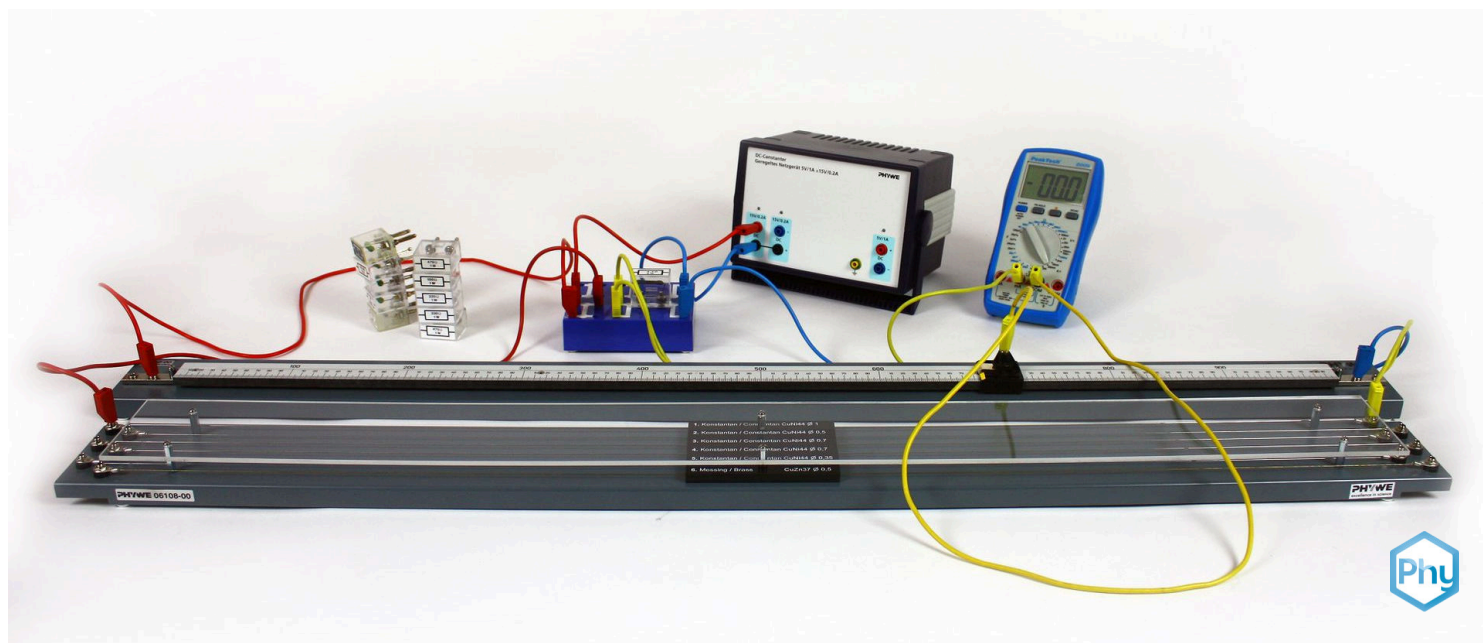


Wheatstone bridge



Physics

Electricity & Magnetism

Electric current & its effects

Physics

Electricity & Magnetism

Simple circuits, resistors & capacitors

Applied Science

Engineering

Electrical Engineering

Properties of Electrical Circuits



Difficulty level

medium



Group size

2



Preparation time

45+ minutes



Execution time

45+ minutes

This content can also be found online at:



<http://localhost:1337/c/6005fef8af145200034376d2>

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General information

Application

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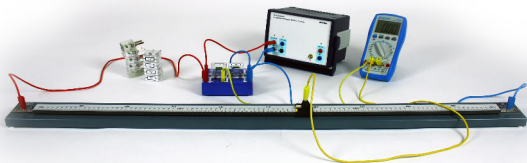


Fig. 1: Experimental set-up of the Wheatstone bridge.

In electronics and electromagnetism, the electrical resistance of an object is a measure of its opposition to the flow of electric current. Resistances are very important in electronics and have wide applications in computing and other kind of circuits.

Other information (1/2)

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**Prior****knowledge****Main****principle**

The prior knowledge for this experiment is found in the Theory section.

The Wheatstone bridge is used to determine an unknown resistance with high accuracy by adjusting a connected combination of known resistors.

Other information (2/2)

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**Learning
objective****Tasks**

The goal of this experiment is to determine resistances via the Wheatstone bridge.

1. Determination of unknown resistors with the Wheatstone bridge.
2. Determination of the total resistance of resistors in series.
3. Determination of the total resistance of resistors in parallel.
4. Measurement of low resistance and determination of the electrical resistivity of CuNi (Constantan).

Theory (1/3)

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The Wheatstone bridge consists of four resistors that are connected as shown in Fig. 2. A voltage source is connected to the junctions a and c, whilst the ammeter G measures the current flow between the junctions b and d.

Kirchhoff's second law implies that the application of a certain voltage between a and c causes an equal potential drop across the legs a-b-c and a-d-c.

Both legs serve as a particular voltage divider. The potentials at the junctions b and d depend on the proportions of the resistors along the respective legs

$$V_b = \frac{R_2}{R_1+R_2} \cdot V_{\text{source}} \quad \text{and} \quad V_d = \frac{R_4}{R_3+R_4} \cdot V_{\text{source}} \quad (1)$$

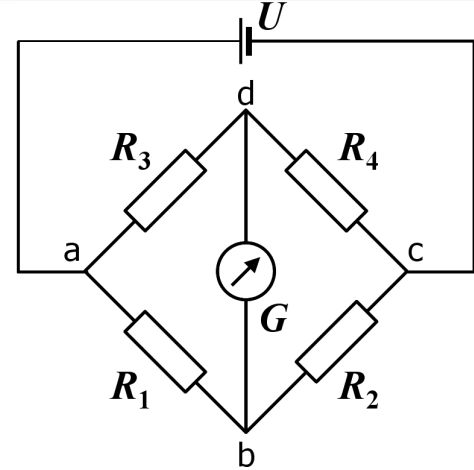


Fig. 2: Wheatstone bridge, basic circuit diagram.

Theory (2/3)

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If the resistor proportions are adjusted in a way so that the potentials V_b and V_d equalize, the current flow through the ammeter vanishes. The detection of zero current is very easy and could also be carried out with a simple galvanometer. This state is called the point of balance of the Wheatstone bridge. In that case, Eq. 1 can be combined:

$$\frac{R_2}{R_1+R_2} = \frac{R_4}{R_3+R_4} \quad (2)$$

$$\Leftrightarrow \frac{R_1}{R_2} = \frac{R_3}{R_4} \quad (3)$$

If three resistors are known and the fourth one, e.g. R_3 , should be identified, it can be calculated after setting the bridge to the point of balance

$$R_3 = \frac{R_1}{R_2} \cdot R_4 \quad (4)$$

Theory (3/3)

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In the present experiment, the resistance in the lower leg is replaced by a slide wire potentiometer as shown in Fig. 3, where a slider contact can be moved along the length of a wire to divide its total resistance in two distinct parts. The wire is made of a homogenous material with a uniform diameter, therefore, its resistance can be specified by $R = \rho \cdot \frac{l}{A}$ (5)

where ρ denotes the electrical resistivity of the wire material, l is the length of the wire, and A is its cross-section. Hence, the resistance of the wire depends on geometrical as well as material-specific properties. Uniform resistivity and cross-section given, the resistance increases proportionally with the length. This implies that the slide wire resistance ratio R_1/R_2 can be expressed by its lengths proportion l_1/l_2 . Kirchhoff's first law implies that the sum over all currents directed towards or away from a junction has to be zero. At the point of balance, with no current flowing through the ammeter, the current flow must remain conserved along both legs of the Wheatstone bridge. Thus Eq. 4 and 5 give the unknown resistance

$$R_x = \frac{l_1}{l_2} \cdot R_C \quad (6)$$

Equipment

Position	Material	Item No.	Quantity
1	Slide wire measurement bridge	07182-00	1
2	Connection box	06000-00	1
3	Resistor 1 Ohm 2%, 2W, G1	06055-10	1
4	Resistor 2 Ohm 5%, 2W, G1	06055-20	1
5	Resistor 5 Ohm 2%, 2W, G1	06055-50	1
6	Resistor 10 Ohm, 1W, G1	39104-01	1
7	Resistor 100 Ohm, 1W, G1	39104-63	1
8	Resistor 150 Ohm, 1W, G1	39104-10	1
9	Resistor 330 Ohm, 1W, G1	39104-13	1
10	Resistor 680 Ohm, 1W, G1	39104-17	1
11	PHYWE Power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
12	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 μF, 20 kHz, -20°C... 760°C	07122-00	1
13	Connecting cord, 32 A, 1000 mm, red	07363-01	1
14	Connecting cord, 32 A, 500 mm, red	07361-01	1
15	Connecting cord, 32 A, 1000 mm, yellow	07363-02	2
16	Connecting cord, 32 A, 1000 mm, blue	07363-04	1
17	Connecting cord, 32 A, 500 mm, blue	07361-04	1
18	Resistor 47 Ohm, 1W, G1	39104-62	1
19	Resistor 220 Ohm, 1W, G1	39104-64	1

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Setup and Procedure

Setup (1/2)

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In advance, up to five randomly selected resistors must be prepared for the measurement. To hide the resistance information, the printed values and optionally the transparent case of the chosen resistors have to be covered with adhesive tape. For separation during the measurement and verification afterwards, the resistors should be labeled with $R_{x1} \dots R_{x5}$. In the following measuring examples, the used designation is:

R_{x1}	R_{x2}	R_{x3}	R_{x4}	R_{x5}
220Ω	2Ω	47Ω	5Ω	680Ω

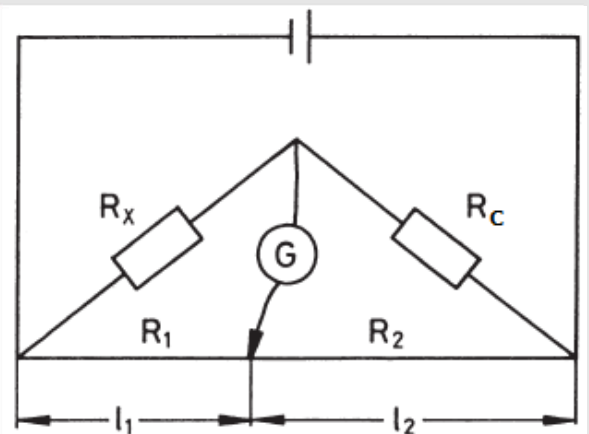


Fig. 3: Wheatstone bridge circuit diagram.

Setup (2/2)

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The experimental set-up is shown in Fig. 1. According to Fig. 4, the first unknown resistance R_x and a known resistor R_C (e.g. 100Ω) are placed on the connection box. The short red cord connects R_x with the red connector of the DC output, while the long red cord connects this junction with the left connector of the slide wire measuring bridge. Likewise, the blue cords are connected with the comparison resistor R_C , the blue connector of the DC output, and the right connector of the slide wire. In between, the yellow cords connect the ammeter G (mA scale, DC mode) with the junction between R_x and R_C as well as the slider of the measuring bridge. The circuit diagram is illustrated in Fig. 3.

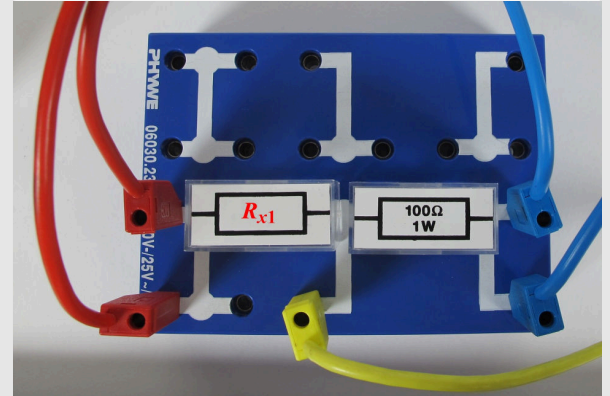


Fig. 4: Set-up of the upper leg of the Wheatstone bridge with an unknown resistance.

Procedure (1/6)

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Determination of unknown resistors

- To obtain the unknown resistance R_x , the slider of the measure bridge has to be moved in a position so that the ammeter displays zero current.
- Depending on the chosen resistors, it is possible that you will detect a remaining current in every slider position. In that case, you have to replace the comparison resistor R_C with a different one. The same procedure is advised if the slider position is close to the wire ends, because the measurement precision will otherwise decrease.
- Determine the slider position l_1 on the ruler and the associated position $l_2 = 100\text{ cm} - l_1$
- Replace R_x and repeat the procedure until all five unknown resistors are determined.

Note:

The power supply provides a current of up to 2A at a voltage of 12V. If the current should exceed that threshold due to e.g. a small resistance in the circuit, the device will reduce the voltage to prevent damage. This is indicated by the glowing of the red LED above the current selector. Nevertheless, the measurement and the results will not be affected by that short-circuit protection.

Procedure (2/6)

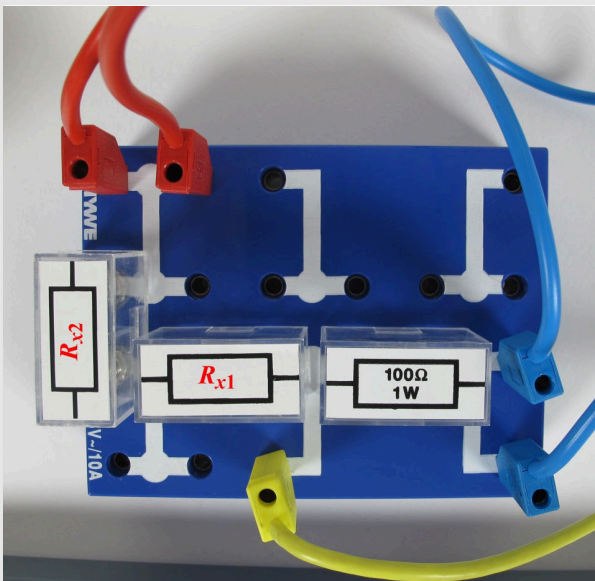
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Determination of the total resistance of resistors in series.

- To determine the resistance of two or three unknown resistors connected in series, the upper leg of the Wheatstone bridge has to be altered according to Fig 5 or Fig. 6, respectively. Resistance R_x is replaced by different combinations of the unknown resistors, while one of the known resistors remains as R_C .
- Perform the measurements just as you did in task 1 for at least two combinations of two, and two combinations of three resistors. Determine the corresponding slider positions l_1 (as well as l_2).

Procedure (3/6)

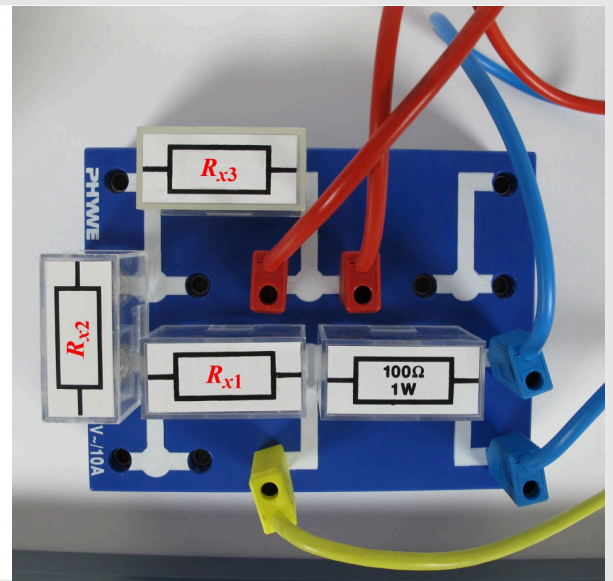
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←
Fig. 5: Set-up for two unknown resistors connected in series.

→

Fig. 6: Set-up for three unknown resistors connected in series.



Procedure (4/6)

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Determination of the total resistance of resistors in parallel.

- To study the effect of two resistors connected in parallel, the set-up has to be adjusted as shown in Fig. 7. Resistance R_x is substituted by two unknown resistors in a parallel circuit, while one of the known resistors serves as R_C .
- Repeat the steps of task 1 for at least three different combinations of resistors and determine the corresponding slider positions l_1 (as well as l_2), again.

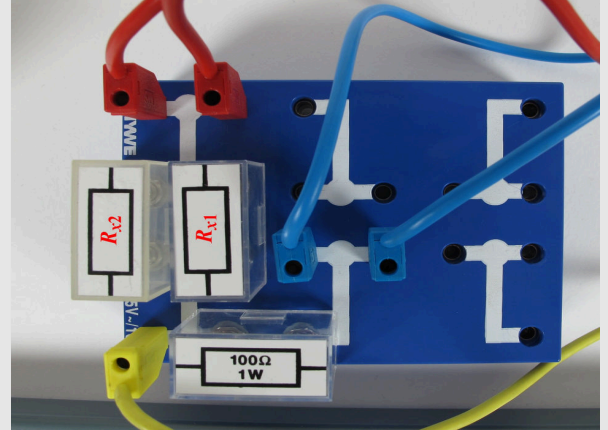


Fig. 7: Set-up of the upper leg of the Wheatstone bridge with two unknown resistors connected in parallel.

Procedure (5/6)

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Determination of the electrical resistivity of CuNi.

- One of the benefits of the Wheatstone bridge is the possibility to precisely determine a low resistance. For demonstration, the resistance of several Constantan wires with varying diameters (and identical length $l = 100\text{ cm}$) should be measured. Thereof, the electrical resistivity of Constantan can be obtained.
- For this purpose, R_C should be replaced by a resistor of approximately 1Ω , and the CuNi44 wire No. 1 of the resistance board has to be connected as R_x (see Fig. 8 and 9).
- Again, the measurement has to be carried out like before until the bridge is balanced.
- Register the slider position l_1 (as well as l_2) and repeat the measurement for the remaining CuNi44 wires No. 2, 3 and 5.

Procedure (6/6)

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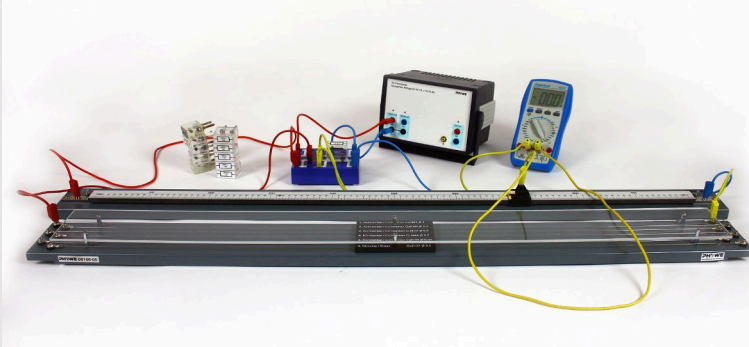


Fig. 8: Experimental set-up using the resistance board.

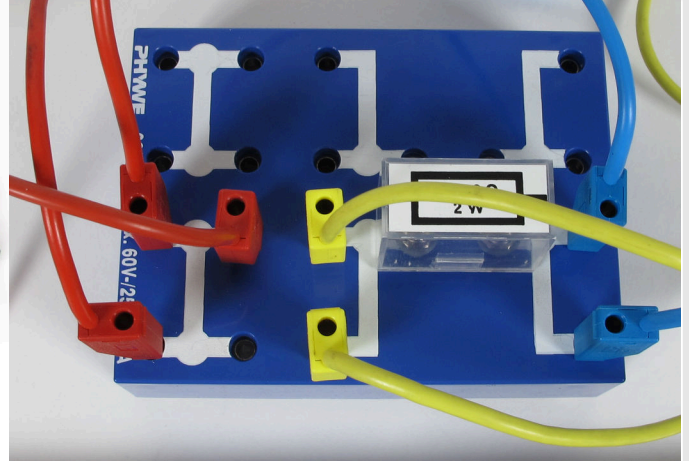
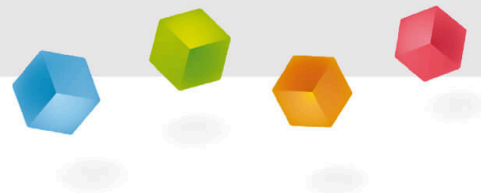


Fig. 9: Set-up of the connection box for use of the resistance board with the Wheatstone bridge.

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Evaluation



Task 1

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Calculate the resistance of the unknown resistors using Eq. 6 and the measured lengths on the slide wire. Reveal the indicated values of the used resistors and compare them to the calculated results (see example in Tab. 1).

You will notice that the deviation increases for values measured close to the wire ends. Nevertheless, the absolute values of measured and actual resistance are in good agreement. In order to reduce tolerance, exchange the comparison resistor R_C with a resistor of comparable magnitude to R_x .

Labeling	R_C [Ω]	l_1 [mm]	l_2 [mm]	R_x [Ω]	actual R_x [Ω]	diviation [%]
R_{x1}	100	690	310	223	220	1.4
R_{x2}	100	22	978	2.25	2	12.5
R_{x3}	100	317	683	46.4	47	-1.3
R_{x4}	100	51	949	5.4	5	8.0
R_{x5}	100	875	125	700	680	2.9

Table 1: Evaluation of unknown resistors with the Wheatstone bridge.

Task 2

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Calculate the total resistance R_x of the unknown resistors in the series circuit using Eq. 6 and the measured lengths on the slide wire. Reveal the indicated values of the used resistors and compare them to the calculated results (see example in Tab. 2).

Used resistors	R_C [Ω]	l_1 [mm]	l_2 [mm]	R_x [Ω]	actual R_x [Ω]	diviation [%]
R_{x3}, R_{x5}	100	882	118	747.5	727	2.8
R_{x1}, R_{x4}	100	690	310	222.6	225	-1.1
R_{x1}, R_{x2}, R_{x3}	100	732	268	273.1	269	1.5
R_{x1}, R_{x3}, R_{x5}	100	909	91	998.9	947	5.5

Table 2: Evaluation of resistors in a series circuit.

According to Kirchhoff's second law, the voltage drop across each leg of the Wheatstone bridge sums up to the total applied voltage at the point of balance. Because of the constant current flow along each leg, Ohm's law gives a total resistance that is equal to the sum of each individual resistance value in a series circuit

$$R_{\text{tot}} = \sum_{i=1}^n R_i \quad (7)$$

Task 3

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Calculate the total resistance R_x of the unknown resistors in the parallel circuit using Eq. 6 and the measured lengths on the slide wire. Reveal the indicated values of the used resistors and compare them to the calculated results (see example in Tab. 3).

Used resistors	R_C [Ω]	l_1 [mm]	l_2 [mm]	R_x [Ω]	actual R_x [Ω]	diviation [%]
R_{x1}, R_{x3}	100	282	718	39.3	38.7	1.4
R_{x2}, R_{x3}	100	17	983	1.7	1.9	-9.9
R_{x4}, R_{x5}	100	44	956	4.6	5.0	-7.3

Table 3: Evaluation of resistors in a parallel circuit.

According to Kirchhoff's first law, the total current in a parallel circuit of resistors equals the sum over the currents in each individual branch whereas the voltage is the same for each component. Thus the total resistance of a parallel circuit can be determined using Ohm's law and adding up the reciprocal values of each components' resistance:

$$\frac{1}{R_{\text{tot}}} = \sum_{i=1}^n \frac{1}{R_i} \quad (8)$$

Adding a parallel branch to the circuit increases the current flow because the present resistance can be bypassed along the extra branch. Therefore, the total resistance of a parallel circuit is always lower than the resistance value of the smallest particular resistor (see Tab. 3).

Task 4 (1/3)

PHYWE

Calculate the total resistance R_x of the wires in the parallel circuit using Eq. 6 and the measured lengths on the slide wire (see example in Tab. 4).

d [mm]	l_1 [mm]	l_2 [mm]	R_x [Ω]
1	392	608	0.645
0.5	717	283	2.53
0.7	564	436	1.29
0.35	840	160	5.25

Table 4: Resistance of various Constantan wires with length $l = 1$ m.

Corresponding to Eq. 5, the electrical resistivity is an intrinsic property that can be calculated from the measured resistance of the wire and its geometry

$$\rho = R \cdot \frac{A}{l} \quad (9)$$

Task 4 (2/3)

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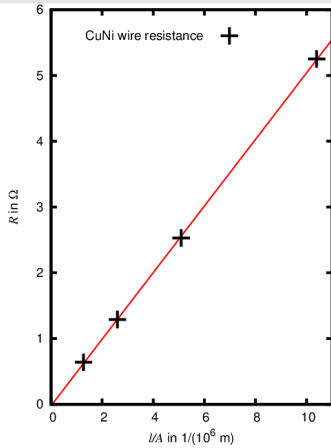


Fig. 10: Resistance of a conductor wire as a function of its geometry l/A .

Given that the resistance has been obtained for several wires made of the same material, the electrical resistivity of CuNi can be determined with increased accuracy by plotting the resistance R against l/A . The proportionality factor ρ corresponds to the slope of the linear fit (as shown in Fig. 10)

$$R = \rho \frac{l}{A} = \rho \frac{l}{\pi r^2} = \rho \frac{4 \cdot l}{\pi d^2} \quad (10)$$

The slope of the fit in Fig. 10 gives an electrical resistivity of

$$\rho = 5.06 \cdot 10^{-7} \Omega \cdot \text{m} \quad (11)$$

that is in very good agreement with the literature value for Constantan of approximately $5.0 \cdot 10^{-7} \Omega \text{m}$

Task 4 (3/3)

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Remark

- In this experiment, the resistance values of the four resistors have been taken into account, only. Actually, the resistance of the used cords, the connections as well as the ammeter could not be avoided and have been neglected as there is only a minor influence on the results.
- It is possible to determine very small resistances with the Wheatstone bridge gaining a high accuracy. Yet, the results lose precision when moving the slider to the far end positions of the potentiometer. For best results, the slider should remain close to the central position, and instead, the comparison resistor should be replaced until its magnitude matches that of the unknown resistor.