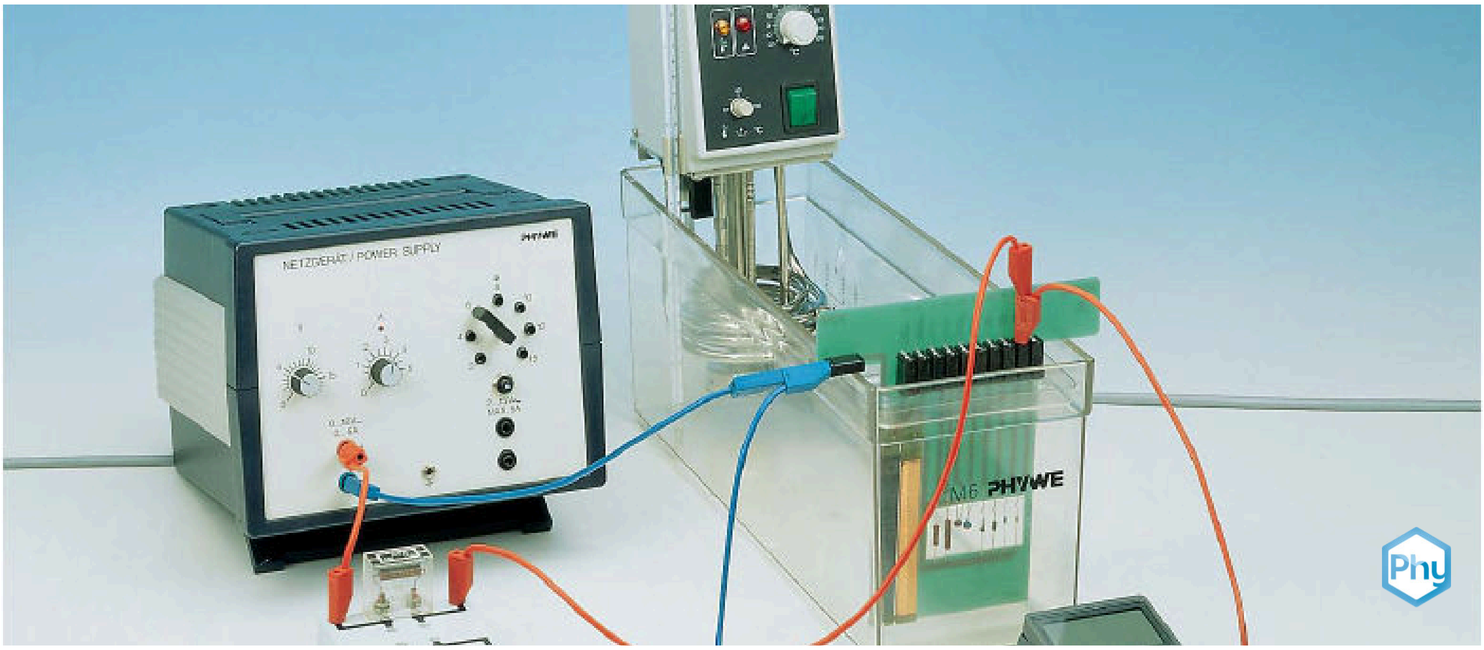
Temperature dependence of different resistors and diodes



The goal of this experiment is to investigate the temperature dependency of different resistors and diodes.

Physics	Electricity & Magnetism	Simple circuits, resistors & capacitors	
Applied Science	Engineering	Materials Science	Thermal & Electrical Properties
Applied Science	Engineering	Electrical Engineering	Properties of Electrical Devices

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

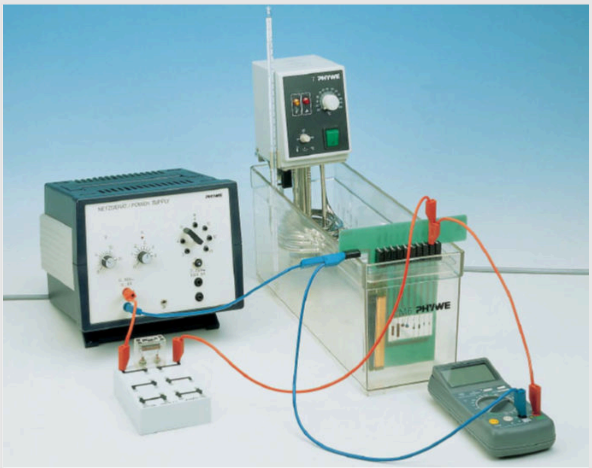
http://localhost:1337/c/607f1052ddcf8e0003548bcf

PHYWE

General information

Application

PHYWE



Setup

Resistors and diodes have many applications in electrical appliances. Their electrical properties are dependent on their temperature.

This experiment investigates this dependency.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Other information (1/2)

PHYWE

Prior knowledge

Basic knowledge about electrical circuits, resistors and diodes and how to measure voltage and resistance with a multimeter is required.

Scientific principle

The temperature dependence of an electrical parameter (e.g. resistance, conducting-state voltage, blocking voltage) of different components is determined. To do this, the immersion probe set is exposed to different temperatures by using a temperature-regulated water bath and the resistance is measured at regular temperature intervals.

Other information (2/2)

PHYWE

Learning objective

The goal of this experiment is to investigate the temperature dependency of different resistors and diodes.

Tasks

1. Measurement of the temperature dependence of the resistance of different electrical components.
2. Measurement of the temperature dependence of the conducting state voltage of semiconducting diodes.
3. Measurement of the temperature dependence of the voltage in the Zener and the avalanche effect.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Theory

In restricted temperature ranges the change in the resistance of the electrical components can be assumed to be linear. In these regions, the general formula for the dependence of the resistance on the temperature is valid

$$R(T) = R_{20} + R_{20} \cdot \alpha \cdot (T - 20\,^{\circ}\mathrm{C})$$

where R(T) = resistance at temperature, R_{20} = resistance at 20 °C, α = temperature coefficient, T = temperature at time of measurement

By rearranging and substituting the measured values the temperature coefficient can be determined using the formula.

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Equipment

Position	Material	Item No.	Quantity
1	Immersion probes for determining ct	07163-00	1
2	Immersion thermostat Alpha A, 230 V	08493-93	1
3	Bath for thermostat, makrolon	08487-02	1
4	External circulation set for thermostat Alpha A	08493-02	1
5	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C	07122-00	1
6	PHYWE Power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
7	Resistor 4.7 kOhm, 1W, G1	39104-27	1
8	Connection box	06000-00	1
9	Connecting cord, 32 A, 500 mm, blue	07361-04	1
10	Connecting cord, 32 A, 750 mm, red	07362-01	2
11	Connecting cord, 32 A, 750 mm, blue	07362-04	2
12	Tubing connector, ID 6-10mm	47516-01	2

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE

Setup and Procedure

Setup and Procedure (1/3)

PHYWE

- At first, enclose the immersion probe set (Fig. 2) in a watertight plastic bag to avoid short-circuiting. Only then place the immersion probe set into the water bath.
- In the first task, measure the resistance values for the PTC, NTC, metallic film and carbon film resistors as well as the Cu and CuNi wire resistors directly with the multimeter (circuit diagram, Fig. 3). This part of the experiment does not require the power supply. Proceed as follows: connect the multimeter to the ground jack, which is connected to all the components, and the jack located under the symbol corresponding to the respective component. Note the different resistance values, and plot them as a function of temperature.

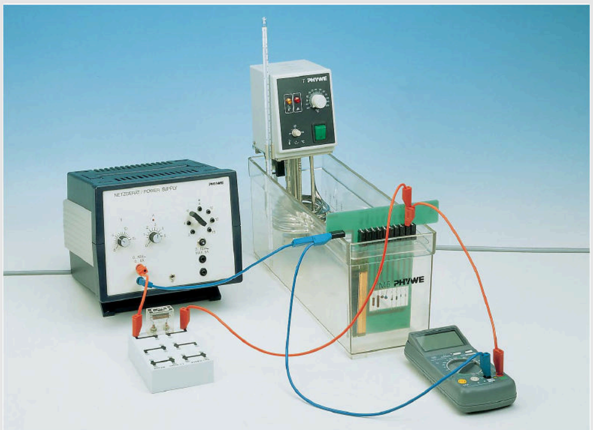


Fig. 1: Setup for the measurement of the semiconductor diodes and the Zener diodes. The measurements of the resistors do not require a power supply.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Setup and Procedure (2/3)

PHYWE

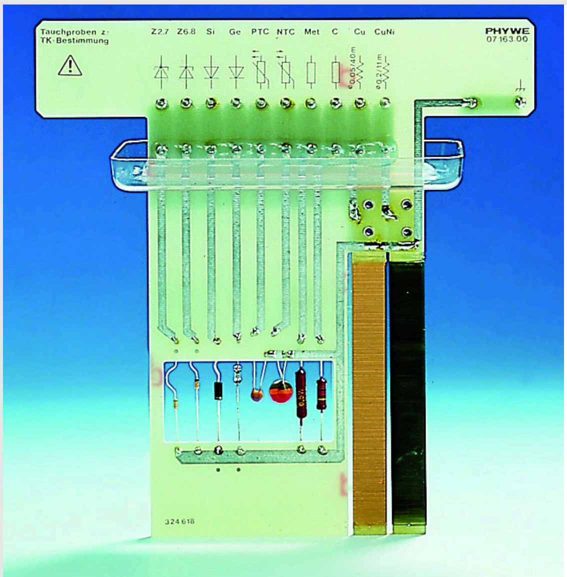


Fig. 2: Immersion probe set

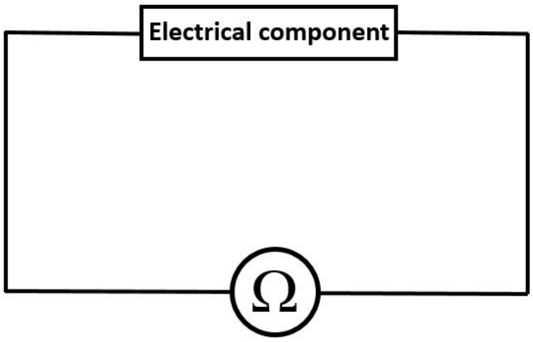


Fig. 3: For measuring the resistors a simple electrical circuit is sufficient to connect the multimeter to the ground jack and the corresponding jacks for the single resistors.

Setup and Procedure (3/3)

PHYWE

- For tasks 2 and 3 (measuring the conducting-state voltages of the semiconduction diodes resp. Zener diodes), connect them to a voltage of 10 V. Connect a 4.7 Ω resistor in series with the component. Set a voltage of 10 V on the universal power supply and adjust the current limiter to its maximum value. Measure the voltage parallel to the component. Note the conducting-state voltages corresponding to the respective temperatures.

- Also measure the blocking voltage for the Zener diodes and avalanche effects. The Zener diodes have already been wired in the blocking direction through their placement in the immersion probe set.

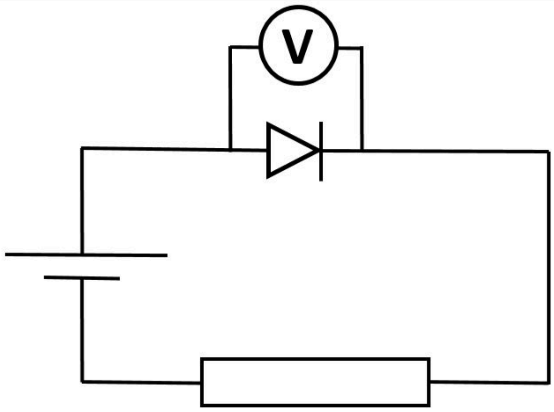


Fig. 4: Circuit diagram for the measurement of the Ge and Si diodes and Zener diodes

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE

Evaluation

Task 1 (1/3)

PHYWE

In copper wire the free path of the electrons in the electron vapour, which contribute to charge transport, becomes shorter with increasing temperature. The change in resistance can be clearly seen: the resistance increases. The result is a positive temperature coefficient

$\alpha_{\mathrm{Cu}} = 5.3 \cdot 10^{-3} / \mathrm{K}$

The resistance of the CuNi wire is nearly constant over the measured range. This is in accordance with Mathies rule, which states that $R_{\mathrm{tot}} = R_{20} + R(T)$. The change in the resistance with the temperature is very slight in the measured temperature range. Consequently, the absolute resistance (R_{20}) is predominant. This experiment provides a negative temperature coefficient of

$\alpha_{\mathrm{CuNi}} = -1.4 \cdot 10^{-4} / \mathrm{K}$

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Task 1 (2/3)

PHYWE

In the carbon-layer resistor, the absolute resistance is very high to begin with. The change with the temperature is, as is the case with CuNi, small and has practically no effect. A negative temperature coefficient results

$\alpha_{\mathrm{C}} = -2.3 \cdot 10^{-3}/\mathrm{K}$

The metallic layer resister also has a relatively high absolute resistance at 20 °C. And the change in the measured temperature range is even lower than for carbon. Thus, the temperature coefficient approaches zero.

$\alpha_{\mathrm{met}} \Longrightarrow 0$

The two NTC and PTC resistors consist of alloys. Depending on their compositions, great changes in resistance can be realized in a small temperature range. The curves that are recorded in this experiment can no longer be considered linear. They serve only to illustrate the behaviour of NTC and PTC resistors.

Task 1 (3/3)

PHYWE

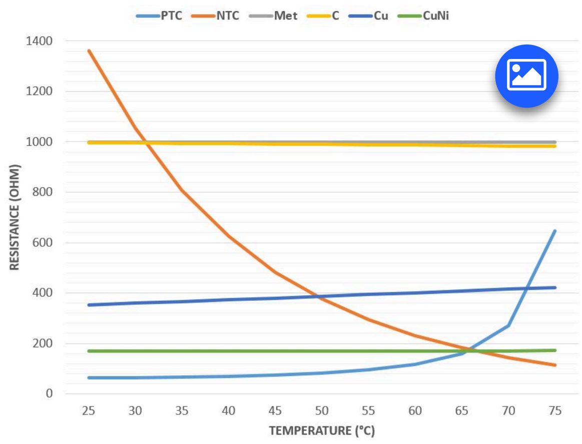


Fig. 5: Diagram of resistances

Literature values:

$\alpha_{\mathrm{Cu}} = 4.0 \cdot 10^{-3}/\mathrm{K}$, $\alpha_{\mathrm{CuNi}} = -3.0 \cdot 10^{-3}/\mathrm{K}$,
$\alpha_{\mathrm{C}} = -2.4 \cdot 10^{-4}/\mathrm{K}$, $\alpha_{\mathrm{met}} = \pm 0 \ldots 50 \cdot 10^{-6}/\mathrm{K}$,
$\alpha_{\mathrm{NTC}} = -6.15\%/\mathrm{K}$, $\alpha_{\mathrm{PTC}} = 20\%/\mathrm{K}$.

The value for PTC is valid in the steepest region of the characteristic line.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Task 2 (1/2)

PHYWE

In semiconductors the number of charge carriers and the charge carrier density increases with temperature (charge carrier generation, electron-hole pair formation). From the law

$\sigma = e \cdot n \cdot \mu$

where σ = Intrinsic conductivity, e = Elementary charge, n = Charge carrier density, μ = Mobility

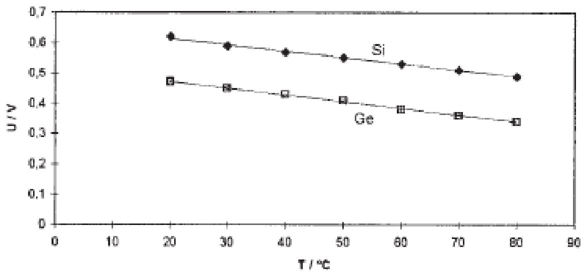


Fig. 6: Diagram for the semiconductors Si and Ge

Task 2 (2/2)

PHYWE

one can see that the intrinsic conductivity of the semiconductor thus increases. The mobility indeed decreases with increasing temperature, but the increase in the charge carrier density compensates for this effect. A definite drop in resistance is observed; this allows one to infer that there is a negative temperature coefficient. Through the calculation with the above-mentioned formula for the temperature dependence, rearranged for the voltage U_p, the following values are obtained.

$\alpha_{\mathrm{Si}} = -3.4 \cdot 10^{-3} / \mathrm{K}$

$\alpha_{\mathrm{Ge}} = -4.6 \cdot 10^{-3} / \mathrm{K}$

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Task 3 (1/2)

PHYWE

At low voltages, around 3 V, a Zener breakdown occurs in Z diodes. As a result of the strong electric field, electron hole pairs are spontaneously generated in the inner electron shells in the barrier-layer zone. Under the influence of the field charge carrier, they cross the barrier layer. A higher temperature increases the energy of the bound charge carriers. As a consequence, the Zener effect can occur at lower voltages. In the avalanche effect, the charge carriers are accelerated by the electric field to such a great degree that they in turn release other charge carriers on colliding with other atoms, which in turn are accelerated.

The higher temperature shortens the free path, so that the voltage must increase with the temperature in order to continue to release charge carriers. From the calculations, the following values result for α:

Task 3 (2/2)

PHYWE

$\alpha_{\mathrm{ZPD2.7}} = -7.3 \cdot 10^{-4}/\mathrm{K}$

$\alpha_{\mathrm{ZPD6.8}} = +4.5 \cdot 10^{-4}/\mathrm{K}$

Literature values:

$\alpha_{\mathrm{ZPD2.7}} = -9 ... -4 \cdot 10^{-4}/\mathrm{K}$

$\alpha_{\mathrm{ZPD6.8}} = +2 ... +7 \cdot 10^{-4}/\mathrm{K}$

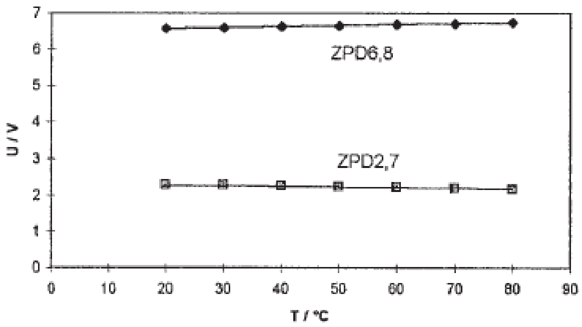


Fig. 7: Diagram for the Z-diodes

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de