Experiment #6 Resistivity Pre-lab Questions

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- **Calculate the cross sectional area for each of the following wires:**
    - **22 AWG = ________________ m^2**
    - **34 AWG = ________________ m^2**
    - **38 AWG = ________________ m^2**
    - **40 AWG = ________________ m^2**

AWG stands for "American Wire Gauge". The gauge is a measurement (as of linear dimension) according to some standard or system. Namely, for our case, it is the diameter of a slender object (as wire or a hypodermic needle). The relationship between the gauge of a wire and its diameter in millimeters is given in the following table:

AWG (gauge) [AU]	Diameter [mm]
22	0.6440
34	0.1600
38	0.1010
40	0.0799

** Aside **

The gauge is a logarithmic scale based upon the radius (in millimeters) of the wire. Notice that as the radius decreases, the gauge increase. It is a unitless value, so we often give it units of [AU] which means "arbitrary units". (This is similar to decibals [for measurements of sound and power]. It's just a standard that was created and has stuck. I guess that electricians just like to have their own "lingo".)

** End aside **

First, let's define the radius of the wire. This is half the diameter of the wire.

$$r = \frac{d}{2}$$

AWG (gauge) [AU]	Diameter [mm]	Radius [mm]
22	0.6440	0.3220
34	0.1600	0.0800
38	0.1010	0.0505
40	0.0799	0.03995

From geometry, recall that the area of a circle is given by:

$$A = \pi r^2$$

But, first, it is a good idea to convert the value of the radius to standard SI units.

For example,

$$0.3220\ mm\left(\frac{1\ m}{1000\ mm}\right) = 0.0003220\ m = 3.22\times10^{-4}\ \ m$$

AWG (gauge) [AU]	Diameter [mm]	Radius [mm]	Radius [m]	Area [m^2]
22	0.6440	0.3220	3.22×10^{-4}	3.26×10^{-7}
34	0.1600	0.0800	8.0×10^{-5}	2.01×10^{-8}
38	0.1010	0.0505	5.05×10^{-5}	7.97×10^{-9}
40	0.0799	0.03995	3.995×10^{-5}	5.01×10^{-9}

- **Find the Resistance for each length of a wire (38 AWG).**

Length (measured)	Voltage (measured)	Current (applied)	Resistance (Calc.)
20 cm	0.3 Volts	0.5 Amps	
40 cm	0.61 Volts	0.5 Amps	
60 cm	0.91 Volts	0.5 Amps	
80 cm	1.22 Volts	0.5 Amps	
100 cm	1.52 Volts	0.5 Amps	

** ASIDE **

In this lab is it easy to confuse “resistance” with “resistivity”. It is worth a few moments to describe the difference between these two quantities.

Resistance is typically written with the capital English letter “R”. It has units of Ohms, [Ω]. This value is dependant upon (and can change based upon) the material’s shape and size. For example, in a wire, if the diameter of the wire increases (this is sometimes called "opening the pipe"), there is room for more "flow" of electrons, and hence *less* resistance. Further, as the length of a wire increases, there is more material to collide into, hence *more* resistance. Resistance is related to current and potential by Ohm's Law. Resistance is also a function of a material's resistivity.

Resistivity is typically written with the lower Greek letter "rho", "ρ". It has units of Ohms-meters [Ωm]. This value is a constant associated with the particular chemical properties of a material. This value does not change. It is inversely related to the conductivity of a material – that is, the more conductive a material is, the less resistive a material is; and vice-versa.

We can define the resistance of a piece of wire based upon its material type (resistivity), length, and cross-sectional area (gauge):

$$R = \frac{\rho L}{A}$$

** END ASIDE **

We must use Ohm's Law to find the resistance for the table above. This is given by:

$$V = IR \qquad R = \frac{V}{I}$$

Length [cm]	Voltage [V]	Current [A]	Resistance [Ω]
20	0.3	0.5	0.6
40	0.61	0.5	1.22
60	0.91	0.5	1.82
80	1.22	0.5	2.44
100	1.52	0.5	3.04

** Notice that the resistance changed when the length changed. It is easy to see that the resistance increased when the length increased from the table above. This is exactly as explained in the aside. So, it's easy to say that narrow (high gauge) wires that are very long have high resistance and hence are a bad idea to use for high quality current/signal transmission. **

- **Use this data to make a graph of Resistance vs. Length. From that graph find the slope of the line. Using this slope, calculate the resistivity of the mystery wire.**

In the aside above, we created an expression for resistance as a function of material type (resistivity), length, and cross-sectional area (gauge). This was given as:

$$R = \frac{\rho L}{A}$$

If we keep the cross-sectional area constant (by using the same gauge wire) and since the resistivity is a constant, this is essentially:

$$R = (const)L + 0$$

Which means that the resistance is some constant times its length. [The constant is exactly the resistivity divided by the gauge – both in standard SI units.]

Recall back to PES 115 lab 2 we used graphs, obtained slopes, etc…

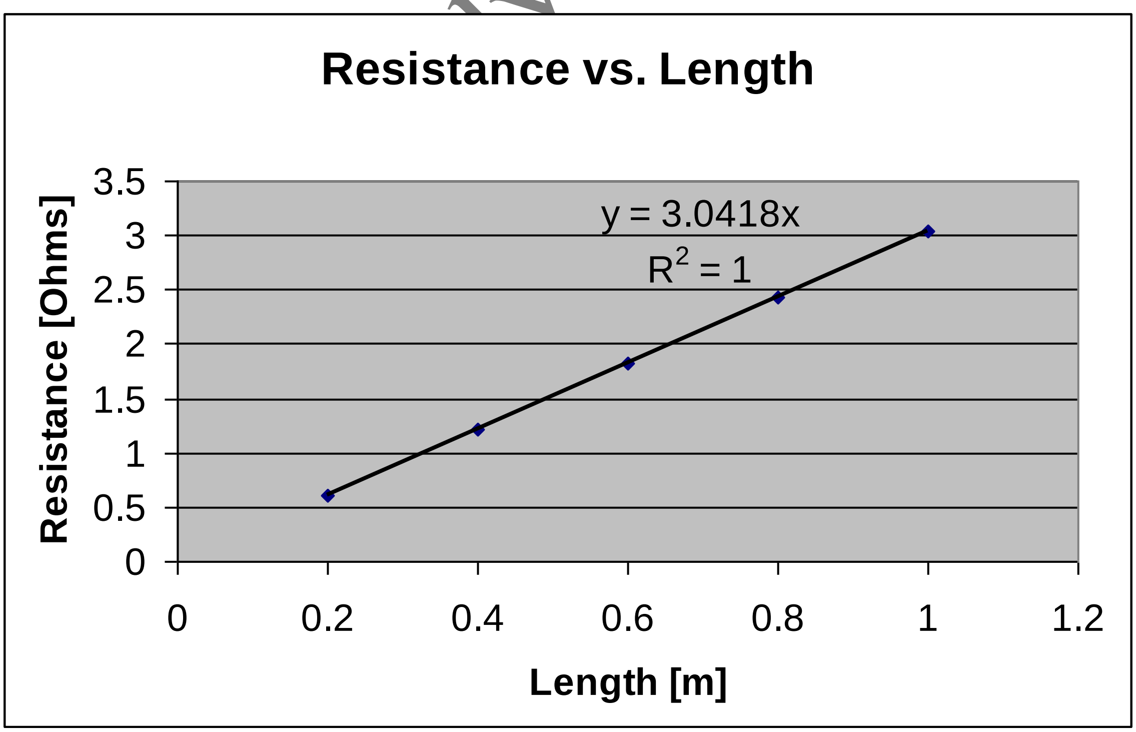
If we compare the equation for resistance to the equation of a straight line:

$$R = \left(\frac{\rho}{A}\right)L + 0$$

$$y = (m)x + b$$

We can see that we want to plot the resistance on the y-axis, plot the length on the x-axis, and the resulting best fit line will give the slope and the y-intercept.

The slope will obviously be the resistivity divided by the cross-sectional area (gauge), and the y-intercept will be zero.



Using the trendline feature in Excel, we got the following best fit line:

$$y = \left(3.0418\frac{\Omega}{m}\right)x + (0)$$

It is of particular interest to note the regression determined by Excel. This came out to be a value of 1.0. This means that the "linearity" of the data is extremely good.

If we compare the equation for resistance with the found trendline, we can easily see by comparison that the following constants correlate directly:

$$R = \left(\frac{\rho}{A}\right)L + 0$$

$$y = \left(3.0418\frac{\Omega}{m}\right)x + (0)$$

Thus:

$$\frac{\rho}{A} = 3.0418\frac{\Omega}{m}$$

If we solve the above relationship for resistivity:

$$\rho = \left(3.0418\frac{\Omega}{m}\right)A$$

Recall that we were told that we are using a 38 gauge wire. We found the cross-sectional area of this gauge in part 1 of this pre-lab. The value is given in the table below:

AWG (gauge) [AU]	Diameter [mm]	Radius [mm]	Radius [m]	Area [m^2]
38	0.1010	0.0505	5.05 x 10^{-5}	7.97 x 10^{-9}

$$\rho = \left(3.0418\frac{\Omega}{m}\right)\left(7.97\times10^{-9}\ m^2\right) = 2.424\times10^{-8}\ \Omega m$$

$$\boxed{\rho = 2.424\times10^{-8}\ \Omega m}$$

- **What is the wire made of?**

Material	Resistivity (x 10^{-8} Ω· m)		Material	Resistivity (x 10^{-8} Ω· m)
Aluminum	2.82		Nichrome	100
Brass	7.00		Osmium	9.5
Carbon	3500		Platinum	10.6
Copper	1.72		Plutonium	141.4
Germanium	46,000,000		Rubber	$1x10^{17}$
Glass	$1x10^{18}$		Silicon	64,000,000,000
Gold	2.44		Silver	1.59
Iron	10.0		Tungsten	5.6
Lead	22		Uranium	30.0

Before performing the comparison, it is useful to notice some "physical" properties of the wire. Say that for this wire we noticed that it had a "goldish" color. This may be useful for distinguishing between two similar materials with similar resistivities.

We found the resistivity of the material from the previous part of the pre-lab. Remember that this is a constant based upon the material type. The value we found was:

$$\rho_{Unknown} = 2.424 \times 10^{-8}\ \Omega m$$

By examining the table given above (and using the knowledge we got from examination [color]), we can see that this more closely correlates to the resistivity for Gold [Au]. Notice we could have also chosen Aluminum [Al]; however, we know that aluminum is "silvery" in color, so it obviously is not Aluminum.

Gold has a resistivity of:

$$\rho_{Au} = 2.44 \times 10^{-8}\ \Omega m$$

If we do a percent difference:

$$\%\ difference = \frac{|x_{Theory}| - |g_{Measured}|}{|x_{Theory}|} x100\%$$

$$\%\ difference = \frac{(2.44 \times 10^{8}\ \Omega m) - (2.424 \times 10^{8}\ \Omega m)}{(2.44 \times 10^{8}\ \Omega m)} x100\%$$

$$\boxed{\%\ difference = 0.6557\%}$$

** ASIDE **
There are a few selections in the list above that just do not make any sense at all. Just asking a chemistry major about a few of these will show you that making wires from several of these materials is not possible or just straight out crazy.

E.g., Plutonium – Symbol: Pu, Atomic number: 94, Atomic weight: [244], Standard state: solid at 298 K, Color: silvery white, Classification: Metallic.

Plutonium was the second transuranium element of the actinide series to be discovered. By far of greatest importance is the isotope ^{239}Pu, which has a half-life of more than 20,000 years. One kilogram is equivalent to about 22 million kilowatt hours of heat energy. The complete detonation of a kilogram of plutonium produces an explosion equal to about 20,000 tons of chemical explosive. The various nuclear applications of plutonium are well known. The isotope ^{233}Pu was used in the American Apollo lunar missions to power seismic and other equipment on the lunar surface. Plutonium contamination is an emotive environmental problem.

Chances are you will *not* have a plutonium wire. ☺

Rubber – Silicone polymers have inherently good electrical insulating qualities. They are nonconductive because of their chemical nature and, when compounded with the proper tillers and additives, are used to produce rubber for a wide range of electrical insulating applications.

Chances are you will *not* have a rubber wire. ☺

Uranium – Symbol: U, Atomic number: 92, Atomic weight: 238.02891 (3) g m, Standard state: solid at 298 K, Color: metallic grey, Classification: Metallic.

Uranium is of great interest because of its application to nuclear power and nuclear weapons. Uranium contamination is an emotive environmental problem. It is not particularly rare and is more common than beryllium or tungsten for instance. Uranium gives interesting yellow and green colors and fluorescence effects when included to glass in conjunction with other additives.

Chances are you will *not* have a uranium wire. ☺

Typical metals used for wires include:

Copper (Brownish metal):

$$\rho_{Cu} = 1.76 \times 10^{-8}\ \Omega m$$

Aluminum (Silvery metal):

$$\rho_{Al} = 2.82 \times 10^{-8}\ \Omega m$$

Gold (Gold metal):

$$\rho_{Au} = 2.44 \times 10^{-8}\ \Omega m$$

Tungsten (Silvery metal – used in light bulbs – glows when a current sent through it):

$$\rho_W = 5.5 \times 10^{-8}\ \Omega m$$

Nichrome (Silvery alloy of Nickel and Chromium):

$$\rho_{Ni+Cr} = 110 \times 10^{-8}\ \Omega m = 1.1 \times 10^{-6}\ \Omega m$$

Brass (Brownish alloy of Copper and Tin/Zinc):

$$\rho_{Cu+Zn} = 6.33 \times 10^{-8}\ \Omega m$$

(For brass, the value may be anywhere in the range from 6.0 x 10^{-8} [Ω m] to 7.0 x 10^{-8} [Ω m]. This is due to the fact that brass my have different amounts of copper and zinc in the wire at different places.)

** END ASIDE **