ω)
1	42.00	58.00	1.381	0.6	0.8286
2	50.55	49.45	0.9782	2.1	2.054
3	51.80	48.20	0.9305	1.3	1.210
4	49.45	50.55	1.022	4.3	4.396
5	52.63	47.37	0.9000	10.0	9.000

Each coil has a specific cross-sectional area and length specified below. We can calculate resistivity for each now. It is relevant to consider the first four coils consist of copper and the last is nickel silver alloy: thus the larger resistivity.

Coil No.	R (Ω)	L (m)	Cross-sectional area ($10^{-8}m^2$)	Resistivity (10^{-8} Ωm)
1	0.59±.12	10±.5	32±2	1.8±.6
2	1.98±.06	10±.5	7±1	1.3±.3
3	1.26±.04	20±.5	32±2	2.0±.2
4	4.30±.07	20±.5	7±1	1.5±.3
5	9.16±.10	10±.5	32±2	29±4

Compared to the literature values: the first five coils are all copper and the last is a nickel silver alloy. The resistivity of both are $1.7*10^{-8}$ Ωm and $33*10^{-8}$ Ωm respectively. Using the two standard error criterion, all of our calculated resistivities agree with the expected values of the metals used for the experiment.

Conclusion:

Using the Wheatstone bridge, the resistance of 5 different wires with various lengths, areas and materials was calculated. Since resistivity is a property of a substance, we should expect the resistivity of all copper wires to match that of the literature value of $1.7*10^{-8}$ Ωm. In reality, we find each of our measurements of resistivity to agree with the literature value within two standard errors. The same result is found for the nickel silver alloy wire with literature resistivity of $33*10^{-8}$ Ωm and measured $(29\pm4)*10^{-8}$ Ωm.