ANALYSIS OF TEMPERATURE COEFFICIENT OF RESISTANCE OF METALLIC WIRES, CARBON FILM RESISTORS AND THERMISTORS

PROJECT REPORT

Submitted by

PARVATHY P S

(AB23PHY010)

Under the guidance of

Dr.SANTHI A

Associate Professor,
Department of Physics and Centre for Research
St. Teresa's College (Autonomous), Ernakulam.

In partial fulfillment of the requirement of award of Bachelor Degree of Science in Physics.

ST. TERESA'S COLLEGE (AUTONOMOUS)
ERNAKULAM
2025-26

ST. TERESA'S COLLEGE (AUTONOMOUS)

ERNAKULAM

CERTIFICATE

This is to certify that the project report entitled "**ANALYSIS OF TEMPERATURE COEFFICIENT OF RESISTANCE OF METALLIC WIRES, CARBON FILM RESISTORS AND THERMISTORS**" is an authentic work done by PARVATHY P S, St Teresa's College, Ernakulam, under our supervision at Department of Physics, St. Teresa's College, Ernakulam, for the partial requirements for the award of Degree of Bachelor of Science in Physics during the academic year 2025-26. The work presented in this dissertation has not been submitted for any other degree in this or any other university.

Supervising Guide

Dr.SANTHI A

Associate Professor.

Department of Physics * St Teresa's College (Autonomous) * Ernakulam

Head of the Department

Dr. MARY VINAYA

Assistant Professor.

ST. TERESA'S COLLEGE (AUTONOMOUS)
ERNAKULAM

B.Sc. PHYSICS
PROJECT REPORT

NAME : PARVATHY P S

REGISTER NUMBER : AB23PHY010

YEAR OF WORK : 2025-26

This is to certify that this project work entitled, "**ANALYSIS OF TEMPERATURE COEFFICIENT OF RESISTANCE OF METALLIC WIRES, CARBON FILM RESISTORS AND THERMISTORS**" is an authentic work done by PARVATHY P S.

Staff member in-charge
Dr. SANTHI A

Head of the Department
Dr. MARY VINAYA

Department of Physics, St. Teresa's College (Autonomous), Ernakulam

Submitted for the University examination held at St. Teresa's College, Ernakulam.

DATE: 16.04.26

EXAMINER: ATHIRA PRAKASH

DECLARATION

I, PARVATHY P S of final B.Sc. Physics students, Department of Physics, St. Teresa's College (Autonomous), Ernakulam, do hereby declare that the project work entitled "**ANALYSIS OF TEMPERATURE COEFFICIENT OF RESISTANCE OF METALLIC WIRES, CARBON FILM RESISTORS AND THERMISTORS**" has been originally carried out under the guidance and supervision of **Smt Dr. Santhi A**, Assistant Professor, Department of Physics, St. Teresa's College (Autonomous), Ernakulam, in partial fulfilment for the award of the Degree of Bachelor of Physics. I further declare that this project is not partially or wholly submitted for any other purpose and the data included in the project is collected from various sources and is true to the best of my knowledge.

PLACE: Ernakulam

NAME : PARVATHY P.S

DATE : 30|03|2026

ACKNOWLEDGEMENT

First, I would like to thank almighty God for all his blessings that enabled me to complete this work. I am deeply grateful to my research guide Professor Dr. Santhi A and for her unwavering support, guidance, and expertise throughout the entire process of our UG project. Her mentorship and insightful feedback have been invaluable in shaping the direction and quality of this work.

Special thanks are due to the Research Centre and the Physics Department of St. Teresa's College, Ernakulam, for providing the necessary laboratory facilities to carry out the experimental work on temperature coefficients of different resistive materials. The availability of proper instruments and lab support made the completion of this study possible.

Additionally, I would like to express my gratitude to my family and friends for their unwavering encouragement, understanding, and patience throughout this academic journey.

Lastly, I acknowledge the contributions of all those who, directly and indirectly, supported me during this endeavour. Your support has been fundamental to the successful completion of this project.

ABSTRACT

This project studies how the electrical resistance of different materials changes with temperature. The temperature coefficient (α) was determined for copper, nichrome, and carbon film resistors, while the beta (β) parameter was calculated for NTC and PTC thermistors. The behaviour of linear and non-linear temperature dependence was analysed through experimental measurements.

The study highlights how different materials respond to temperature variations and explains the practical importance of temperature coefficients in electrical and electronic applications.

CONTENT

Chapter 1 Introduction ____ 1

Motivation for this Project ____ 1

1.1 Temperature Dependence of Resistance ____ 1

1.1 Linear Temperature Dependence (Temperature Coefficient of Resistance – α) ____ 3

1.3 Non-Linear Temperature Dependence (Temperature Coefficient – β) ____ 5

Chapter 2 Experiment and Methodology ____ 7

2.1 Aim of the Experiment ____ 7

2.2 Apparatus ____ 7

2.3 Procedure ____ 8

Chapter 3 Metal Wires and Alloys ____ 10

3.1 Mechanism of temperature dependence of resistance of metals and metallic alloys ____ 10

3.2 Observations ____ 11

3.3 Calculations ____ 14

3.4 Inference ____ 15

Chapter 4 Carbon Film Resistors ____ 16

4.1 Structure and Internal Mechanism of Carbon Film Resistors ____ 16

4.2 Observations ____ 17

4.3 Inference ____ 23

Chapter 5 Thermistors (NTC and PTC) ____ 24

5.1 Thermistors ____ 24

5.2 Observations ____ 26

5.3 Inference ____ 30

Conclusion ____ 31

Reference ____ 32

CHAPTER 1

INTRODUCTION

Motivation for this Project

The change in electrical resistance with temperature across materials is certainly a phenomenon to consider in a wide variety of electronic applications. Stability and accuracy are two important requirements for a working design. For example, a resistor or thermistor or a sensor in a circuit will operate in varying thermal conditions and will perform based on their resistive response to temperature changes.

The resistance of a material is a critical factor in the selection of a material for a particular application. For example, in the protection circuit, materials with a positive temperature coefficient are used; and for temperature sensing devices, materials with a negative temperature coefficient are preferred. Thermistors are widely used because of their high temperature dependence to measure and control temperature accurately.

The core aim of this project is to investigate and analyze experimentally how resistance for different materials changes with temperature, including the computation of the temperature coefficient. In the study of thermistors, resistors of carbon film and metallic wires the project intends to recognize and compare the sensitivity and the temperature behavior, linear or non-linear. This study will demonstrate the importance of the temperature coefficient of resistive materials and its significance in electronics.

1.1 Temperature Dependence of Resistance

The property of a material to resist the flow of free charges across its cross-section is called the Electrical Resistance of a material. According to Ohm's law, "The electrical resistance of a circuit is the ratio between the voltage applied to the current flowing through it." The unit of electrical resistance is ohms (Ω).

In conductors, free electrons are the main charge carriers responsible for the flow of electric current. When an external electric field is applied, these electrons gain a drift velocity in the opposite direction of the applied electric field and flow through the crystal lattice structure of the material. At normal temperature and pressure, the atoms in the lattice are at rest at their equilibrium positions, thus allowing free flow of electrons between them.

But when the temperature of the conductor rises, the atoms gain thermal energy and start vibrating around their equilibrium positions in the lattice structure. These additional lattice vibrations hamper the flow of electrons and cause frequent collisions. Consequently, the flow of electrons is restricted, and this results in an increased opposition to the flow of electric current, hence an increase in electrical resistance.

1.1.1 Brief Historical Overview of the Temperature Dependence of Resistance

The relationship between temperature and electrical resistance was first systematically studied in the early nineteenth century when scientists began investigating how heat affects electrical conduction in metallic wires. One of the earliest contributors was Sir Humphry Davy, who observed that heating a metal wire changed its electrical behaviour during his experiments on electrical conduction.

Later, more detailed and quantitative investigations were carried out by William Thomson and James Prescott Joule, who studied the relationship between heat, current, and resistance. Their work helped establish that resistance is not a constant property, but depends on temperature due to changes occurring within the material.

In the late nineteenth century, the electron theory of metals was further developed by Paul Drude, who explained electrical conduction in terms of the motion of free electrons. This provided the physical basis for understanding why resistance increases in metals with temperature, due to increased collisions between electrons and vibrating atoms.

These foundational studies eventually led to the formulation of the temperature coefficient of resistance (α) for metals and the exponential temperature coefficient (β) for semiconductors. These parameters are now widely used in practical applications such as temperature sensing, electronic circuit design, and material characterisation.

1.1.2 Temperature Coefficient of Resistance

The parameter used to quantify the change in resistance of a material with respect to the change in temperature is known as the temperature coefficient of resistance.

The linear change in resistance with respect to temperature is quantified by the parameter α (alpha), known as the linear temperature coefficient of resistance.

When the change in resistance with temperature is nonlinear, especially in thermistors, it is quantified by the parameter β (beta), known as the nonlinear temperature coefficient constant.

1.1 Linear Temperature Dependence (Temperature Coefficient of Resistance – α)

In many conductors such as metals, the variation of resistance with temperature follows an approximately linear relationship over a limited temperature range. This behaviour is known as linear temperature dependence of resistance. In such cases, the change in resistance is directly proportional to the change in temperature.

For small temperature variations around a reference temperature T_0, the resistance at temperature T can be expressed as:

$$R_T = R_0(1+\alpha\Delta T)$$

Where,
R_T = resistance at temperature T,
R_0 = resistance at reference temperature T_0,
$\Delta T = (T - T_0)$

The temperature coefficient of resistance α (alpha) is defined as the fractional change in resistance per unit change in temperature at the reference temperature. Mathematically,

$$\alpha = \frac{(R_T - R_0)}{R_0(T - T_0)}$$

The unit of α is $^{\circ}C^{-1}$

In reality, resistance is a function of temperature and can be expressed as a series expansion about the reference temperature T_0 :

$$R = R_0(1+\alpha\Delta T+\beta\Delta T^2+\gamma\Delta T^3+\dots)$$

Here, α, β, γ are temperature coefficients of different orders.

The linear temperature dependence formula is obtained by neglecting the higher-order terms (ΔT^2, ΔT^3 etc.) and retaining only the first-order term. This is called a first-order approximation. The higher-order terms involve powers of ΔT, so when the temperature change is small, these terms become very small compared to the first-order term i.e,

($\Delta T^2 << \Delta T$) and can be ignored without introducing significant error. Thus the simplified equation is obtained.

1.2.1 Positive and Negative Behaviour of Temperature Coefficient (α)

The temperature coefficient of resistance (α) may be either positive or negative depending on the nature of the material.

(a) Positive Temperature Coefficient ($\alpha > 0$)

A material is said to have a positive temperature coefficient when its resistance increases with increase in temperature.This behaviour is generally observed in metallic conductors such as copper, aluminium and nichrome. In metals, free electrons are the primary charge carriers. When temperature increases, lattice vibrations increase. These enhanced vibrations cause increased scattering of electrons, thereby reducing their mobility. As a result, resistance increases with increase in temperature.

Here , $(R_T - R_0) > 0$

Since resistance increases proportionally with temperature over a moderate range, the value of α for metals is positive.

(b) Negative Temperature Coefficient ($\alpha < 0$)

A material is said to have a negative temperature coefficient when its resistance decreases with increase in temperature.This behaviour is commonly observed in semiconducting materials and carbon-based resistors. In such materials, the number of charge carriers is strongly dependent on temperature. At lower temperatures, only a limited number of electrons have sufficient energy to move into the conduction band. When the temperature increases, additional thermal energy is supplied to the material. This energy excites more electrons from bound states into conduction states, thereby increasing the number of free charge carriers available for conduction.

Although lattice vibrations also increase with temperature and reduce carrier mobility, the increase in carrier concentration is much more significant than the decrease in mobility. As a result, the overall conductivity increases and resistance decreases with temperature.

Here, $(R_T - R_0) < 0$

Therefore, these materials exhibit a negative temperature coefficient of resistance.

1.2.2 Applications

The linear temperature coefficient relation is widely used in:

- Estimating resistance change in metallic conductors.
- Designing temperature compensation circuits.
- Calibration of resistance temperature detectors (RTDs).
- Material characterization studies where small temperature variations are involved.

1.3 Non-Linear Temperature Dependence (Temperature Coefficient – β)

In certain materials, especially thermistors and semiconducting devices, the variation of resistance with temperature does not follow a linear relation. Instead, the resistance changes rapidly and non-proportionally with temperature. This type of behaviour is known as non-linear temperature dependence. In such cases, the linear approximation is not valid.

For thermistors, particularly NTC types, the resistance varies approximately according to an exponential relation:

$$R=R_0e\wedge[\beta(\frac{1}{T}-\frac{1}{T_0})]$$

Where,
R = resistance at absolute temperature T
R_0 = resistance at reference temperature T_0
β = material constant (beta coefficient)
T and T_0 are in Kelvin.

Thus the temperature coefficient of Resistance β can be equated as,

$$\beta= \ln(\frac{R_0}{R})/(\frac{1}{T}-\frac{1}{T_0})$$

The unit of K^{-1}

In semiconducting materials, electrical conduction depends strongly on temperature because the number of charge carriers increases exponentially with thermal energy. The conductivity of such materials follows an activation energy relation derived from semiconductor physics:

$$\sigma \propto e^{(-E_a/2K_BT)}$$

where
Ea is the activation energy,
K_B is Boltzmann's constant,
T is absolute temperature.

Since resistance is inversely proportional to conductivity, this leads to an exponential dependence of resistance on temperature. The beta parameter (β) is related to the activation energy of the material. Thus, unlike the linear α-model which is obtained by first-order approximation, the β-model arises from the intrinsic thermal excitation behaviour of semiconducting materials.
The β coefficient also has positive and negative behaviour which is thoroughly discussed in Chapter-5 of Thermistors.

1.3.1 Applications

The non-linear beta relation is widely used in:

- NTC thermistors for temperature sensing
- Inrush current limiting devices
- Temperature compensation circuits
- Precision thermal monitoring systems

CHAPTER 2

EXPERIMENT AND METHODOLOGY

2.1 Aim of the Experiment

The aim of the experiment is to determine the temperature coefficient of resistance of the given materials by studying the variation of resistance with temperature under controlled heating and cooling conditions.

2.2 Apparatus

The following components were used to perform the experiment:

1. Digital Multimeter (to measure resistance)
2. QA burner (to provide controlled heating)
3. Thermometer (to measure temperature)
4. Beaker containing water
5. Test tube containing coconut oil
6. Given resistive materials (metal wires, carbon film resistors, thermistors)
7. Connecting wires and supporting stand.

2.2.1 Justification for the use of water bath and coconut oil

The water bath was chosen as the external source of heat because of its capability to provide uniform and controlled heating. The boiling point of water under normal atmospheric pressure is about 100°C. This limits the maximum temperature of the system. This is important because it prevents the system from getting too hot, which may damage the test material. The water bath is also safe, readily available, and stable at the range of temperatures needed.

Liquids with boiling points below that of water such as alcohol or acetone would restrict the temperature range and evaporate rapidly, leading to unstable heating conditions. Liquids with higher boiling points such as glycerin or silicone oil would allow higher temperatures but require additional safety precautions, which were unnecessary for this study.

Coconut oil was used inside the test tube as it is electrically non-conductive and thermally stable within the experimental range. Its insulating nature ensures that the resistance measured corresponds only to the sample and is not influenced by the surrounding medium.

Alternative insulating liquids such as liquid paraffin or transformer oil could also be used; however, coconut oil was preferred due to availability and suitability for moderate temperature measurements.

Thus, the selected combination ensures safe, uniform, and reliable temperature control for resistance measurement.

2.3 Procedure

The two ends of the material under observation was connected to a digital multimeter using sufficiently long connection wires, then immersed in a test tube filled with coconut oil. The test tube containing oil was then partially immersed in a beaker filled with water. The beaker was placed over a QA burner. Thus, the burner did not directly heat the material or the oil. Instead, heat was transferred from the burner to the water and from the hot water to the oil in the test tube.

This indirect heating arrangement served two important purposes:

- It ensured gradual and uniform heat transfer.
- It prevented the oil from exceeding 100°C, since the boiling point of water limits the maximum temperature of the surrounding medium.

By maintaining this arrangement, overheating of the material was avoided, thereby preventing thermal damage and ensuring reliable measurements.

The resistance of the material was measured using the digital multimeter. Initially, the resistance of the material was recorded at room temperature. The corresponding temperature was noted using a thermometer.

The burner was then ignited, and the temperature of the water was increased gradually. As the temperature rose, readings of resistance were recorded at regular intervals of 5°C.

At each temperature step, the water in the beaker was stirred continuously for the uniform distribution of heat. The thermometer was kept close to the material as to verify that the oil and the material attained the same temperature before recording the resistance value.

The temperature was increased until the maximum measurable temperature (close to 100°C) was reached.

After reaching the maximum temperature, the burner was switched off. The entire setup was allowed to cool naturally. During the cooling process, resistance values were again recorded at the same temperature intervals.

For each temperature, two resistance values were obtained:

- Resistance during heating

➢ Resistance during cooling

To reduce experimental error and hysteresis effects, the mean of the heating and cooling resistance values was calculated for each temperature.

These mean resistance values were then used to plot the Temperature (T) versus Resistance (R) graph for the respective materials.

The slope of the graph was used to determine the temperature coefficient of resistance for materials exhibiting linear behaviour. For thermistors, the appropriate non-linear relation was applied

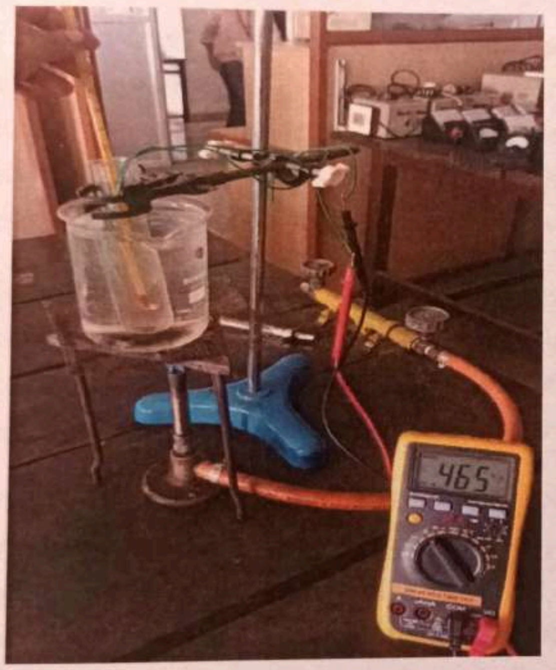


Fig.2.3(a) Experimental setup

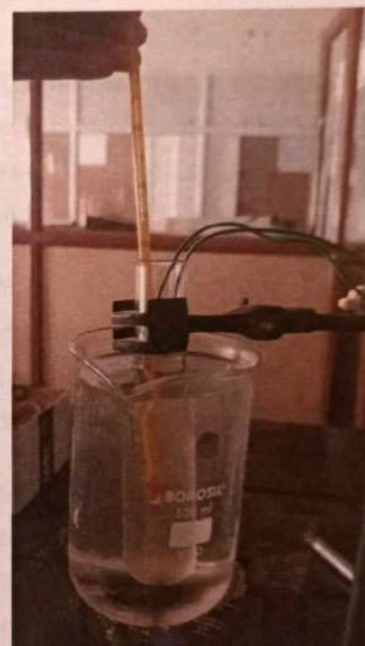


Fig.2.3(b) The component under study dipped in coconut oil in a test tube which is immersed in a water bath

CHAPTER 3

METAL WIRES AND ALLOYS

3.1 Mechanism of temperature dependence of resistance of metals and metallic alloys

In the present experiment, copper was used as the pure metallic conductor and nichrome as the alloy. The temperature dependence of resistance in both materials arises due to changes in electron scattering mechanisms within the lattice.

In copper, free electrons move through a periodic crystal lattice. When temperature is increased, vibrations of the lattice also increase. These quantised vibrations of the lattice are called phonons. When temperature is increased, the electron-phonon interaction also increases, which results in an increase in the scattering of electrons resulting in the gradual increase of resistance of the copper wire.

Nichrome, being an alloy primarily composed of nickel and chromium, has a more disordered lattice structure compared to pure copper. The presence of different atomic species introduces structural irregularities and impurity scattering even at room temperature. These impurity atoms act as additional scattering centers for electrons.

When nichrome is heated, lattice vibrations (phonons) also increase, contributing to additional electron scattering. However, because impurity scattering is already significant in alloys, the relative increase in resistance with temperature is smaller compared to copper. This results in a lower temperature coefficient of resistance for nichrome.

Thus, both copper and nichrome exhibit positive temperature dependence of resistance, but the magnitude of change differs due to differences in lattice structure and scattering mechanisms.

3.2 OBSERVATIONS

a) COPPER WIRE

Temperature (°C)	Resistance (heating) (Ω)	Resistance (cooling) (Ω)	Mean Resistance (Ω)
28	11.5	11.7	11.6
33	11.7	11.9	11.8
38	11.9	12	11.95
43	12.1	12.1	12.1
48	12.2	12.2	12.2
53	12.3	12.3	12.3
58	12.4	12.4	12.4
63	12.5	12.5	12.5
68	12.7	12.7	12.7
73	12.9	12.9	12.9
78	13.1	13.1	13.1
83	13.2	13.2	13.2
88	13.4	13.4	13.4
93	13.6	13.6	13.6
95	13.8	13.8	13.8

Table 3.2(a) Represents the change in the resistance of the copper wire when heated gradually In steps of 5°C

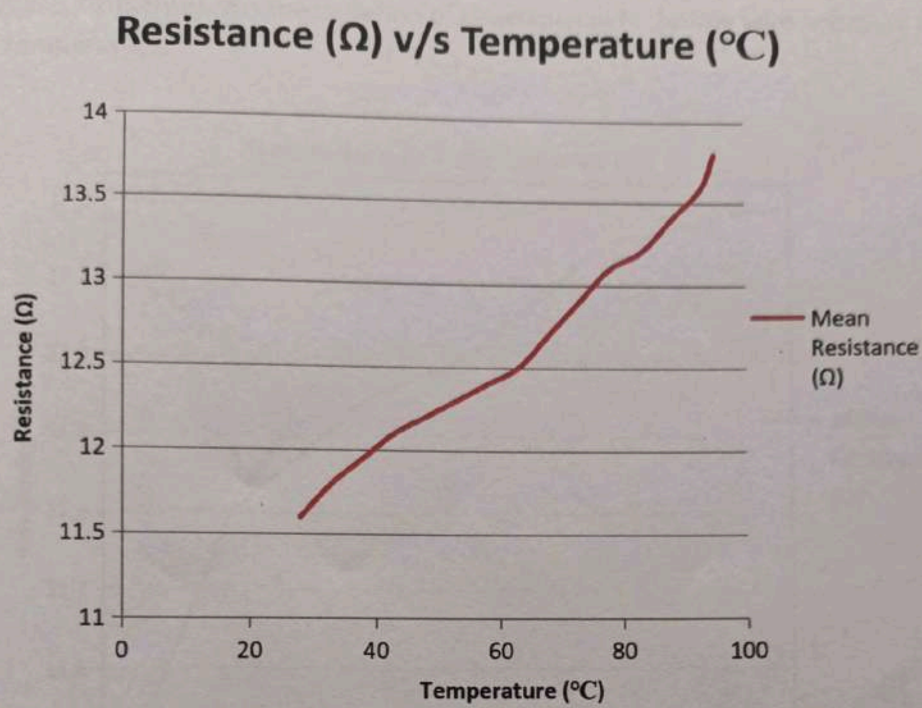


Fig 3.2 (a) Variation of resistance with temperature of copper. The graph shows a linear increase in resistance with temperature, indicating a positive temperature coefficient of resistance for copper within the experimental range.

b) NICHROME WIRE

Temperature (°C)	Resistance (heating) (Ω)	Resistance (cooling) (Ω)	Mean Resistance (Ω)
28	11.2	11.8	11.5
38	11.7	11.9	11.8
43	11.8	11.9	11.85
53	12	11.9	11.95
63	12	12	12
73	12.1	12.1	12.1
78	12.1	12.2	12.15
95	12.2	12.2	12.2

Table 3.2(b)Represents the variation of resistance in Nichrome wire with every 5°C rise in temperature.

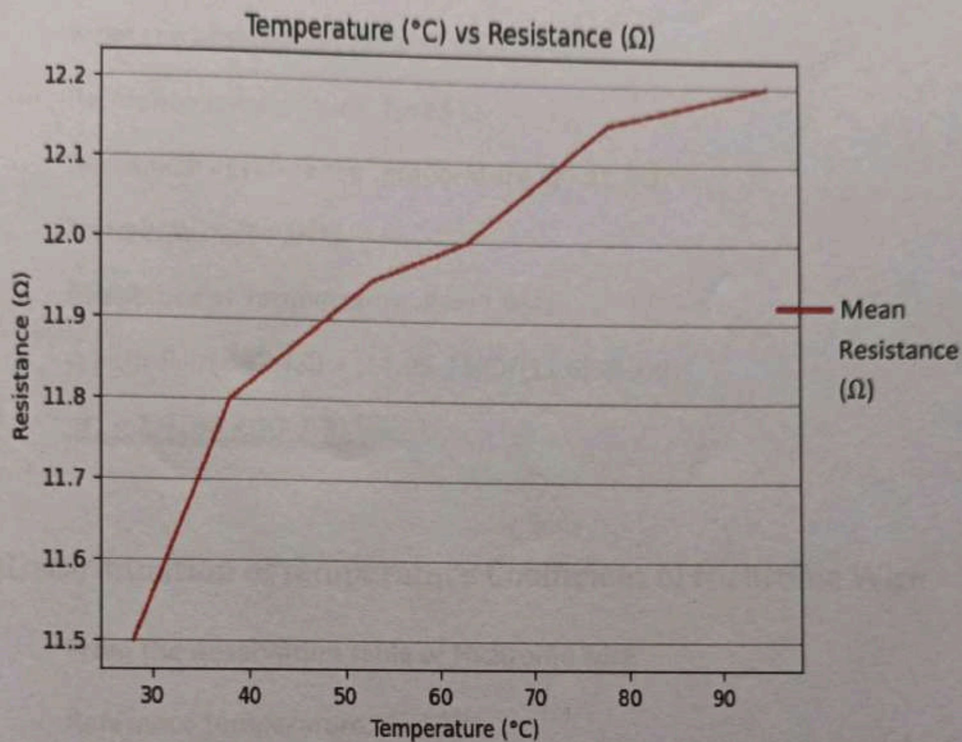


Fig 3.2(b) Variation of resistance with temperature for nichrome. The graph shows an overall increasing trend of resistance with temperature for nichrome within the experimental range.

3.3 CALCULATIONS

a)Determination of temperature Coefficient of Copper Wire

From the observation table of Copper Wire

Reference temperature, T_0=28°C

Resistance at reference temperature,R_0= 11.6Ω

Temperature,T =38°C

Resistance at Temperature, R_T=11.95Ω

$\alpha = (R_T-R_0)/(R_0[T-T_0]) = (11.95-11.6)/(11.6[38-28])$

$\alpha = 2.9288 \times 10\text{-}3\ ^\circ C^{-1}$

b)Determination of temperature Coefficient of Nichrome Wire

From the observation table of Nichrome wire

Reference temperature, T_0=53°C

Resistance at reference temperature,R_0= 11.95Ω

Temperature,T =63°C

Resistance at Temperature, R_T=12Ω

$\alpha = (R_T-R_0)/(R_0[T-T_0]) = (12-11.95)/(11.95[63-53])$

$\alpha = 4.1667 \times 10\text{-}4\ ^\circ C^{-1}$

3.4 INFERENCE

From this experiment,

the temperature coefficient of Copper wire is α = $2.9288 \times 10^{-3}\ ^{\circ}C^{-1}$
the temperature coefficient of Nichrome wire is α = $4.1667 \times 10^{-4}\ ^{\circ}C^{-1}$

It is observed that the temperature coefficient of copper is significantly higher than that of nichrome. This indicates that the resistance of copper changes more rapidly with temperature compared to nichrome.

The comparatively lower α value of nichrome confirms that alloys exhibit smaller temperature sensitivity than pure metals. This is because impurity scattering in alloys already contributes to resistance at room temperature, thereby reducing the relative effect of temperature-induced lattice vibrations. Both materials show positive temperature coefficients, confirming that their resistance increases with temperature within the experimental range. The results are consistent with the expected behaviour of metallic conductors and alloys.

CHAPTER 4

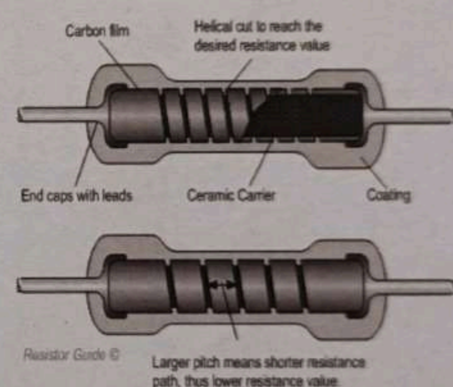
CARBON FILM RESISTORS

4.1 Structure and Internal Mechanism of Carbon Film Resistors

A carbon film resistor is made by depositing a thin carbon layer onto a ceramic substrate under high temperature and vacuum conditions. This process involves thermally decomposing hydrocarbon gas, which forms a uniform carbon film on the surface of a ceramic rod. The resistance value is mainly determined by the thickness of this carbon film, and is further adjusted by cutting a spiral groove into the carbon layer to increase the effective resistive path. The surface is coated with an epoxy resin to protect the resistor from environmental factors and mechanical damage.

The key structural parts of a typical carbon film resistor are:

- Ceramic core: Provides mechanical support and insulation.
- Carbon film layer: Acts as the resistive element.
- Helical groove: Controls effective resistance by increasing the current path length.
- Metal end caps and leads: Allow external electrical connections.
- Protective epoxy coating: Shields the carbon film from moisture and physical impact.



In carbon film resistors, the carbon layer behaves as a semiconducting material. Electrical conduction occurs through charge carriers that flow across carbon grains and grain boundaries. With an increase in temperature, more charge carriers gain thermal energy, which enhances conductivity. As a result, the resistance decreases with increasing temperature, giving carbon film resistors a negative temperature coefficient (NTC) of resistance.

In this experiment Carbon Film resistors of multiple resistance ranges were studied and the temperature coefficient α for each range was obtained.

4.2 OBSERVATIONS

4.2.1 1MΩ Carbon Film Resistor

Temperature (°C)	Resistance (heating) (MΩ)	Resistance (cooling) (MΩ)	Mean Resistance(MΩ)
28	1.193	1.193	1.193
33	1.187	1.19	1.1885
38	1.183	1.186	1.1845
43	1.179	1.181	1.18
48	1.175	1.177	1.176
53	1.171	1.173	1.172
58	1.167	1.169	1.168
63	1.164	1.166	1.164
68	1.16	1.163	1.1615
73	1.157	1.159	1.158
78	1.153	1.156	1.1545
83	1.15	1.152	1.151
88	1.146	1.148	1.147
90	1.145	1.145	1.145

Table 4.2.1(a) Variation of Resistance of 1 MΩ-Carbon film resistor with every 5°C rise in temperature

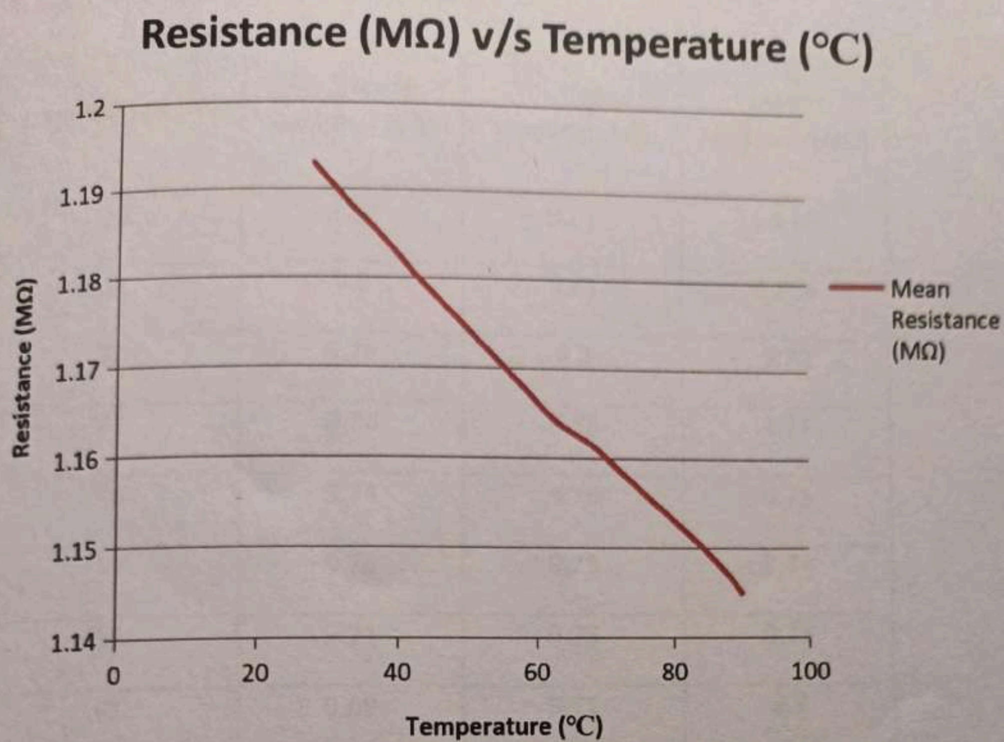


Fig 4.2.1(a) The graph shows a decreasing trend of resistance with increasing temperature for carbon film resistors, indicating negative temperature dependence.

4.2.1 Calculations

From the observation table of 1MΩ Carbon Film Resistor

Reference temperature, T_0=28°C

Resistance at reference temperature, R_0= 1.193MΩ

Temperature, T =38°C

Resistance at Temperature, R_T=1.1845MΩ

$\alpha = (R_T - R_0)/(R_0[T - T_0]) = (1.184-1.193)/(1.193[38-28])$

$\alpha = -7.12\times 10^{-4}\ ^{\circ}C^{-1}$

4.2.2 10kΩ Carbon Film Resistor

Temperature (°C)	Resistance (heating) (kΩ)	Resistance (cooling) (kΩ)	Mean Resistance (kΩ)
26	9.82	9.81	9.815
31	9.8	9.81	9.805
36	9.78	9.8	9.79
41	9.76	9.78	9.77
46	9.74	9.76	9.75
51	9.73	9.75	9.74
56	9.71	9.73	9.72
61	9.69	9.71	9.7
66	9.68	9.7	9.69
71	9.66	9.68	9.67
76	9.65	9.67	9.66
81	9.63	9.65	9.64
86	9.61	9.64	9.625
91	9.6	9.62	9.61
96	9.6	9.61	9.605
98	9.6	9.6	9.6

Table 4.2.2(a) Variation of Resistance of 10 kΩ -Carbon film resistor with every 5°C rise in temperature

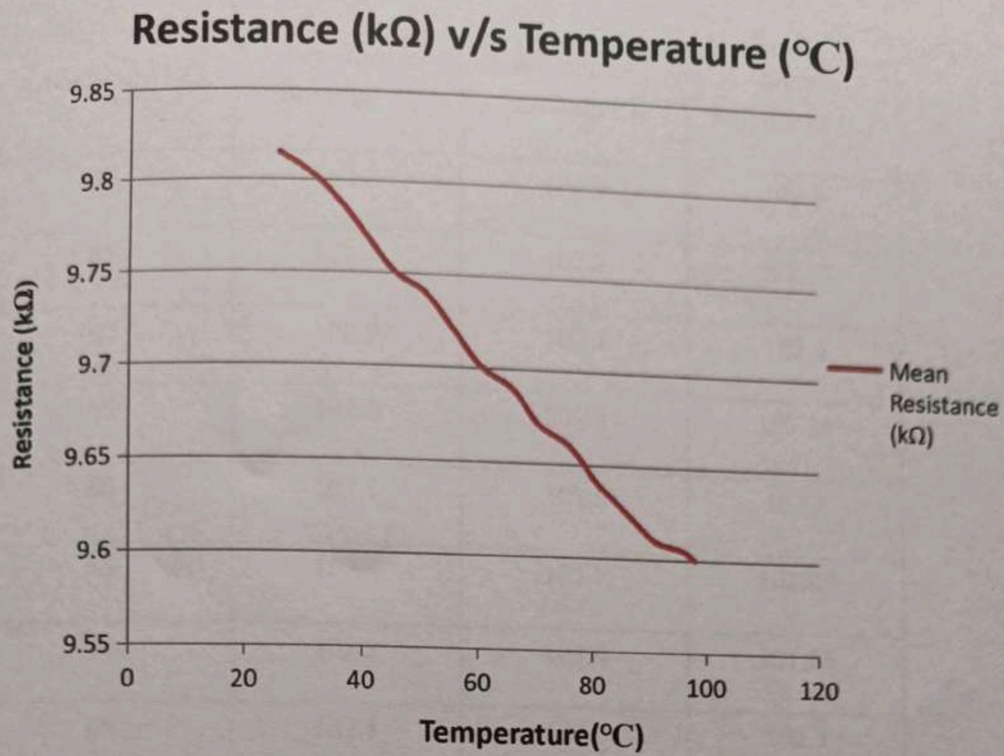


Fig 4.2.2(a) The graph shows a decreasing trend of resistance with increasing temperature for carbon film resistors, indicating negative temperature dependence.

4.2.2 Calculations

From the observation table of 10kΩ Carbon Film Resistor

Reference temperature, T_0=31°C

Resistance at reference temperature, R_0= 9.805kΩ

Temperature, T =41°C

Resistance at Temperature, R_T=9.77kΩ

$\alpha = (R_T-R_0)/(R_0[T-T_0]) = (9.77-9.805)/(9.805[41-31])$

$\alpha = -3.569\times 10^{-4}\ °C^{-1}$

4.2.3 100Ω Carbon Film Resistor

Temperature (°C)	Resistance (heating) (Ω)	Resistance (cooling) (Ω)	Mean Resistance (Ω)
30	103.2	102.6	102.9
35	103.1	102.2	102.65
40	102.9	102.1	102.5
45	102.6	102.1	102.35
50	102.5	101.9	102.2
55	102.4	101.7	102.05
60	102.3	101.4	101.85
65	102.1	100.9	102.1
70	102	100.8	101.4
75	102	100.6	101.3
80	101.9	100.5	101.2
85	101.7	100.4	101.05
90	101.5	100.1	100.8
95	101.4	100.1	100.75

Table 4.2.3(a) Variation of Resistance of 100Ω -Carbon film resistor with every 5°C rise in temperature.

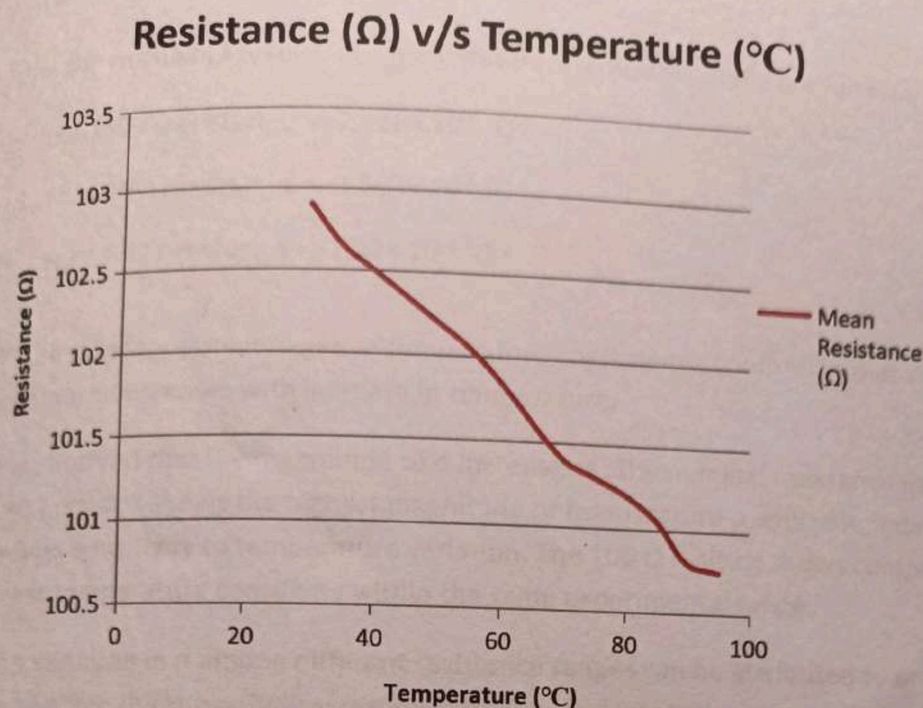


Fig 4.2.2(a) The graph shows a decreasing trend of resistance with increasing temperature for carbon film resistors, indicating negative temperature dependence.

4.2.3 Calculations

From the observation table of 100Ω Carbon Film Resistor

Reference temperature, T_0=40°C

Resistance at reference temperature, R_0= 102.5Ω

Temperature, T =50°C

Resistance at Temperature, R_T=102.2Ω

$\alpha = (R_T-R_0)/(R_0[T-T_0]) = (102.2-102.5)/(102.5[60-50])$

$\underline{\alpha = -2.926\times 10^{-4}\,°C^{-1}}$

4.3 INFERENCE

From the calculated results, the temperature coefficients of the carbon film resistors are:

1. For 100 Ω resistor: $\alpha = -2.926\times 10^{-4}\ ^{\circ}C^{-1}$
2. For 10 kΩ resistor: $\alpha = -3.569\times 10^{-4}\ ^{\circ}C^{-1}$
3. For 1 MΩ resistor: $\alpha = -7.12\times 10^{-4}\ ^{\circ}C^{-1}$

All the resistors exhibit negative temperature coefficients, confirming that their resistance decreases with increase in temperature.

It is observed that the magnitude of α increases as the nominal resistance increases. The 1 MΩ resistor shows the highest magnitude of temperature coefficient, indicating greater sensitivity to temperature variation. The 100 Ω resistor shows comparatively lower temperature sensitivity within the same experimental range.

This variation in α among different resistance ranges can be attributed to differences in carbon film thickness, helical trimming length, and internal micro-structure, which influence how temperature affects carrier transport in the resistive layer.

CHAPTER 5

THERMISTORS (NTC AND PTC)

5.1 THERMISTORS

A thermistor is a temperature-sensitive resistor whose resistance changes significantly with temperature. Unlike ordinary resistors, thermistors exhibit a strong and non-linear temperature dependence. The term "thermistor" is derived from the combination of the words thermal and resistor.

Thermistors are generally made from semiconducting ceramic materials formed by sintering metal oxides such as manganese, nickel, cobalt, or barium compounds. Due to their semiconducting nature, their resistance varies more sharply with temperature compared to metallic conductors.

5.1.1 TYPES OF THERMISTORS

Thermistors are broadly classified into two types based on their temperature behaviour:

1. Negative Temperature Coefficient (NTC) Thermistors

An NTC thermistor is one in which resistance decreases with increase in temperature. In NTC materials, conduction is governed by thermally activated charge carriers. At lower temperatures, only a limited number of carriers are available for conduction. As temperature increases, more charge carriers gain sufficient thermal energy to move into conduction states. This leads to a rapid increase in conductivity and hence a decrease in resistance. Thus, NTC thermistors exhibit strong non-linear and negative temperature dependence.

2. Positive Temperature Coefficient (PTC) Thermistors

A PTC thermistor is one in which resistance increases with increase in temperature. PTC thermistors are commonly made from doped ceramic materials such as Barium Titanate. At lower temperatures, they behave like semiconductors with moderate conductivity. However, near a specific temperature known as the Curie temperature, a structural phase transition occurs in the material.This phase transition increases the potential barrier at grain boundaries, restricting charge carrier movement. As a result, resistance increases sharply within a narrow temperature range.

Unlike NTC thermistors, the resistance change in PTC devices is often abrupt rather than gradual. The temperature dependence is highly non-linear.

Thus, while NTC behaviour is dominated by carrier concentration increase, PTC behaviour is influenced by structural changes within the material.

5.1.2 APPLICATIONS

Due to their high sensitivity to temperature, thermistors are widely used in practical applications such as:

- Temperature sensing and measurement
- Digital thermometers
- Temperature compensation circuits
- Inrush current limiting (NTC type)
- Overcurrent protection devices (PTC type)
- Battery pack temperature monitoring

Compared to metallic resistance temperature detectors (RTDs), thermistors provide higher sensitivity but operate over a more limited temperature range.

5.2 OBSERVATIONS

5.2.1 NTC Thermistor

Temperature (°C)	Resistance (heating) (kΩ)	Resistance (cooling) (kΩ)	Mean Resistance (kΩ)
27	55.3	55.3	55.3
32	34.8	46.5	40.65
37	29.7	37.4	33.55
42	25	32.1	28.55
47	22.2	26.7	24.45
52	17.62	20.8	19.21
57	14.82	17.67	16.245
62	12.93	14.65	12.93
67	11.09	13.29	12.19
72	9.56	10.91	10.235
77	7.79	7.57	7.68
82	7.52	7.28	7.4
87	6.55	6.69	6.62
92	4.9	4.93	4.915
93	4.77	4.72	4.745

Table 5.2.1(a) Variation of Resistance of NTC Thermistor with every 5°C rise in temperature.

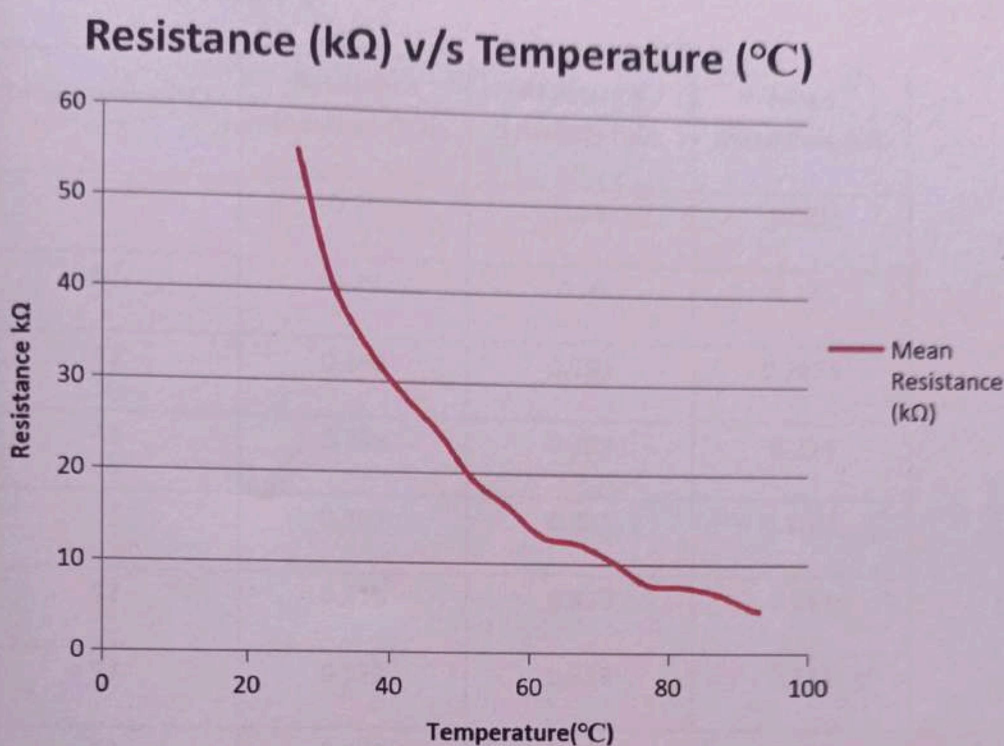


Fig 5.2.1(a) The graph shows a decreasing trend of resistance with increasing temperature for NTC Thermistor, indicating negative temperature dependence.

5.2.1 Calculations

Determination of β temperature coefficient of resistance of NTC thermistor

Reference Temperature T0=32°C=305K

Resistance at Reference Temperature R0=40.65k Ω

Temperature, T = 42°C=315K

Resistance at temperature R=28.55k Ω

$\beta = \ln(\frac{R_0}{R})/(\frac{1}{T} - \frac{1}{T_0})$=ln(28.55/40.65)/(1/315-1/301)

$\underline{\beta = 3.40\times 10^{3}\ K^{-1}}$

5.2.2 PTC Thermistor

Temperature (°C)	Resistance (heating) (kΩ)	Resistance (cooling) (kΩ)	Mean Resistance (kΩ)
27	0.29	0.28	0.285
32	0.29	0.28	0.285
37	0.294	0.281	0.2875
42	0.299	0.289	0.294
47	0.307	0.298	0.3025
52	0.319	0.315	0.317
57	0.323	0.339	0.331
62	0.339	0.367	0.339
67	0.368	0.44	0.404
72	0.418	0.449	0.4335
77	0.491	0.51	0.5005
82	0.607	0.619	0.613
87	0.844	0.844	0.844

Table 5.2.2(a) Variation of Resistance of PTC Thermistor with every 5°C rise in temperature.

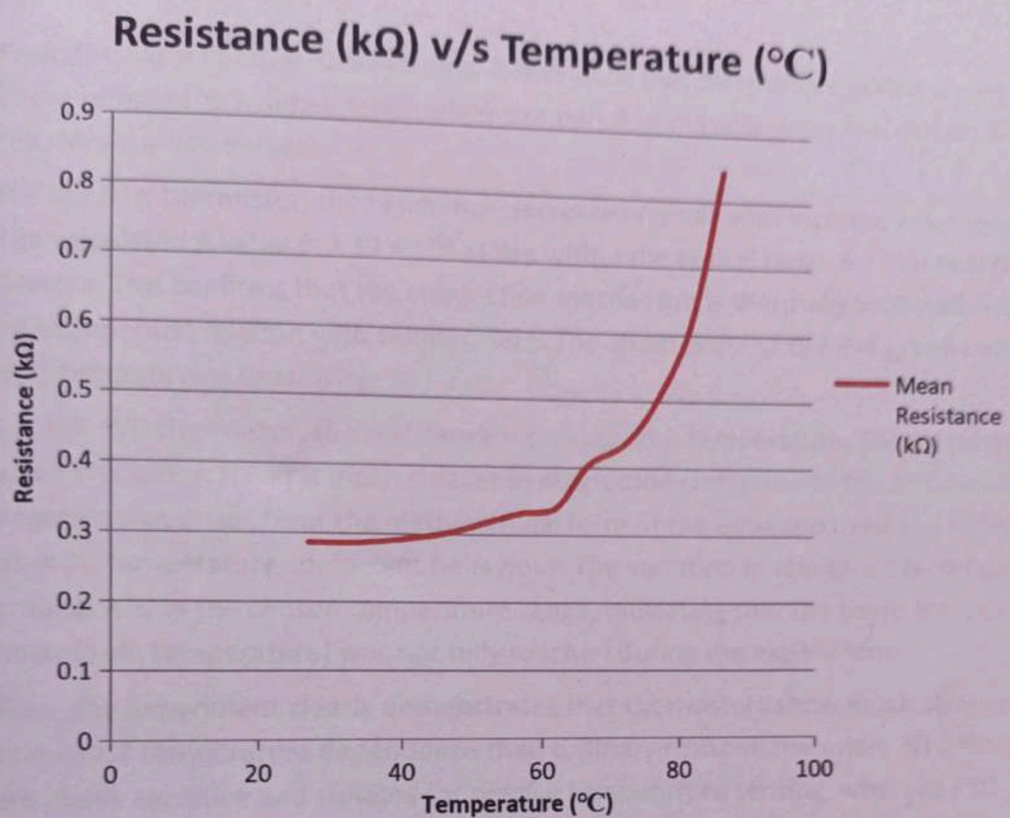


Fig 5.2.2(a) The graph shows an increasing trend of resistance with increasing temperature for carbon film resistors, indicating positive temperature dependence.

5.2.2 Calculations

Determination of β temperature coefficient of resistance of PTC Thermistor

Reference Temperature T0=32°C=305K

Resistance at Reference Temperature R0=0.285k Ω

Temperature, T = 42°C=315K

Resistance at temperature R=0.294k Ω

$\beta = \ln(\frac{R_0}{R})/(\frac{1}{T} - \frac{1}{T_0}) = \ln(0.294/0.285)/(1/315-1/305)$

<u>$\beta = -0.298\times10^3\ K^{-1}$</u>

5.3 INFERENCE

From the experimental observations, it is evident that thermistors exhibit strong non-linear temperature dependence when compared to metallic wires and carbon film resistors studied earlier.

For the NTC thermistor, the resistance decreases rapidly with increase in temperature. The calculated β value (~3.39×10^3 K) lies within the typical range for practical NTC devices. This confirms that the conduction mechanism is thermally activated and follows an exponential relation with temperature. The steep slope of the R–T graph indicates high temperature sensitivity.

For the PTC thermistor, the resistance increases with temperature. The calculated β value (~0.2.99 × 10^3 K) is much smaller in magnitude compared to the NTC value. The negative sign arises from the mathematical form of the equation used and reflects the positive temperature coefficient behaviour. The variation in resistance is comparatively gradual within the chosen temperature range, indicating that the sharp transition region (near Curie temperature) was not fully reached during the experiment.

Thus, the experiment clearly demonstrates that thermistors show much stronger and non-linear temperature dependence than ordinary resistive materials. NTC thermistors are highly sensitive and suitable for precise temperature sensing, whereas PTC thermistors are more suitable for protection and control applications due to their resistance-increasing behaviour.

Overall, the experiment verifies the theoretical understanding of thermistor behaviour and highlights the practical significance of β as a parameter representing temperature sensitivity.

CONCLUSION

The present study was carried out to analyse the variation of electrical resistance with temperature for different types of resistive materials, namely metallic wires (copper), alloy (nichrome), carbon film resistors of different ranges, and thermistors (NTC and PTC). Through systematic heating and cooling observations, the temperature coefficient parameters were determined and compared.

From the study of copper wire, it was observed that resistance increases almost linearly with temperature, and the calculated positive temperature coefficient confirmed the expected metallic behaviour. In the case of nichrome, the variation in resistance was comparatively smaller, indicating lower temperature sensitivity. This helped in understanding why alloys are preferred in applications requiring thermal stability.

The investigation of carbon film resistors showed negative temperature coefficients, with the magnitude varying depending on resistance range. This highlighted how material composition and internal structure influence thermal behaviour even in fixed resistors.

The study of thermistors provided deeper insight into non-linear temperature dependence. The NTC thermistor exhibited a strong exponential decrease in resistance with temperature, and the calculated β value confirmed high thermal sensitivity. The PTC thermistor showed increasing resistance with temperature, demonstrating a fundamentally different internal mechanism associated with material structure.

Overall, this experiment strengthened our understanding of how microscopic material properties influence macroscopic electrical characteristics. It also emphasized that the temperature coefficient is not merely a numerical parameter, but a physical indicator of the underlying conduction mechanism. The comparative approach adopted in this work helped in clearly distinguishing linear metallic behaviour from non-linear semiconductor behaviour.

REFERENCE

Books

1. D. P. Kothari and I. J. Nagrath, Basic Electrical Engineering, Tata McGraw-Hill Education

2. V. K. Mehta and Rohit Mehta, Principles of Electronics, S. Chand Publishing

3. B. L. Theraja and A. K. Theraja, A Textbook of Electrical Technology – Volume I, S. Chand Publishing

4. S. O. Kasap, Principles of Electronic Materials and Devices, McGraw-Hill Education.

Websites

5. "Understanding Carbon Film Resistors." UTMEL Blog. https://www.utmel.com/blog/categories/resistor/understanding-of-carbon-film-resistors

6. "Thermistor." Wikipedia. https://en.wikipedia.org/wiki/Thermistor