Lab Sim 08: Resistance and Resistivity of Graphite

Introduction

Resistivity is the tendency of a material to behave as a resistor. You already know that not everything conducts electricity equally well and that some materials (like copper) resist very little, while others (like rubber) provide enough resistance to effectively prevent the flow of current. Resistivity (ρ) is a fundamental material property (like density or melting point), while the total resistance (R) depends on the material, the temperature (higher T typically increases the resistance of a conducting material), and the geometry. Both the cross-sectional area (A) and length (L) impact the total resistance. We can easily test the length dependence and simultaneously find the resistivity of a simple pencil lead.

Objectives

- Consider the difference between resistance and resistivity
- Measure the dependence of resistance on the length of a graphite rod
- Calculate the resistivity of graphite and compare it to the known value
- Graphically demonstrate the dependence of resistance on the temperature of a graphite rod
- Examine and explain the discrepancy between the experimental and the known values

Pivot Interactives

This exercise requires the online simulation (Lab 08: Resistance and Resistivity of Graphite). You should sign in to your Pivot account and choose the correct Interactive from the PHYS 1420 selection.

Resistance vs. Resistivity

Let's visualize a simple geometry: a straight wire with length L and a circular cross-section ($A = \pi r^2$). Resistance is literally the answer to the question: How hard is it to move electrons through this wire? Okay, it's a gross oversimplification to imagine electrons shooting down the wire from one end to the other like cars on the interstate or water through a pipe, but images like this can help us conceptualize the parameters that control the resistance.

The total resistance R (in Ohms, Ω) of a material is expressed as:

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

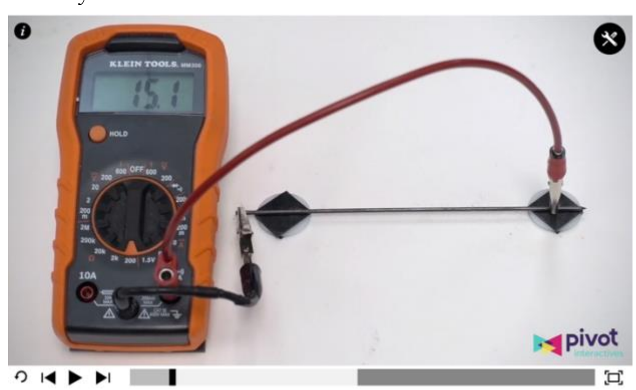
where ρ is the resistivity in $\Omega \cdot \mathrm{m}$, and L (in m) and A (in m^2) are the length and cross-sectional area, respectively.

1) (2 points) Briefly explain why increasing the length L increases the resistance. Hint: Using the interstate or the pipeline example is a valid tool for constructing your argument!
2) (2 points) Now explain why increasing the area A has the opposite effect, decreasing the total resistance.
3) (1 point) Let's visualize water flowing through a pipe. Now, a second identical pipe, but this one has honey flowing through it. Does changing the fluid from water to honey change the effect of length or area? That is, will the honey pipe have the same dependence on L and A as the water pipe?
   A. Yes.
   B. No.
4) (2 points). Swapping the water for honey (which is a much thicker (higher viscosity) fluid) has what effect? This is the precise idea of resistivity: given the same pipe, the material makes a difference. If the water pipe and the honey pipe were electrical resistors, which would have the higher resistivity (and hence the higher total resistance)? Why? Hint: Remember, this analogy is somewhat flawed, so it is not the literal explanation. But it's still a really useful visual tool!

Resistivity of Graphite

A pencil lead (not really lead) is an interesting 'wire' to push electrons through. Graphite is a conductive material, but just how conductive?

In the video below, you will measure how changing the length of the graphite wire affects the resistance. The digital multimeter is set to read the resistance in Ohms directly.



5) (2 points) Before you begin recording data, explain briefly how you will position and use the ruler tool to maximize the accuracy of your length measurements. Hint: There's more than one way to do this, and you might want to let the video play out, then try a few different methods.
6) (1 point) What is the uncertainty in your length measurement? (Mind your units!)
   A. $\partial L = \pm 0.05\mathrm{m}$
   B. $\partial L = \pm 0.025\mathrm{m}$
   C. $\partial L = \pm 0.005\mathrm{m}$
   D. $\partial L = \pm 0.0025\mathrm{m}$

7) (8 points) Next, make and record measurements, and plot a graph to find the relationship between resistance and length of the conductor. Record and plot **at least eight** data points.

Trial	Length L (m)	Resistance R (Ω)

8) (1 point) Before we start any numerical analysis, just look at your graph. How confident are you in the data? What can you point to that specifically gives you either a high or low level of confidence? Hint: This one's binary: either yes or no! No hedging and saying maybe! Also, look at your regression.

9) (1 point) Before we get to the slope, let's look at that intercept. Logically, if the length of the graphite wire is zero, its resistance ought to be zero. Why is your intercept non-zero?
   A. What? It is zero.
   B. There is *so* much random scatter in the data. The effects of the random measuring errors result in the non-zero intercept. You can tell just from looking at the data that by drawing a slightly different best-fit line, you would get a zero intercept. Adding more data would adjust the trendline and make the intercept zero.
   C. The non-zero intercept indicates that something systematic affected every measurement in exactly the same way. Well, the same non-graphite alligator clips are used to complete the circuit every time. The clip resistance *cannot* be zero, and it *would* be the same for each trial.

10) (1 point) Recall that the resistivity of a conductor is: $R = \frac{\rho L}{A}$, and our data was collected by varying L. What is the slope of your graph?
   A. slope $m = \rho$
   B. slope $m = \rho A$
   C. slope $m = \frac{\rho}{A}$
   D. slope $m = \frac{A}{\rho}$

11) (1 point) The diameter of the graphite wire is $d = 2.2\text{mm}$. Calculate the cross-sectional area of the wire in m^2. Hint: $A = \pi r^2$ and $r = \frac{d}{2}$.

12) (2 points) Now calculate your resistivity ρ using the slope and cross-sectional area.

13) (1 point) The known resistivity of pure graphite is $\rho = 1.38 \times 10^{-5} \Omega \cdot \text{m}$. Uh-oh. This looks pretty bad. Calculate your percent error anyway.

This looks pretty bad. How do we make any sense of that big of an error?!? Well, this *is* science. Answer the question with another question: Is there something else we could test? Would it help?

Of course there is, and of course it would (this *is* science).

So, I have helpfully run another test for you. We mentioned at the outset that resistance should also depend on temperature. Below are some data for the same pencil lead as above. The length of the lead was kept constant: $L = 16\text{cm} = 0.16\text{m}$, and it has the same diameter ($d = 2.2\text{mm} = 0.0022\text{m}$).

Temperature T (°C)	Resistance R (Ω)
20	15.13
50	14.75
100	14.17
150	13.63
200	13.01
250	12.47

Theoretically, the temperature dependence looks like this: $R = R_o[1 + \alpha(T - T_o)]$, where α is the temperature coefficient and R_o is the resistance at $T_o = 20°\text{C}$.

14) (6 points) Graph the data and extract the temperature coefficient α. Like ρ, this is a material constant that we can look up and compare. Hint: $y = mx + b$ becomes $\frac{R}{R_o} = \alpha(T - T_o) + 1$. You'll need to add some columns to your table (always label and include units!).

15) (1 point) The known value for graphite is $\alpha = -0.0005°\text{C}^{-1}$. Yes, it's negative. Is your value close to this? Calculate the percent error.

Is This Graphite?

Your resistance increases linearly with length, as expected. Your resistance decreases linearly with temperature, which is also expected for graphite. Both data sets are really, *really* linear—you can't blame careless data collection!

So why are your results so terrible?

16) (3 points) You are, no doubt, familiar with '#2' pencils. If you are an artist, you're definitely aware that pencil leads are definitely not all the same. If you use a mechanical pencil, you have probably seen that you can buy 'HB' or '2H' refills for your leads. What do these designations mean, and what does it have to do with your results? Was it a realistic expectation to think you should have gotten within 5% or so (we have been typically this accurate or better all semester long) of the accepted value? Hint: Google 'pencil lead composition' (pro tip: image search).

When you have completed this lab exercise in Pivot, please be sure to submit your responses. This lab is due no later than Thursday, 04 August 2022, at 11:59 PM CDT.