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HIGHER LEVEL PHYSICS EXTENDED ESSAY

“The effect of temperature on resistances of materials used in electrical cables and circuits’’

Word Count: 3453

Research Question:

"How does temperature affect the resistances of materials used in electrical cables and circuits?"

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1. Introduction

1.1. Explanation of the Experiment and Personal Interest

Superconductors look like ordinary materials but their superpowers are revealed when the temperature decreases.

While researching the topics of the Nobel Physics Awards, the topic of superconductivity caught my attention. A superconductor conducts electricity perfectly. In other words, the electric current in a superconducting wire continues to flow in circles for billions of years. One of the discoveries that brought the Nobel Prize was 'superconductivity'. Heike Kamerlingh Onnes, who studied the electrical resistance of solid mercury, observed some differences in the material when operating below 4.2 Kelvin (about -270 C). Subsequently, Meissner and Ochsenfeld discovered the “Meissner effect”. This effect makes the superconductors repel magnetic fields and the magnets rise into the air. In 1935, Fritz and Heinz London put forward the superconductor theory by showing that zero resistance and the Meissner effect are caused by the same phenomenon.[1]

There is a transmission mechanism behind the scenes of our devices such as computers or mobile phones that we use every day. Conduction is provided as electrons move between electronic components with the potential difference applied from outside. However, some energy is lost as heat due to the resistance created during transmission. In this case, it also causes a decrease in the efficiency of the equipment we use. The more resistance-free the transmission is, the more energy we gain. In an ideal world, we would have superconducting materials connected to our electronics and power grids. This saves a great deal of energy and allows us to squeeze circuits into confined spaces.

The fact that energy-saving close to the ideal world can be achieved with superconductivity prompted me to investigate the effect of resistance temperature on the conductivity of materials. In this extended essay I aim to investigate the relationship between the increase in temperature of the wire and the resistance of the wire was investigated

[1]Smith, T. Fred. “The Superconductivity Revolution?” *Impact of Science on Society*, v. 149, 1988, pp. 15-24

1.2. Background Information

1.2.1. Resistance

Resistance is an electric attribute that describes a substance's opposition to the flow of electrical current. Almost every electronic item we use in our everyday lives relies on resistance to function. In order to function properly, electronic equipment require a constant resistance.

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

R is the electrical resistance

l is the length of the piece of the material in meters

A is the cross-sectional area of the material

ρ is the resistivity. [2]

In some situations, the temperature of the surroundings might have a detrimental impact on the operation of electrical devices. The purpose of this article is to investigate the link between temperature and resistance. The experiment of measuring the resistance of materials at various temperatures is given more attention in order to identify situations of resistance when the temperature is raised. [3]

The initial goal of this research is to see how changing the temperature of a material affects resistance. It entails having a look at the situation.

It will be planned to adjust the surrounding thermal conditions of the cable and watch how voltage and ampere vary in order to examine how temperature affects current resistance. It is expected that the resistance will change as a result. The quantity of resistance is predicted to fluctuate as the temperature rises, since the kinetic energy of the molecules in the examined matter increases correspondingly.[4]

[2,4]"What Is a Resistor?" *EE Power*,

[3]Ocak, Mahir E. "Süperiletkenlik Nedir?" *TÜBİTAK Bilim Genç*, 16 March 2015

1.2.2. Ohm's Law

Understanding the relationship between voltage, current, and resistance is based on Ohm's law (George Ohm, 1827). It claims that the electric current is directly proportional to the potential difference applied for good conductors, provided that temperature and other physical factors remain constant. When the other two variables are known, the equation can be used to calculate an unknown variable. When R is calculated for direct current (AC), it is important to remember that R represents impedance. In contrast to resistance, which is impacted solely by magnitude, impedance refers to the opposition of flow affected by both magnitude and phase.

A resistance of 1 Ω is stated to exist between two points of a conductor when a potential difference of 1V is put between them and a current of 1 A is produced.

Current can be predicted; $I = \frac{V}{R}$

Resistors can be connected in series or parallel in a circuit. A series current is one in which the resistors are connected in a series, allowing the current to flow in only one direction. A parallel circuit is one in which the resistors' heads are connected to one other and their tails are connected to each other. Each resistor has the same voltage across it.

Both electrical current and voltage will be measured simultaneously throughout the experiment, the resistance may be estimated using the equation:

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

This research subject is important investigating because the best substance and temperature for electrical circuits can be determined through testing. Various types of equipment will be utilized during this experiment to verify that the data obtained is accurate. [5]Also, there are various restrictions that may prohibit reliable data gathering, such as the room's temperature conditions and the quality of the substance under investigation. These are recognized to be insignificant factors for collecting data for the experiment and will have no impact on the outcome of the results.

[5]"Ohm's Law - How Voltage, Current, And Resistance Relate" *All About Circuits*,

1.2.3. Calculating Current Under Heat Effect by Using Ohm's Law

The link between the current and voltage of an ideal conductor is helped by Ohm's law. "The potential difference (voltage) across an ideal conductor is proportional to the current flowing through it," says this relationship. Because the potential difference across it varies linearly with the current, materials that obey Ohm's Law are referred to as "ohmic" and "linear" materials. To be calculatable, all of the items under investigation in this article are ohmic materials. After the heating process, Ohm's Law will be utilized to compute the resistance using known current and voltage values. [6]

When it comes to troubleshooting your thermal system, Ohm's Law can help. If the electrical current or heat output from your power and temperature controller's fluctuations, you may use Ohm's Law to verify the static values of circuit components and find voltage readings between components.

An increase in voltage or a decrease in resistance might create a high current measurement in your circuit. Any change in voltage may be detected by your test instrument, allowing you to compute the resistance using Ohm's Law to see if the problem is caused by damaged components or loose electrical connections. In such situation, low I and high W would result in an increase in resistance, with high W meaning increased heat at the terminations. [7]

Current (I): Current is the flow of electrons via a conductor, and it is measured in amperes (A).

Electrical potential (E): The electric current force is measured in volts (V).

Resistance (R): It is the complete opposition to the flow of electric current, measured in ohms (Ω).

Wattage (W): Watts (W) are the units of measurement for the amount of power delivered by a resistance element in a heater over a specific period of time. You may determine the electricity usage of a thermal system by calculating the wattage use of an electric heater. The electrical usage of a thermal system.

Ohm's law equation, the mathematical model:

$$\text{Voltage} = \text{Current} \times \text{Resistance, so } E = I \times R$$

[6]"What Is Ohm's Law and How Does It Apply to Thermal Systems?" *Watlow*, 5 April 2021,

[7]*Gilbert-Kawai Edward T. and Marc D. Wittenberg. "Ohm's Law, Voltage, Current and Resistance." Essential Equations for Anaesthesia: Key Clinical Concepts for the FRCA and EDA, pp. 28–30,*

The relationship between voltage, current, and resistance is calculated using Ohm's Law by design engineers. It is not, however, considered a universal rule. When there is an inductive load or when the resistance is not constant, Ohm's Law does not apply. Some heaters do not have a consistent resistance as the temperature increases. Tungsten lights and silicon carbide heaters are examples of this.

There are exceptions to this rule, especially when the current flowing isn't proportional to the potential difference across the conductor. Ohm's Law does not apply to devices with a non-linear voltage-current connection, such as thermistors.

2. Research Question and Hypothesis

Research Question: "How does temperature affect the resistances of materials used in electrical cables and circuits?"

Hypothesis: “If the temperature of materials used in electrical cables and circuits increases, the resistance of materials increases accordingly.’’

Temperature extremes are a problem for electronic devices. Laptops, phones, and PDAs' Liquid Crystal Displays (LCDs) do, in fact, freeze. Laptops are meant to operate in a safe temperature range of 50 to 95 degrees Fahrenheit (10 - 35 degrees C). This temperature range relates to the outside environment's ideal use temperature as well as the temperature at which the laptop should be warmed before use. [8]

The gadgets will either shut down automatically or give you a warning if the temperature rises too high. The scenario is different for industrial equipment that makes little modifications, such as thermal cameras, measuring devices, batteries, or microprocessors. Higher temperatures might have an adverse effect on these industrial gadgets, potentially resulting in a disaster. In this article, it will be examined if temperature has an influence on the resistances of circuits or cables, which might cause problems with their operation.

[8]“Laptops and Temperature Extremes: Laptops Really Do Freeze!” *Hampshire College*,

3. Designing and Conducting the Experiment

3.1. Variables

3.1.1. Independent Variable:

1. The electric cables (copper, silver, zinc, aluminum)

2. Heater Temperature – At room temperature 25 ^{o}C, 40 ^{o}C and 70 ^{o}C, the measurements will be done. (The range is big because of measuring the difference of resistance)

3.1.2. Dependent Variables:

1. Resistance of electric wire

3.1.3. Controlled Variables:

1. The room Temperature – The room temperature is 25^{o}C

2. Location of Wire – All wires are placed in the exact same distance from the fire

3. Location of Temperature Sensor – The temperature probe is placed to exact same position to the fire.

4. Multimeter –The same multimeters used to prevent errors

5. Voltage – The voltage given to circuit is 1.5 Volts

3.2. Materials used in the Experiment

1. 1 10 cm silver wire
2. 1 10 cm copper wire
3. 1 10 cm zinc wire
4. 1 10 cm aluminum wire
5. DC Energy Source and two Multimeters
6. LabQuest Device and Temperature Probe
7. 6 crocodile clips
8. Heater

3.3. Steps Followed in Conducting the Experiment

1. Make a connection between the wire and the circuit.

2. Using a multimeter, record the voltage and using another multimeter, record the current.

3. Using the LabQuest Device and the Temperature Sensor, record the temperature of the wire.

4. Increase the wire's temperature by using heater.

5. Using multimeter, re-record voltage and current.

6. Replace out wire with a different material and repeat the process.

7. In all steps be careful about controlled variables for accurate results.

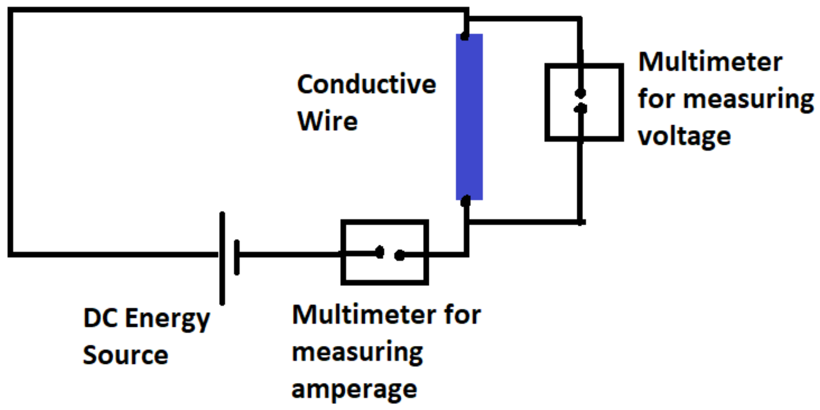


Figure 1: Circuit Diagram

In the diagram to measure amperage, the multimeter is connected in series, to measure voltage, the multimeter is connected parallel. Because the inner resistance of amperemeter is very small, it is negligible. The inner resistance of voltmeter is very huge.

Using the Multimeter

Testing Continuity:

First step:

The continuity test tells us whether two things are electrically connected. If there is continuity for something (like a wire), we can say that electric current will flow freely through that object from one end to the other.

If there is no continuity in a system, it means that there is a disconnection somewhere in the circuit. This can also indicate a blown fuse, an incorrectly connected circuit, or a poorly soldered port.

Second step:

To begin with, make sure that no current is flowing through the circuit or component you want to test. This may require turning off the switch, unplugging, or removing the batteries.

Next, plug the black probe into the COM port of your multimeter.

Connect the control lead of your multimeter to the V, Ω, mA input.

Third step:

Turn on your multimeter for use and put it in sound wave 'search' mode for continuity check.

Note: Not all multimeters include this mode. If you do not have this feature, go to step 6 for the alternative method.

Fourth Step:

While the multimeter is performing the continuity test, it sends a small current at one of the control terminals and examines whether this current is received from the other control terminal.

If the control terminals are connected to each other either as a continuous circuit or directly by touching each other; the test current will pass through the circuit and reach the other end. The multimeter display will show zero or very close to it. In this case, the multimeter will beep.

If the test current could not be measured in this way, it means that there is no continuity. If the screen is either 1 or OL (open loop) open (not connected) circuit.

Fifth Step:

To complete the continuity test, touch the end of the test rod to the part to be measured or to both ends of the circuit. Note: It doesn't matter which control tip touches which terminal; because the plus or minus end of the continuity control does not matter.

If there is continuity as before, a beep will also sound as the display shows zero or a number close to it.

If the display shows 1 or the OL (open circuit) sign, there is no continuity. That is, the current does not pass from one end to the other.

Sixth Step:

The multimeter is set to the lowest resistance mode. Note: Resistance is measured in ohms and indicated by the symbol Ω.

Seventh Step:

In this mode, the Multimeter measures current from one control end while sending current from the other end. [9]

[9]"Direnç Nasıl Ölçülür?" *Fluke,*

If the control leads are connected, current will flow through this circuit. In this case, a value of zero or close to it will appear on the display.

Because resistance is connected to highly sensitive voltage and amperage levels, the environment must be properly controlled, and various measuring instruments must be utilized to assure the results. The findings are affected not just by the environment or measuring instruments, but also by human mistakes committed during the circuit construction. Even a hand touch can create static electricity, which can affect the accuracy of the results. As a result, to reduce experimental errors, the circuit will be built remotely and without the touching of human hands. Body static is a relatively motionless and accumulative charge in the human body caused by walking, operating, touching and separating with other objects, or other factors such as electrostatic induction and space charge adsorption, which throws the body's positive and negative polarity out of balance. To reduce the risk of people becoming body static, a large number of human body static elimination technologies have been developed, such as wearing anti-static shoes and suits, using a grounding wrist strap to connect the human body to the ground, increasing ambient humidity, and using a human body static elimination device, all of which are currently active technologies.

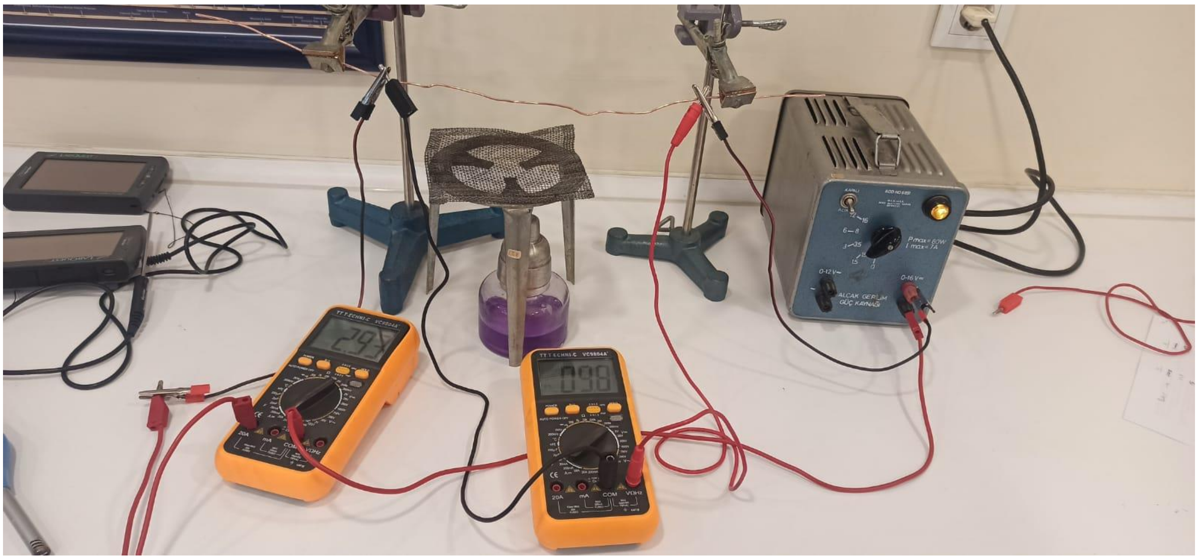


Figure 2: Experiment Setup

To avoid temperature mismeasurement, the thermometer was positioned in touch with the cable and as far away from the heater as practicable. The goal is to determine the temperature of the wire. To prevent static electricity and changing material utilization, two insulative legs are employed. Amperage is measured with a multimeter and voltage is measured with another multimeter. LabQuest and a temperature probe are used to measure and graph temperature. To extend the variable scale, several kinds of wire were employed. The wires are zinc, aluminum, copper and silver.

Figure-2 is designed for copper at room temperature. For each temperature value and for each wire the experiment is settled up.

3.4. Safety Issues

In this experiment, safety precautions were taken. The fact that the temperature was increased by fire and working with electricity were situations that required extra attention. Heat protective gloves were used. This glove was also made of insulating materials to prevent electric shocks. The heater was always kept in a fixed place to prevent possible accidents.

4. Data Collection

MATERIAL OF WIRE	TEMPERATURE/CELCIUS DEGREE **±0.2C^{O}**	VOLTAGE /V **±0.01 V**			CURRENT /A **±0.01A**		
		Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
SILVER	**25 ^{o}C**	**2,36 x 10^{-6}**	**2,39 x 10^{-6}**	**2,41 x 10^{-6}**	**2,63**	**2,68**	**2,70**
	50 ^{o}C	**2,51 x10^{-6}**	**2,53 x10^{-6}**	**2,57 x10^{-6}**	**2,58**	**2,60**	**2,64**
	75 ^{o}C	**2,68 x10^{-6}**	**2,69 x10^{-6}**	**2,72 x10^{-6}**	**2,55**	**2,56**	**2,59**
COPPER	**25 ^{o}C**	**1,18 x 10^{-6}**	**1,16 x 10^{-6}**	**1,13 x10^{-6}**	**3,53**	**3,48**	**3,36**
	50 ^{o}C	**1,29 x10^{-6}**	**1,26 x10^{-6}**	**1,24 x10^{-6}**	**3,36**	**3,41**	**3,45**
	75 ^{o}C	**1,36 x10^{-6}**	**1,34 x10^{-6}**	**1,31 x10^{-6}**	**3,31**	**3,36**	**3,42**
ZINC	**25 ^{o}C**	**0,279**	**0,276**	**0,273**	**2,41**	**2,40**	**2,55**
	50 ^{o}C	**0,281**	**0,288**	**0,294**	**2,34**	**2,40**	**2,47**
	75 ^{o}C	**0,295**	**0,296**	**0,297**	**2,21**	**2,27**	**2,32**
ALUMINUM	**25 ^{o}C**	**0,71x10^{-6}**	**0,74x10^{-6}**	**0,75x10^{-6}**	**2,98**	**3,09**	**3,10**
	50 ^{o}C	**0,73 x10^{-6}**	**0,76 x10^{-6}**	**0,78 x10^{-6}**	**2,90**	**2,92**	**2,94**
	75 ^{o}C	**0,76 x10^{-6}**	**0,80 x10^{-6}**	**0,83 x10^{-6}**	**2,83**	**2,85**	**2,88**

Table 1: Raw Data Including Current and Voltage Results Under Different Temperatures

The silver, copper, aluminum, zinc wires are used to set up the experiment. The DC voltage generator has some voltage values, I decided to prefer 1.5V for each measurement because more voltage makes the resistance more heated. When the voltage is given to the wire, the voltage on the wire is measured by the multimeter and the current flow is measured by the other multimeter. There are three temperature values and constant DC generator voltage, which is 1.5V, for each the voltage and current is measured on the wire. The first temperature is 25^0C at room temperature on each wire, voltage and amperage values are measured. The collecting data part is repeated for 50^0C and 75 ^{0}C. for electric wires.

The changing temperature is checked by Vernier's temperature probe and LabQuest.

In table-1 the current and changes in voltage are recorded. At the end, Ohm's Law is used to calculate the resistance. Table-2 is processed data, it includes average voltage and average current.

To calculate uncertainty error part the method of

$$\frac{\text{max trial value – min trial value}}{2}$$

is used.

MATERIAL OF WIRE	TEMPERATURE/CELCIUS DEGREE ±0.2C^O	AVERAGE VOLTAGE /V	UNCERTAINTY VOLTAGE /V	AVERAGE CURRENT /A	UNCERTAINTY CURRENT /A
SILVER	**25 ºC**	**$2{,}39\times10^{-6}$**	**$2{,}39\times10^{-6}\pm0{,}25\times10^{-9}$**	**2,67**	**2,67±0,035**
	50 ºC	**$2{,}53\times10^{-6}$**	**$2{,}53\times10^{-6}\pm0{,}30\times10^{-9}$**	**2,61**	**2,61±0,03**
	75 ºC	**$2{,}57\times10^{-6}$**	**$2{,}57\times10^{-6}\pm0{,}20\times10^{-9}$**	**2,56**	**2,56±0,02**
COPPER	**25 ºC**	**$1{,}16\times10^{-6}$**	**$1{,}16\times10^{-6}\pm0{,}25\times10^{-9}$**	**3,45**	**3,45±0,085**
	50 ºC	**$1{,}26\times10^{-6}$**	**$1{,}26\times10^{-6}\pm0{,}25\times10^{-9}$**	**3,41**	**3,41±0,045**
	75 ºC	**$1{,}34\times10^{-6}$**	**$1{,}34\times10^{-6}\pm0{,}25\times10^{-9}$**	**3,36**	**3,36±0,055**
ZINC	**25 ºC**	**0,276**	**0,276±0,003**	**2,45**	**2,45±0,075**
	50 ºC	**0,288**	**$0{,}288\times10^{-6}\pm0{,}006$**	**2,40**	**2,40±0,065**
	75 ºC	**0,296**	**$0{,}296\times10^{-6}\pm0{,}001$**	**2,27**	**2,27±0,055**
ALUMINUM	**25 ºC**	**$0{,}73\times10^{-6}$**	**$0{,}73\times10^{-6}\pm0{,}02\times10^{-9}$**	**3,06**	**3,06±0,06**
	50 ºC	**$0{,}76\times10^{-6}$**	**$0{,}76\times10^{-6}\pm0{,}02\times10^{-9}$**	**2,92**	**2,92±0,02**
	75 ºC	**$0{,}80\times10^{-6}$**	**$0{,}80\times10^{-6}\pm0{,}03\times10^{-9}$**	**2,85**	**2,85±0,025**

Table: 2 Processed data including Average voltage and average current for different materials at different temperatures

The calculation;

Ohm's Law

Silver wire, at **25ºC;**

Resistance, R = $\frac{Voltage,V}{Current,I}$

Average Resistance = $\frac{Average\ voltage}{Average\ Current} = \frac{2{,}39x10^{-6}}{2{,}67}$ = $0{,}89\times10^{-6}$ Ω

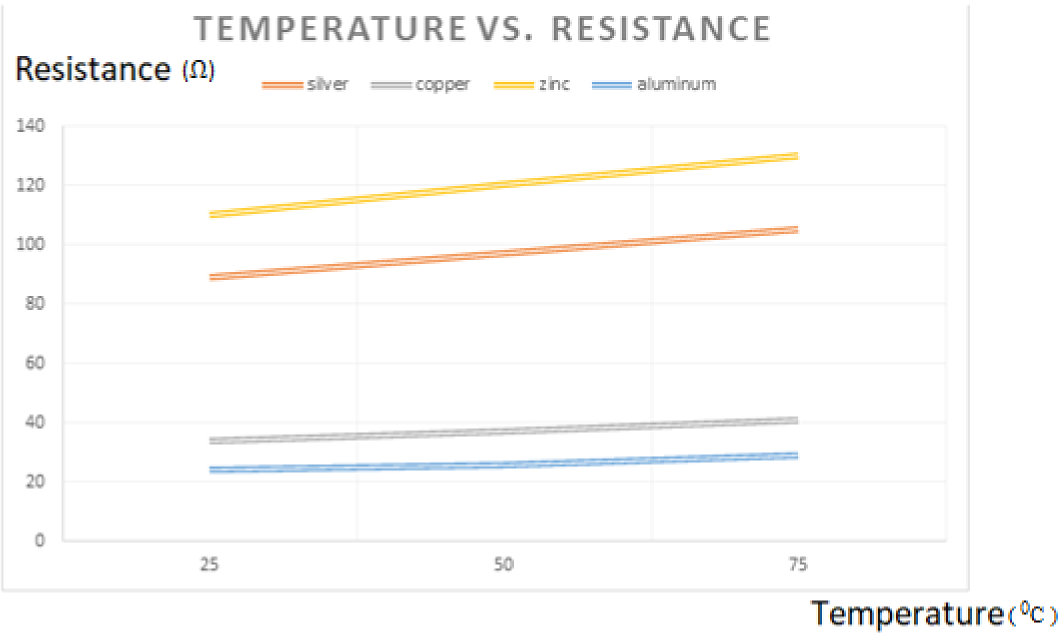
For each wire and temperature values, the calculation is done and noted in Table-3.

MATERIAL OF WIRE	TEMPERATURE/CELCIUS DEGREE ±0.2C^{O} ^{0}C	RESISTANCE/R Ω
SILVER	25	0,89x10^{-6}
	50	0,97 x10^{-6}
	75	1,05 x10^{-6}
COPPER	25	0,34 x10^{-6}
	50	0,37 x10^{-6}
	75	0,41 x10^{-6}
ZINC	25	0,11
	50	0,12
	75	0,13
ALUMINUM	25	0,24 x10^{-6}
	50	0,26 x10^{-6}
	75	0,29 x10^{-6}

Table 3: Resistance for each temperature

5. Analysis

It is an excellent approach to plot graph in order to evaluate the data obtained better and deeper. To analyze the change in resistance with temperature, a scatter graph is chosen.



Graph 1: Temperature vs Resistance of Silver, Copper, Zinc and Aluminum

6. Discussion

In the literature,

Resistance is determined by the geometry of a conductor as well as the material it is constructed of, but it is also affected by temperature (although we will often neglect this).

Consider a basic resistance model to better understand the temperature relationship. Atoms and molecules obstruct electron transport through a conductor. The electrons have a tougher time passing through these atoms and molecules the more they bounce around. As a result, resistance rises as the temperature rises.

The resistivity of a material changes linearly with temperature for small temperature changes:

$r = r_o$ (1 + a DT), where a is Resistivity temperature coefficient.

Therefore, resistance is $R = R_o$ (1 + a DT)

This indicates we're expecting that length and area remain constant regardless of temperature. We can get away with this assumption since the linear expansion coefficient is usually significantly less than the temperature coefficient of resistance.

The temperature coefficient of resistivity in some materials (such as silicon) is negative, implying that resistance decreases as temperature rises. An increase in temperature in such materials can liberate more charge carriers, resulting in an increase in current. [1]

This may be used to create a resistor with a resistance that is practically temperature independent. Two resistors are connected in series to make the resistor. The temperature coefficient of one resistor is positive, whereas the temperature coefficient of the other is negative. The resistance values are adjusted so that the increase in resistance experienced by one resistor is countered by the reduction in resistance experienced by the other when the temperature changes.

7. Conclusion

7.1. Strengths and Weakness

Since the materials were supplied, the experimental setup was set up in the university laboratory with the permission of the university.

The setup of the experiment was prepared according to the principles of connecting the ammeter and voltmeter to the circuit. The working principle of the multimeter was investigated, and this was mentioned in the report. The multimeter is connected to the electrical circuit.

In this experiment, the relationship between the increase in temperature of the wire and the resistance of the wire was investigated. When the electrical circuit was set up and connected to the power supply, the heater was not the only factor that increased the temperature. The power supply caused a temperature rise in the electrical wire. Therefore, three measurements were taken and averaged. The reason why not every measurement was the same was because the temperature of the wire increased.[9]

[9]"Temperature Dependence of Resistance." Boston University Art and Science,

When taking temperature measurement with the Vernier LabQuest thermometer Probe, only the temperature of the wire could not be measured. The thermometer probe measured the temperature of the wire and the temperature of the environment together. This prevented exact readings, but did not affect the measurement rate as the room temperature was always the same.

On the other side, the experiments could be completed successfully. All the steps of procedure were done during the experiment.

7.2. Errors

There can be some differences between the experiment results and real-life results. The experimental error can be because of lab Quest, both resistance temperature and environment temperature were measured by using the device.

To eliminate random errors, the experiment was repeated three times for each different wire and each temperature value. The connected cables in the setup have inner resistance. Therefore, the measured voltage is affected by inner resistance of the connected cables.

7.3. Further research

If we study the collected data after the experimental and calculating methods, we can conclude that heat has a significant impact on the conduction of materials, independent of the element/s contained in the wire. In all of the four cases, it is clear that the wire resistance increased significantly and influenced the conduction which confirms my hypothesis and answers our research question. If this were to be applied to an industrial case or even a piece of small home-use equipment, the item would either fail or cease operating if the required current or voltage was not available. For example, if this occurs at a nuclear power plant where the mechanism that measures the radiation level of the coolant water malfunctions, the heavy water released into the environment water system might harm bio life and potentially alter meteorological occurrences.

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