STUDY THE RESISTANCE VERSUS TEMPERATURE CURVE OF THE GIVEN THERMISTOR MATERIAL. ALSO DESIGN AND STUDY ITS USE AS A SENSOR.

APPARATUS REQUIRED:

1. Thermistor
2. Water Bath
3. Thermometer
4. Burner
5. Resistance Measuring Device (PO Box, Multimeter etc.)

THEORY

A thermistor is a semiconductor device made from oxides of metals like manganese, nickel, cobalt, or iron. The term "thermistor" comes from "thermal resistor." Its resistance changes significantly with temperature, depending on its composition. Thermistors can have either a positive temperature coefficient (PTC) or a negative temperature coefficient (NTC). NTC thermistors, made from iron, nickel, and cobalt oxides, decrease in resistance as temperature rises. PTC thermistors, based on barium titanate, increase their resistance dramatically with slight temperature changes. These are commonly used in temperature-controlled switches.

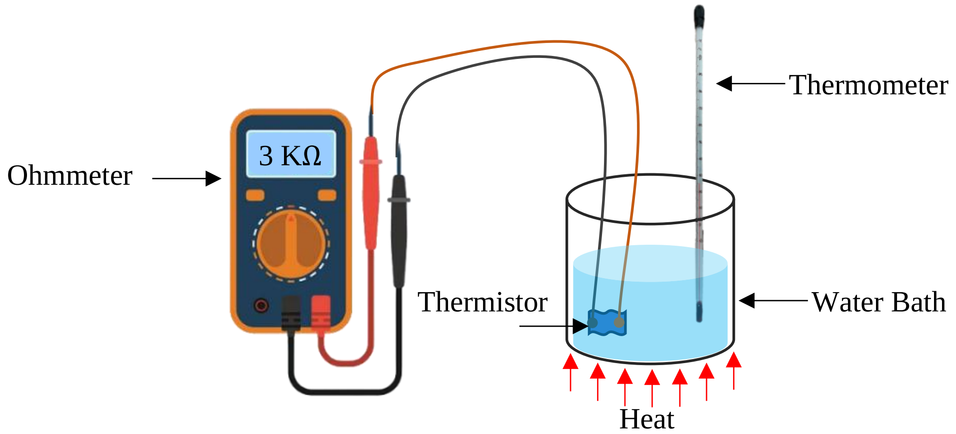

Figure 1: Experimental setup for measurement of temperature and resistance.

A semiconductor material is characterized by the property that its conductivity increases sharply with rise in temperature. This is because the number of charge carrier is increased in an exponential manner as characterized by the factor $\exp\{-E_g/kT\}$. The resistance (R) of semiconductor material is given by

$$\frac{1}{R} = \left(\frac{1}{R_0}\right) e^{-\frac{E_g}{kT}} \tag{1}$$

Here R_0 is the resistance at highest temperature. Taking log both sides we get,

$$\ln\left(\frac{1}{R}\right) = \ln\left(\frac{1}{R_0}\right) - \frac{E_g}{kT} \tag{2}$$

The slope of the plot between $\ln\left(\frac{1}{R}\right)$ and $\left(\frac{1}{T}\right)$ is $-\left(\frac{E_g}{k}\right)$. Thus, band gap of the given semiconductor material can be calculated if we linearly fit our observations, according to equation (2). The value of resistance is measured using multimeter. And the temperature is measured with the help of thermometer. The slope of straight line gives the band gap E_g of given semiconductor material.

OBSERVATION

Least count of ohmmeter = 0.01 KΩ

The temperature difference is 2 degrees centigrade.

Table 1: Increasing and decreasing temperature and respective resistance.

SN	Increasing Temperature (℃)	Resistance for Increasing Temp. (KΩ)	Decreasing Temperature (℃)	Resistance for Decreasing Temp. (KΩ)
1.	30	8.22	86	1.01
2.	32	7.64	84	1.02
3.	34	7.21	82	1.08
4.	36	6.89	80	1.2
5.	38	6.7	78	1.3
6.	40	6.2	76	1.45
7.	42	5.83	74	1.72
8.	44	5.21	72	1.83
9.	46	4.6	70	2.05
10.	48	4.1	68	2.17
11.	50	4	66	2.25
12.	52	3.9	64	2.4
13.	54	3.5	62	2.52
14.	56	3.1	60	2.72
15.	58	2.87	58	2.9
16.	60	2.41	56	3.08
17.	62	2.27	54	3.29
18.	64	1.96	52	3.52
19.	66	1.8	50	3.79
20.	68	1.7	48	4.02
21.	70	1.3	46	4.34
22.	72	1.23	44	4.69
23.	74	1.19	42	5.06
24.	76	1.14	40	5.48
25.	78	1.07	38	5.93
26.	80	1.04	36	6.44
27.	82	1.01	34	7.01
28.	84	1.01	32	7.74
29.	86	1.01	30	8.22

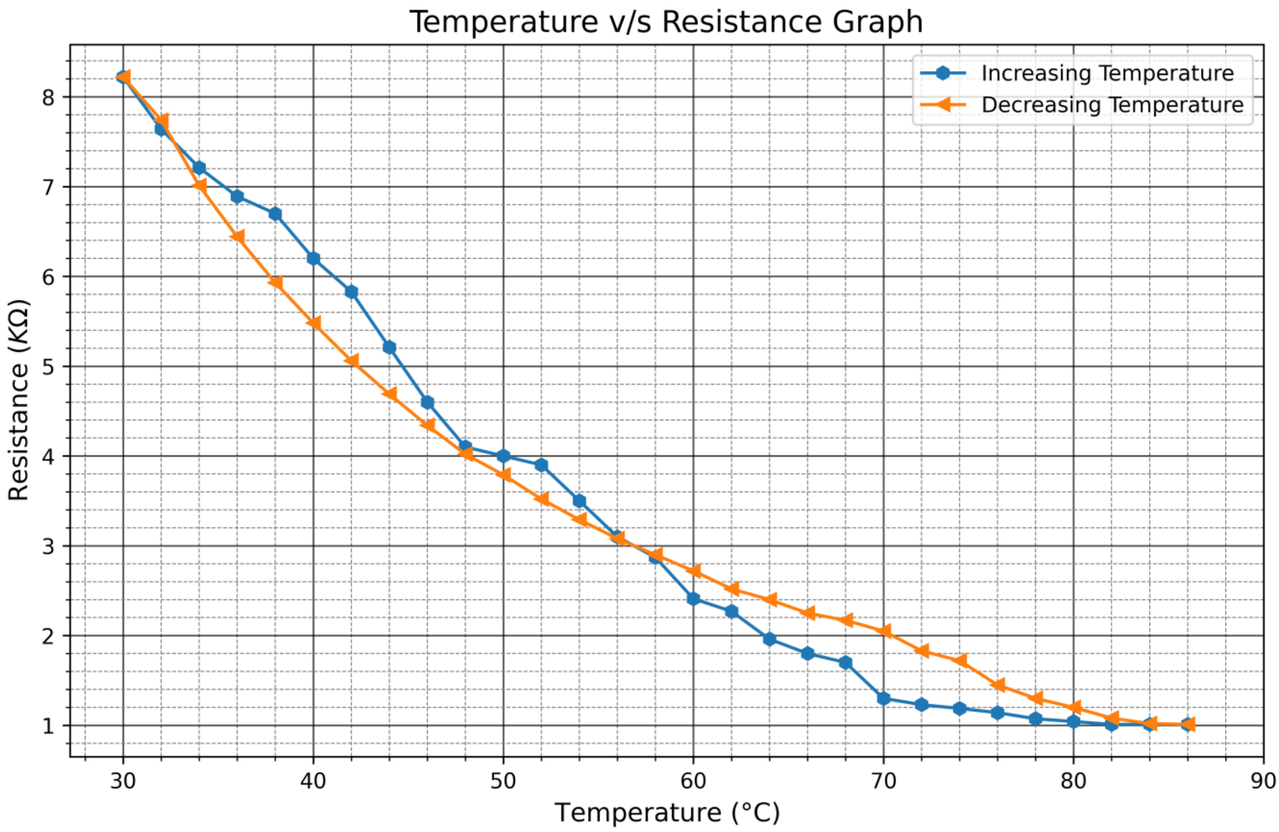

Figure 2: Variation of resistance with increasing and decreasing temperature.

BEST FIT CALCULATION:

Let $y = \ln\left(\frac{1}{R}\right)$ and $x = \left(\frac{1}{T}\right)$ then equation (2) can be expressed as

$$y = mx + c \tag{3}$$

Represents the best fitted line, where m is the slope and c the intercept.

Taking sum, then above equation takes the form:

$$\sum y = m\sum x + nc \tag{4}$$

Multiplying (5) by $\sum x$ we get,

$$\sum xy = m\sum x^2 + c\sum x \tag{5}$$

Multiplying (6) by $\sum x$ and (6) by n and solving these expressions for the slope (m), we get,

$$m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2} \tag{6}$$

And intercept (c) is given by,

$$c = \frac{\sum y - m\sum x}{n} \tag{7}$$

Where, slope $m = -\left(\frac{E_g}{k}\right)$.

Table 2: Best fit calculation for increasing temperature.

SN	Temp in K	Resistance (Ω)	$x = 1/T$ $(\times 10^{-3})$	y =ln(1/R)	x^2 $(\times 10^{-6})$	xy $(\times 10^{-2})$
1.	303	8220	3.30	-9.01	10.89	-2.98
2.	305	7640	3.28	-8.94	10.75	-2.93
3.	307	7210	3.26	-8.88	10.61	-2.89
4.	309	6890	3.24	-8.84	10.47	-2.86
5.	311	6700	3.22	-8.81	10.34	-2.83
6.	313	6200	3.19	-8.73	10.21	-2.79
7.	315	5830	3.17	-8.67	10.08	-2.75
8.	317	5210	3.15	-8.56	9.95	-2.70
9.	319	4600	3.13	-8.43	9.83	-2.64
10.	321	4100	3.12	-8.32	9.70	-2.59
11.	323	4000	3.10	-8.29	9.59	-2.57
12.	325	3900	3.08	-8.27	9.47	-2.54
13.	327	3500	3.06	-8.16	9.35	-2.50
14.	329	3100	3.04	-8.04	9.24	-2.44
15.	331	2870	3.02	-7.96	9.13	-2.41
16.	333	2410	3.00	-7.79	9.02	-2.34
17.	335	2270	2.99	-7.73	8.91	-2.31
18.	337	1960	2.97	-7.58	8.81	-2.25
19.	339	1800	2.95	-7.50	8.70	-2.21
20.	341	1700	2.93	-7.44	8.60	-2.18
21.	343	1300	2.92	-7.17	8.50	-2.09
22.	345	1230	2.90	-7.11	8.40	-2.06
23.	347	1188	2.88	-7.08	8.31	-2.04
24.	349	1141	2.87	-7.04	8.21	-2.02
25.	351	1073	2.85	-6.98	8.12	-1.99
26.	353	1042	2.83	-6.95	8.03	-1.97
27.	355	1010	2.82	-6.92	7.93	-1.95
28.	357	1010	2.80	-6.92	7.85	-1.94
29.	359	1010	2.79	-6.92	7.76	-1.93
			$\sum x =$ **87.84**	$\sum y =$ **-229.04**	$\sum x^2 =$ **266.74**	$\sum xy =$ **-69.69**

Calculations of m and c using equation (6) and (7)

We have, $n = 29$

$$\therefore m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2} = \frac{29 \times (-69.69 \times 10^{-2}) - 87.84 \times 10^{-3} \times (-229.04)}{29 \times 266.74 \times 10^{-6} - (87.84 \times 10^{-3})^2} = -4686.74$$

$$\therefore c = \frac{\sum y - m\sum x}{n} = \frac{-229.04 - (-4686.74) \times 87.84 \times 10^{-3}}{29} = 6.30$$

We use the value of slope to find the value band gap in the given semiconductor.

Slope $(m) = -4686.74 = -\frac{E_g}{k}$

Thus, Band gap $E_g = k \times 4686.74 = 1.38 \times 10^{-23} \times 4686.74 = 6.47 \times 10^{-20} J = 0.40\ eV$

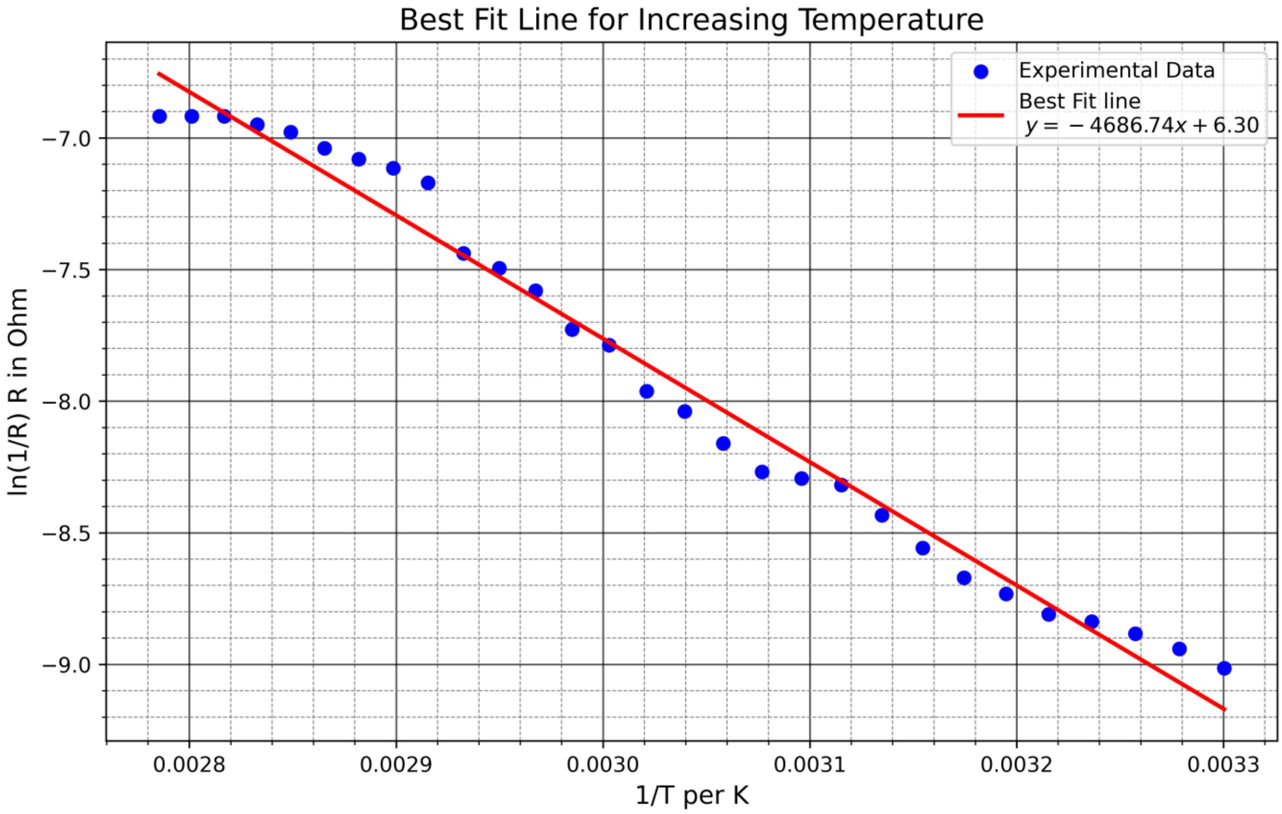

Figure 3: Inverse of resistance versus inverse of temperature plot with best fit line.

Error Analysis

Table 3: Table for error analysis for increasing temperature.

SN	$x = 1/T$ $(\times 10^{-3})$	y =ln(1/R)	$\hat{y} = mx + c$	$(x - \bar{x})^2$ $(\times 10^{-9})$	$d_i^2 = (y - \hat{y})^2$ $(\times 10^{-3})$
1.	3.30	-9.01	-9.17	73.67	24.24
2.	3.28	-8.94	-9.07	62.39	16.24
3.	3.26	-8.88	-8.97	52.18	7.27
4.	3.24	-8.84	-8.87	42.99	1.01
5.	3.22	-8.81	-8.77	34.79	1.42
6.	3.19	-8.73	-8.68	27.55	3.19
7.	3.17	-8.67	-8.58	21.23	8.10
8.	3.15	-8.56	-8.49	15.79	5.11
9.	3.13	-8.43	-8.39	11.21	1.57
10.	3.12	-8.32	-8.30	7.46	0.26
11.	3.10	-8.29	-8.21	4.50	6.69
12.	3.08	-8.27	-8.12	2.31	21.25
13.	3.06	-8.16	-8.03	0.85	15.82
14.	3.04	-8.04	-7.95	0.11	8.38
15.	3.02	-7.96	-7.86	0.06	10.10
16.	3.00	-7.79	-7.78	0.67	0.12
17.	2.99	-7.73	-7.69	1.92	1.23
18.	2.97	-7.58	-7.61	3.79	0.83
19.	2.95	-7.50	-7.53	6.25	1.02
20.	2.93	-7.44	-7.45	9.28	0.06

21.	2.92	-7.17	-7.37	12.87	38.44
22.	2.90	-7.11	-7.29	16.99	29.65
23.	2.88	-7.08	-7.21	21.63	16.55
24.	2.87	-7.04	-7.13	26.76	8.39
25.	2.85	-6.98	-7.05	32.36	5.86
26.	2.83	-6.95	-6.98	38.43	0.91
27.	2.82	-6.92	-6.90	44.95	0.18
28.	2.80	-6.92	-6.83	51.89	7.63
29.	2.79	-6.92	-6.76	59.24	25.76
				D=$\sum(\boldsymbol{x}-\bar{\boldsymbol{x}})^2$ =684.1244	$\boldsymbol{\sum d_i^2 = 267.2762}$

Mean $\bar{x}$ =3.03× 10^{-3}

The error in slope is, $\Delta m = \sqrt{\left(\frac{\sum d_i^2}{n-2}\right) \times \frac{1}{D}} = \sqrt{\frac{267.2762\times10^{-3}}{29-2} \times \frac{1}{684.1244\times10^{-9}}} = \pm120.29\ K^{-1}$

The error in band gap energy (ΔE) = $k \cdot \Delta m = \ 1.38\ \times\ 10^{-23} \cdot \pm120.29\ K^{-1} = \pm1.66 \times 10^{-21}\ J$

$\therefore\ \Delta E = 0.01\ eV$

So, the band gap energy (E) = $(0.40 \pm 0.01)\ eV$

Table 4: Best fit calculation for decreasing temperature.

SN	Temp in K	Resistance (Ω)	$\boldsymbol{x = 1/T}$ ($\times \mathbf{10^{-3}}$)	y =ln(1/R)	$\boldsymbol{x^2}$ ($\times \mathbf{10^{-6}}$)	$\boldsymbol{xy}$ ($\times \mathbf{10^{-2}}$)
1.	359	1010	2.79	-6.92	7.76	-1.93
2.	357	1020	2.80	-6.93	7.85	-1.94
3.	355	1080	2.82	-6.98	7.93	-1.97
4.	353	1200	2.83	-7.09	8.03	-2.01
5.	351	1300	2.85	-7.17	8.12	-2.04
6.	349	1450	2.87	-7.28	8.21	-2.09
7.	347	1720	2.88	-7.45	8.31	-2.15
8.	345	1830	2.90	-7.51	8.40	-2.18
9.	343	2050	2.92	-7.63	8.50	-2.22
10.	341	2170	2.93	-7.68	8.60	-2.25
11.	339	2250	2.95	-7.72	8.70	-2.28
12.	337	2400	2.97	-7.78	8.81	-2.31
13.	335	2520	2.99	-7.83	8.91	-2.34
14.	333	2720	3.00	-7.91	9.02	-2.37
15.	331	2900	3.02	-7.97	9.13	-2.41
16.	329	3080	3.04	-8.03	9.24	-2.44
17.	327	3290	3.06	-8.10	9.35	-2.48
18.	325	3520	3.08	-8.17	9.47	-2.51
19.	323	3790	3.10	-8.24	9.59	-2.55
20.	321	4020	3.12	-8.30	9.70	-2.59
21.	319	4340	3.13	-8.38	9.83	-2.63
22.	317	4690	3.15	-8.45	9.95	-2.67
23.	315	5060	3.17	-8.53	10.08	-2.71
24.	313	5480	3.19	-8.61	10.21	-2.75
25.	311	5930	3.22	-8.69	10.34	-2.79

26.	309	6440	3.24	-8.77	10.47	-2.84
27.	307	7010	3.26	-8.86	10.61	-2.88
28.	305	7740	3.28	-8.95	10.75	-2.94
29.	303	8220	3.30	-9.01	10.89	-2.98
			$\sum x =$ **87.84**	$\sum y =$ **-230.94**	$\sum x^2 =$ **266.74**	$\sum xy =$ **-70.23**

Calculations of m and c using equation (6) and (7)

We have, $n = 29$

$$\therefore m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2} = \frac{29 \times (-70.23 \times 10^{-2}) - 87.84 \times 10^{-3} \times (-230.94)}{29 \times 266.74 \times 10^{-6} - (87.84 \times 10^{-3})^2} = -4029.36$$

$$\therefore c = \frac{\sum y - m\sum x}{n} = \frac{-230.94 - (-4029.36) \times 87.84 \times 10^{-3}}{29} = 4.24$$

We use the value of slope to find the value band gap in the given semiconductor.

Slope $(m) = -4029.36 = -\frac{E_g}{k}$

Thus, Band gap $E_g = k \times 4029.36 = 1.38 \times 10^{-23} \times 4029.36 = 5.56 \times 10^{-20} J = 0.35\ eV$

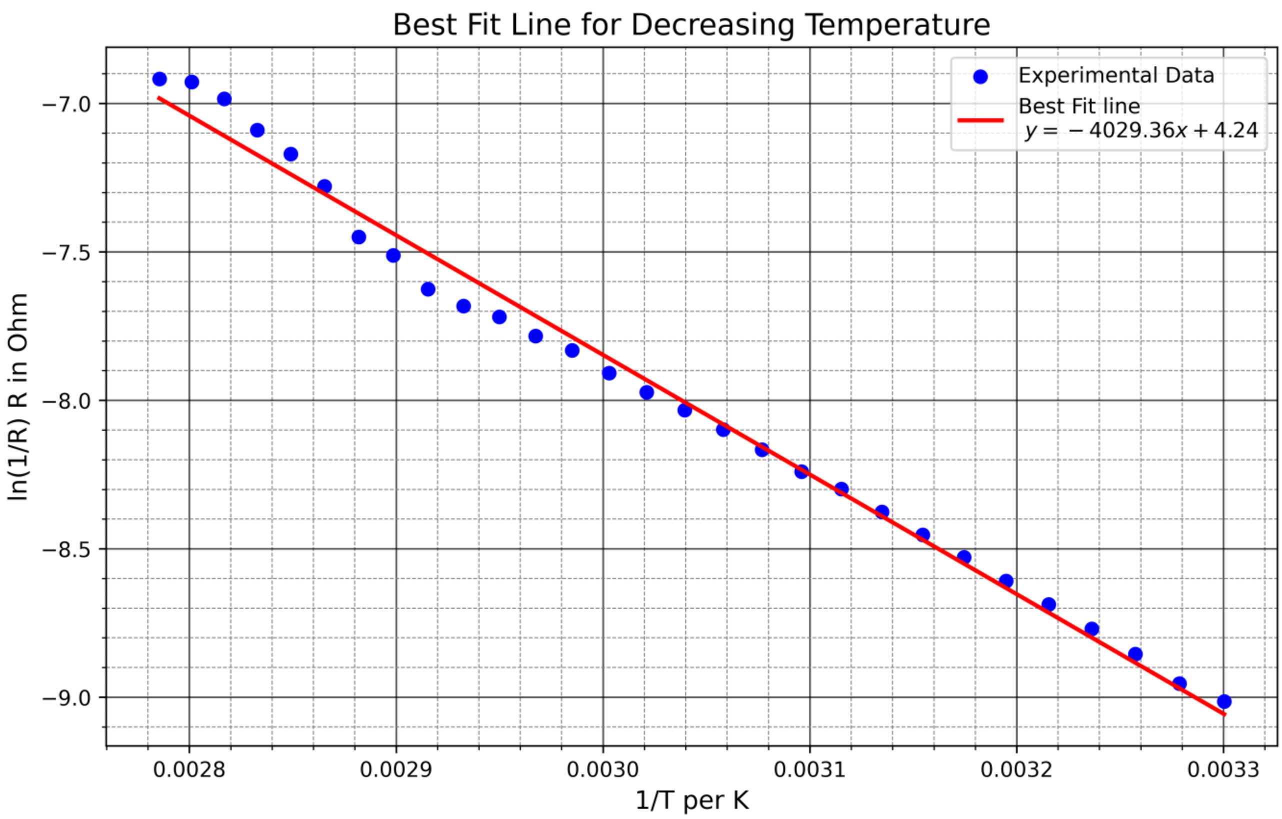

Figure 4: Inverse of resistance versus inverse of temperature plot with best fit line.

Error Analysis

Table 5: Table for error analysis for decreasing temperature.

SN	$x = 1/T$ $(\times 10^{-3})$	y =ln(1/R)	$\hat{y} = mx + c$	$(x-\bar{x})^2$ $(\times 10^{-9})$	$d_i^2 = (y-\hat{y})^2$ $(\times 10^{-3})$
1.	2.79	-6.92	-6.98	59.24	4.23
2.	2.80	-6.93	-7.05	51.89	13.94
3.	2.82	-6.98	-7.11	44.95	15.50

4.	2.83	-7.09	-7.17	38.43	6.96
5.	2.85	-7.17	-7.24	32.36	4.68
6.	2.87	-7.28	-7.30	26.76	0.63
7.	2.88	-7.45	-7.37	21.63	6.27
8.	2.90	-7.51	-7.44	16.99	5.46
9.	2.92	-7.63	-7.51	12.87	14.23
10.	2.93	-7.68	-7.58	9.28	11.51
11.	2.95	-7.72	-7.64	6.25	5.44
12.	2.97	-7.78	-7.72	3.79	4.59
13.	2.99	-7.83	-7.79	1.92	2.04
14.	3.00	-7.91	-7.86	0.67	2.43
15.	3.02	-7.97	-7.93	0.06	1.62
16.	3.04	-8.03	-8.01	0.11	0.70
17.	3.06	-8.10	-8.08	0.85	0.31
18.	3.08	-8.17	-8.16	2.31	0.09
19.	3.10	-8.24	-8.23	4.50	0.04
20.	3.12	-8.30	-8.31	7.46	0.15
21.	3.13	-8.38	-8.39	11.21	0.21
22.	3.15	-8.45	-8.47	15.79	0.28
23.	3.17	-8.53	-8.55	21.23	0.46
24.	3.19	-8.61	-8.63	27.55	0.55
25.	3.22	-8.69	-8.72	34.79	0.74
26.	3.24	-8.77	-8.80	42.99	0.82
27.	3.26	-8.86	-8.88	52.18	0.83
28.	3.28	-8.95	-8.97	62.39	0.25
29.	3.30	-9.01	-9.06	73.67	1.83
				D=$\sum(\boldsymbol{x}-\bar{\boldsymbol{x}})^2$ =684.1244	$\sum \boldsymbol{d_i}^2 = \mathbf{106.78}$

Mean $\bar{x}$ =3.03$\times 10^{-3}$

The error in slope is, $\Delta m = \sqrt{\left(\frac{\sum \mathrm{d}_i{}^2}{n-2}\right) \times \frac{1}{D}} = \sqrt{\frac{106.78\times10^{-3}}{29-2} \times \frac{1}{684.1244\times10^{-9}}} = \pm 76.03\ K^{-1}$

The error in band gap energy (ΔE) = $k \cdot \Delta m = \ 1.38\ \times\ 10^{-23} \cdot \pm 76.03\ K^{-1} = \pm 1.05 \times 10^{-21} J$

$\therefore\ \Delta E = 0.0065\ eV$

So, the band gap energy (E_g) = $(0.35 \pm 0.0065)\ eV$

Now, Average of this,

We have,

$E_{g1} = 0.40\ eV, \Delta E_{g1} = 0.01 eV, E_{g2} = 0.35\ eV, \Delta E_{g2} = 0.0065\ eV$

Now, Weight of each value,

$$\omega_1 = \frac{1}{(\Delta E_{g1})^2} = \frac{1}{0.01^2} = 10000, \omega_2 = \frac{1}{(\Delta E_{g2})^2} = \frac{1}{0.0065^2} = 23668.63$$

$$\therefore \overline{E_g} = \frac{\omega_1 E_{g1} + \omega_2 E_{g2}}{\omega_1 + \omega_2} = \frac{10000 \times 0.40 + 23668.63 \times 0.35}{10000 + 23668.63} = 0.365\ eV$$

$$\Delta\overline{E_g} = \sqrt{\frac{1}{\omega_1 + \omega_2}} = \sqrt{\frac{1}{10000 + 23668.63}} = 0.0054\ eV$$

$$\therefore \Delta\bar{E}_g = 0.365 \pm 0.0054\ eV$$

Uses of Thermistor

A thermistor is a resistor that helps sense and regulate temperature. It's used in many everyday devices:

- **Microwaves:** Thermistors prevent overheating by monitoring internal temperatures, reducing fire risks.
- **Circuit Protectors:** Found in surge protectors, they control energy surges, preventing overheating and device damage.
- **Automotive:** Cars use thermistors to monitor oil and coolant temperatures, helping drivers spot issues early.
- **Digital Thermometers:** Thermistors measure body temperature accurately.
- **Rechargeable Batteries:** They prevent overheating during charging by reducing resistance when things get too hot.

APPLICATION:

A digital thermometer uses a thermistor to measure temperature. Here's how it works:

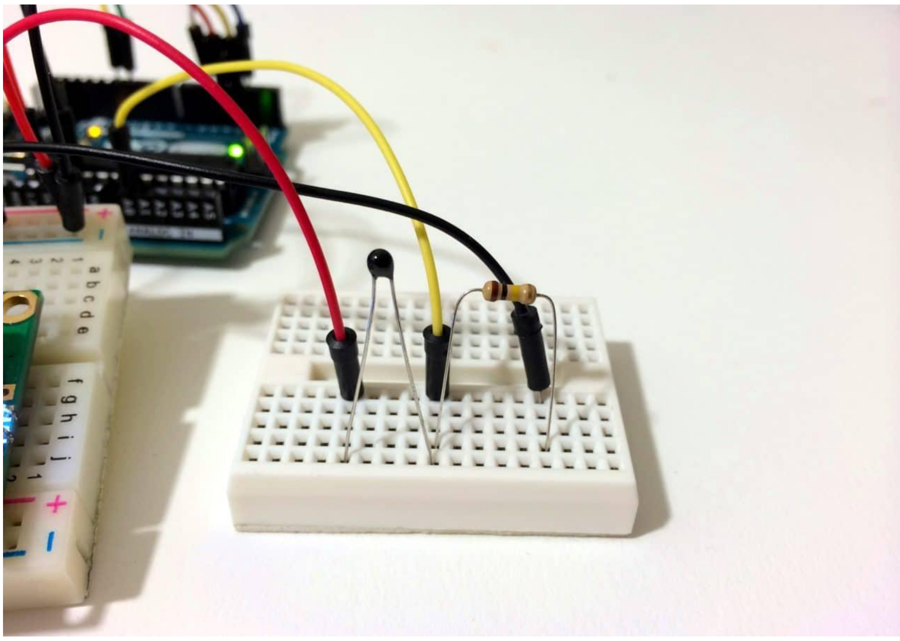

Figure 5: Circuit for application of thermistor to measure temperature..

1. **Thermistor Selection**:

   Choose a thermistor with a negative temperature coefficient (NTC), meaning its resistance decreases as temperature increases. The resistance of the thermistor will be highly sensitive to small changes in body temperature.

2. **Circuit Setup**:

   The thermistor is placed in a voltage divider circuit, where it forms part of the voltage divider with a fixed resistor. The voltage across the thermistor will vary with temperature, and this change in voltage can be measured by a microcontroller (e.g., Arduino or Raspberry Pi).

3. **Data Conversion**:

   The microcontroller reads the voltage and uses an algorithm (or pre-calibrated table) to convert the measured voltage into a temperature reading. The thermistor's resistance is related to temperature via a known curve, which can be approximated using the Steinhart-Hart equation or other models.

4. **Display**:
   The temperature data is then sent to a digital display (e.g., an LCD or LED screen), where the user can view the current body temperature.

5. **Use in Practice**:

   - The thermometer is placed suitable location.
   - The thermistor detects the change in temperature, which is then translated into a readable digital format for the user.

RESULT

It is found that the resistance of given thermistor increases with the decrease in the temperature. In addition, we found that the band gap of the given semiconductor is $\mathbf{0.365 \pm 0.0054\ \mathit{eV}.}$

INTERPRETATION OF RESULT

1. **Resistance Increases with Decreasing Temperature:**
   This behavior is characteristic of negative temperature coefficient (NTC) thermistors. In such thermistors, resistance decreases as temperature increases because the thermal energy excites more electrons into the conduction band, increasing conductivity.

2. **Band Gap of 0.365 ± 0.0054 eV:**
   The band gap is the energy required to move an electron from the valence band to the conduction band in a semiconductor. A band gap of 0.365 eV indicates this thermistor is made of a material that is highly sensitive to temperature changes, as small energy changes (thermal fluctuations) can significantly affect the electron population in the conduction band. The uncertainty of ±0.0054 eV represents the precision of the measurement.

………………

(Signature)