Electricity

Fundamentals of electricity
Ohm's law

Verifying Ohm's law and measuring specific resistances

Objects of the experiment

- Measuring the voltage and the current on four constantan wires with different cross-sectional areas.
- Measuring the voltage and the current on two constantan wires with different lengths.
- Measuring the voltage and the current on a constantan wire and on a brass wire.
- Verifying Ohm's law and determining the resistances.

Principles

In circuits made up of metallic conductors, the voltage U at a conductor is, to a good approximation, proportional to the current I flowing through the conductor, i.e. Ohm's law

$$U = R \cdot I \tag{I}$$

holds. The proportionality constant R is called the resistance of the conductor.

The resistance R of a wire with the length ℓ and the cross-sectional area A is given by

$$R = \rho \cdot \frac{\ell}{A} \tag{II}$$

ρ: specific resistance of the wire material.

In the experiment, the proportionality between the current and the voltage is confirmed for metal wires with various thicknesses and lengths and for wires made of different materials. In each case, the resistance is determined as the proportionality constant. The dependence of the proportionality constant on the length and on the cross-sectional area is examined and the specific resistance of the material used is determined according to Equation (II).

Fig. 1: Experimental setup for verifying Ohm's law

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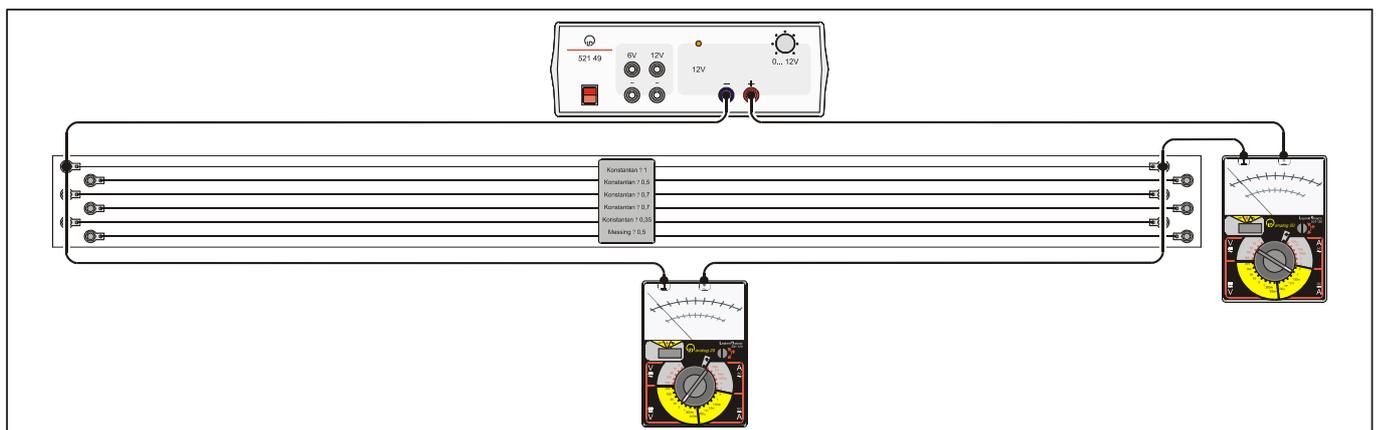
Apparatus

1 Apparatus for resistance measurement 550 57
1 AC/DC Power supply 0 - 12 V............................ 521 49
1 Pair cables 100 cm, red/blue 501 46
3 Connecting lead 100 cm black........................... 501 33
1 Connecting lead 25 cm black............................ 501 23

Version (a)
1 Ammeter, DC, $I \leq 3$ A................................. e.g. 531 120
1 Voltmeter, DC, $U \leq 15$................................ e.g. 531 120

Version (b)
1 Pocket-CASSY 524 006
1 UIP-Sensor S... 524 0621
1 CASSY Lab... 524 200
Additionally required:
1 PC with Windows 2000/XP/Vista

Setup and carrying out the experiment

The experimental setup measuring with the ammeter and voltmeter (version (a)) is illustrated in Fig. 1. For using measuring with the CASSY system refer to the chapter "*How to record and evaluate with the CASSY system*" (appendix).

- Connect the voltmeter to the constantan wire 1 mm dia. and connect the voltage source and the ammeter in series to this arrangement (ranges 3 V DC and 3 A DC).

- Adjust voltage drops U between 0 V and 1.2 V in steps of 0.1 V, each time reading the current I and taking U and I down.

- Connect the constantan wire 0.7 mm dia. and record the series of measurements in steps of 0.2 V (ranges 3 V DC and 3 A DC).

- Record further series of measurements on the constantan wire 0.5 mm dia. in steps of 0.4 V up to 3.6 V and on the constantan wire 0.35 mm dia. in steps of 0.8 V up to 4 V (ranges 10 V DC and 3 A DC).

- For the series connection of the two constantan wires 0.7 mm dia. (total length ℓ = 2 m), connect the two sockets on one side via a short cable.

- Connect the voltmeter, the ammeter and the voltage source to the sockets on the opposite side.

- Record another series of measurements in steps of 0.4 V (ranges 3 V DC and 3 A DC).

- Record a series of measurements on brass 0.5 mm dia. in steps of 0.1 V (ranges 1 V DC and 3 A DC), and compare it with the series of measurements on constantan 0.5 mm dia.

Measuring example

Table 1: constantan wires with equal length (ℓ = 1 m) and different thickness

d = 1.0 mm A = 0.8 mm²		d = 0.7 mm A = 0.4 mm²		d = 0.5 mm A = 0.2 mm²		d = 0.35 mm A = 0.1 mm²	
$\dfrac{U}{V}$	$\dfrac{I}{A}$	$\dfrac{U}{V}$	$\dfrac{I}{A}$	$\dfrac{U}{V}$	$\dfrac{I}{A}$	$\dfrac{U}{V}$	$\dfrac{I}{A}$
0.1	0.16	0.2	0.15	0.4	0.15	0.8	0.16
0.2	0.32	0.4	0.32	0.8	0.32	1.6	0.32
0.3	0.48	0.6	0.48	1.2	0.47	2.4	0.48
0.4	0.64	0.8	0.64	1.6	0.63	3.2	0.63
0.5	0.78	1.0	0.78	2.0	0.78	4.0	0.78
0.6	0.96	1.2	0.94	2.4	0.96		
0.7	1.12	1.4	1.10	2.8	1.12		
0.8	1.28	1.6	1.25	3.2	1.26		
0.9	1.44	1.8	1.41	3.6	1.42		
1.0	1.60	2.0	1.56				
1.1	1.76	2.2	1.70				
1.2	1.92						

Table 2: constantan wires with equal thickness (d = 0.7 mm) and different length

ℓ = 1 m		ℓ = 2 m	
$\dfrac{U}{V}$	$\dfrac{I}{A}$	$\dfrac{U}{V}$	$\dfrac{I}{A}$
0.2	0.15	0.4	0.17
0.4	0.32	0.8	0.30
0.6	0.48	1.2	0.48
0.8	0.64	1.6	0.62
1.0	0.78	2.0	0.78
1.2	0.94	2.4	0.93
1.4	1.10	2.8	1.10
1.6	1.25	3.2	1.23
1.8	1.41	3.6	1.40
2.0	1.56	4.0	1.56
2.2	1.70	4.4	1.70

Table 3: brass wire and constantan wire with equal thickness (d = 0.5 mm) and equal length (ℓ = 1 m).

Brass		Constantan	
$\dfrac{U}{V}$	$\dfrac{I}{A}$	$\dfrac{U}{V}$	$\dfrac{I}{A}$
0.1	0.27	0.4	0.15
0.2	0.54	0.8	0.32
0.3	0.82	1.2	0.47
0.4	1.06	1.6	0.63
0.5	1.36	2.0	0.78
0.6	1.62	2.4	0.96
0.7	1.88	2.8	1.12
		3.2	1.26
		3.6	1.42

Evaluation

a) Qualitative comparison

A comparison of all measured values in one line of Table 1 shows that the voltage *U* is doubled when the cross-sectional area is halved at equal current *I*.

Table 2 shows that the voltage *U* is doubled when the wire length is doubled at equal current *I*.

b) Quantitative evaluation

The measured values of Tables 1, 2 and 3 are plotted in Figures 2, 3 and 4, respectively. The agreement of the measured values with the straight lines through the origin drawn in the diagrams confirms that in all cases the voltage *U* at the wire is proportional to the current *I* flowing through the wire. The resistances R obtained as the slope of the straight lines are listed in Tables 4, 5 and 6.

Table 4: resistance *R* of a 1 m long constantan wire as a function of the cross-sectional area *A*, determined from the slopes of the measured curves in Fig. 2

$\dfrac{A}{mm^2}$	$\dfrac{R}{\Omega}$	Symbol
0.1	5.08	●
0.2	2.53	○
0.4	1.28	■
0.8	0.63	□

Table 5: resistance *R* of a 0.7 mm thick constantan wire as a function of the length ℓ, determined from the slopes of the measured curves in Fig. 3

$\dfrac{\ell}{mm}$	$\dfrac{R}{\Omega}$	Symbol
1 m	1.28	■
2 m	2.58	⊠

Table 6: resistance *R* of constantan wire and brass wire, determined from the slopes of the measured curves in Fig. 4

Material	$\dfrac{R}{\Omega}$	Symbol
Brass	0.37	◉
Constantan	2.53	○

Fig. 2: Relation between the voltage *U* and the current *I* for constantan wires with the cross-sectional areas *A* = 0.1 mm² (●), 0.2 mm² (○), 0.4 mm² (■) and 0.8 mm² (□)

Fig. 3: Relation between the voltage *U* and the current *I* for constantan wires with the lengths ℓ = 1 m (■) and 2 m (⊠)
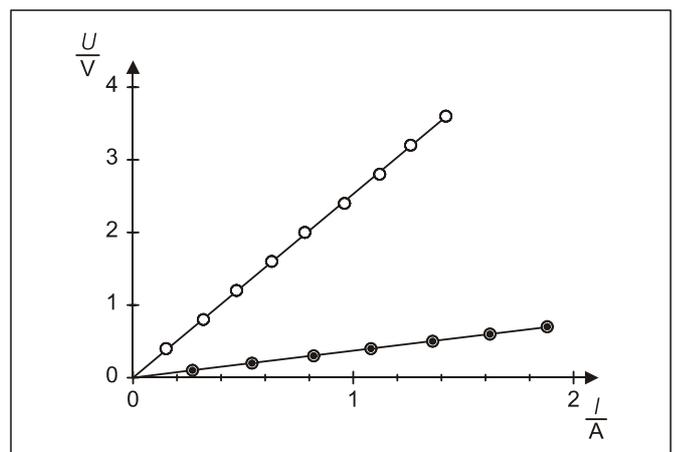

Fig. 4: Relation between the voltage *U* and the current *I* for constantan wire (○) and brass wire (◉) with equal cross-sectional area and equal length

Dependence on the cross-sectional area A:

The dependence of the resistance on the cross-sectional area of the wire is displayed graphically in Fig. 5 with the values from Table 4. The curve drawn in the figure obeys – in agreement with Equation (II) – the equation

$$R = \frac{5.06\ \Omega\text{mm}^2}{A}.$$

That means, when the cross-sectional area is doubled, the resistance of the wire is halved.

Dependence on the length ℓ :

As is seen from Fig. 3 and Table 5, respectively, the resistance is doubled if the wire length is doubled. This result, too, is in agreement with Equation (II).

Fig. 5: Dependence of the resistance *R* on the cross-sectional area A for a 1 m long constantan wire

Dependence on the material:

According to Fig. 4 and Table 6, respectively, the resistance of a brass wire is considerably smaller than the resistance of a constantan wire with equal dimensions ($A = 0.2$ mm^2 and $\ell = 0.1$ m).

With Equation (II) the following specific resistances are obtained:

Constantan: $\rho = 0.51 \dfrac{\Omega\text{mm}^2}{\text{m}}$ (Table: $0.49 \dfrac{\Omega\text{mm}^2}{\text{m}}$)

Brass: $\rho = 0.074 \dfrac{\Omega\text{mm}^2}{\text{m}}$ (Table: $0.065 \dfrac{\Omega\text{mm}^2}{\text{m}}$)

Results

The voltage at a metallic conductor is proportional to the current flowing through the conductor (Ohm's law). The proportionality constant, the ohmic resistance, depends on the length, the cross-sectional area and the material of the conductor.
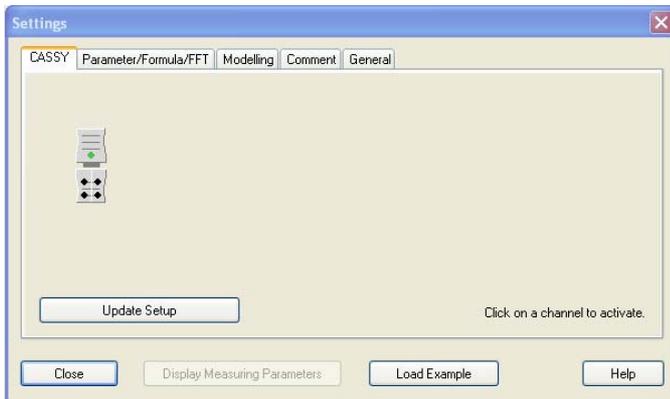
Appendix

How to record and evaluate with the CASSY system

In this chapter the experimental procedure using the CASSY system is described. Fig. 6 shows the experimental setup with the Pocket-CASSY and the UIP-Sensor S.

- Connect the Pocket-CASSY to the computer via the USB port.
- Connect the UIP-Sensor S to the Pocket-CASSY.
- Connect the voltmeter socket of Pocket-CASSY to the constantan wire 1 mm dia. (Fig. 6).
- Connect the voltage source and the ammeter of the Pocket-CASSY in series to this arrangement (Fig. 6).

- If not yet installed install the software CASSY Lab and run the software.
- Open the window "Settings" using the tool box button or function key F5 from the top button bar:

- Pocket-CASSY with the connected UIP-Sensor S should be displayed at the tab "CASSY" if Pocket-CASSY is connected via the USB port to the computer.

Fig. 6: Experimental setup for verifying Ohm's law − measuring with the CASSY system

- Activate connected voltage U and current I sockets of Pocket-CASSY by clicking at the corresponding voltage and current field.

Note: Further details about connecting sensors to Sensor CASSY can be found in the manual "CASSY Lab Quick Start".

- In the window "Measuring Parameters" (lower corner left side) set "Manual Recording".
- Click with the right mouse button on the window "Voltage U_1" or the corresponding button in the top menu bar to select the measuring range "10 V".
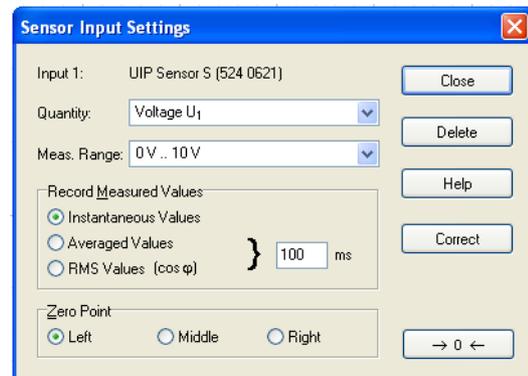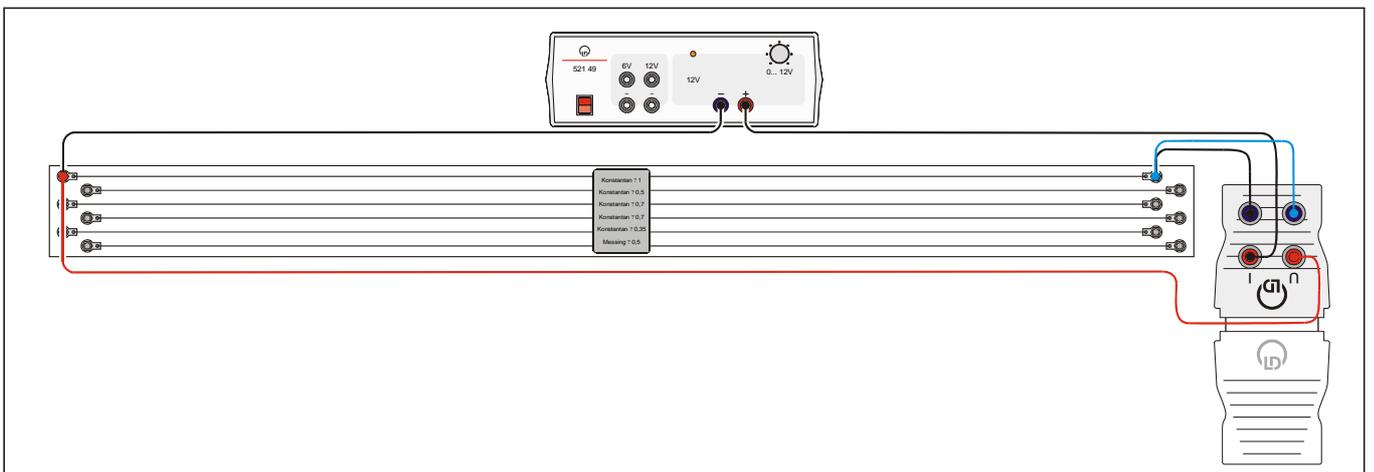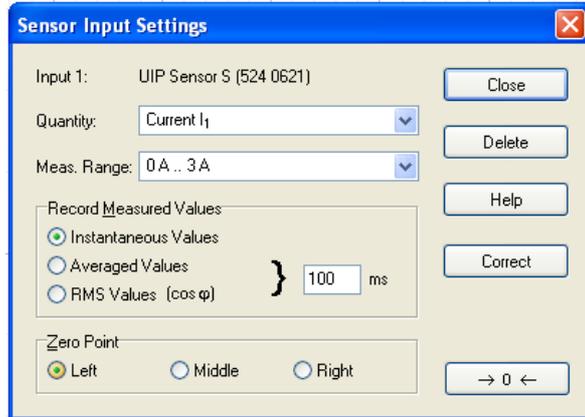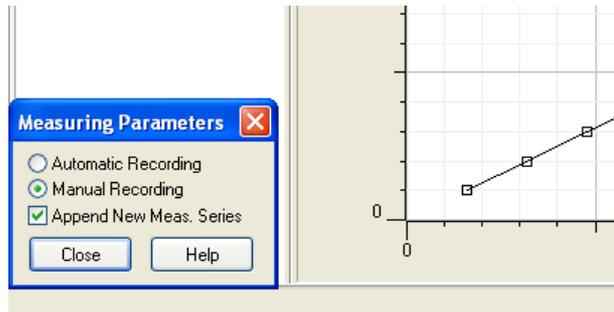- Select "Zero Point" left.

- Click with the right mouse button on the window "Current I$_1$" or the corresponding button in the top menu bar to select the measuring range "3 A".
- Select "Zero Point" left.

- To display the voltage U$_1$ as a function of the current I$_1$ click on the tool box button 🔧 or function key F5: select U$_1$ as x-Axis and I$_1$ as y-Axis.

Carrying out the experiment

- Adjust voltage drops *U* between 0 V and 1.2 V in steps of 0.1 V, each time record the current I$_1$ and U$_1$ by clicking the clock button 🕐 or the function key F9. The following picture shows the result of this measurement series:

Note: You may save your measurements by pressing the button 💾 or using the function key F2.

Note: To change the settings of the graphic or copy the data click with the right mouse button on the display, tables and axes to open the desired pop up menu.

- To append an additional measurement series double click on the tool box button 🔧 and select "Append New Measurement Series".
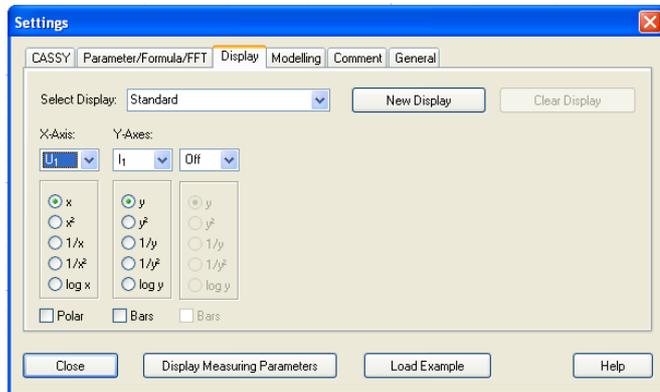

- Connect the constantan wire 0.7 mm dia. and record the series of measurements in steps of 0.2 V.
- Double click on the tool box button 🔧 and select "Append New Measurement Series".
- Record further series of measurements on the constantan wire 0.5 mm dia. in steps of 0.4 V up to 3.6 V and on the constantan wire 0.35 mm dia. in steps of 0.8 V up to 4 V.

The following picture shows the result of this measurement series:
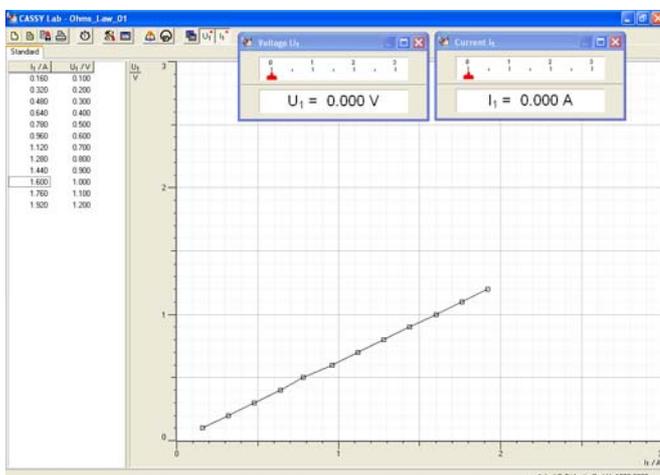

Note: The measured data values are plotted only. To set the graphics settings click with the right mouse button in to the display and choose your setting, e.g. "Set Value display".

Note: A template file can be created by just clearing an existing measurement with the button 📄 (one click only) or the function key F4 and saving the file to the hard disk by pressing the button 💾 or using the function key F2.
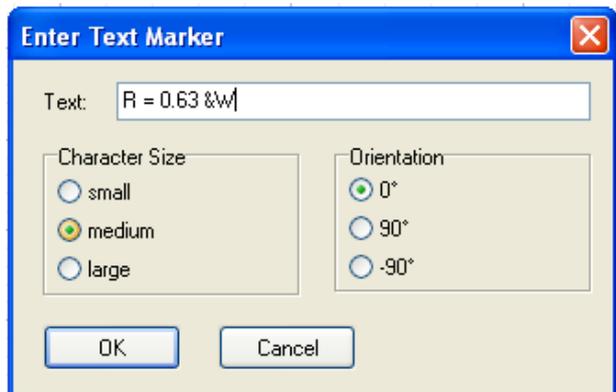
Evaluation and results

- To determine the resistance R click the right mouse button into the graph to access the "Fit Function" tool. Chose "Fit Function" and select "Straight Line through Origin".
- Select the data to be fitted by dragging the mouse pointer over the data points to be fitted, i.e. the first measurement series and release the mouse button.

Note: Further details about how to enter Greek letters can be found can be found in the manual "CASSY Lab FAQ".

- To display the result of the linear regression click the right mouse button into the graph to access the "Set Marker Tool" / "Text".
- Enter R for the slope "A".
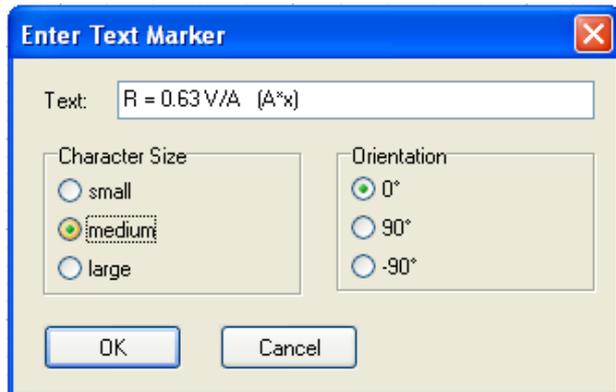
- The units "V/A" can be replaced by the Greek letter for Ohm, by typing "&W".

- Select e.g. "medium" and press "OK" and place the result near the fitted measuring series.
- Repeat the linear regression procedure for the other measurement series.

Note: To display evaluation results in the plot or label measuring series you may use the short cut key Alt-T.

Note: Further details about how to enter Greek letters can be found can be found in the manual "CASSY Lab Quick Start".
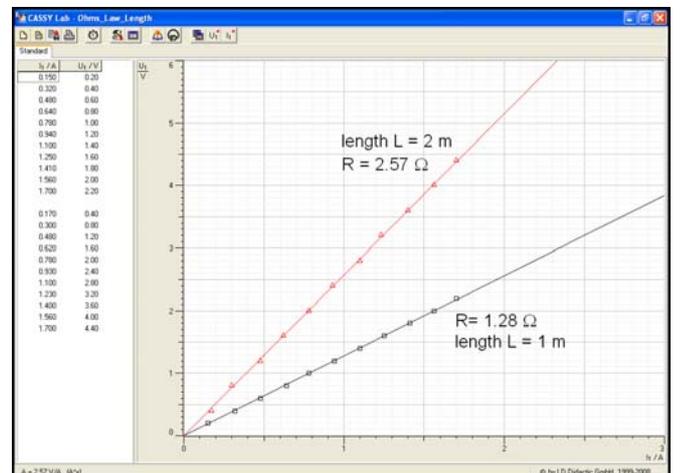
The following picture shows the result of this measurement series:
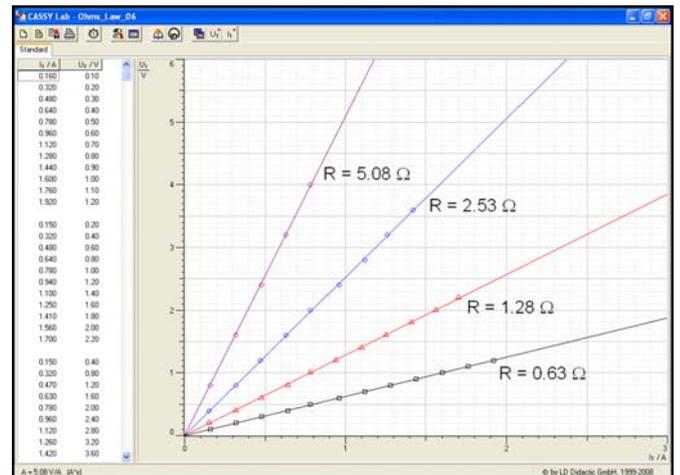
The measurement series for constantan wires 0.7 mm dia. (total length ℓ = 1 m and ℓ = 2 m) can be performed in similar manner. The measuring results with CASSY are shown in the following picture:
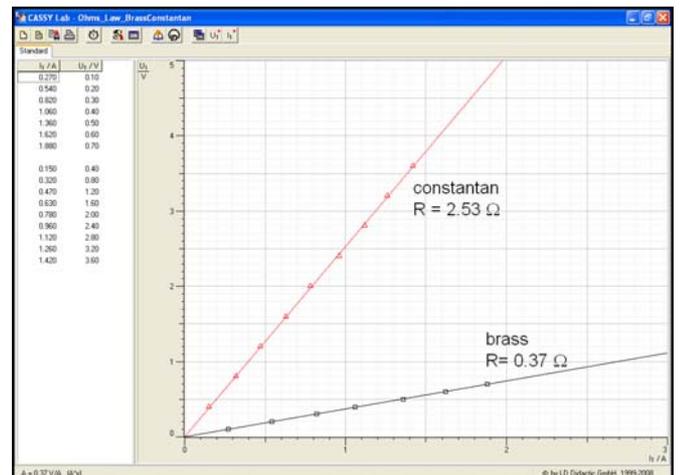
The measurement series on brass 0.5 mm dia. in steps of 0.1 V and the measurement series on constantan 0.5 mm dia can also be performed in a similar manner. The measuring results with CASSY are shown in the following picture:


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Advanced Data Evaluation with CASSY Lab:

To investigate the Dependence of the cross-sectional area A on the resistance R the CASSY Lab software offers advanced data evaluation features:
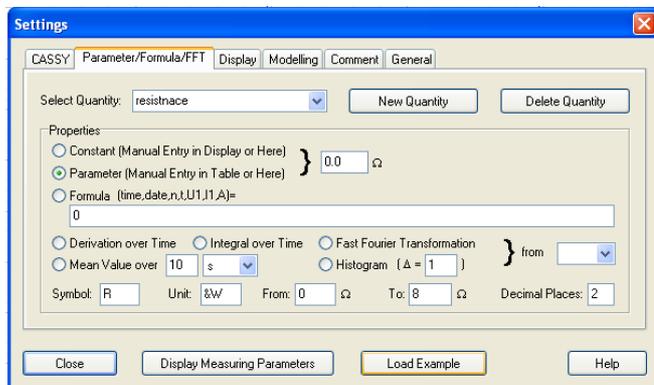
Defining the cross sectional area A

- If the window "Settings" is not open press the button 🖳 or function key F5 and select the tab "Parameter/Formula/FFT".
- Click on the button "New Quantity" to define the parameter cross sectional area A (enter this name) and choose "Parameter".
- Enter "A" to define the symbol.
- Enter "mm" for the unit.
- Enter the range from 0 mm to 1 mm
- Choose Decimal Places to 1.
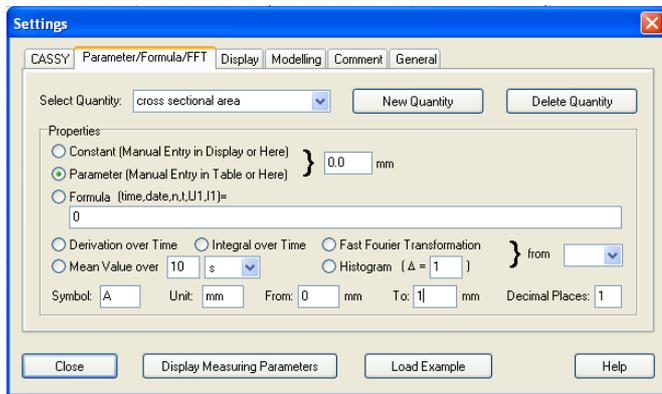
Defining the resistance R

- If the window "Settings" is not open press the button 🖳 or function key F5 and select the tab "Parameter/Formula/FFT".
- Click on the button "New Quantity" to define the parameter resistance R (enter this name) and choose "Parameter".
- Enter "R" to define the symbol.
- Enter "&J" for the unit.
- Enter the range from 0 Ω to 8 Ω
- Choose Decimal Places to 2.

To display the resistance R as a function of the cross sectional A define a new graphic display "Evaluation":

- If the window "Settings" is not open press the button 🖳 or function key F5 and select the tab "Display".
- Press the button "New Display" to generate a new display and enter the name, e.g. Evaluation.
- Choose A to be the x-Axis and R to be the y-Axis.
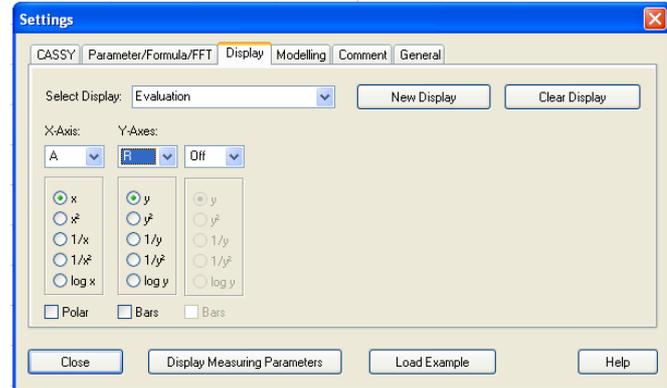
If you perform a fit of a straight line trough origin the drag and drop capability of the software allows you to shift the result of the fit (i.e. the value of the determined resistance) into the table of the new defined Display "Evaluation".

Note: For details concerning drag and drop capability refer to the help menu of CASSY Lab using the help button "?" inside CASSY Lab.

The corresponding value of the cross sectional area A have to be entered manually in the table of the new defined Display "Evaluation".

Using the fitting tool (right mouse click into the graphic "Evaluation" and choosing "Hyperbola 1/x") gives the following results: