Thermistors in Series

Will thermistors in series follow the same trends as normal resistors in series at varying temperature conditions?

Overview

While studying the factors affecting the resistance in a resistor, I came across some interesting circuit elements known as thermistors. Thermistors are more dependent on temperature for the change in their resistance than normal resistors. Where a normal resistor would simply increase its resistance at a slow rate with increase in temperature, thermistors have two categories, NTC (Negative Temperature Coefficient) and PTC (Positive Temperature Coefficient) which increase their resistance with decrease in temperature and increase in resistance with increase in temperature respectively.

After further research on the topic, I found that NTC Thermistors are normally connected in parallel when utilised in circuits, and this led me to think about how they would function if arranged in a series, and what effect temperature would have on these resistors being arranged as such, along with their combined resistance.

Hypothesis

The NTC thermistors used in the circuit, when connected in series, conform to the equation $R_{Total} = R_1+R_2+R_3+...+R_n$, and the change in the resistance of the thermistors against temperature can be represented by graphing an exponential equation.

Designing the Experiment

I started with a circuit arrangement with an LED bulb connected in a closed circuit to ensure that the flow of current was taking place, once that was affirmed, the Thermistor was added in the circuit and the bulb was removed so as to avoid irregularities in the values obtained. The Voltage Sensor was connected in parallel to the thermistors in series, and a current sensor was added in series after the thermistors and the circuit was completed once more. The current sensor proved to be faulty, and to replace this, I added a Multimeter.

I faced a problem while trying to control the temperature of the thermistor. Initially I decided to use a Heating Mantle to heat the thermistors above room temperature. Unfortunately, the room temperature I was starting at was already nearing 30 °C, and to obtain comprehensive results, it would need to be heated much further than that, risking damaging the thermistors. Additionally, should the placement come loose and should the thermistor fall into the mantle, I would risk damaging the thermistor again. For this reason, I decided to use ice to cool the thermistors rather than heat them, and I placed the ice in a Petri dish so as to avoid spilling. The thermistors were placed on the ice and the Temperature Probe was touching the side of the Thermistor not touching the ice.

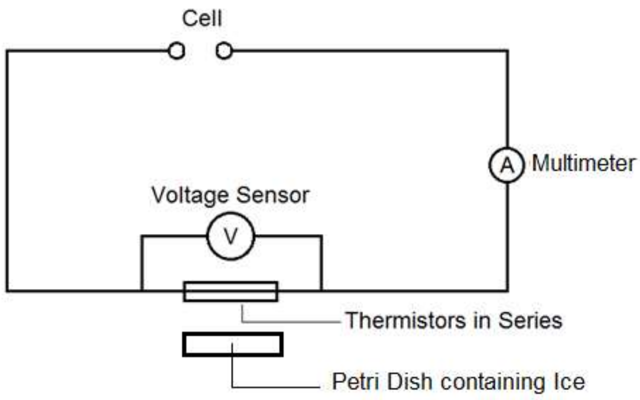
The 4 values for the thermistors were taken as 4 kΩ, 10 kΩ and 22 kΩ to obtain a wide range of values for this experiment.

Experiment:

Aim
To verify the functioning of resistance of thermistors conforming to the formula $R_S = R_1+R_2+R_3...+R_n$ at different temperatures

Materials Required

1. Cell 5V DC
2. NTC Thermistors (5 each) of
    a. 4 kΩ
    b. 10 kΩ
    c. 22 kΩ
3. Ice (To cool thermistors)
4. Temperature probe
5. Voltage probe
6. Multimeter
7. Vernier's LabQuest
8. Connecting Wires



Procedure

1. Set up the circuit as shown below:

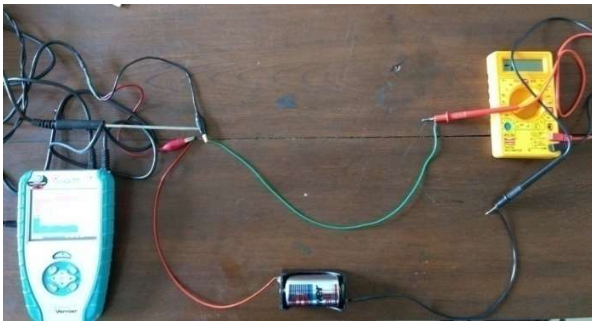


Image 2

2. Place the end of the thermistors on an ice block but make sure that the wires and remaining portion of the thermistors do not touch the ice block so that the only path for the current is through the thermistor.
3. The samples were taken for 1 to 5 thermistors in series at 3 temperatures in order to obtain the values for the resistance of the thermistors in combination.
4. Readings obtained at 25.6 °C for a single 4 kΩ thermistor are found below:

Images 3 & 4 (4 kΩ at 25.6 °C)

Calculations

The readings obtained from the sensors and the Multimeter are the current and the voltage, and using the formula R=V/I, we can find the Resistance of the Thermistors.

Example (4 kΩ at 25.6 °C):
R = 1.51×106/340
R = 4441 Ω

Uncertainty Calculations:

Apparatus or Value	Uncertainty
Voltage Sensor (Voltage)	±0.0005 V
Multimeter (Current)	±0.0000005 A
Temperature Probe (Temperature)	±0.05 °C

Table 1

Therefore Uncertainty = [(0.0005/Voltage)+(0.0000005/Current)]×Resistance
Example (4 kΩ at 25.6 °C): ΔR = [(0.0005/1.51)+(0.0000005/(340×10^{-6}))]×4441
ΔR = 8.001412154
ΔR = ±8 Ω

Readings

Readings for thermistors of 4 KΩ:

No. of Thermistors in Series	Temp. (°C)	Current (μA) [I]	Voltage (V) [V]	Resistance (Ω) [R=(V×10^6)/I]	Uncertainty (Ω)
1	29.7	422	1.52	3602	±5
2	29.7	214	1.52	7103	±19
3	29.7	145	1.52	10483	±40

4	29.7	105	1.52	14476	±74
5	29.7	86	1.52	17674	±109
1	25.6	340	1.51	4441	±8
2	25.6	171	1.51	8830	±29
3	25.6	112	1.51	13482	±65
4	25.6	85	1.51	17764	±110
5	25.6	69	1.51	21884	±166
1	22.7	212	1.51	7123	±19
2	22.7	107	1.51	14112	±71
3	22.7	72	1.51	20972	±153
4	22.7	53	1.51	28491	±278
5	22.7	43	1.51	35116	±420

Table 2

Readings for thermistors of 10 KΩ:

No. of Thermistors in Series	**Temp.** (°C)	**Current (μA) [I]**	**Voltage (V) [V]**	**Resistance (Ω) [R=(V×10^6)/I]**	**Uncertainty (Ω)**
1	28.1	185	1.51	8162	±25
2	28.1	93	1.51	16237	±93
3	28.1	61	1.51	24754	±211
4	28.1	45	1.51	33556	±384
5	28.1	36	1.51	41944	±596
1	25.1	153	1.51	9869	±36
2	25.1	77	1.51	19610	±134
3	25.1	52	1.51	29038	±289
4	25.1	38	1.51	39737	±536
5	25.1	31	1.51	48710	±802
1	20.5	57	1.51	26491	±241
2	20.5	29	1.51	52069	±915
3	20.5	19	1.51	79474	±2118
4	20.5	15	1.51	100667	±3389
5	20.5	12	1.51	125833	±5285

Table 3

Readings for thermistors of 22 KΩ:

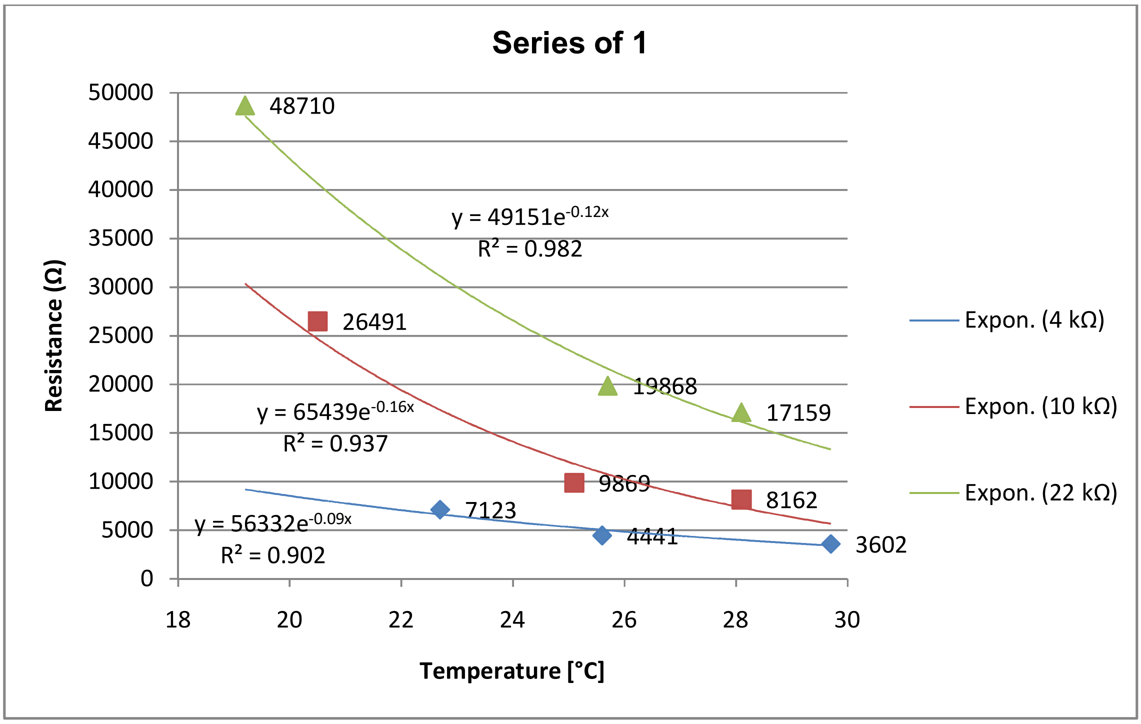
No. of Thermistors in Series	**Temp.** (°C)	**Current (μA) [I]**	**Voltage (V) [V]**	**Resistance (Ω) [R=(V×10^6)/I]**	**Uncertainty (Ω)**
1	28.1	88	1.51	17159	±103

2	28.1	47	1.51	32128	±352
3	28.1	30	1.51	50333	±856
4	28.1	22	1.51	68636	±1583
5	28.1	17	1.51	88824	±2642
1	25.7	76	1.51	19868	±137
2	25.7	37	1.51	40811	±565
3	25.7	25	1.51	60400	±1228
4	25.7	19	1.51	79474	±2118
5	25.7	15	1.51	100667	±3389
1	19.2	31	1.51	48710	±802
2	19.2	14	1.51	107857	±3888
3	19.2	11	1.51	137273	±6285
4	19.2	7	1.51	215714	±15480
5	19.2	6	1.51	251667	±21056

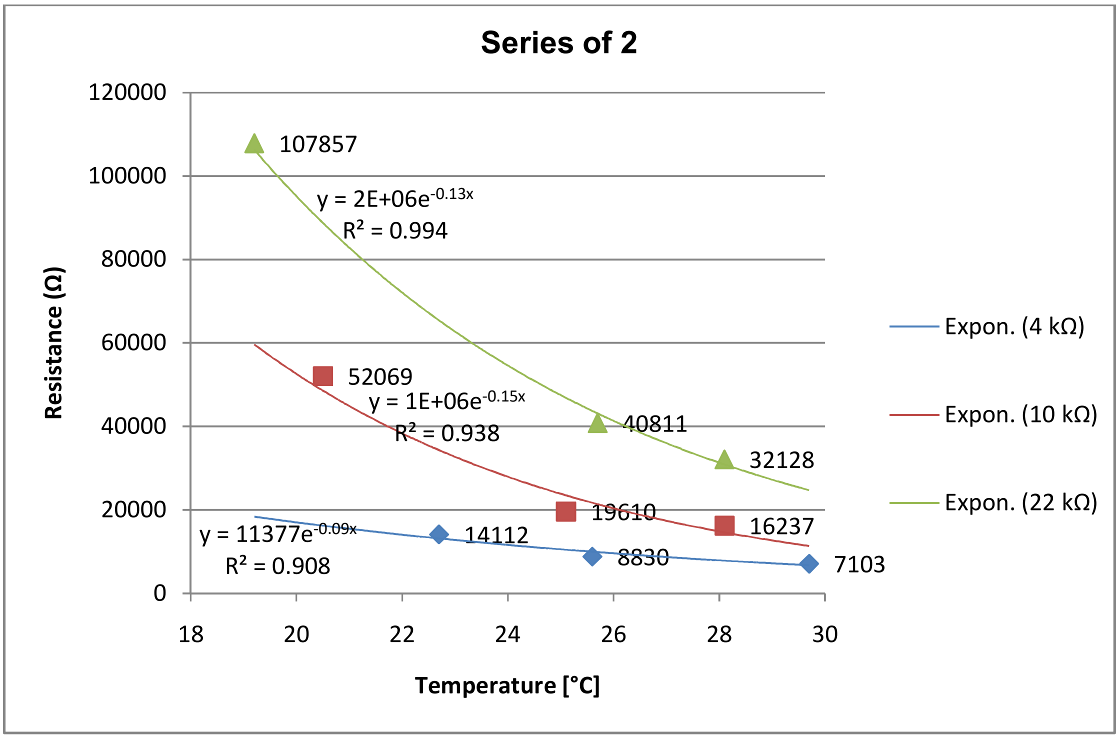
Table 4

Analysis

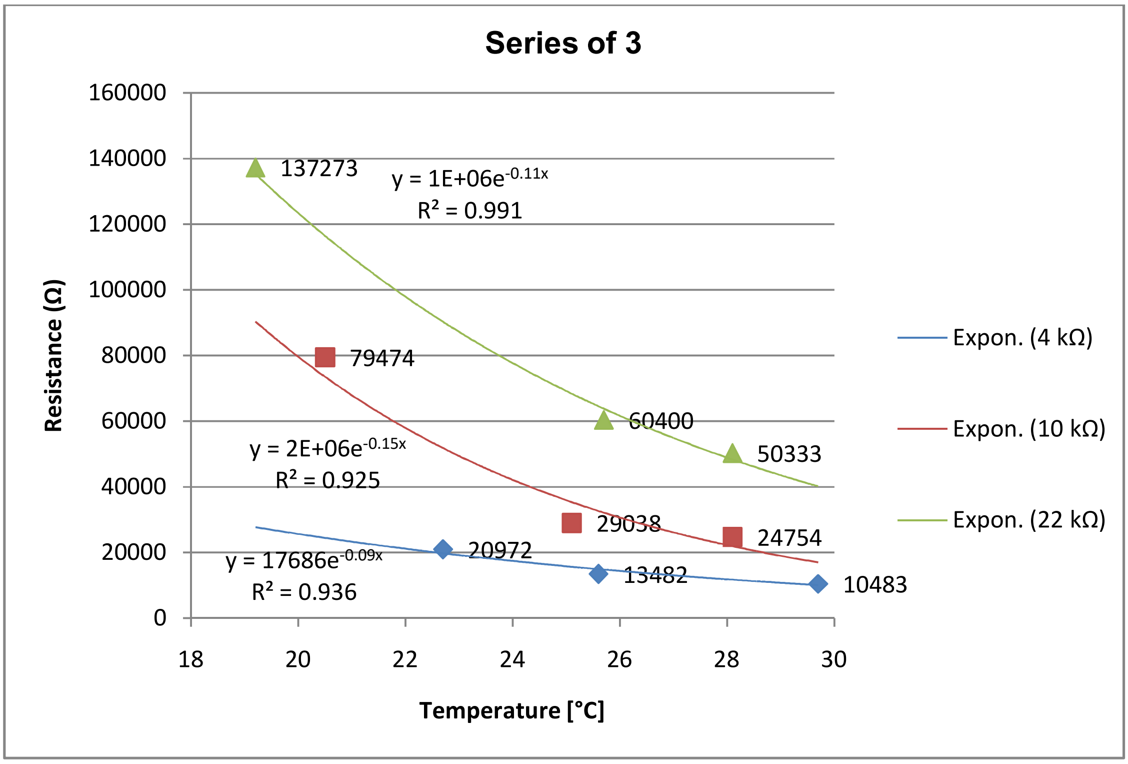
Graphs of Resistance vs Temperature for each Thermistor and Series



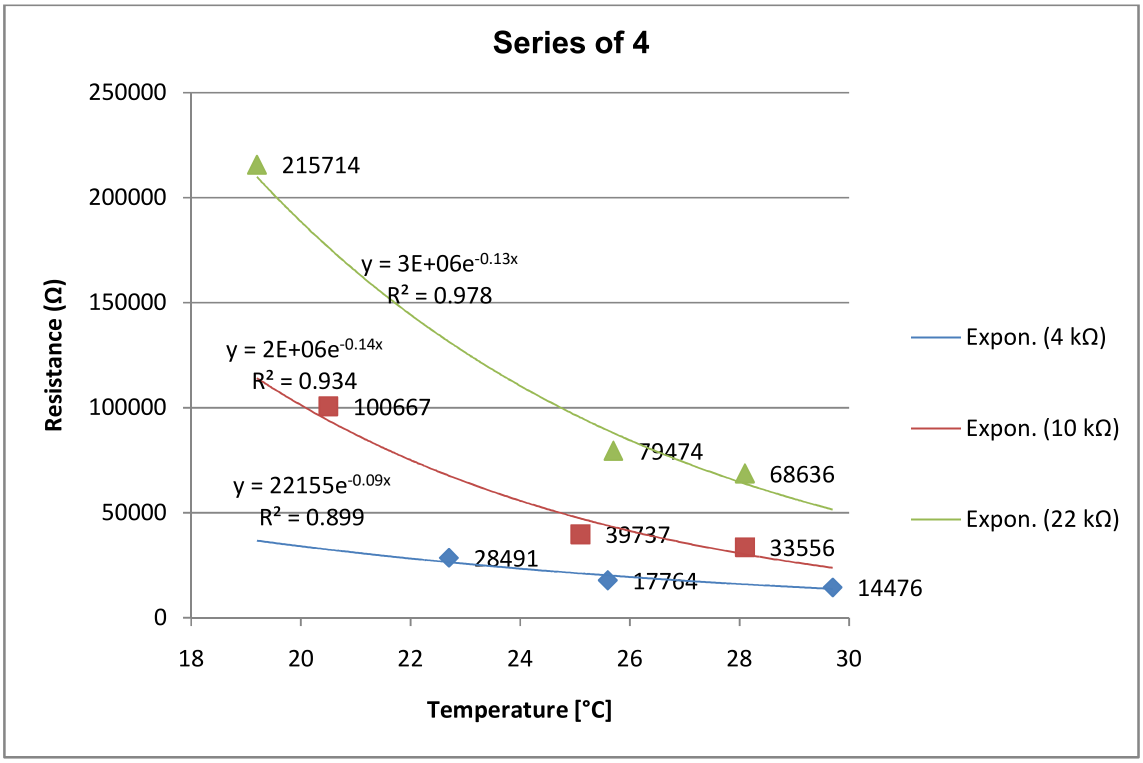
Graph 1



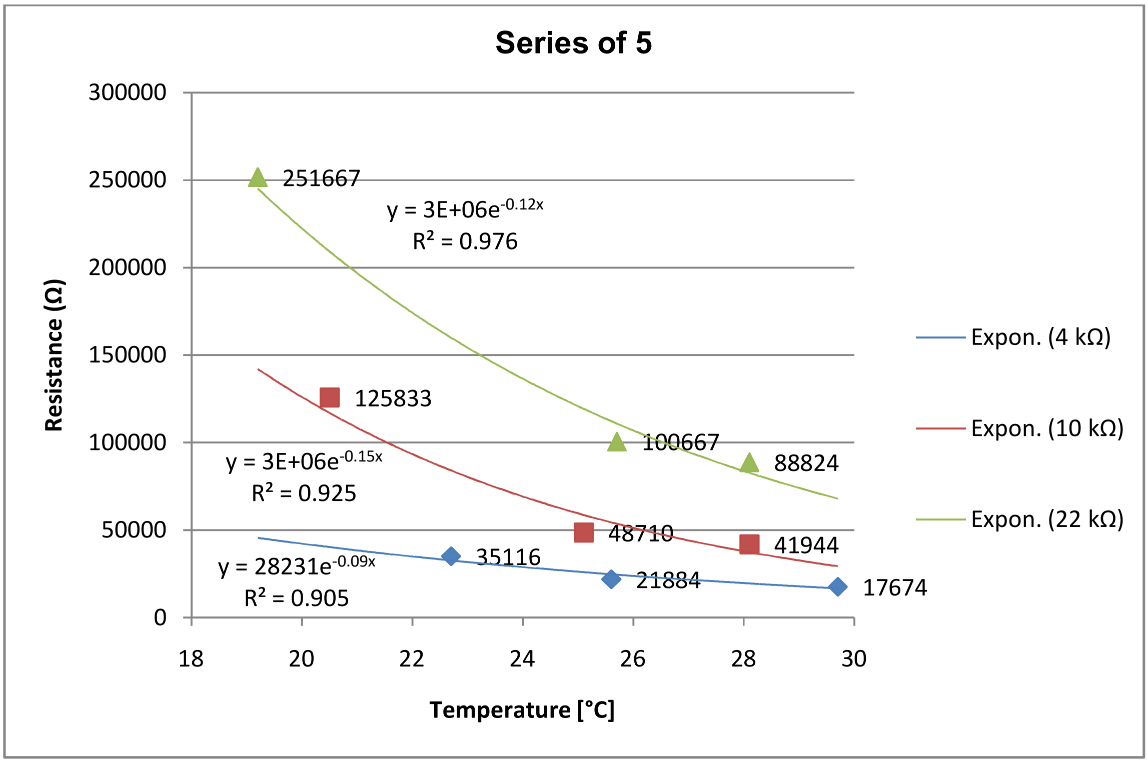
Graph 2



Graph 3



Graph 4



Graph 5

From the readings, we can see that with each thermistor added in the series, the resistance grows linearly such that the resistance is 1×R in a series of 1, 2×R in a series of 2, and thus we can assume a equation of n×R, when the thermistors are of the same value, and 'n' is the number of thermistors connected in series, with accommodation being made for the uncertainty

In the graphs we can analyse the change of the resistance of the thermistors with temperature and we can see that they all follow an exponential trendline and maintain the linear equation of n×R at each temperature reading, with the uncertainties being considered.

Series	**R^2 of 22 kΩ Trendline**	**R^2 of 10 kΩ Trendline**	**R^2 of 4 kΩ Trendline**
1	0.982	0.937	0.902
2	0.994	0.938	0.908
3	0.992	0.925	0.932
4	0.978	0.934	0.899
5	0.976	0.925	0.905
Average	0.984	0.932	0.909

Table 5

Additionally by analysing the R^2 values obtained in the graphs, we can see that the 22 kΩ thermistor trendlines have an approximate accuracy of 98.4%, the 10 kΩ thermistor trendlines have an approximate accuracy of 93.2%, and the 4 kΩ thermistor trendlines have an approximate accuracy of 90.9%. Thus we can assume the model functions obtained for the trendlines to be extremely accurate.

Observation

As is observed from the graphs and the readings obtained, a general repetitive trend is followed by the thermistors with a decrease in temperature and when they are arranged in series. While the thermistors are in series, they do appear to conform to the equation R_{Total} = n×R, where n is the number of thermistors in series, provided all the thermistors are of the same value. The small irregularities in their values can be attributed to the uncertainty and to the small fluctuations in current.

Evaluation and Improvement

The sensors and apparatus used in this experiment were extremely accurate, and very little scope for improvement is there in regards to this experiment. However a more accurate method of changing the temperature rather than cooling it with ice or using a heating mantle would improve the experiment so as to obtain values for different thermistors at the same constant temperature so as to obtain a more uniform comparison and analysis of the experiment.

Additionally since we have tested for only a series of 5, we know that thermistors will function accordingly for a series of 5 and we draw our conclusion and prediction of future trends from this. However if there are any irregularities in series of greater numbers, this experiment will not be able to find it unless greater number of thermistors are connected in series and the values obtained for those.

Safety Measures & Precautions

1. Keep ambient temperature constant or steady, in order to avoid damaging the thermistors.
2. Thermistor temperature may fluctuate due to the heating effect of current being passed through it. This temperature change should be kept in mind while recording values.
3. Do not let the metal portions of the thermistors that are connected to the circuit touch the ice. Additionally make sure that they are not stored in a humid or dusty location, or in the presence of deoxidizing and/or corrosive gases to avoid damaging the thermistors.
4. Allow around 7-8 seconds to pass before taking measurements to ensure accuracy of results and/or stability of the circuit

Conclusion

Obtaining the values of resistance of the thermistors for different temperatures allows me to have an equation that can predict the trend of the relation of Resistance against Temperature. Additionally by taking values for thermistors in series, we prove the hypothesis that thermistors do indeed follow the formula of $R_S = R_1+R_2+R_3...+R_n$, and behave similarly to normal resistors, with the obvious difference of exponential changes in the resistance of the thermistor with change in temperature, and increasing in resistance with a decrease in temperature in thermistors as opposed to a decrease in resistance with a decrease in temperature in normal resistors.

Scope:

Using the results and verifications obtained in this experiment, one can plan out which thermistors to use and in what combinations, at various temperatures so as to obtain the desired resistance they need in a circuit. It also provides equations for the change in resistance of a thermistor with temperature and this can be used to predict trends in NTC thermistors.

The conclusions from this experiment can also be utilized in connecting thermistors in series in circuits when operating at high temperatures in order to obtain low enough resistance but still limit the flow of current to an extent by connecting the thermistors in series.

Bibliography

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Appendix

I [μA]	I [A]	V [V]	ΔI [A]	ΔV [V]	R=V/I [Ω]	ΔR=(ΔV/V+ΔI/I)×R [Ω]
422	0.000422	1.52	±0.0000005	±0.0005	3602	±5.452640933
214	0.000214	1.52	±0.0000005	±0.0005	7103	±18.93230755
145	0.000145	1.52	±0.0000005	±0.0005	10483	±39.59663113
105	0.000105	1.52	±0.0000005	±0.0005	14476	±73.69517544
86	0.000086	1.52	±0.0000005	±0.0005	17674	±108.5696297
340	0.00034	1.51	±0.0000005	±0.0005	4441	±8.001412154
171	0.000171	1.51	±0.0000005	±0.0005	8830	±28.74255451
112	0.000112	1.51	±0.0000005	±0.0005	13482	±64.65173841
85	0.000085	1.51	±0.0000005	±0.0005	17764	±110.3762369
69	0.000069	1.51	±0.0000005	±0.0005	21884	±165.8260678
212	0.000212	1.51	±0.0000005	±0.0005	7123	±19.15813757
107	0.000107	1.51	±0.0000005	±0.0005	14112	±70.61677292
72	0.000072	1.51	±0.0000005	±0.0005	20972	±152.5832597
53	0.000053	1.51	±0.0000005	±0.0005	28491	±278.2171248
43	0.000043	1.51	±0.0000005	±0.0005	35116	±419.953396
185	0.000185	1.51	±0.0000005	±0.0005	8162	±24.76210847
93	0.000093	1.51	±0.0000005	±0.0005	16237	±92.67218899
61	0.000061	1.51	±0.0000005	±0.0005	24754	±211.0983281
45	0.000045	1.51	±0.0000005	±0.0005	33556	±383.9557027
36	0.000036	1.51	±0.0000005	±0.0005	41944	±596.4442973
153	0.000153	1.51	±0.0000005	±0.0005	9869	±35.51951478
77	0.000077	1.51	±0.0000005	±0.0005	19610	±133.8310398

52	0.000052	1.51	±0.0000005	±0.0005	29038	±288.8267702
38	0.000038	1.51	±0.0000005	±0.0005	39737	±536.0132102
31	0.000031	1.51	±0.0000005	±0.0005	48710	±801.7743004
57	0.000057	1.51	±0.0000005	±0.0005	26491	±241.1490473
29	0.000029	1.51	±0.0000005	±0.0005	52069	±914.98277
19	0.000019	1.51	±0.0000005	±0.0005	79474	±2117.736947
15	0.000015	1.51	±0.0000005	±0.0005	100667	±3388.90011
12	0.000012	1.51	±0.0000005	±0.0005	125833	±5284.708223
88	0.000088	1.51	±0.0000005	±0.0005	17159	±103.1761063
47	0.000047	1.51	±0.0000005	±0.0005	32128	±352.4256446
30	0.00003	1.51	±0.0000005	±0.0005	50333	±855.5498896
22	0.000022	1.51	±0.0000005	±0.0005	68636	±1582.636243
17	0.000017	1.51	±0.0000005	±0.0005	88824	±2641.882509
76	0.000076	1.51	±0.0000005	±0.0005	19868	±137.2893343
37	0.000037	1.51	±0.0000005	±0.0005	40811	±565.0135762
25	0.000025	1.51	±0.0000005	±0.0005	60400	±1228
19	0.000019	1.51	±0.0000005	±0.0005	79474	±2117.736947
15	0.000015	1.51	±0.0000005	±0.0005	100667	±3388.90011
31	0.000031	1.51	±0.0000005	±0.0005	48710	±801.7743004
14	0.000014	1.51	±0.0000005	±0.0005	107857	±3887.749953
11	0.000011	1.51	±0.0000005	±0.0005	137273	±6285.136454
7	0.000007	1.51	±0.0000005	±0.0005	215714	±15479.57133
6	0.000006	1.51	±0.0000005	±0.0005	251667	±21055.58344

Table 6