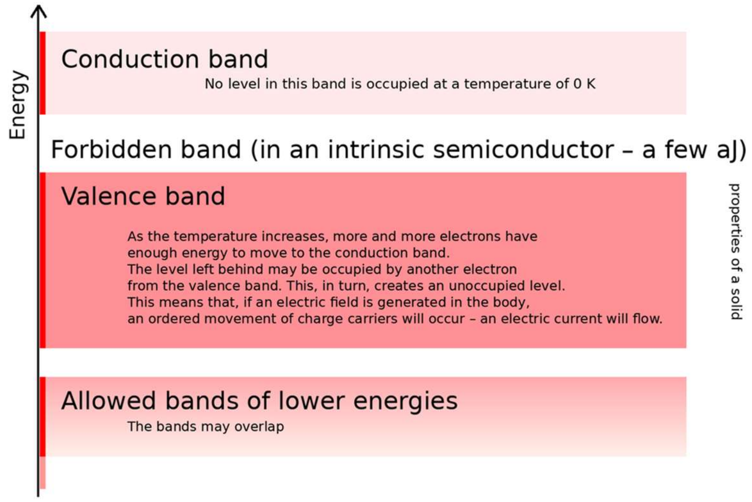
Theoretical Introduction

Experiment “T H E R M I S T O R”

The phenomenon of conduction in semiconductors cannot be explained on the basis of classical physics, unlike in conductors, where the electron theory is sufficient.
The phenomenon of conduction in semiconductors is explained using a model called the “energy band structure”. It presents a vertically expanded diagram of the allowed energies of electrons in a solid body, as shown in the figure below. From the diagram, or more precisely from the allowed energy ranges, so-called allowed bands are drawn to the right, including the valence band and the conduction band.



The use of band graphics makes it possible to visualize electron transitions between energy levels.
The relationship between the resistance of an intrinsic semiconductor and temperature is described by the function:

$$R(T) = A \cdot e^{\frac{\Delta E}{2k}}$$

Where:
ΔE is the width of the energy gap between the valence band and the conduction band,
T – temperature on the absolute scale,
k – Boltzmann constant.

The parameter A has the dimension of resistance - it is the resistance at infinitely high temperature.
The above equation is equivalent to the logarithmic form on both sides:

$$\ln(R) = \ln(A) + \frac{\Delta E}{2kT}$$

which can be presented as:

$$2k \cdot \ln(R) = \Delta E \cdot \frac{1}{T} + 2k \cdot \ln(A).$$

The theory of extrinsic semiconductors is more complex, because narrow zones of donor or acceptor levels appear inside the forbidden band.

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Preparation Questions:

1. What is a thermistor?
2. What types of thermistors are there and what are their characteristics?
3. What is an insulator?
4. What is a conductor?
5. Draw the dependence of resistance on temperature for a conductor.
6. Draw the dependence of resistance on temperature for an NTC thermistor.
7. Is the width of the energy gap greater for an insulator or for a thermistor?
8. In what units is the value of the energy gap width given?
9. Give the method of converting J to eV.
10. Give the method of converting eV to J.
11. Give the method of converting temperature given in °C to K.
12. How is an atom built?
13. What charge does an electron have?
14. What is a forbidden band?
15. Give applications of thermistors.

Course of the Exercise:

1. Turn on the electronic thermometer and the ohmmeter.
2. With the instructor's permission, connect the heating mantle to the power supply, start the stirrer and set the target heating temperature.
3. Record temperature and resistance measurements at equal temperature intervals, not exceeding $45°C$.
4. After collecting ten temperature values and ten resistance values, disconnect the heating mantle from the power supply.
5. After completing the measurements, tidy up the workstation.
6. Perform the calculations according to the instruction and prepare a trial graph in a spreadsheet. In the calculations, remember to use the basic SI units for all results.
7. Prepare a measurement protocol and measurement uncertainties.

NOTE:

- Do not exceed the temperature of $45°C$, due to the action of glycol vapours used in the exercise to heat the thermistor.
- The temperature value should be read from the thermometer - not from the display of the heating mantle.

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Methodological Template

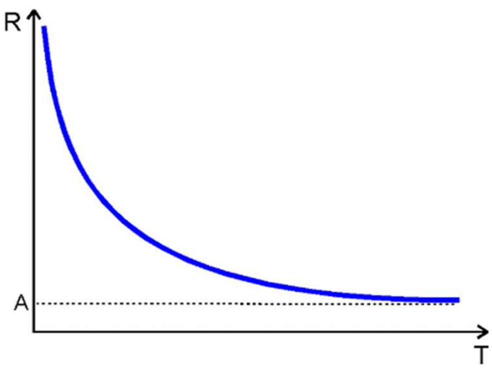
Student 1: Determination of the width of the forbidden band in a semiconductor (thermistor).
Student 2: Verification of the dependence of thermistor resistance on temperaturę.

Theoretical Basis:

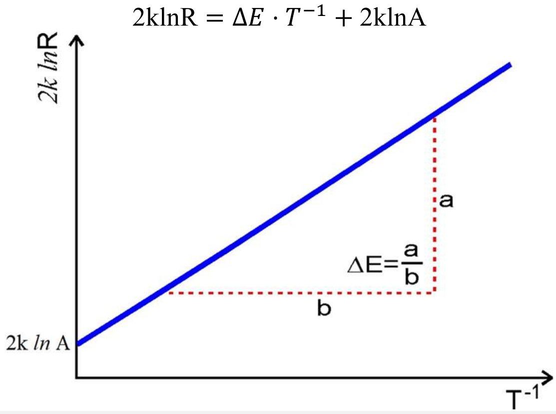
The dependence of thermistor resistance on temperature is expressed by the following equation:

$$R(T) = A \cdot e^{\frac{\Delta E}{2kT}}$$

where:
ΔE– width of the energy gap,
T– temperature on the absolute scale,
k– Boltzmann constant, (1,380658·10^{-23} J/deg)
A – material constant of the semiconductor, indicating the asymptotic resistance at infinitely high temperature.



$$2\mathrm{klnR} = \Delta E \cdot T^{-1} + 2\mathrm{klnA}$$



Therefore, in order to determine the width of the forbidden band, one should:

- perform measurements of the dependence of thermistor resistance on temperature,
- prepare a graph of the dependence:

  2k·ln(R) as a function of: T^{-1}

- read the width of the forbidden band from it, which is the slope coefficient.

$$\ln \mathrm{R} = \frac{\Delta E}{2\mathrm{k}} T^{-1} + \ln \mathrm{A}$$

Therefore, in order to verify the theoretical dependence of thermistor resistance on temperature, one should:

- perform measurements of resistance as a function of temperature,
- prepare a graph of the dependence:

  ln(R) as a function of: T^{-1}

- analyse its linearity

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Report Guidelines – Determination

Student 1: Determination of the width of the forbidden band in a semiconductor, thermistor.

I. Methodology (conceptual plan of the exercise)

II. Course of the exercise

II.1. Course of activities

II.2. Sketch of the measurement setup

III. Results

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
T_c	[°C]										
R	[kΩ]										

$\Delta T = \ldots$

$\Delta R = \ldots$

2. Calculation (example calculations - referring, for example, to measurement no.3)

$$T_k = T_c + 273 = \ldots$$

$$\frac{1}{T_K} = \ldots$$

$$\Delta\frac{1}{T_K} = \left|\frac{1}{T_K} - \frac{1}{T_K + \Delta T}\right| = \ldots$$

$$2k \cdot \ln R = \ldots$$

$$\Delta(2k\ln R) = 2k \cdot |\ln R - \ln(R + \Delta R)| = \ldots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\frac{1}{T_K}$	[K^{-1}]										
$2k\ln R$	[…]										
$\Delta\frac{1}{T_K}$	[…]										
$\Delta(2k\ln R)$	[…]										

4. Graph

- calculation of ΔE, the slope of the "best-fit" straight line
- calculation of $\Delta E'$, the slope of the deviated straight line
- calculation of the accuracy of the method as: $|\Delta E - \Delta E'|$

5. Summary

The determined value of the energy gap width is …
Accuracy of the method: …
Additional conclusions, observations, causes of measurement uncertainties.

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Report Guidelines – Verification

Student 2: Verification of the dependence of thermistor resistance on temperature.

I. **Methodology** (conceptual plan of the exercise)

II. **Course of the exercise**

  II.1. Course of activities

  II.2. Sketch of the measurement setup

III. **Results**

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
T_c	[°C]										
R	[kΩ]										

ΔT= ...

ΔR = ...

2. Calculation (example calculations - referring, for example, to measurement no.3)

$$T_k = T_c + 273 = \ldots$$

$$\frac{1}{T_K} = \ldots$$

$$\Delta\frac{1}{T_K} = \left|\frac{1}{T_K} - \frac{1}{T_K + \Delta T}\right| = \ldots$$

$$\ln R = \ldots$$

$$\Delta(\ln R) = |\ln R - \ln(R + \Delta R)| = \ldots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\frac{1}{T_K}$	[K^{-1}]										
$\ln R$	[…]										
$\Delta\frac{1}{T_K}$	[…]										
$\Delta(\ln R)$	[…]										

4. Graph

5. Summary

Since on the graph … it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …

Alternatively:

The deviation from linearity in the range … may result from …

Additional conclusions, observations, causes of measurement uncertainties.