Temperature coefficient of resistance

Resources and methods for learning about these subjects (list a few here, in preparation for your research):

Questions

Question 1

It is a common phenomenon for the electrical resistance of a substance to change with changes in temperature. Explain how you would experimentally demonstrate this effect.

file 00506

Question 2

An electronics instructor wants to demonstrate to his students the effect of electrical resistance changing with temperature. To do this, he selects a carbon resistor about 3 centimeters in length and 5 millimeters in diameter, black in color, with a wire at each end, and connects it to an ohmmeter. Whenever he grasps the resistor between his fingers, the ohmmeter instantly responds by showing a greatly reduced resistance.

What is wrong with this experiment?

file 00507

Question 3

If we were to plug an electric saw into a very long extension cord, and then plug the other end of the cord into a power receptacle, we would notice a decreased level of performance from the saw, as compared with how it performs when directly plugged into the same receptacle (with no extension cord).

Determine if the saw's performance becomes better or worse as the ambient temperature increases, and explain your answer.

file 00508

Question 4

The electrical resistance of a conductor at any temperature may be calculated by the following equation:

$$R_T = R_r + R_r \alpha T - R_r \alpha T_r$$

Where,

R_T = Resistance of conductor at temperature T
R_r = Resistance of conductor at reference temperature T_r
α = Temperature coefficient of resistance at reference temperature T_r

Simplify this equation by means of factoring.

file 00509

Question 5

Write an equation solving for the temperature of a conductor (T), given its resistance at that temperature (R_T), its resistance at a standard reference temperature $(R_r @ T_r)$, and its temperature coefficient of resistance at that same reference temperature $(\alpha @ T_r)$.

file 00510

Question 6

Precision wire-wound resistors are often made of a special metal alloy called *manganin*. What is it about this alloy that makes it preferable for use in precision resistor construction?

file 00511

Question 7

A length of copper wire ($\alpha = 0.004041$ at 20° C) has a resistance of 5 ohms at 20 degrees Celsius. Calculate its resistance if the temperature were to increase to 50 degrees Celsius.

Now, take that calculated resistance, and that new temperature of 50° C, and calculate what the resistance of the wire should go to if it cools back down to 20° C. Treat this as a separate problem, working through all the calculations, and don't just say "5 ohms" because you know the original conditions!
file 01484

Question 8

Calculate the resistance of each of these specimens, given their resistance at the reference temperature (R_r @ T_r), and their present temperatures (T):

- Specimen 1: Copper ; $R_r = 200\ \Omega$ @ $T_r = 20^oC$; $T = 45^oC$; $R_T =$
- Specimen 2: Copper ; $R_r = 10\ k\Omega$ @ $T_r = 20^oC$; $T = 5^oC$; $R_T =$
- Specimen 3: Aluminum ; $R_r = 1,250\ \Omega$ @ $T_r = 20^oC$; $T = 100^oC$; $R_T =$
- Specimen 4: Iron ; $R_r = 35.4\ \Omega$ @ $T_r = 20^oC$; $T = -40^oC$; $R_T =$
- Specimen 5: Nickel ; $R_r = 525\ \Omega$ @ $T_r = 20^oC$; $T = 70^oC$; $R_T =$
- Specimen 6: Gold ; $R_r = 25\ k\Omega$ @ $T_r = 20^oC$; $T = 65^oC$; $R_T =$
- Specimen 7: Tungsten ; $R_r = 2.2\ k\Omega$ @ $T_r = 20^oC$; $T = -10^oC$; $R_T =$
- Specimen 8: Copper ; $R_r = 350\ \Omega$ @ $T_r = 10^oC$; $T = 35^oC$; $R_T =$
- Specimen 9: Copper ; $R_r = 1.5\ k\Omega$ @ $T_r = -25^oC$; $T = -5^oC$; $R_T =$
- Specimen 10: Silver ; $R_r = 3.5\ M\Omega$ @ $T_r = 45^oC$; $T = 10^oC$; $R_T =$

file 00512

Question 9

A spool of #10 AWG aluminum wire is 500 feet long. If the ambient temperature is 80° F, what is its end-to-end electrical resistance? Explain all the calculations necessary to solve this problem.
file 00513

Question 10

An incandescent light bulb has a filament resistance of 5.7 Ω when at room temperature (20° C), but draws only 225 mA when powered by a 12 volt DC source. Given that the filament is made out of tungsten metal, calculate its temperature in degrees F when powered by the 12 VDC source.
file 00514

Answers

Answer 1

It is a simple thing to demonstrate a substance's change in resistance with temperature. I'm interested in finding out how you might discern a *quantitative* measurement of this change. That is, how would you design an experiment so as to "attach a number" to the effect of resistance changing with temperature?

Answer 2

If the change in resistance is truly due to a change in resistor temperature, it should not be *instant.*

Answer 3

The saw's performance worsens as ambient temperature increases.

Answer 4

$$R_T = R_r[1 + \alpha(T - T_r)]$$

Follow-up question: when plotted on a graph with temperature (T) as the independent variable and resistance (R_T) as the dependent variable (i.e. a two-axis graph with T on the horizontal and R on the vertical), is the resulting plot linear? Why or why not? How is it possible to tell just by looking at the equation, prior to actually plotting on a graph?

Answer 5

$$T = \frac{\frac{R_T}{R_r} - 1}{\alpha} + T_r$$

Answer 6

The α value of manganin alloy is nearly zero.

Answer 7

$R_{50^\circ C} = 5.606 \, \Omega$

If you got an answer of $R_{20^\circ C} = 4.927 \, \Omega$ for the second calculation, you made a common mistake that is not always warned against in textbooks! Try the math again. If you got the proper answer of $5 \, \Omega$ upon doing the second calculation, try to figure out why someone may have calculated $4.927 \, \Omega$ taking the temperature from 50° C down to 20° C.

Answer 8

- Specimen 1: $R_T = 220.2 \, \Omega$
- Specimen 2: $R_T = 9.394 \, k\Omega$
- Specimen 3: $R_T = 1.681 \, k\Omega$
- Specimen 4: $R_T = 23.35 \, \Omega$
- Specimen 5: $R_T = 679 \, \Omega$
- Specimen 6: $R_T = 29.18 \, k\Omega$
- Specimen 7: $R_T = 1.909 \, k\Omega$
- Specimen 8: $R_T = 386.8 \, \Omega$
- Specimen 9: $R_T = 1.648 \, k\Omega$
- Specimen 10: $R_T = 3.073 \, M\Omega$

Answer 9

0.7899 Ω

Answer 10

$T = 3{,}484^{o}\text{F}$

Notes

Notes 1

This question is an excellent starting point for an in-class experiment. There are several ways in which this effect could be demonstrated.

Notes 2

I must confess, the genesis of this question was an experience from my own education. This really happened! I still remember staring at the demonstration, perplexed that the resistance would change so quickly and so greatly when the instructor grasped the resistor. I also recall the mild insult the instructor directed at me as I attempted to communicate my confusion: "What's the matter? Too complicated for you?" Please, never treat your students like this.

Some students may believe the experiment is flawed because they expect the resistance to rise with increased temperature, rather than fall. This, however, makes a fundamental assumption about the nature of temperature-induced resistance changes, which is a bad thing in science. Let the experimental evidence tell you how the phenomenon works, don't tell it what it should do!

Discuss with your students what they think the *real* mechanism of resistance change is in this experiment, and how they might modify the experiment so as to isolate temperature as the only changing variable.

Notes 3

Discuss the nature of the problem, with reference to Ohm's Law. Ask your students to explain the effect in terms of Ohm's Law, and the cord's ability to deliver electrical power to the saw motor.

Notes 4

Just an exercise in algebra here!

Notes 5

Students may be able to find this equation in a textbook somewhere, but the point of this question is really to have them perform algebraic manipulation to derive this equation from another.

Notes 6

Ask your students what a wire-wound resistor made of copper or iron wire might do, if subjected to changes in temperature.

An historical side-note: during World War II, allied forces made extensive use of *analog computers* for directing the firing of projectiles and the dropping of bombs. Unlike digital computers, which perform mathematical operations using on/off signals and are thus immune to errors caused by slight changes in component value, electronic analog computers represent physical variables in the form of continuous voltages and currents, and depend on the precision of its constituent resistors to produce precise results. I remember reading one of the pioneering engineers in that field describe great gains in accuracy being due mostly to improvements in resistor construction. Without some crucial improvements in resistor accuracy and stability, analog computers of the war-time era would have suffered from substantial inaccuracies. Of all things, the lowly *resistor* was an influential piece of the allied war effort!

Notes 7

One thing students need to learn is they can't simply use the resistance-temperature formula as it is normally given if the "reference" (starting) temperature is not the same as the temperature at which α is specified at!

Notes 8

Students may find difficulty obtaining the proper answers for the last three specimens (8, 9, and 10). The key to performing calculations correctly on these is the *assumed temperature* at which the α figure is given for each metal type. This reference temperature may not be the same as the reference temperature given in the question!

Here are the α values I used in my calculations, *all at a reference temperature of 20° Celsius:*

- Copper = 0.004041
- Aluminum = 0.004308
- Iron = 0.005671
- Nickel = 0.005866
- Gold = 0.003715
- Tungsten = 0.004403
- Silver = 0.003819

Your students' sources may vary a bit from these figures.

Notes 9

Solving this problem requires several concepts be integrated: calculating the resistance of a wire given its metal type, length, and gauge; converting between different temperature units; and calculating shift in resistance due to temperature.

Notes 10

Solving this problem requires several concepts be integrated: Ohm's Law, converting between different temperature units, and calculating temperature from shift in resistance.