Leybold Physik
Physics
Physique

Elektrik
Electricity
Electricité

Basic Electrical Circuits

588 332
Students' work sheets
(Masters for copying)

Schülerversuche Naturwissenschaften
SVN
STM
Science Teaching Modules

STM-Physics
Electricity
Basic Electrical Circuits

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General instructions on the use of STM work folders

The need for complete editorial revision of the literature in the STM series (Science Teaching Modules) describing experiments for schools was the ideal opportunity to give the series a fresh, practical orientation:

The student's worksheets form the main focus of each work folder. These are laid out as a series of reference sheets, loose-leaf pages designed for use as master copies and capable of meeting the demands of a modern educational environment.

The associated teacher's workbook is an exact replica of the worksheets. In addition to defining the actual assignments, however, it also describes the object of each experiment and includes special hints and tips on each working step in the experiment, as well as additional information, calculated sample measurements and the answers to questions asked in the students' worksheets.

How the experiments are laid out:

The structure of the worksheets is essentially the same for all experimental topics. The basic information, such as the nature of the assignment itself, the list of apparatus required, setup diagrams etc. always appear in the same place and in the same order. For additional convenience, however, the experiments are also divided up into a series of consecutively numbered working steps. Diagrams and illustrations are also numbered consecutively. Any supplementary illustrations which appear in the teacher's notes are numbered according to the decimal classification system.

Symbols used:

The following symbols are used in the students' worksheets:

⚠ Caution! hazardous for the experimenter or experimental apparatus
Follow working instructions exactly.

▶ Refer to another point

About the apparatus:

To familiarise students with the equipment they will be using, the worksheets are preceded by a detailed section describing the various pieces of apparatus.

In addition to the list of apparatus and other aids which appears before each experiment (complete with catalogue numbers in the teacher's workbook), you will also find a complete list of all the apparatus used at the end of the book (after the reference sheets), showing all the apparatus and other equipment required for the particular subject area under examination

Each folder also contains a constantly updated list of the entire range of STM literature.

Preface

This book contains introductory descriptions of experiments for discovering the basic principles of electricity taken from the STM series (Science Teaching Modules).

All these experiments can be performed using apparatus sets EL1 and EL2, plus some additional apparatus (power supply units, measuring instruments).

Power supply, power supply units, apparatus

As we mentioned above, the power supply unit and measuring instruments are not included in the sets of apparatus.

So for example, you may decide to use a 12 V battery with a voltage divider as your power supply unit, or other kinds of more easily obtainable multimeter instead of the measuring instruments we have suggested.

This is why we have represented these items of equipment by their symbols in the student's worksheets.

To obviate any consequent difficulties, we have prefaced the experiment descriptions with a set of notes for student and teacher which describe how to use the low-voltage power supply unit and measuring instruments recommended.

Time required to perform the experiments

Each experiment has been designed in such a way that it should be possible to complete the entire experiment in one double lesson. This includes the preparatory talk, handing out the apparatus, setting it up correctly, performing the actual experiment and writing it up.

You can save time by omitting certain steps or one or more parts of the experiment, and also by sharing the work involved in preparing test reports.

In this way, it should always be possible to adapt each experiment to the needs and abilities of a particular class.

In the teacher's notes, the objectives of each experiment are outlined for each topic.

A quick look at these summaries is sufficient to gain a general impression of the subject matter of each experiment.

About the apparatus

1 Low-voltage power supply unit, 3 A (522 16)

The job of the low-voltage power supply unit is to supply electrical circuits with voltage. It does not generate this voltage itself, but transforms the high and dangerous mains voltage available from a mains socket into safe, low voltage.

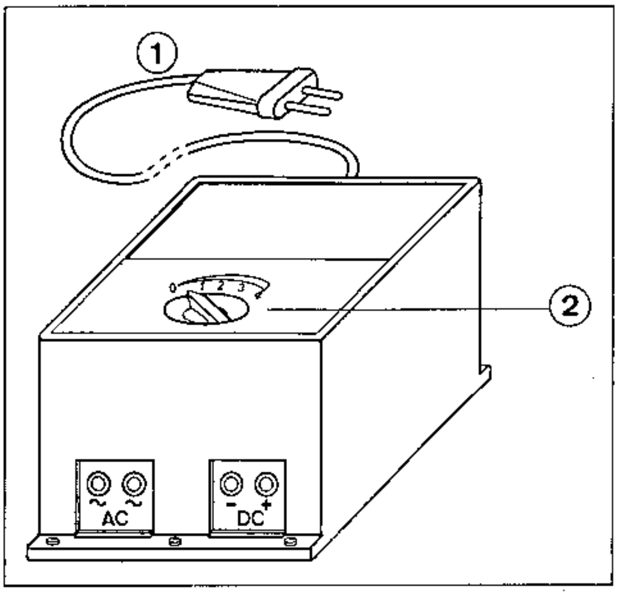


Fig. 1 Low-voltage power supply unit, 3 A (522 16)

Using the controls:

1.1 Lead with mains plug (1)

You should always start by plugging the mains plug attached to the power supply unit into the mains socket, so that the unit is supplied with the correct input voltage.

1.2 Stepped switch (2)

If you are not making any observations or measurements, the stepped switch should be set to 0.

You can turn the switch to one of four voltage levels in ascending steps from 1 to 4 (each step defines an increment of ca. 3 V). The voltage you set is applied across the outputs marked AC and DC.

DC = direct current

AC = alternating current

1.3 DC output terminal

Red socket = ⊕-pole
Blue socket = ⊖-pole

In the experiments, the red socket is always connected to the circuit by a red lead, and the blue socket by a blue lead. This helps you to avoid making mistakes while you are connecting up the circuit.

1.4 AC output terminal

This is a pair of black sockets marked with the AC symbol ~. Alternating voltage across these sockets means that the ⊕-pole and the ⊖-pole are constantly swapping over (50 times a second at 50 Hz). Because both sockets are equivalent to each other, they both have the same colour. For the same reason, there is no need to distinguish between the leads used to connect the sockets to the circuit.

1.5 Thermal fuse

Once it is plugged in, the low voltage power supply unit starts to heat up. It even heats up if the selector switch is set to 0. If too much current flows for too long while the switch is turned to one of the voltage levels, the unit overheats internally, causing a thermal fuse (a bimetallic-element switch) to turn off the output so that there is no longer any voltage available. This does not mean that there is anything wrong with the power supply unit. However, it usually takes a little while for the bimetallic-element switch to cool down before it switches on the voltage again.

1.6 **Symbolic representation**

The power supply unit is not illustrated realistically in the experiment descriptions. Only the symbols for the sockets are displayed, together with a symbol identifying the type of voltage.

▶ Figs. 2 and 3.

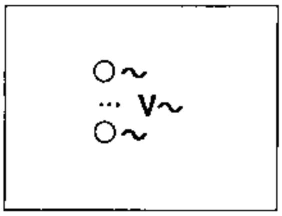


Fig. 2 AC voltage source

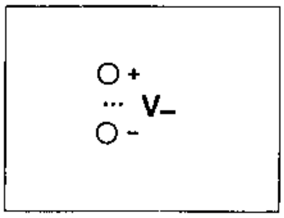


Fig. 3 DC voltage source

2 **Voltmeter (531 68)**

The voltmeter (fig. 4) is a moving-coil instrument. As you can see by looking at it, it contains a moving coil. You can only use this kind of voltmeter to measure DC voltage (identified by V–). "V" stands for "Volt". This is the unit of measurement for electrical voltage or potential. The highest DC voltage this instrument can measure is marked above the right-hand socket; in this case, 15 V.

2.1 **Input sockets**

The blue socket marked with "–" is always connected to the circuit by a blue lead. The other socket is always connected by a red lead. You may choose from three sockets marked with (+). The number above each socket, accompanied by a V (for Volts), specifies the measuring range selected if you plug the lead jack into that particular socket.

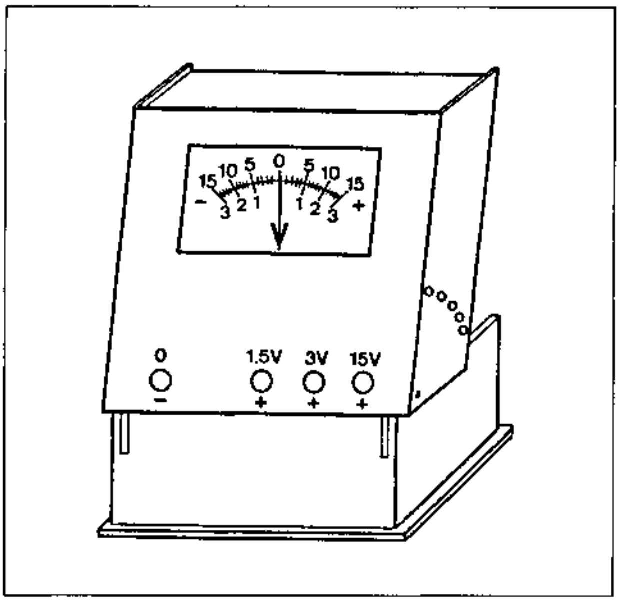


Fig. 4 Voltmeter (531 68)

2.2 **Measuring ranges**

The measuring range specifies the voltage which will cause the pointer tp deflect up to the last graduation mark on the scale, i.e. defines the full scale deflection (amplitude).

Exercise 1

A glance at the scale will show you whether the numbers at the top or bottom of the scale belong to the chosen measuring range.

Put a checkmark next to the right answer in Table 1!

2.3 **Scale**

As you can see, the zero point is located in the middle of the scale. This means you can measure voltages which reverse direction without having to swap over the connections. Unlike measuring instruments with zero points at the left-hand end of the scale, you will not damage this voltmeter if you mix up the ⊕ and ⊖-poles while you are connecting it to the circuit.

Now take a close look at the scale, the way it is graduated and the numbers by each graduation mark.

You can only read off a measured value accurately if you know what the measuring range is.

You can easily make a mistake when you are reading off measured values. Before you read off a measured value, always ask yourself this question:

How much does the voltage increase by every time the pointer moves up one increment?

Exercise 2

As a test, complete Table 2.

Write down every figure you read off, so not just 1 V, but 1.0 V. You should also write down any estimated figures (including zero).

2.4 **Symbol for voltmeter**

The voltmeter is always represented by its symbol in the instructions for the experiments. ▶ Fig. 5.

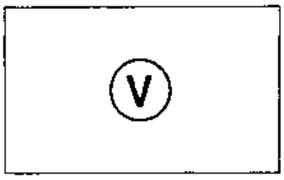


Fig. 5 Voltmeter-Symbol

3 **Ammeter (531 69)**

The ammeter (fig. 6) is a moving-coil instrument. As you can see by looking at it, it contains a moving coil. This ammeter will only measure direct current (symbolised by A–).

3.1 **Input sockets**

You should always connect the socket marked "–" to the circuit by a blue lead.

The other socket should be connected by a red lead. You have a choice between three sockets marked "+". The number above each socket, accompanied by an A (for Ampère), defines the measuring range selected if you plug the lead jack into that socket.

3.2 **Measuring ranges**

The measuring range indicates the strength of current at which the pointer deflects to the last graduation mark on the scale, i.e. the full-scale deflection.

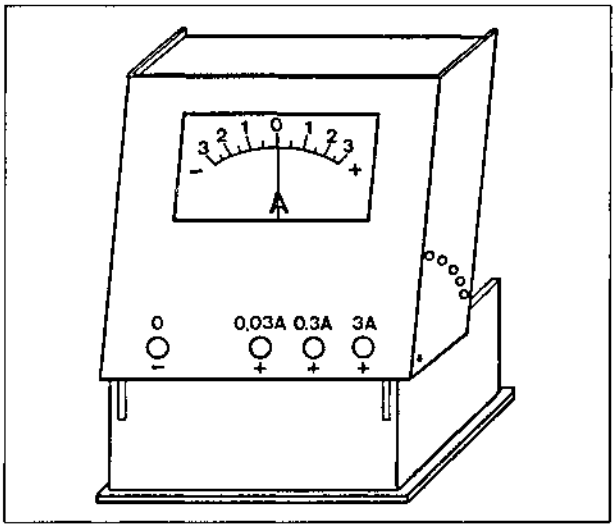


Fig. 6

3.3 **Scale**

As you can see, the zero point is located in the middle of the scale. This means you can measure currents which reverse direction without having to swap connections. Unlike measuring instruments with a zero point at the left-hand end of the scale, you will not damage this ammeter if you mix up the ⊕ and ⊖-poles by mistake.

Now take a close look at the scale, the way it is graduated and the numbers by each graduation mark. You can only read off a measured value accurately if you know what the measuring range is.

You can easily make a mistake when you are reading off measured values. Before you read off a measured value, always ask yourself this question:

How much does the current increase by every time the pointer moves up one increment?

Exercise 3

As a test, complete Table 3.

3.4 **Symbol for ammeter**

"A" stands for "Ampère". This is the unit of measurement for electrical currents. The largest measurable direct current (3 A–) is available from the right-hand socket (fig. 7).

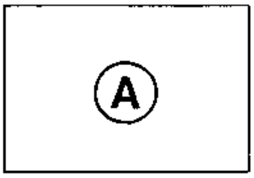


Fig. 7 Ammeter-Symbol

Solutions to the exercises:

for 2: voltmeter

Exercise 1

Table 1

Measuring range	Upper scale	Lower scale
15 V–	*x*	
3 V–		*x*
1.5 V–	*x*	

Exercise 2

Table 2

Measuring range	Voltage per increment
15 V–	*1.0* V–
3 V–	*0.20* V–
1.5 V–	*0.10* V–

for 3: ammeter

Exercise 3

Table 3

Measuring range	Current intensity per increment
3 A–	*0.5* A–
0.3 A–	*0.05* A–
0.03 A–	*0.005* A–

Student's Sheet 1

The simple circuit

Assignment: To build simple circuits and draw the corresponding circuit diagrams.

Apparatus:

1 layout plug-in board, DIN A4
1 lamp holder (screw-in holder, E10, lateral)
1 type A bulb (2.5 V / 0.1 A)
1 type B bulb (12 V / 3 W)
1 red lead, 50 cm
1 monocell holder
1 monocell
1 on/off switch (toggle switch)
3 jumper plugs

Student's Sheet 2

Setup:

1. Fit the monocell to the layout plug-in board using the monocell holder (fig. 1).

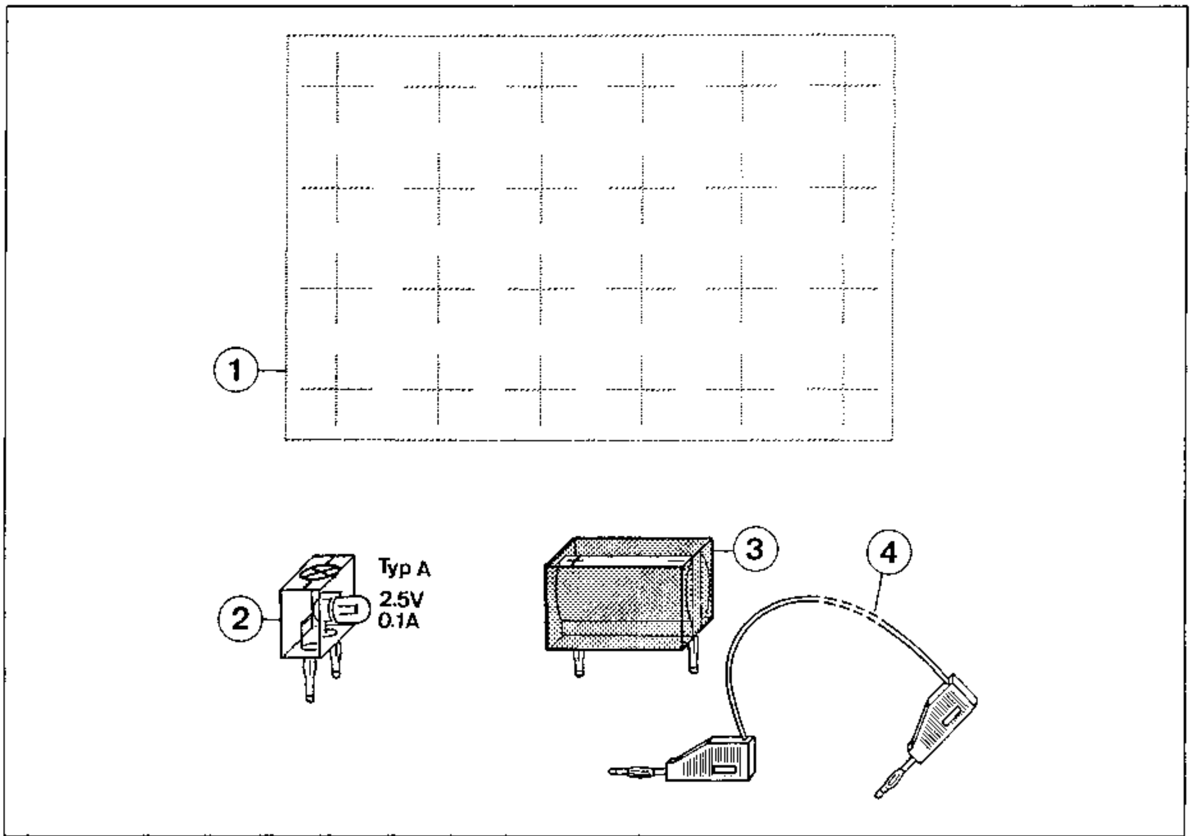


Fig. 1 Apparatus simple circuit
(1) Layout plug-in board
(2) E10 lateral screw-in lamp holder, fitted with a type A bulb (2.5 V / 0.1 A)
(3) Monocell holder with monocell
(4) Lead

Carrying out the experiment:

Experiment part 1:

Simple circuit without a switch

2. Screw the type A bulb (▶ fig. 2) into the lamp holder.
3. Construct a circuit using the monocell as the power supply unit and the lamp as the current indicator. Fig. 1 illustrates the equipment you can use.

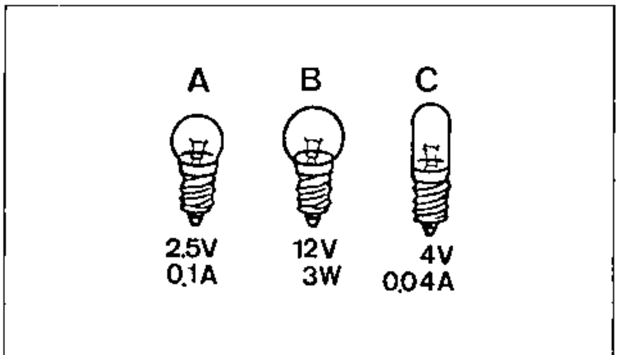


Fig. 2 Bulbs described in the experiments

4. How do you turn off the lamp?

____

____

Student's Sheet 3

5. Draw the circuit diagram for the circuit you have built. Take the symbols for the individual components from fig. 3.

Fig. 2.1 Solution 1 for exercise 3

Fig. 2.2 Solution 2 for exercise 3

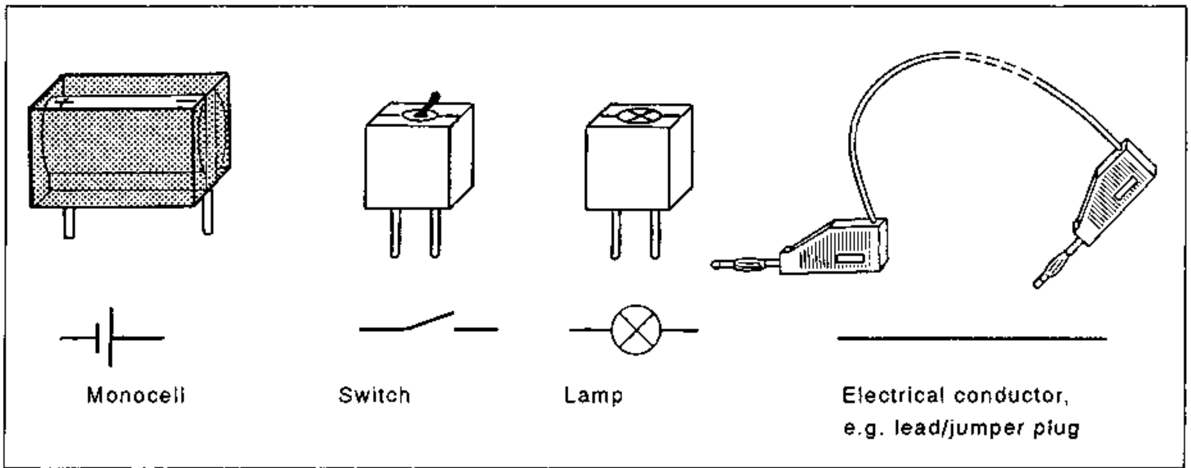


Fig. 3 Circuit components and their symbols

Fig. 3.1 Circuit diagrams for the circuits shown in figs. 2.1 and 2.2

Experiment part 2:

Simple circuit with switch

A switch is a device for breaking or making a circuit safely.

6. Monocell, switch, lamp (type A) and lead should be connected together in a simple circuit, as shown in the circuit diagram in fig. 4.
7. Check whether the connections between the individual components (monocell, switch, bulb) can be interchanged without affecting the brightness of the lamp.

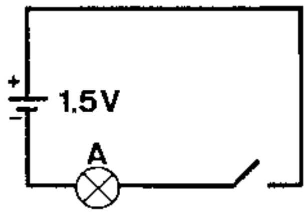


Fig. 4 Circuit diagram: Simple circuit with monocell and lamp

8. How many different ways can you combine the three components shown in fig. 4 in a circuit?

   Draw a circuit diagram showing the three components in a different order!

Fig. 4.1 Circuit diagram: ▶ Exercise 8

____

____

a) _______________

b) _______________

9. Using the bulb as your current indicator, can you see any difference in the intensity of the current if you change the order in which the components are connected?

   ____

10. Screw a type B bulb into the lamp holder instead of the type A bulb. Build the circuit shown in fig. 4. Actuate the switch.

    What do you see?

    ____

Student's Sheet 5

11. Replace the lead with jumper plugs in the circuit shown in fig. 4.
    Does the lamp change in brightness?

    ____

    ____

Fig. 4.2 Circuit ▶ Exercise 11

Evaluation:

12. A bulb should be connected to a monocell by leads. How many leads do you need for a bulb to light up?

    ____

13. What is the graphical symbol for an electrical conductor? Which components in the assembly act as conductors?

    ____

    ____

    ____

14. Does the intensity of the current in a circuit change if you change the order of the components (monocell, switch, lamp)?

    ____

Conductors and non-conductors (insulators)

Assignment: To test different materials and electrical components (resistances) for conductivity.

Apparatus:

1 layout plug-in board, DIN A4
3 jumper plugs
1 lamp holder (E10 screw-in holder, lateral)
1 type B bulb (12 V, 3 W)
1 type A bulb (2.5 V, 0.1 A)
1 toggle switch
1 pair of plug-in clamps
1 lead, red, 25 cm
1 lead, blue, 25 cm
1 set of 6 conductors/non-conductors (aluminium, brass, wood, polystyrene, Pertinax, perspex*)
1 voltage source, 12 V–, e.g. low-voltage power supply unit, 3 A, 220 V

Additional requirements for experiment part 2:

1 resistor, 47 Ω
1 resistor, 100 Ω

Note:
You may use a monocell instead of a power supply unit. If you do, you should use a type A bulb (2.5 V, 0.1 A) instead of a type B bulb (12 V, 3 W).

Also required:
1 jumper plug

---

* *As delivered, the perspex sheet is wrapped in protective paper. You should remove this paper before using the sheet for the first time.*

Setup:

1. Build the circuit shown in fig. 1.

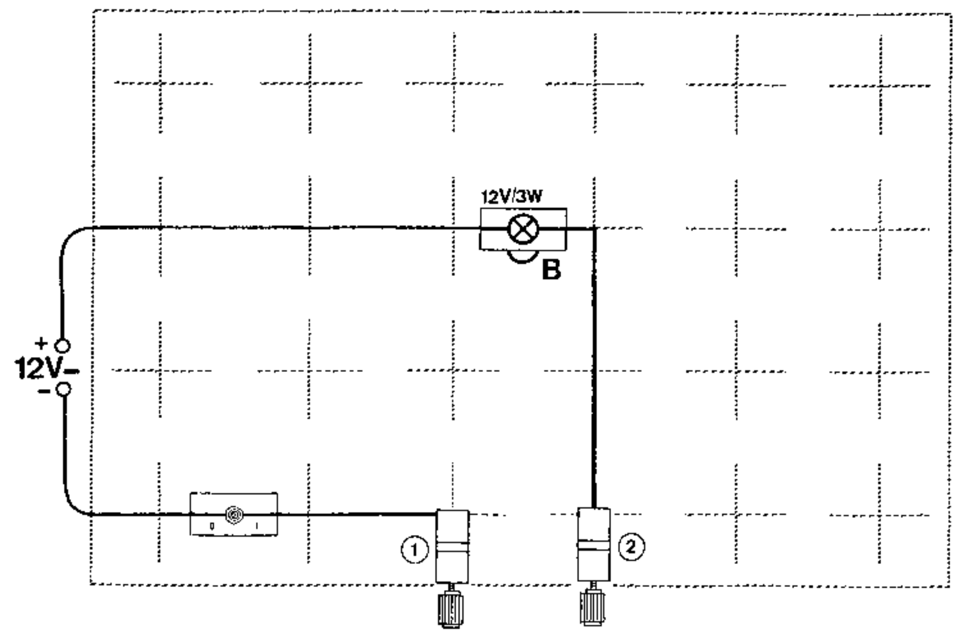


Fig. 1 Experiment setup:
Test of conductivity
Clamp each sample between the plug-in clamps (1) and (2)

Preparing your report:

2. Copy the table into your report book.

Carrying out the experiment:

Experiment part 1:

Testing various substances for conductivity

3. Test the substances listed in the table for conductivity, using the circuit shown in fig. 1.
Which substances conduct current, and which do not conduct current?
Classify each substance under one of the headings "Conductors" or "Non-conductors" in the table.

▶ *Table*

4. Draw the circuit diagram of the test circuit shown in fig. 1.
Symbol for a test section: ▶ fig. 2

▶ *Fig. 2.1.*

Fig. 2 Graphic symbol for a test section

Fig. 2.1 Circuit diagram ▶ Exercise 4

Report:

Table

Substance	Conductor	Non-conductor
Aluminium		
Brass		
Wood		
Polystyrene (grey)		
Pertinax (brown)		
Perspex		

Experiment part 2:

Testing resistances

5. Modify the circuit shown in fig. 1 so that you can test the conductivity of the plug-in resistors.

   ▶ *Fig. 2.2.*

6. Close the circuit by inserting the 47 Ω (Ω = Ohm) resistor.
   Actuate the switch and watch the bulb.

   Observation:

   ____

Fig. 2.2 Experiment setup: Testing the conductivity of resistors located at (1)

7. Repeat step 6 using the 100 Ω resistor.
   Does more or less current flow through this resistor, compared to the 47 Ω resistor?

Evaluation:

Experiment part 1:

8. Which substances are conductors, and which non-conductors (insulators)?

Experiment part 2:

9. Do all electrical conductors conduct current equally well?

Student's Sheet 1

Switching over

Assignment: To build a circuit with two lamps and one changeover switch. One or other of the lamps should light up, depending on the position of the switch.

Apparatus:
1 layout plug-in board
1 changeover switch
2 lamp holders (screw-in holders, E10, lateral)
2 type B bulbs (12 V, 3 W)
1 jumper plug
1 lead, 25 cm, red
1 lead, 25 cm, blue
1 voltage source, 12 V–
e.g. low-voltage power supply unit, 3 A, 220 V

Setup:

1. Draw the circuit diagram for the circuit shown in fig. 1. The symbol for a changeover switch is shown in fig. 2.

2. Build the circuit shown in fig. 1.

3. Actuate the changeover switch.
What position is the switch in when L_1 lights up? and when L_2 lights up?

____

____

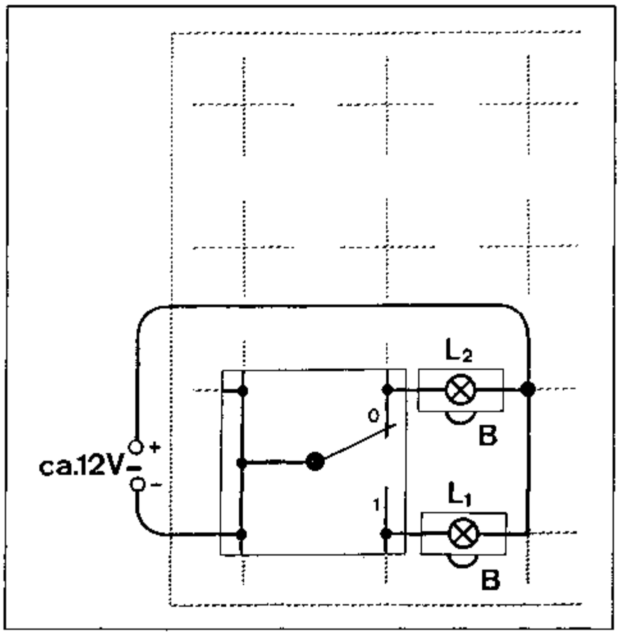


Fig. 1 Experiment setup: Switching over

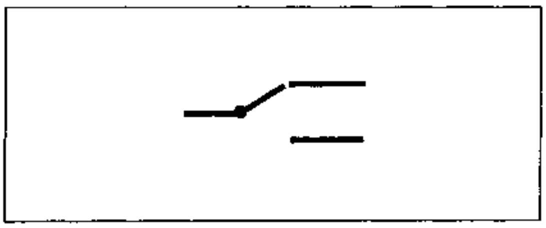


Fig. 2 Graphical symbol: Changeover switch

Fig. 2.1 Circuit diagram for the circuit shown in fig. 1 ▶ 1.

4. Arrange the changeover switch and lamps as shown in fig. 3.

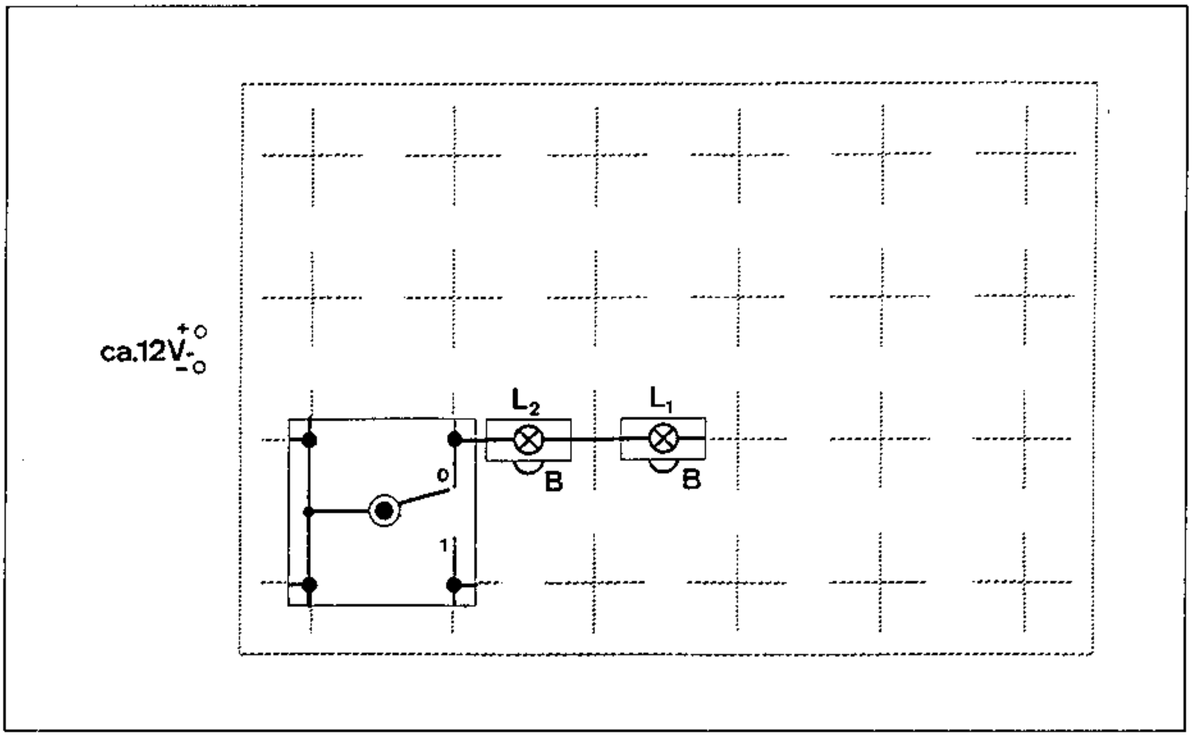


Fig. 3 Arrangement of plug-in components for a changeover circuit ▶ 4.

5. Depending on the position of the switch, one or other of the lamps should light up, as before. How many leads do you need to complete the circuit?
Draw the circuit diagram.

Fig. 3.1 Circuit diagram for a changeover circuit arranged as shown in fig. 3 ▶ 5.

6. Wire up the circuit according to the circuit diagram.

Fig. 3.2 Changeover circuit: Wiring up the components shown in fig. 3 ▶ 6.

Evaluation:

7. How many terminals does a changeover switch have?

____

8. Which of the changeover switch's terminals is always linked to one pole of the voltage source, regardless of the position of the switch?

____

____

9. Where would you use a changeover switch?

____

____

Student's Sheet 1

Two-way circuit

Assignment: To build a circuit in which a lamp can be turned on and off from two different points.

Apparatus:
1 layout plug-in board
1 jumper plug
1 lamp holder (screw-in holder, E 10, lateral)
1 type B bulb (12 V/3 W)
2 changeover switches, single-pole
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 voltage source, 12 V–
e.g. low-voltage power supply unit, 3 A

Setup/carrying out the experiment:

1. Draw the circuit diagram for the circuit in fig. 1. The symbol for a changeover switch is shown in fig. 2.

2. Build the circuit shown in fig. 1.

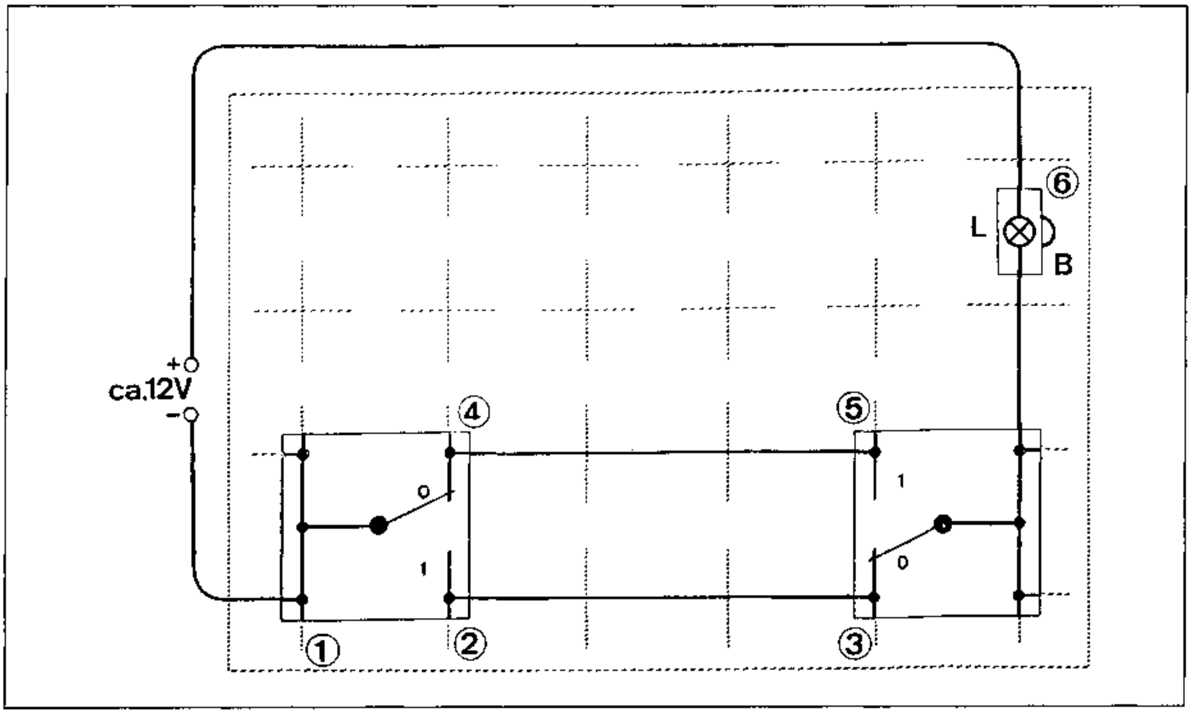


Fig. 1 Experiment setup: Two-way circuit
(1), (2), (3) ... (6) connection points on the layout plug-in board

Student's Sheet 2

3. Switch the lamp on and off from each of the two switches.
4. Which positions are the left- and right-hand switches in when the lamp in the circuit shown in fig. 1 lights up?

a)

b)

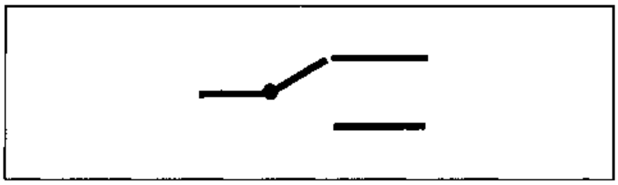


Fig. 2 Graphical symbol: changeover switch

Fig. 2.1 Circuit diagram for the setup in fig. 1 ▶ 1.

5. This kind of circuit (with two switches) is called a two-way circuit.
Which connections can you change round without impairing the function of either one of the switches?

6. Arrange the changeover switches and lamp as shown in fig. 3.

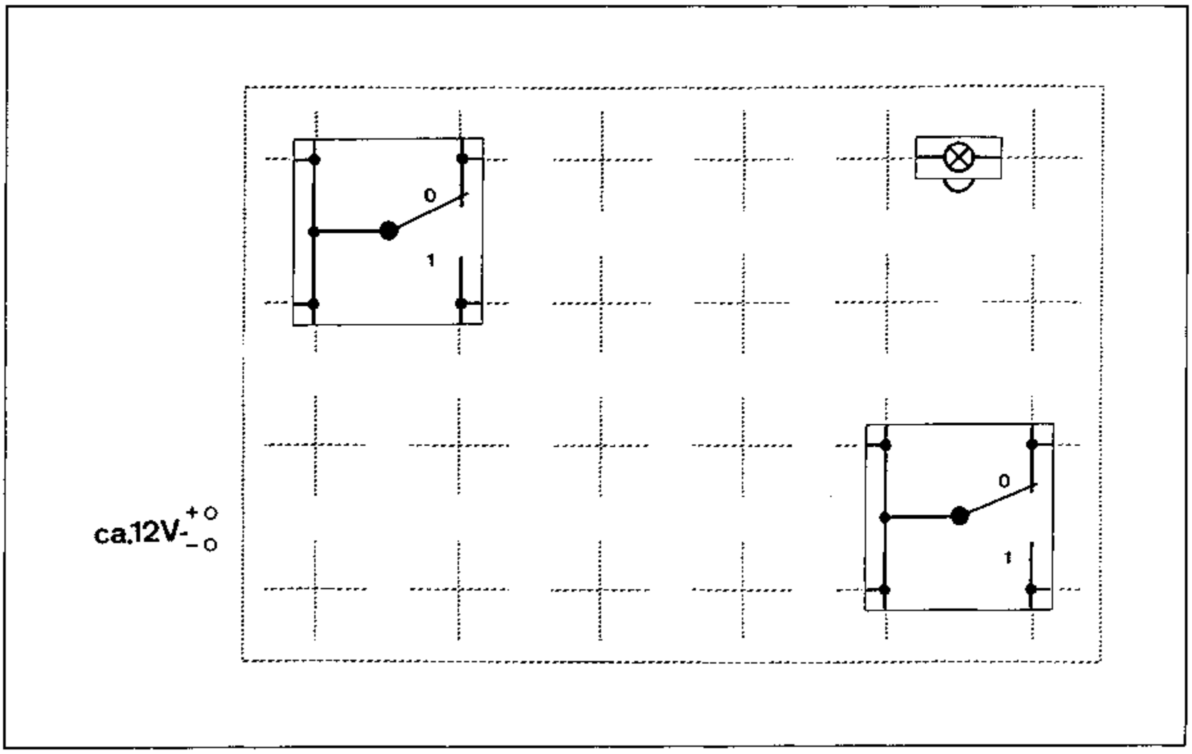


Fig. 3 Arrangement of lamp and changeover switches in a two-way circuit ▶ 6.

Student's Sheet 3

7. You are going to use leads to connect together the components so they form a two-way circuit. Start by drawing the corresponding ciruit diagram.

8. Wire up the circuit as shown in the circuit diagram.

Fig. 3.1 Circuit diagram for a two-way circuit arranged as shown in fig. 3 ▶ 7.

Fig. 3.2 Two-way circuit: Connecting up the components shown in fig. 3 ▶ 8.

Evaluation:

9. What tasks does a two-way circuit perform?

___

___

10. Which of the changeover switches' terminals should be linked together in a two-way circuit? Are there a number of alternatives?

11. What happens if you actuate both switches in a two-way circuit simultaneously?

Fig. 3.3 Connection option 1 ▶ 10.

Fig. 3.4 Connection option 2 ▶ 10.

Student's Sheet 1

AND gate, OR gate

Assignment: To investigate the series and parallel connection of switches in a circuit.

Apparatus:
1 layout plug-in board, DIN A4
2 changeover switches, single-pole
1 lamp holder (screw-in holder, E10, lateral)
3 jumper plugs
1 lead, 25 cm, red
1 lead, 25 cm, blue
1 voltage source, 12 V–
e.g. a 3 A low-voltage power supply unit
1 bulb, 12 V, 3 W (type B)

Setup:

Experiment 1: AND-gate

1. Set up the experiment as shown in fig. 1.

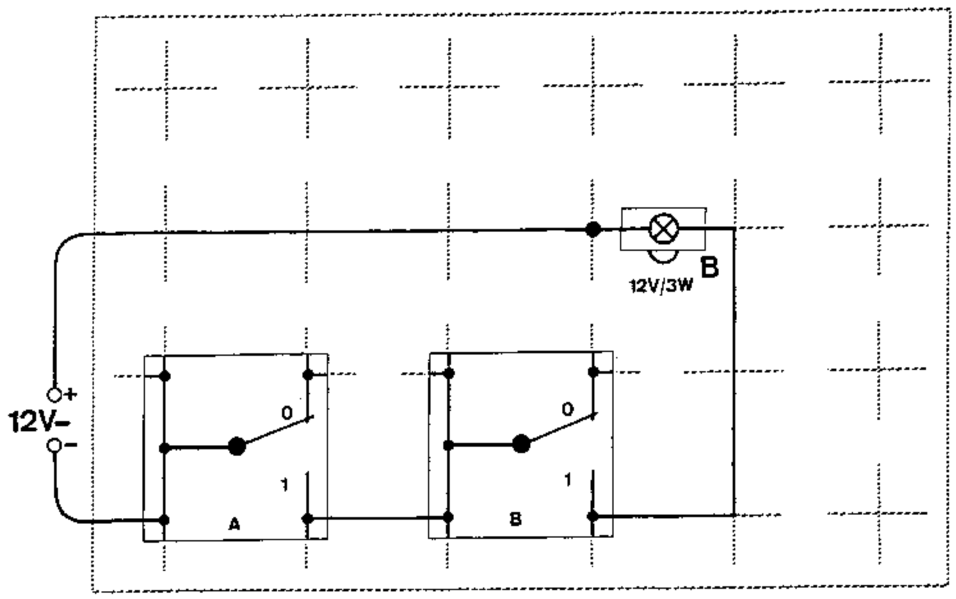


Fig. 1 Experiment setup: AND-gate

Carrying out the experiment:

Table: AND-gate

Switch A position of switch	Switch B position of switch	Lamp lights up no = 0 / yes = 1
0	0	
0	1	
1	0	
1	1	

2. Actuate the switches and determine whether the lamp lights up every time you change the switches' positions. ▶ Table.

Evaluation:

3. What positions are the switches in when the lamp lights up?

   Why is this circuit called an "AND-gate"?

4. Give an example of an application for this kind of circuit.

Fig. 1.1 AND-gate in an electrical appliance (tumble-drier)

▶ *Fig. 1.1*

Student's Sheet 3

Experiment 2

OR-gate

5. Set up the experiment as shown in fig. 2

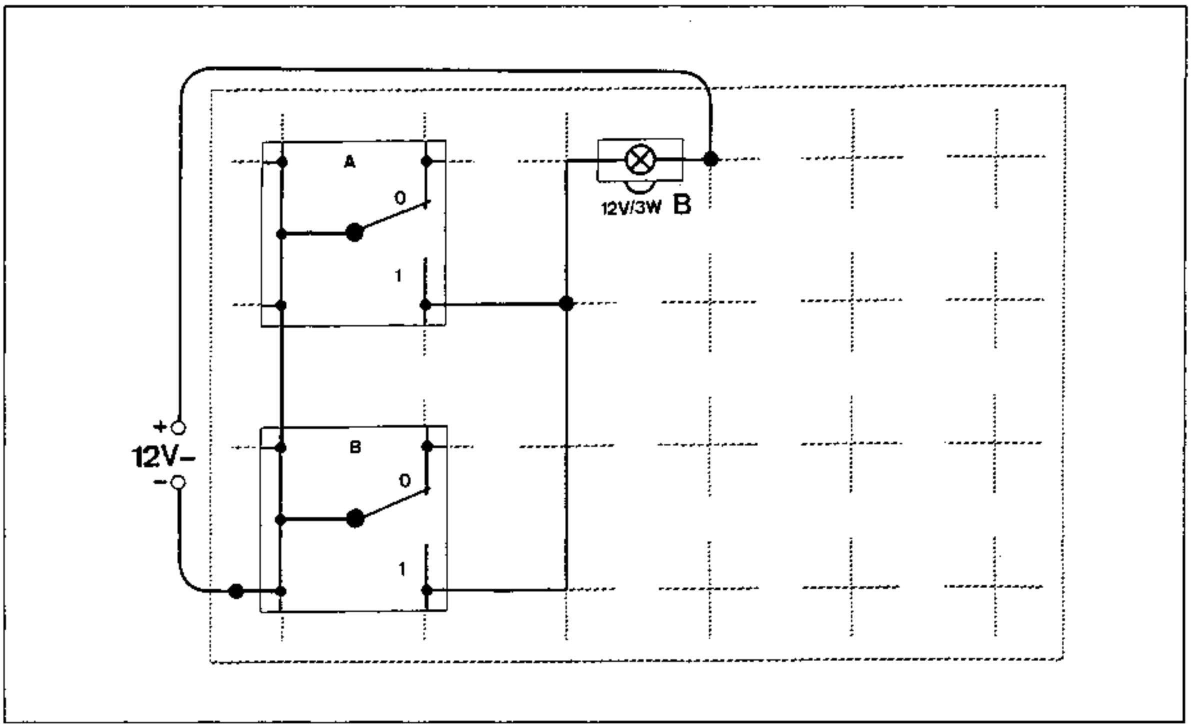


Fig. 2 Experiment setup: OR-gate

Carrying out the experiment:

Table: OR-gate

Switch A position of switch	Switch B position of switch	Lamp lights up no = 0 / yes = 1
0	0	
0	1	
1	0	
1	1	

6. Actuate the switches and find out which switch positions cause the lamp to light up. ▶ Table.

Evaluation:

7. What positions are the switches in when the lamp lights up?

   Why is this circuit called an "OR-gate"?

   ___

   ___

8. Give an example of an application for this kind of circuit.

   ___

   ___

   ___

   ___

▶ *Fig. 2.1.*

Fig. 2.1 OR-gate in a bell system

Measuring current –
Current intensity in a simple circuit

Assignment: To measure the intensity of the current at various points in a simple circuit.
Is the current of equal intensity at every point in the circuit?

Apparatus:

1 layout plug-in board
6 jumper plugs
2 lamp holders (screw-in holders, E10, lateral)
2 type B bulbs (12 V, 3 W)
1 type C bulb (4 V/0.04 A)
1 toggle switch (on/off switch)
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 voltage source, 12 V–,
e.g. low-voltage power supply unit, 3 A

Measuring instrument:
1 ammeter, 0.3 A–; 0.03 A–

Student's Sheet 2

Setup:

1. Build a circuit without a voltage source, as shown in fig. 1. The switch is open.

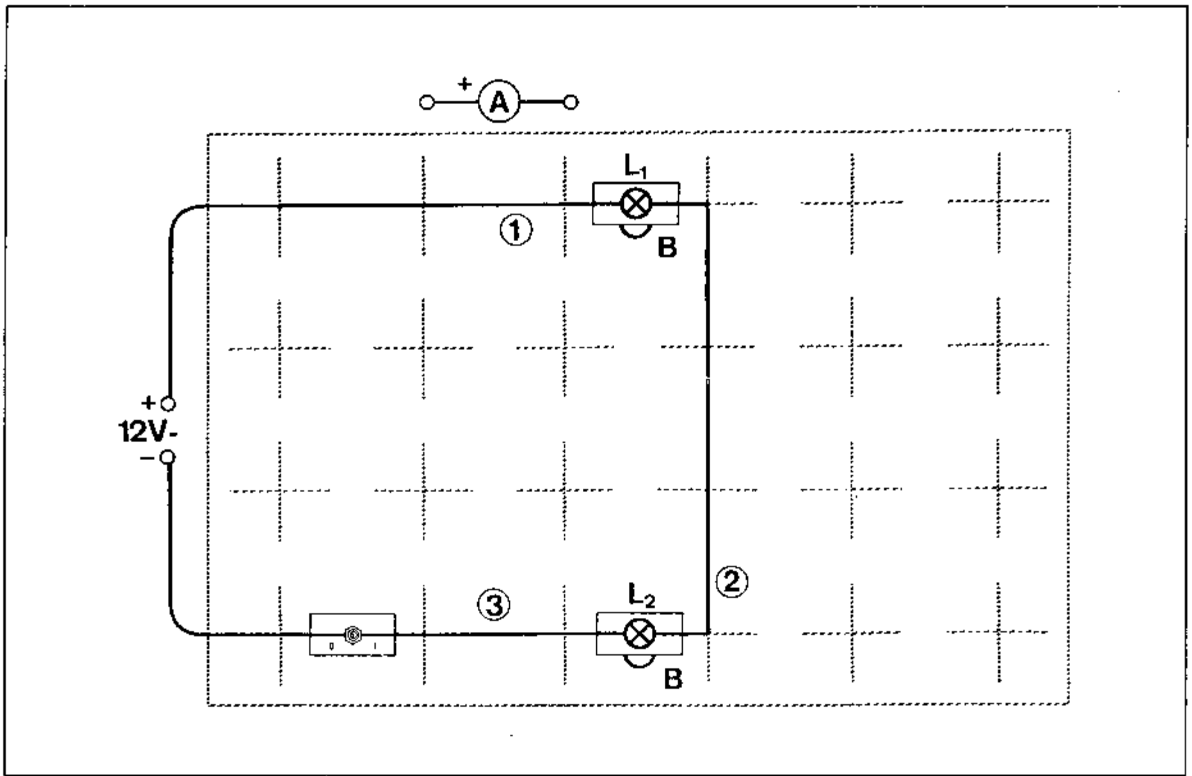


Fig. 1 Experiment setup: Measuring the current in a simple circuit
In this experiment, the ammeter is incorporated into the circuit at points (1), (2) and (3), replacing a jumper plug in each case.

2. Turn the selector switch on the voltage source to 0 before inserting it into the circuit.
3. Connect the red terminal (the ⊕-pole) of the DC voltage source to the circuit by a red lead, and the blue terminal (the ⊖-pole) by a blue lead.

   Note: The different colours help you to avoid making mistakes when connecting up the circuit.

4. To start with, do not connect the ammeter (A symbol).

Preparing your report:

5. ▶ Copy the table into your report book.

Carrying out the experiment:

6. Start by choosing the largest possible DC measuring range:
   Insert a blue lead in the ammeter's ⊖-input (0) and insert a red lead in the ⊕-input marked 3 A.

7. Insert the ammeter at the point in the circuit marked **(1)**. To do so, remove the jumper plug located there.

⚠ **Caution!**
In a direct current circuit, the ⊕-input of an ammeter should be connected directly – or via other components – to the ⊕-terminal of the voltage source.

If you connect it up incorrectly, the instrument will deflect to the "wrong" side and may be damaged if it is not designed to do this. If the instrument has a zero point in the middle of the measuring scale, there is no danger of this happening.

8. Draw the circuit diagram for the circuit you have built.

Fig. 1.1 Circuit diagram for circuit shown in fig. 1 ▶ 8

9. Close the switch. Select voltage levels 0, 1, 2, 3, 4 one after the other and watch the ammeter's display.

10. Select the small 0.3 A measuring range.
    What are the advantages of doing so?

    ____

    ____

    ____

11. Read off the value for current intensity at voltage level 4 and enter it in the table.
12. Measure the current at points **(2)** and **(3)** as you did in step 11 and enter the measured values in the table.
13. Replace lamp L_2 (type B bulb, 12 V, 3 W) with a type C bulb (4 V, 0.04 A).
14. As before, measure the current at points **(1)**, **(2)** and **(3)**.
    Select the 0.3 A direct current measuring range. Enter the measured values in the table.
    ▶ *Table.*

Report:

Table

Lamps in the circuit	Measuring points	Current intensity
type B	**(1)**	
with type B	**(2)**	
in series	**(3)**	
type B	**(1)**	
with type C	**(2)**	
in series	**(3)**	

Evaluation:

15. What should you do if you want to measure the current intensity in a DC circuit?

____

____

____

16. What statement can you make about the current intensity in a circuit?

____

Measuring voltage – Voltages in a simple circuit

Assignment: To measure the voltage at various points in a simple circuit.
Is the voltage the same at every point in the circuit?

Apparatus:

1 layout plug-in board
4 jumper plugs
2 lamp holders (screw-in holders, E10, lateral)
1 bulb, type B (12 V, 3 W)
1 bulb, type C (4 V/0.04 A)
1 toggle switch (on/off switch)
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 voltage source, 12 V–
e.g. low-voltage power supply unit

Measuring instrument:
1 voltmeter, 15 V–

Student's Sheet 2

Setup:

1. Build the circuit shown in fig. 1 – leaving out the voltage source.
   The switch is open.

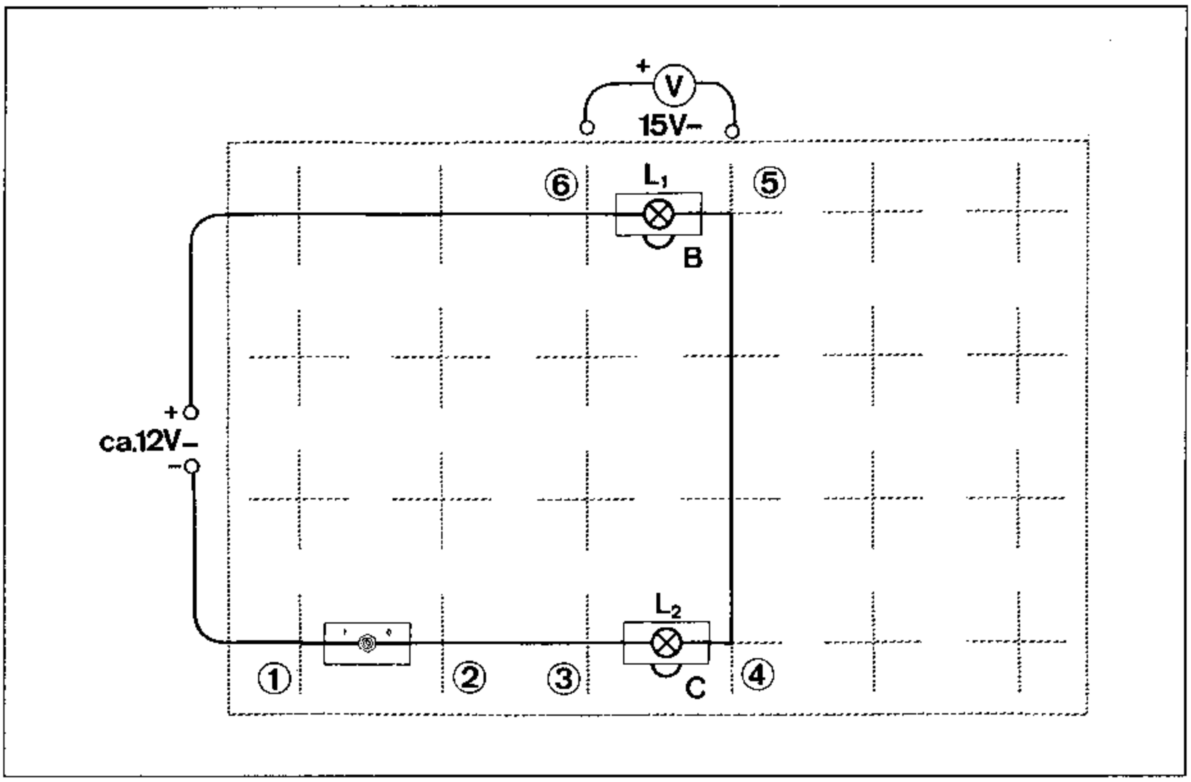


Fig. 1 Experiment setup: Measuring the voltage in a simple circuit
(1), (2), (3) ... (6): connection points on the layout plug-in board

2. Turn the switch on the voltage source to 0 before connecting it to the circuit.
3. Connect the ⊕-terminal of the direct voltage source using a red lead and the ⊖ terminal using a blue lead.
   The different colours help you to avoid making mistakes while connecting up the circuit.
4. To start with, do not connect the voltmeter (symbol: V).

Preparing your report:

▶ Copy the table into your report book.

Student's Sheet 3

Carrying out the experiment:

Voltage is always measured between two points. The procedure is different from measuring a current, in that you do not have to break the circuit. Voltmeters are always connected in parallel to a section of the circuit (voltmeter connections shown in fig. 2). When you are measuring DC voltages, you should make sure that the polarity of the connections is correct, which means that the ⊕-terminal of the voltage source must be connected to the ⊕-socket of the measuring instrument, and the ⊖ socket of the measuring instrument to the ⊖ terminal of the voltage source. This also applies if there are other components in the circuit between the voltage source's terminals and the measuring instrument's sockets.

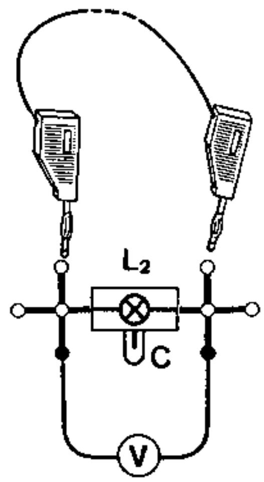


Fig. 2 Using a lead to short-circuit a lamp L_2

5. Fill in the first two columns in the table and ask the teacher to check them.
6. Choose a DC voltage range of 15 V– and connect the voltmeter in parallel to lamp L_1.
7. Select DC voltage level 4 (ca. 12 V–) and close the switch.
8. Read off the voltage value and enter it in the table.
9. Perform all the other voltage measurements indicated in the table in the same way.
   Enter the measured values in the table.
   To make the last measurement, you must short-circuit the lamp as shown in fig. 2.

Report:

Table: voltage measurements

Component	negative terminal (blue) ⊖	positive terminal (red) ⊕	measured voltage *U*
Voltage source with switch open	(1)	(6)	
Voltage source with switch closed			
Switch (open)			
Switch (closed)			
Jumper plug	(2)		
Lamp L_1			
Lamp L_2			
short-circuited lamp L_2 (▶ fig. 2)			

Student's Sheet 4

Evaluation:

10. You are asked to measure the voltage across one component in a DC circuit. How should you connect the measuring instrument?

11. Are there any components across which it is not possible to pick up a voltage?

12. How large is the voltage you can measure across a break in the circuit (e.g. across an open switch)? What does it depend on?

13. Compare the voltages measured in the circuit shown in fig. 1 when the switch is closed (▶ Table).
    Is there any relationship between the voltages measured across the lamps and across the voltage source?

14. The table shows that the voltage at the power source changes if current is flowing.
    By how many volts is the voltage at the power supply unit reduced as a result of the load?

Ohm's law

Assignment: To determine the connection between the applied voltage *U* and the current intensity *I*.

Apparatus:

1 layout plug-in board
4 jumper plugs
1 wire winding board
1 on/off switch (toggle switch, single-pole)
1 chrome nickel wire, 0.25 mm ⌀, 204 cm long
1 resistor, 100 Ω
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 power source, 0 ... 12 V–
adjustable in increments
e.g. low-voltage power supply unit

Measuring instruments:
1 ammeter, 0.3 A–
1 voltmeter, 15 V–

in addition:
1 pair of pincers

Student's Sheet 2

Setup:

1. Wind the chrome nickel wire (⌀ 0,25 mm) onto the winding board.
2. Construct the circuit shown in figs. 1 and 2. The switch is open.
3. Carefully check that all the measuring instruments have been connected up correctly.

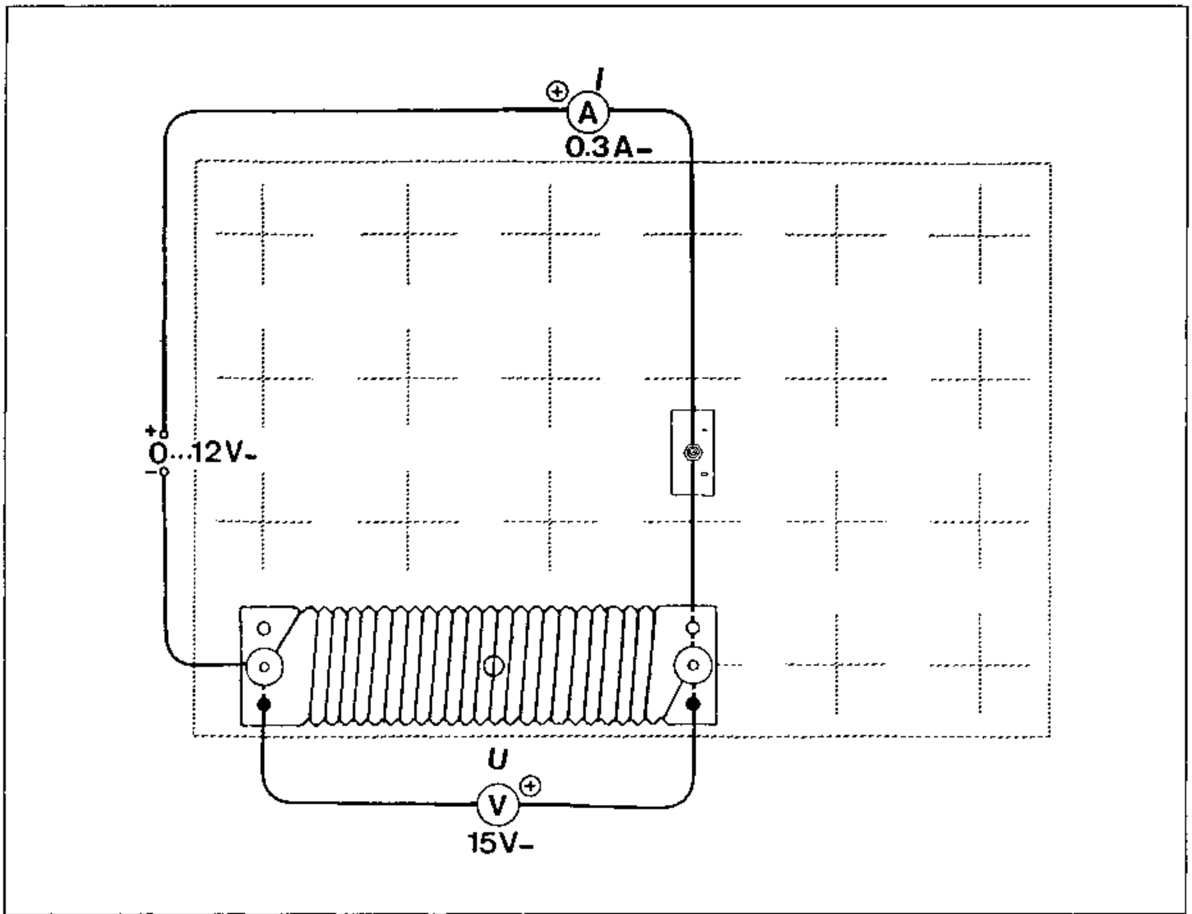


Fig. 1 Experiment setup: Ohm's law

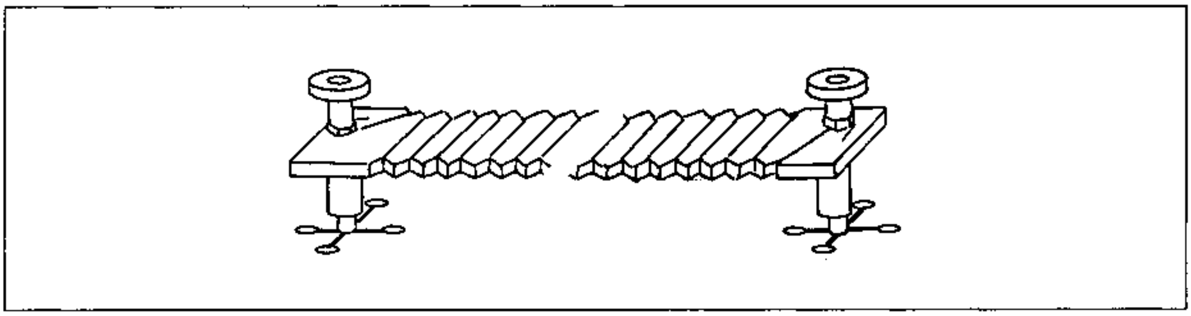


Fig. 2 Illustration accompanying fig. 1
Setting up the wire winding board using clamping plugs

Student's Sheet 3

Preparing your report:

4. Copy the table and coordinate system with all its inscriptions into your report book (on squared paper).
   Choose one square for every 1 volt or 0.01 A.

Carrying out the experiment:

Experiment part 1: measurements with chrome nickel wire

5. Close (make) the circuit. For each voltage level you select on the power supply unit, measure the voltage across the wire and the intensity of the current.
6. Enter the measured values in the coordinate system (▶ 10). Can you draw a straight line through the points? Draw away! Mark this graph with the number 1.

Experiment part 2: measurements with a fixed resistor

7. Switch the voltage back to 0. Fit the 100 Ω resistor instead of the wire.
   ▶ Setup as shown in fig. 3

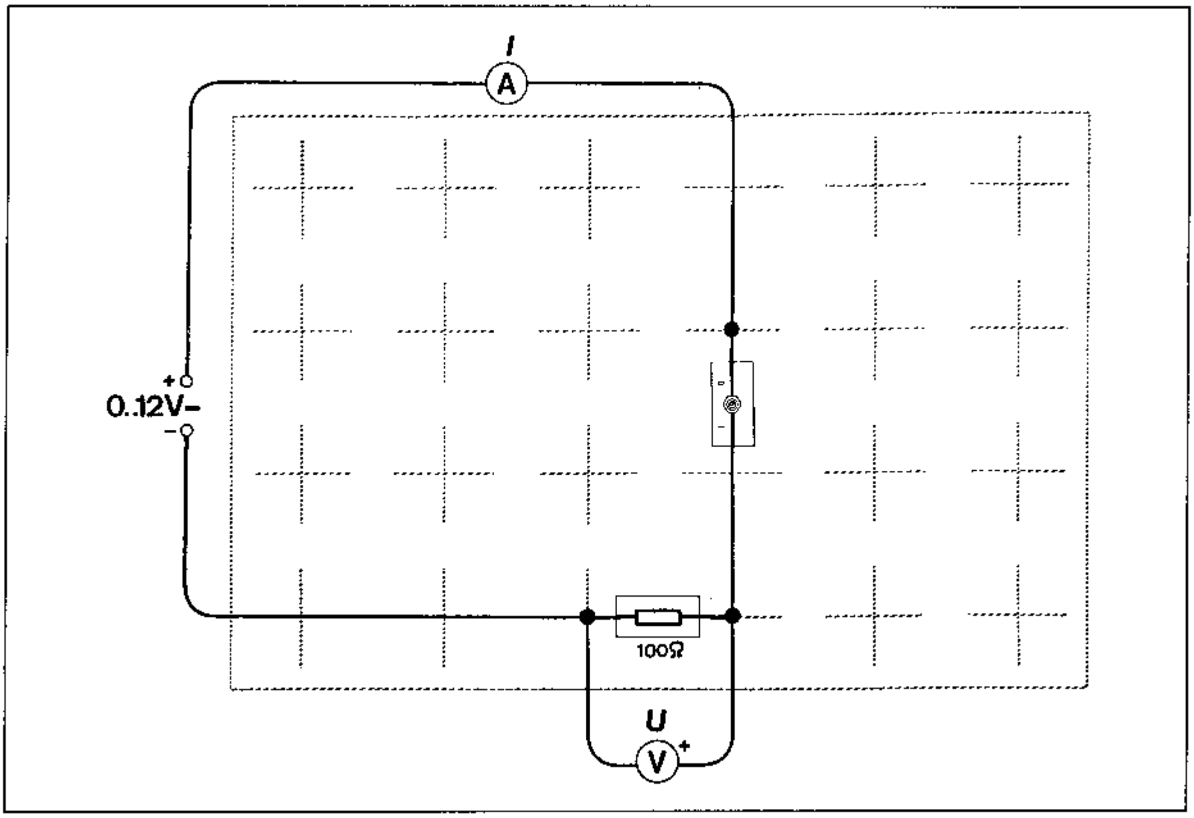


Fig. 3 Experiment setup: Ohm's law with a fixed resistor ▶ 7.

8. Make the circuit. Measure the voltage and current for every voltage level on the power supply unit. Enter the measured values in the table.
9. Copy the measured values over into the coordinate system (▶ 10). Can you join the points together by drawing a straight line? Draw away! Mark this graph with the number 2.

____

Report:

Table 1

Measurements across the chrome nickel wire

Voltage level	*U*	*I*
0		
1		
2		
3		
4		

Table 2

Measurements across the 100 Ω resistor.

Voltage level	*U*	*I*
0		
1		
2		
3		
4		

Evaluation:

10. Graph. ▶ Diagram (at the end of the chapter).
11. How does the current *I* through a wire (chrome nickel) change if the voltage *U* is doubled? Look at the graph.

____

12. What is the relationship between *U* and *I* in the examples taken in your experiments?

$\frac{U}{I}$ equals electrical resistance *R*

R is measured in Ω (ohms). $1\ \Omega = \frac{1\ V}{1\ A}$

What condition does *R* satisfy in our wire or in our "resistor" component?

____

____

____

Student's Sheet 5

13. The relationship between the current *I*, voltage *U* and electrical resistance *R* should be represented in the form of an equation. What remark should you not forget to make?

____

____

____

14. According to your measurements, how great is
   a) the resistance R_1 of the chrome nickel wire?
   b) the resistance R_2 of the 100 Ω component? You should read the voltage values corresponding to a current of 0.1 A from your graph, and calculate R_1 and R_2 from them.

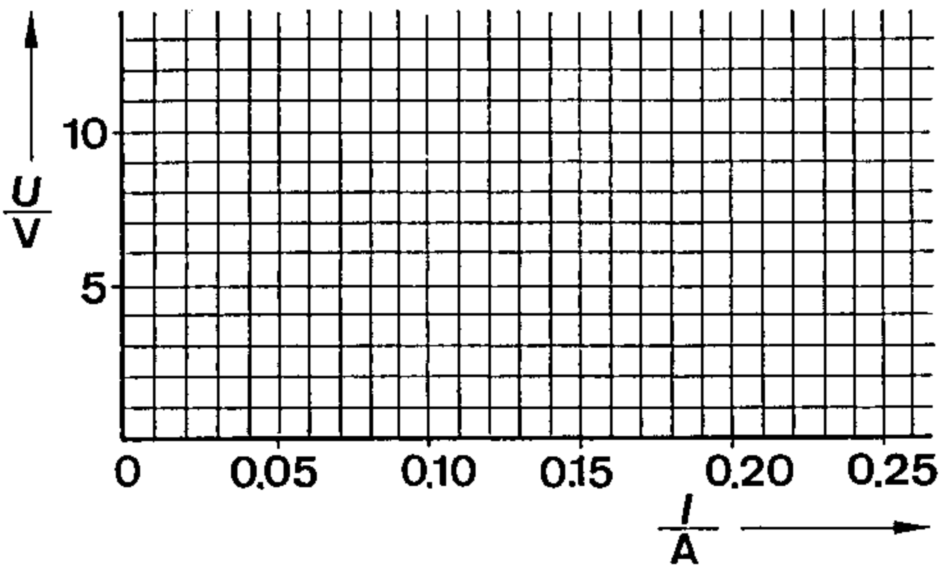
a) ____

____

b) ____

____

Graph



(1) Chome nickel wire (2) Resistor, 100 Ω

How a wire's resistance depends on its material, length and cross-section

Assignment: To find out what the electrical resistance of a wire depends on.

Apparatus:

1 layout plug-in board
2 jumper plugs
1 wire winding board
2 clamping plugs
1 crocodile clip
1 on/off switch (toggle switch)
1 chrome nickel wire
0.25 mm ⌀, 204 cm long
1 chrome nickel wire
0.35 mm ⌀, 204 cm long
1 constantan wire, 0.35 mm ⌀, 204 cm long
3 leads, red, 25 cm
3 leads, blue, 25 cm
1 lead, red, 50 cm
1 lead, blue, 50 cm
1 voltage source, 12 V–
e.g. low-voltage power supply unit

Measuring instruments:
1 ammeter, 0.3 A
1 voltmeter, 15 V

Setup:

1. Wind the ⌀ 25 mm chrome nickel wire onto the winding board. Set up the winding board using the clamping plugs! Use the screws to clamp each end firmly.
2. Build the circuit shown in fig. 1. Make sure you have connected the ⊕ and ⊖ terminals correctly, and set the right measuring ranges on the measuring instruments. The switch should only be closed while a measurement is being made.

   The switch on the power supply unit should be set to voltage level 0 to start with.

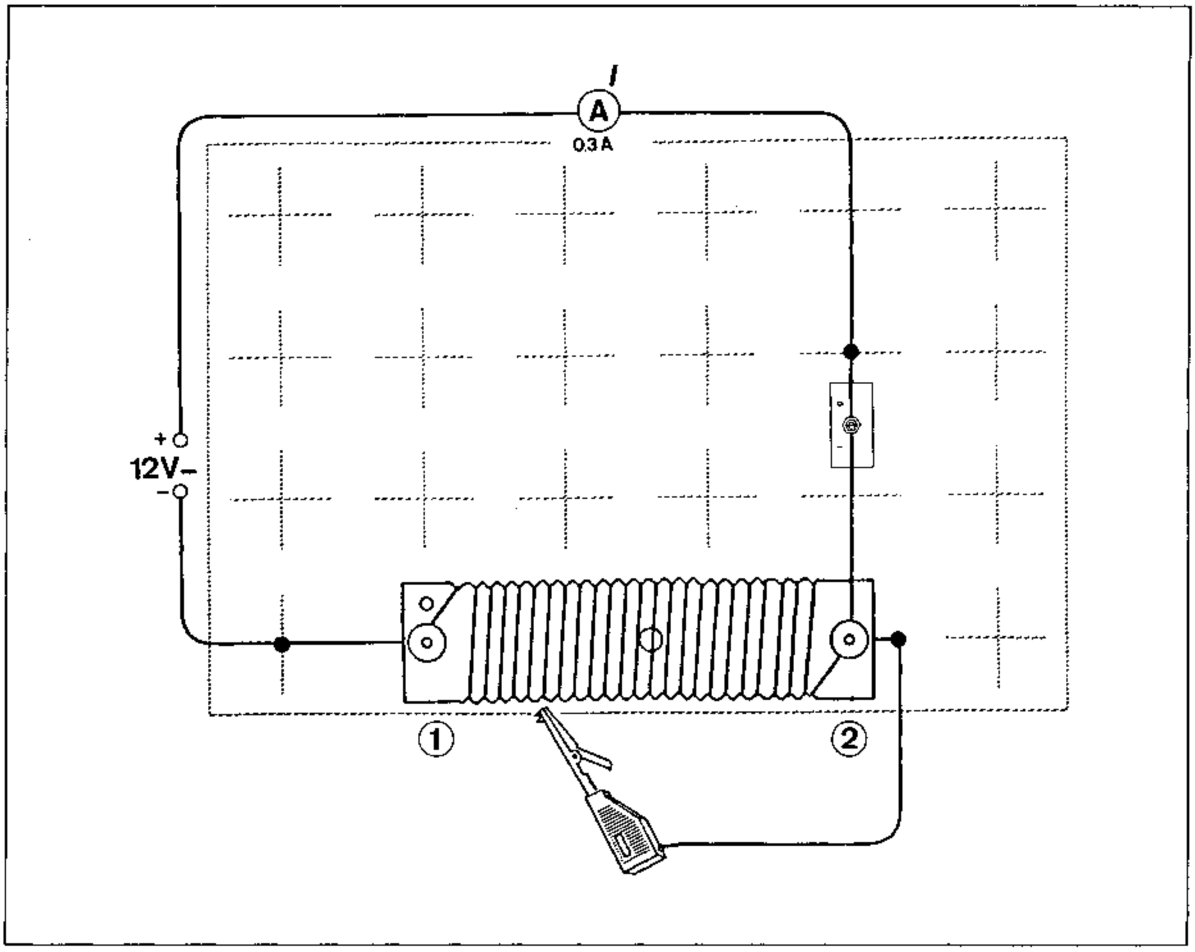


Fig. 1 Experiment setup:
How the resistance of a wire depends on its material, length and cross-section
(1) and (2): Screws for clamping the wire firmly

Preparing your report:

3. Copy the table and the axes for the graph into your report book.

Student's Sheet 3

Carrying out the experiment:

4. Select voltage level 1 (ca. 3 V–). Close the switch. Tap 6 windings while bypassing the remaining 19 windings.
   The length of the wire in each winding is 8 cm.
   Measure the voltage *U* and current *I* and enter the measured values in the table under "Step 4".

5. Tap 12 windings. Measure *U* and *I* and enter the measured values under "Step 5" in the table. Also enter the length of the wire.
6. Repeat step 5 for 18 windings.
   ▶ "Step 6" in the table.
7. Remove the bypass lead from the circuit. Measure the voltage *U* and current *I* for a length of 2 m (25 wire windings). Enter the measured values in the table under "Step 7".
8 Switch the power supply unit back to a voltage level of 0 and open the switch.
9. Select the chrome nickel wire with a diameter (⌀) of 0.35 mm (instead of 0.25 mm). Wind it onto the winding board, clamp the ends firmly using the screws and fit the board back into the circuit.
10. Set the selector switch to voltage level 1. Close the toggle switch. Measure *U* and *I*.
    (▶ Table, step 10).
11. Repeat steps 8 to 10 for the constantan wire, ⌀ 0.35 mm.
    (▶ Table, step 11).

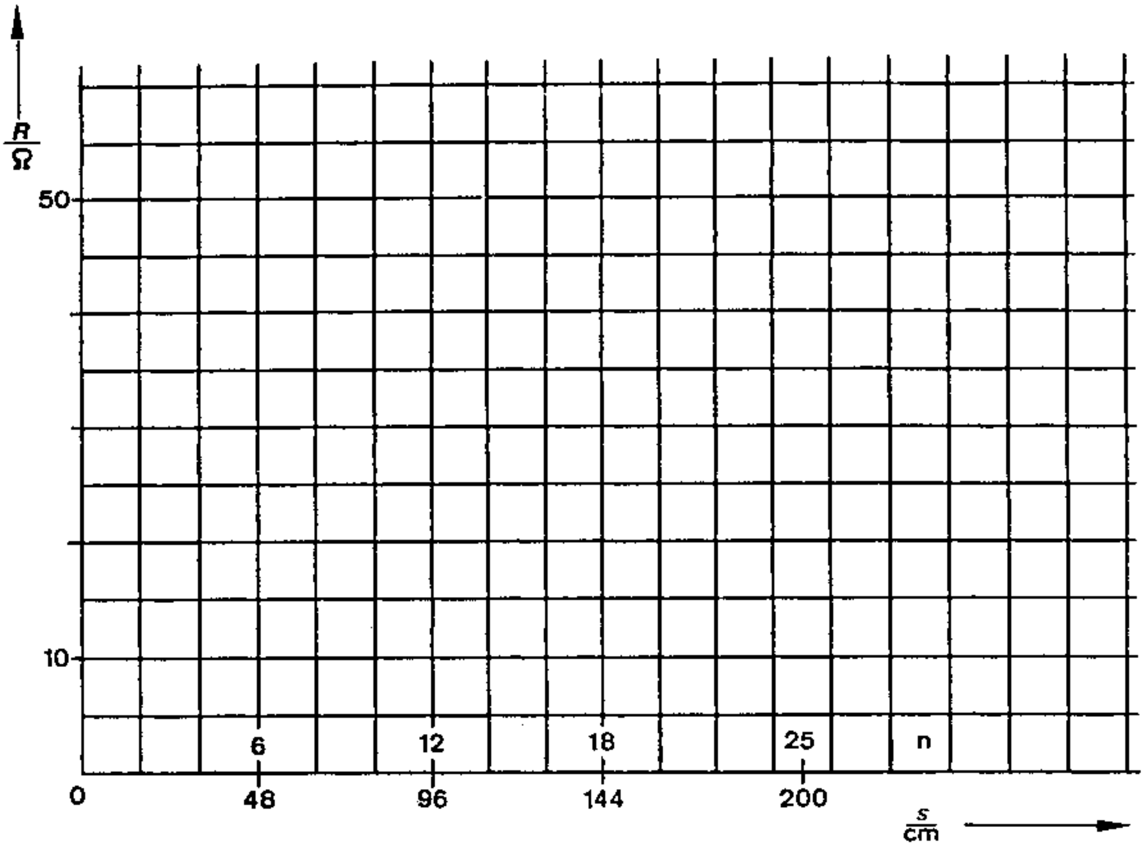
Report:

Table

Step	Material of wire	Diameter	Number of windings n	Length *s*	*U*	*I*	$R = \frac{U}{I}$
4	chrome nickel	0.25 mm	6	48 cm			
5	"	"	12				
6	"	"	18				
7	"	"	25	200 cm			
10	"	0.35 mm	25	200 cm			
11	constantan	0.35 mm	25	200 cm			

12. Calculate $R = \frac{U}{I}$ for every pair of *U* and *I* values in the table, and enter the result in the last column.

Graph



n = number of windings s = length of the wire

Evaluation:

13. How does the resistance of a wire depend on its length?

    What measurements will give you an answer to this question? (▶ 14). Give the numbers of the relevant steps.

    ____

14. Illustrate the dependence R (s) for the ⌀ 0.25 mm chrome nickel wire in the form of a graph. (▶ Graph).

    ____

    ____

Student's Sheet 5

15. A wire diameter of 0.35 mm means that the wire's cross-sectional area is twice as large as that of a wire with a diameter of 0.25 mm. How does the resistance of a wire change if its cross-section (= cross-sectional area) is doubled? Which two measurements must you evaluate in order to obtain the answer to this question?

____

____

16. Does the resistance of a wire depend on the material from which the wire is made? Which two measurements will give you an answer to this question?

____

____

Student's Sheet 1

Voltage distribution in a current-carrying wire (potentiometer)

Assignment: To investigate the voltage characteristics of a current-carrying wire.

Apparatus:
1 layout plug-in board
1 wire winding board
2 clamping plugs
1 chrome nickel wire, 0.25 mm ⌀, 204 cm long
1 crocodile clip
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 voltage source, ca. 12 V–
e.g. low-voltage power supply unit

Measuring instrument:
1 voltmeter, 15 V–, 1.5 V–

Setup:

1. Wind the chrome nickel wire onto the wire winding board and clamp the ends firmly under the screws.
2. Build the circuit shown in fig. 1. Make sure all your connections are the right way round (pay attention to the polarity!).

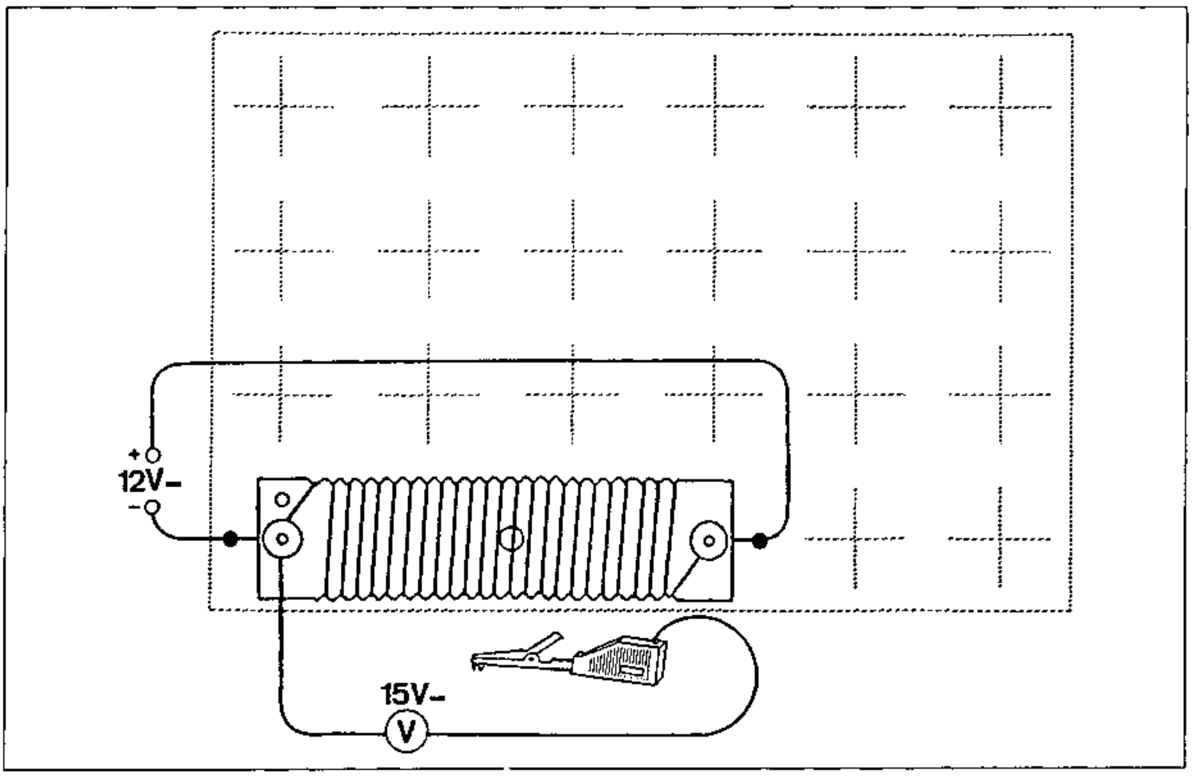


Fig. 1 Experiment setup: Voltage distribution in a current-carrying wire

Preparing your report:

3. Copy the table and the coordinate system into your report book.

Carrying out the experiment:

4. Using the crocodile clip, measure the voltage along the lengths of the wire specified in the table. Enter the voltage values *U* in the table.
5. Enter the pairs of values into the coordinate system and draw the graph.

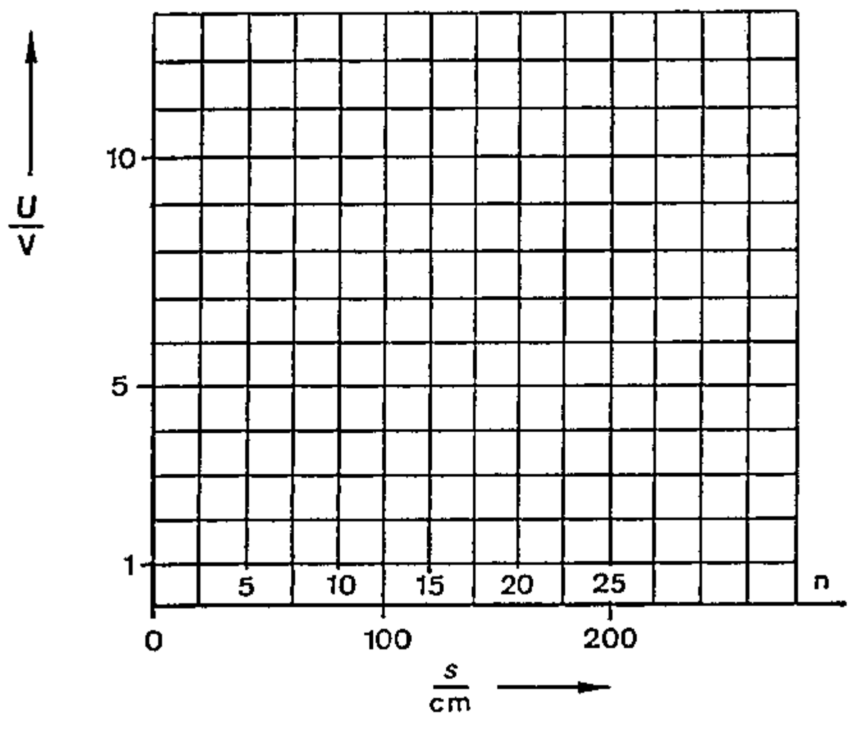
Report:

Table

Type of wire: chrome nickel wire, 0.25 mm ⌀

Number of windings	Length of wire *l*	Voltage *U*
0	0 cm	
5	40 cm	
10	80 cm	
15	120 cm	
20	160 cm	
25	200 cm	

Graph:



Student's Sheet 3

Evaluation:

6. How does the voltage decrease along the wire?

7. What is the relationship between the voltages and the lengths of the wire sections?

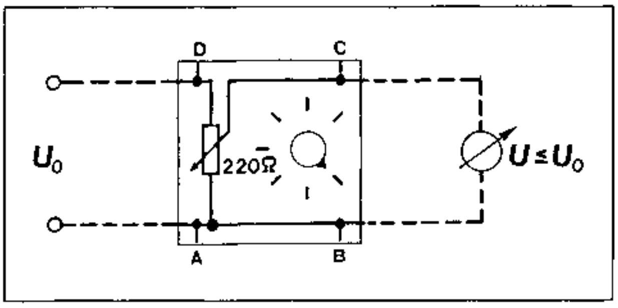


Fig. 2 Potentiometer circuit

Student's Sheet 1

Connecting resistors in series

Assignment: To determine the total resistance which results if you connect two individual resistors one after the other (in series).

Apparatus:
1 layout plug-in board, DIN A4
1 on/off switch (toggle switch)
2 resistors, 100 Ω
1 resistor, 47 Ω
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 voltage source, 12 V–
e.g. low-voltage power supply unit
Measuring instruments:
1 ammeter, 0.3 A–
1 voltmeter, 15 V–

Setup:

1. Construct the circuit shown in fig. 1.

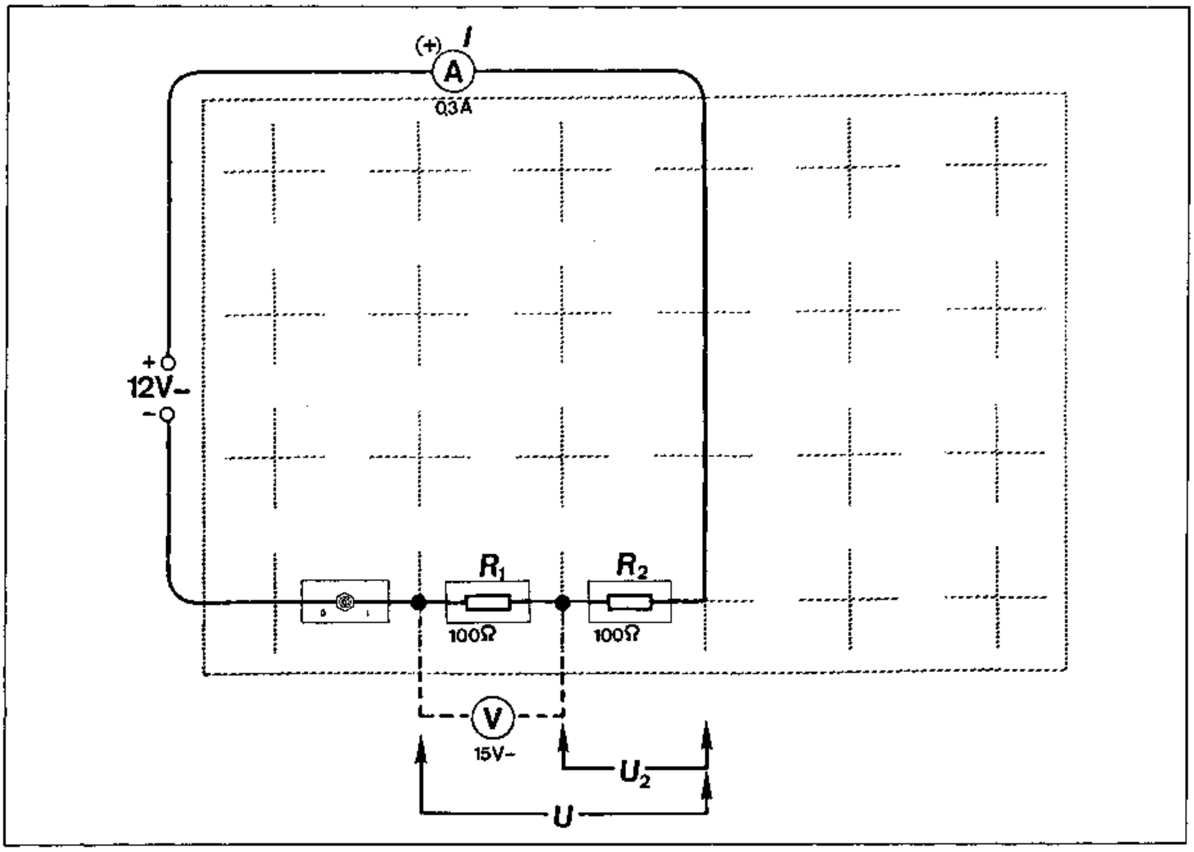


Fig. 1 Experiment setup: Connecting resistors in series

Preparing your report:

2. Copy the table into your report book.

Carrying out the experiment:

3. Set the selector switch to voltage level 4. Measure the intensity of the current. Enter the measured value into the table.
4. Measure the voltage U_1 across resistor R_1, U_2 across resistor R_2 and U across the total resistance supplied by R_1 and R_2 connected in series. Enter the measured values in the table.
5. Replace R_2 with the 47 Ω resistor. Measure the current intensity I and enter the value in the table.
6. Measure the voltages U_1, U_2 and U for this circuit as well, and enter the measured values in the table.

Report:

Table 1

	R_1	R_2	I	U_1	U_2	U
a)	[100 Ω]	[100 Ω]				
b)	[100 Ω]	[47 Ω]				

The values printed on the components are shown here in square brackets.

Evaluation:

7. What is the relationship between voltages U_1, U_2 and U across resistors connected in series?

____

____

____

8. Calculate the following values:

Table 2

	$R_1 = \frac{U_1}{I}$	$R_2 = \frac{U_2}{I}$	$R = \frac{U}{I}$
a)			
b)			

9. How would you calculate the total resistance R of two resistors R_1 and R_2 connected in series?

___

___

Connecting resistors in parallel

Assignment: To determine the total resistance which results if you connect two resistors in parallel.

Apparatus:
1 layout plug-in board, DIN A4
5 jumper plugs
2 resistors, 100 Ω
1 resistor, 47 Ω
1 on/off switch (toggle switch, single-pole)
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 lead, red, 50 cm
1 lead, blue, 50 cm
1 voltage source, 12 V–/9 V– e.g. low-voltage power supply unit
Measuring instruments:
1 ammeter, 0.3 A–
1 voltmeter, 15 V–

Setup:

1. Construct the circuit shown in fig. 1. To start with, the switch is left open and the power supply unit is switched to voltage level 0.

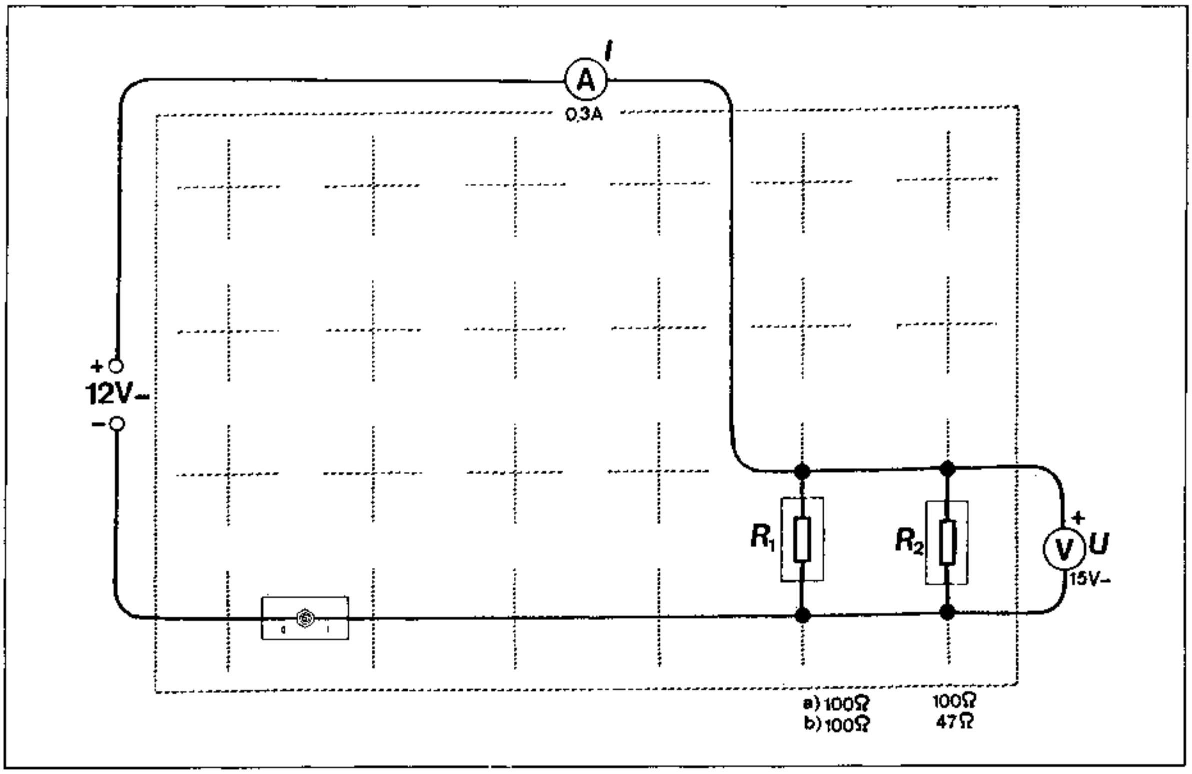


Fig. 1 Experiment setup: Connecting resistors in parallel

2. Check the circuit once more, carefully. Have you made all the right connections and chosen the right measuring ranges? The way in which the two resistors are connected is known as *connection in parallel.*
3. Make quite sure you are clear which way the current is going to flow when the switch is closed.

Carrying out the experiment:

Experiment part 1: connecting equal resistors in parallel

Question: how high is the resistance $R_{1,2}$ where $R_1 = 100\ \Omega$ and $R_2 = 100\ \Omega$?

4. Copy the following incomplete equation into your report book:

---

5. Close the switch.
6. Watch the ammeter and slowly turn the power unit's switch up to voltage level 4, step by step.

⚠ **Caution:**

If the pointer deflects to the end of the scale, switch back to 0 immediately! Find the fault (ask your teacher!)

7. Enter the measured values for the voltage U and the current I in the empty spaces in the equation for finding the value of $R_{1,2}$.
8. Open the switch and turn the power unit's selector switch back to 0.

Experiment part 2: connecting different resistors in parallel

Question: how high is the resistance $R_{1,3}$ in a parallel connection where $R_1 = 100\ \Omega$ and $R_3 = 47\ \Omega$?

9. In the circuit shown in fig. A, the resistor $R_2 = 100\ \Omega$ should be replaced alongside the resistor $R_3 = 47\ \Omega$. (▶ Fig. B).
10. Copy the following incomplete equation into your report book:

---

11. Close the switch.
12. Watch the ammeter. Slowly turn the power unit's selector switch to voltage level 3.
Why are you not allowed to turn it any higher?

⚠ **Caution:**

If the pointer deflects to the end of the scale, switch back to 0 immediately! Find the fault (ask your teacher!)

13. Enter the measured values for the voltage U and the current I in the empty spaces in the equation for calculating $R_{1,3}$.
14. Open the switch and turn the power unit's selector switch back to 0.

Student's Sheet 3

Evaluation:

Experiment part 1

15. Work out $R_{1,2}$ and enter the value (▶ report book)
16. Compare the total resistance $R_{1,2}$ which you have just calculated with the two resistances R_1 and R_2 (100 Ω each) connected in parallel.

____

____

____

Experiment part 2

17. Work out $R_{1,3}$ and enter the value (▶ report book).
18. Compare the resistance $R_{1,3}$ of the parallel connection to the resistances R_1 and R_3. Which is the smallest?

____

19. Complete the following sentence:
    The resistance of a parallel circuit is _____ than the ______ individual resistance.
20. The reciprocal $\frac{1}{R}$ of a resistance R is described as conductance, for example:

$R_1 = 100\ \Omega$, conductance $\frac{1}{R_1} = \frac{1}{100\ \Omega} = \frac{0.01}{\Omega}$

$R_3 = 47\ \Omega$, conductance $\frac{1}{R_3} = \frac{1}{47\ \Omega} = \frac{0.02}{\Omega}$

Work out the conductance for the resistance $R_{1,3}$ which you calculated previously:

$\frac{1}{R_{1,3}} = \frac{1}{33.3} = \frac{0.03}{\Omega}$

Is any kind of formal relationship apparent if you compare the conductances $\frac{1}{R_1}$, $\frac{1}{R_3}$ und $\frac{1}{R_{1,3}}$?

____

____

____

21. Check the formula

$$\frac{1}{R_{1,2}} = \frac{1}{R_1} + \frac{1}{R_2} \text{ for } R_1 = R_2 = 100\ \Omega.$$

Compare the calculated value with the value you determined in your experiment.

Connecting monocells in series and in parallel

Assignment: To see if connecting monocells in parallel or in series results in a voltage source with modified characteristics.

Apparatus:

1 layout plug-in board, DIN A4
10 jumper plugs
2 clamping plugs
2 monocell holders
2 monocells, 1.5 V
1 on/off switch (toggle switch)
2 lamp holders (screw-in holders, E10, lateral)
2 bulbs
(Type A, 2.5 V/0.1 A)
1 constantan wire, 0.35 mm ⌀, 20 cm long
1 lead, red, 25 cm
1 lead, blue, 25 cm

Measuring instrument:
1 Voltmeter, 3 V, 1.5 V–

Student's Sheet 2

Setup

▶ Fig. 1

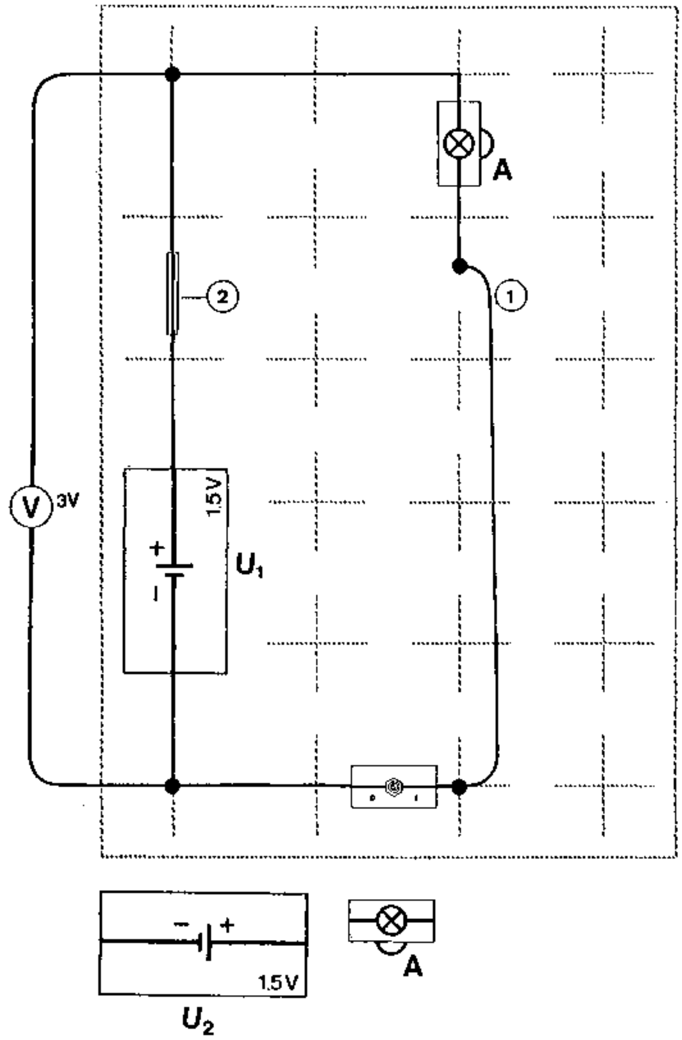


Fig. 1 Experiment setup: Connecting monocells in series
(1) lead
(2) jumper plug

Carrying out the experiment:

Experiment part 1:
Connecting monocells in series

1. Actuate the switch in the circuit shown in fig. 1 and note the brightness of the lamp.
2. Open the switch again and insert a second similar lamp into the circuit (e.g. at position **(1)**). Close the circuit. What do you notice?

____

3. Open the switch again, remove the jumper plug from position **(2)** and fit a second monocell into the resulting gap. Make sure its polarity is the same as for the other monocell.
4. Actuate the switch. Do the lamps light up or glow brightly, weakly or not at all?

____

5. Insert the second monocell so that its polarity is reversed. What do the lamps do this time?

____

____

____

6. Monocells connected in series are known as a battery. On your voltmeter, choose the measuring range 3 V–. Measure the following voltages and enter them in your table:
   a) Voltage U_1 across monocell 1
   b) Voltage U_2 across monocell 2
   c) Voltage U across the battery (monocell 1 and monocell 2 connected in series).

Student's Sheet 4

Experiment part 2:
Connecting monocells in parallel, with a small load

7. Change the circuit round as shown in fig. 2.

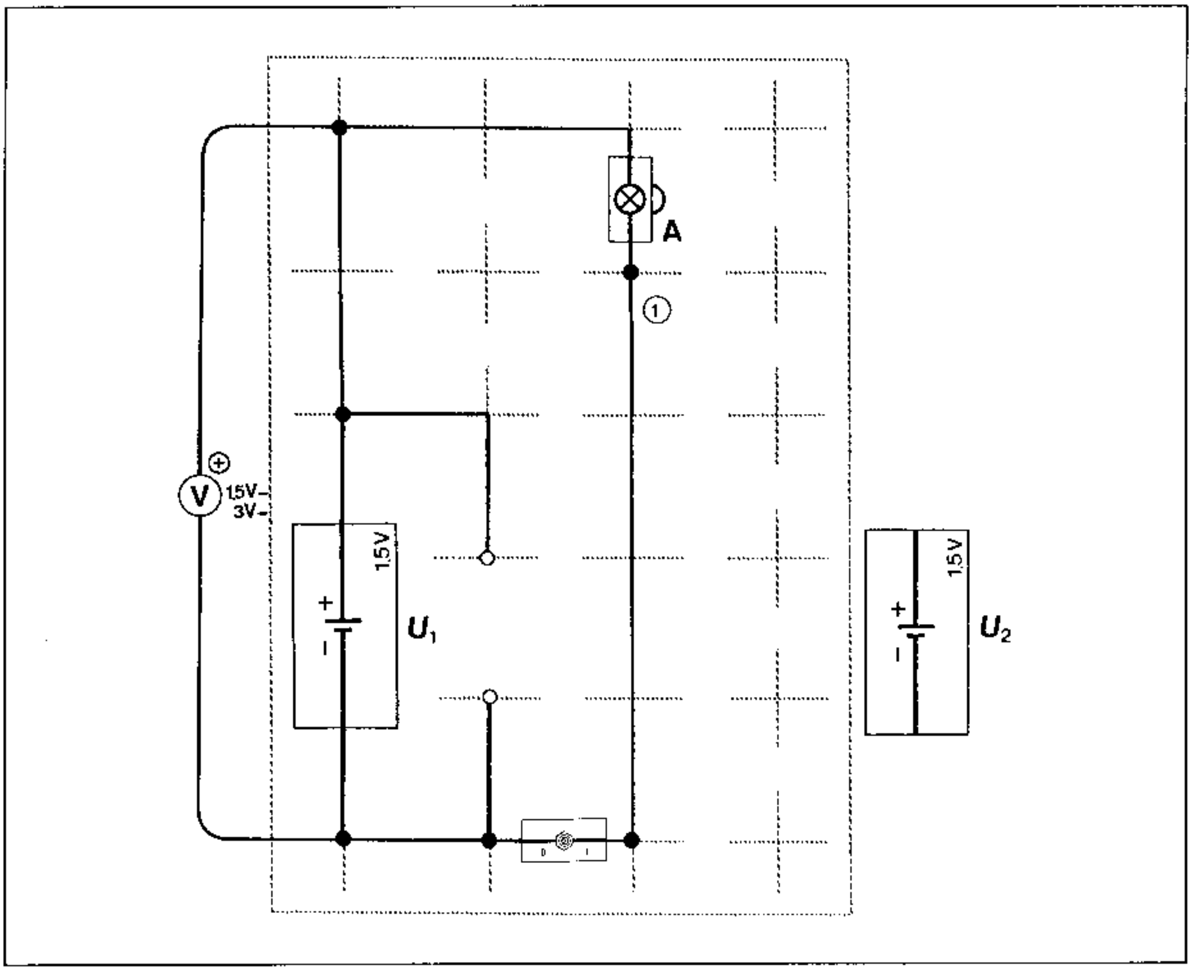


Fig. 2 Experiment setup: Connecting monocells in parallel ▶ 7.

8. Measure the voltages across the monocells. (Measuring range: 1.5 V).
   Switch on the lamp and note the brightness.

9. Fit the second monocell in place alongside the first monocell in such a way that the voltage poles on both monocells point in the same directions. Is there any change in the brightness of the lamp?

10. What voltage does the voltmeter indicate? Enter these values for two monocells connected in parallel in the table, under heading d).

11. Now insert one of the monocells the other way round, swapping its "+" and "–" poles. What can you observe now?

Student's Sheet 5

Experiment part 3:

Connecting monocells in parallel under heavy load

12. Build the circuit shown in fig. 3. The switch starts in the open position. Straighten out the 20 cm long constantan wire and connect it in parallel with the lamp. Its resistance *R* is low and places a heavy load on the voltage source.

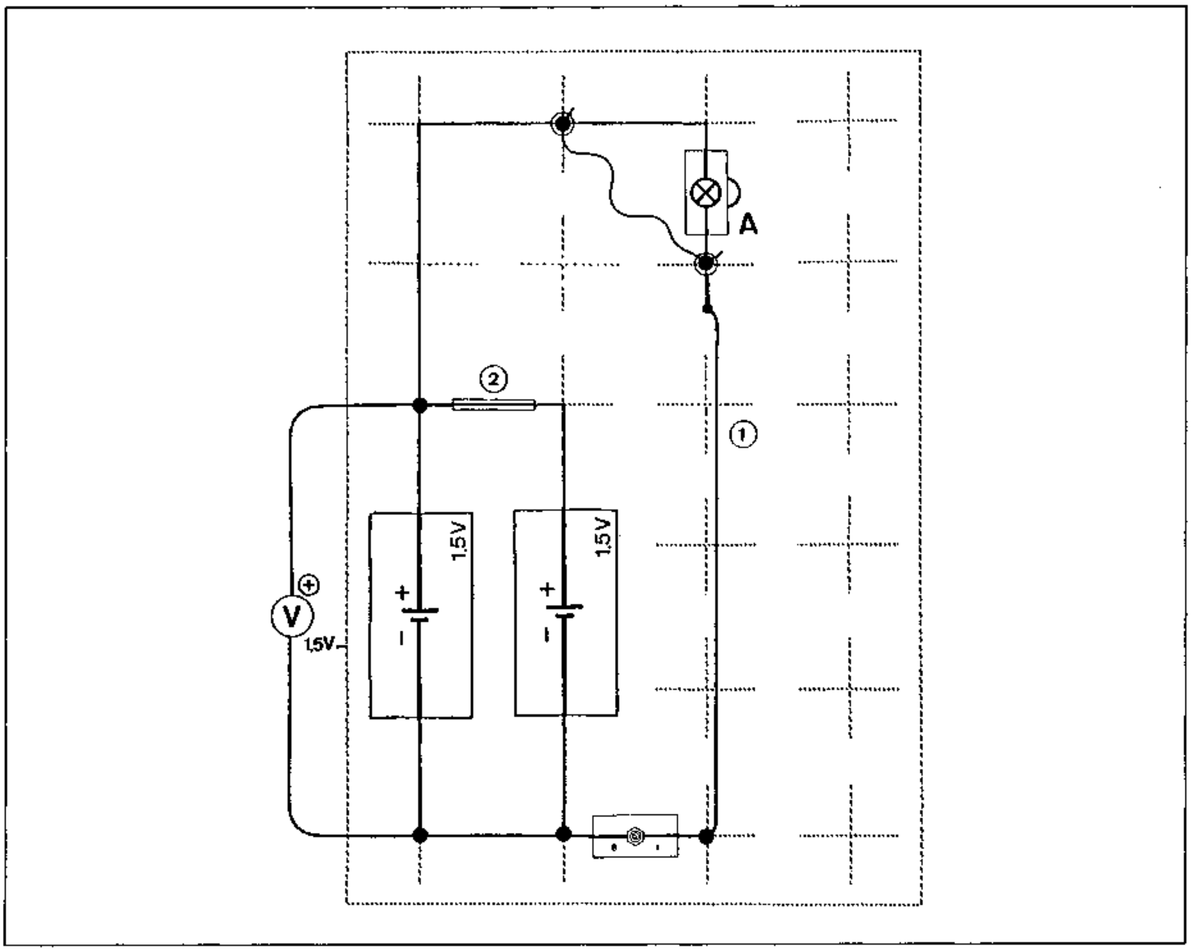


Fig. 3 Experiment setup: Monocells connected in parallel under heavy load
(1) lead

13. Close the switch – *for a brief period only.*

Note the brightness of the lamp.

Fit jumper plugs at position **(2)** (▶ Fig. 3) and use them to connect the second monocell in parallel to the first. How does this affect the brightness of the lamps, when you close the switch briefly once again?

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____

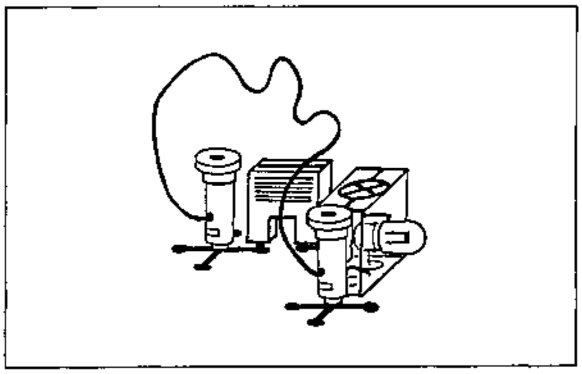

Fig. 4 Side view:
A 20 cm long constantan wire connected in parallel to lamp 1.

Student's Sheet 6

14. Repeat step 13. Watch the voltmeter.

Report on the experiment:

Table

a)	Monocell 1:	
b)	Monocell 2:	
c)	Series connection:	
d)	Parallel connection:	

Evaluation:

15. How do you connect two monocells in order to create a battery with a higher voltage?

16. How does the voltage across a battery reflect the voltage of the two monocells?

17. When is it useful to connect monocells in parallel?

Student's Sheet 1

Terminal voltage and internal resistance of a voltage source

Assignment: To determine the voltage across the terminals of a monocell as a function of load (current drawn).
Having made these measurements, to calculate the internal resistance (impedance) of the voltage source.

Apparatus:

1 layout plug-in board, DIN A4
1 monocell holder
1 monocell
1 wire winding board
1 chrome nickel wire, 0.35 mm ⌀
length: 20 cm
1 crocodile clip
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 voltmeter, 1.5 V–
1 ammeter, 3 A–

Student's Sheet 2

Setup:

1. Set up the experiment as shown in fig. 1. Clamp the wire using the clamping plugs **(3)**. To do this, wind the ends of the wire twice around the screw shafts, then tighten the screw clamps firmly.

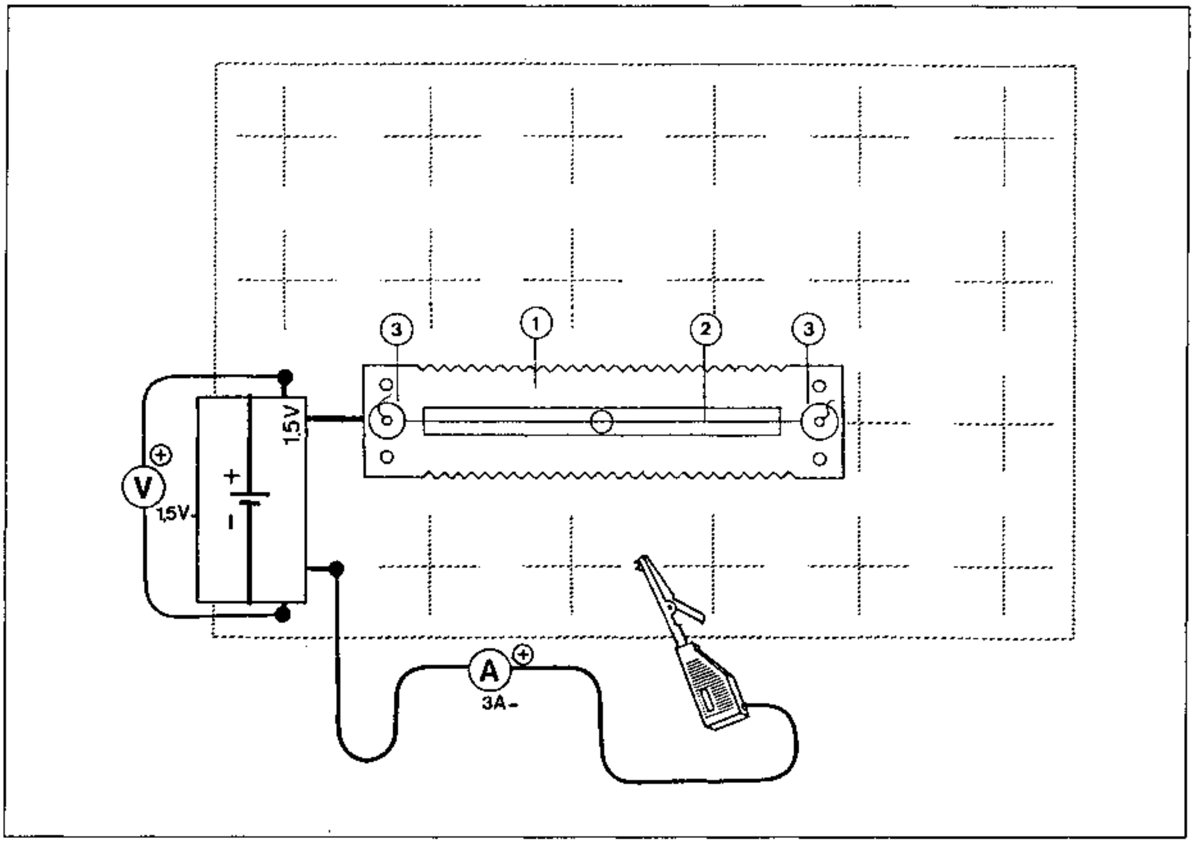

Fig. 1 Experiment setup: Terminal voltage and internal resistance of a voltage source
(1) wire winding board
(2) wire
(3) screw clamps

2. What value is the voltmeter shown in the circuit in fig. 1 measuring?

____

____

____

Carrying out the experiment:

The voltage *U* across the monocell should be measured as a function of the intensity of the current drawn *I*.

Table (with some measurement examples)

$\frac{I}{A}$	$\frac{U}{V}$
0	
1.0	
1.5	
2.0	

3. Measure the voltage *U* across the monocell when the circuit is open (*I* = 0). Enter the measured value in the first line in the table.
4. Clamp the crocodile clip to the right-hand edge of the wire winding board. Measure *U* and *I*. Enter the measured values. ▶ Table, 2nd line.
5. Push the crocodile clip along the wire, until the display shows *I* = 1 A. Measure *U*. Enter the value. ▶ Table.
6. In the same way, determine the voltages when *I* = 1.5 A and *I* = 2.0 A. Enter the values. ▶ Table.
7. You should enter *U* and *I* for a short-circuited voltage source in the last line of the table. To measure *U*, short-circuit the monocell with a lead, i.e. connect the ⊕- Pole and ⊖- poles of the monocell together. Enter the measured result.
8. Why do we measure an abnormal short-circuit voltage if we leave the ammeter connected to the short-circuited circuit?

____

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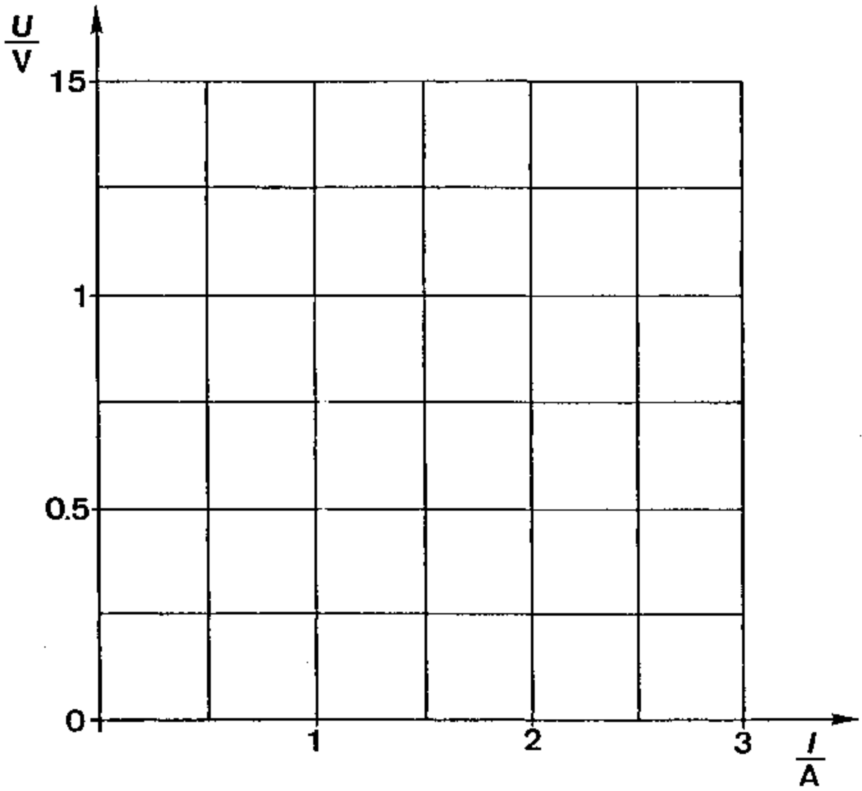
9. To measure the short-circuit current, connect the ammeter directly to the voltage source – for a very brief moment only. Enter the measured value. ▶ Table

Evaluation:

10. Draw a graph of the terminal voltage *U* as a function of the current intensity *I*.
▶ Graph.

Terminal voltage *U* as a function of the current intensity *I*:



11. What can you read from this graph?

____

____

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____

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Student's Sheet 5

12. Draw the circuit diagram for the circuit shown in fig. 1. Fig. 2 illustrates the switching elements.

    In an equivalent circuit diagram, we can imagine the monocell composed of

    - a direct voltage source with an electromotive force of U_0 and
    - an internal resistance of R_0, connected in series.

13. The voltage U which you measure across a voltage source is described as the *"terminal voltage"*.

    With the help of the equivalent circuit diagram for a monocell (▶ Fig. 2), you should set up an equation representing the terminal voltage as a function of the current I (load).

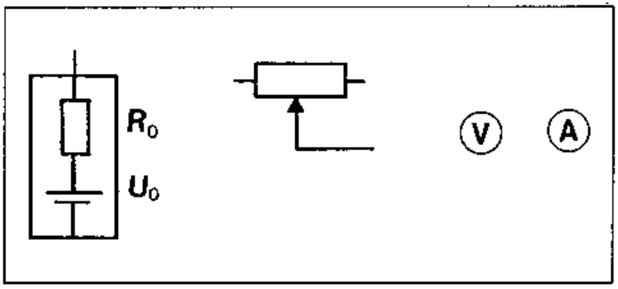

Fig. 2 from left to right:
- equivalent circuit diagram for a direct voltage source
- (e.g. monocell, U_0 = e.m.f., R_0 = internal resistance)
- adjustable resistance R_1 with a sliding contact (wiper)
- voltmeter symbol
- ammeter symbol

Fig. 2.1 Circuit diagram for the circuit shown in fig. 1 ▶ 12.

14. How can you calculate the internal resistance R_0? Give two examples of calculations.

15. How does the monocell's internal resistance R_0 manifest itself in the graph?
How large is it?

Student's Sheet 1

Self-heating and temperature sensitivity in wire-wound resistors

Assignment: To test whether the resistance of wires depends on temperature.

Apparatus:

1 layout plug-in board
1 jumper plug
1 on/off switch (toggle switch, single-pole)
1 wire winding board
2 clamping plugs
1 iron wire, 0,20 mm ⌀, 120 cm long
(≈ 8 x length of the winding board)
1 constantan wire, 0,35 mm ⌀, 90 cm long
(≈ 6 x length of the winding board)
1 red lead
2 blue leads

in addition:
matches, (candle)
1 pair of pincers
1 voltage source, 12 V– e.g.
low-voltage power supply unit

Measuring instrument:
1 ammeter, 3 A

Student's Sheet 2

Setup:

1. Construct the circuit shown in fig. 1 (without the wire filament). To start with, the switch is open. If you are using a DC voltage source, make sure the ammeter is connected correctly:
   The measuring instrument's "+" input (red socket) must be connected to the voltage source's ⊕-pole, the "–" input (blue socket) to the ⊖-pole.

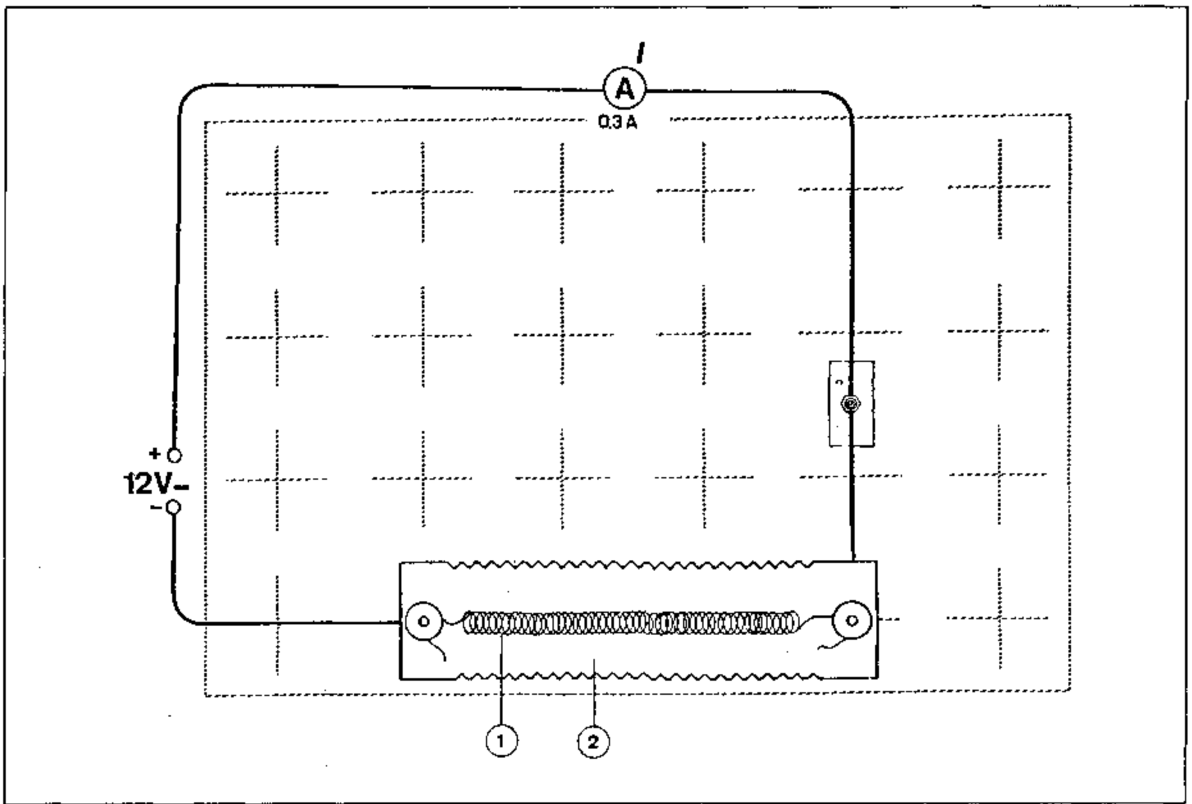

Fig. 1 Experiment setup: Self-heating and temperature sensitivity in wire-wound resistors
(1) wire filament ▶ Fig. 2; (2) wire winding board

2. Check the current range!
3. Cut a length of iron which is as long as the wire winding board from the dispenser.
4. Wind the iron wire in such a way that it forms a filament (e.g. with the aid of a pencil (fig. 2).

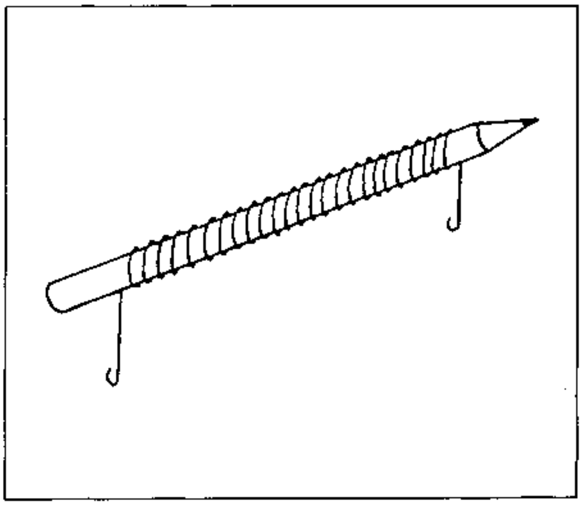

Fig. 2 Winding a wire to form a filament e.g. with the help of a pencil

Student's Sheet 3

5. Fasten the filament to the screw clamping the winding board, as shown in fig. 3.

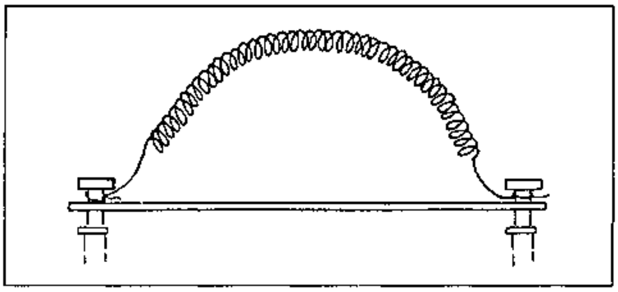

Fig. 3 Fastening the wire filament to the wire winding

Preparing your report:

6. Copy the table into your report book.

Carrying out the experiment:

Experiment part 1: taking measurements with an iron wire

7. Close the switch and select voltage level 1 (ca. 3 V–). Touch the wire with your finger. What do you notice?

___

8. Select voltage levels 2 to 4, on after the other, and hold your hand above the wire. Careful! Do not touch the wire!

9. At voltage level 4 (ca. 12 V–), wait for a moment until the ammeter has stabilised. Read off the value for the current and enter it in the table.

10. Blow on the filament or fan air along the filament (using your report book, for example). What does the ammeter show? (▶Table).

___

11. Explain the behaviour of the electric current.

___

___

12. What would happen if you heated up the wire filament? – Propose a theory:

___

___

13. Test your theory! To do so, hold a burning match (or a candle flame) under the filament. What is the intensity of the current measured? (▶Table).

___

Experiment part 2: taking measurements with a constantan wire

14. From the dispenser, cut a length of constantan wire (0.35 mm ⌀) which is 6 times as long as the wire winding board! Wind the constantan wire into a filament and clamp it in place of the iron wire. Repeat steps 9 to 13.
15. What is the current flowing through the constantan wire?
    a) at room temperature?
    b) when cooled externally?
    c) when heated externally?
    (▶ Table).

Report on the experiment:

Table

			Current intensity		
Material	Wire length ca.	⌀	a) no external influences	b) when cooled externally	c) when heated externally
Iron	120 cm	0.20 mm			
Constantan	90 cm	0.35 mm			

Evaluation:

16. How is the temperature of a wire affected by current flowing through it?
17. How does the electrical resistance of iron behave when the temperature of the iron rises?
18. Constantan is a copper-nickel alloy. The name is taken from the Latin and effectively means "unchanging". Why does Constantan have this name?

Model of a fuse

Assignment: To investigate the way a fuse works.

Apparatus:

1 layout plug-in board
1 pair of plug-in clamps
1 contact strip
2 clamping plugs
2 lamp holders (screw-in holders, E10, lateral)
1 on/off switch (toggle switch, single-pole)
4 jumper plugs
1 lead, red, 25 cm
2 leads, blue, 25 cm
1 lead, black, 25 cm
1 piece of cardboard, ca. 5 cm x 5 cm
1 bulb, 12 V/3 W (type B)
1 bulb, 4 V/0.04 A (type C)
1 iron wire; 0.2 mm ⌀, 7 cm long
Steel wool thread, medium strength,
thin paper (ca. 1 cm x 2 cm)
Sellotape, ca. 3 cm long
piece of cardboard, ca. 5 cm x 5 cm
1 voltage source, 6 V–

Student's Sheet 2

Setup:

1. Construct the circuit shown in fig. 1. At position **(1)** is fixed a 5 cm long piece of conductor, consisting of uninsulated iron wire (0.2 mm ⌀). This is fixed in place by cable connectors and clamping plugs, as shown in the neighbouring illustration.

⚠ **Caution!**
Place cardboard beneath the wire.
Size: 5 cm x 5 cm.

The bulb (type C, 4 V) is connected to the iron wire **(1)** by a lead **(2)**.

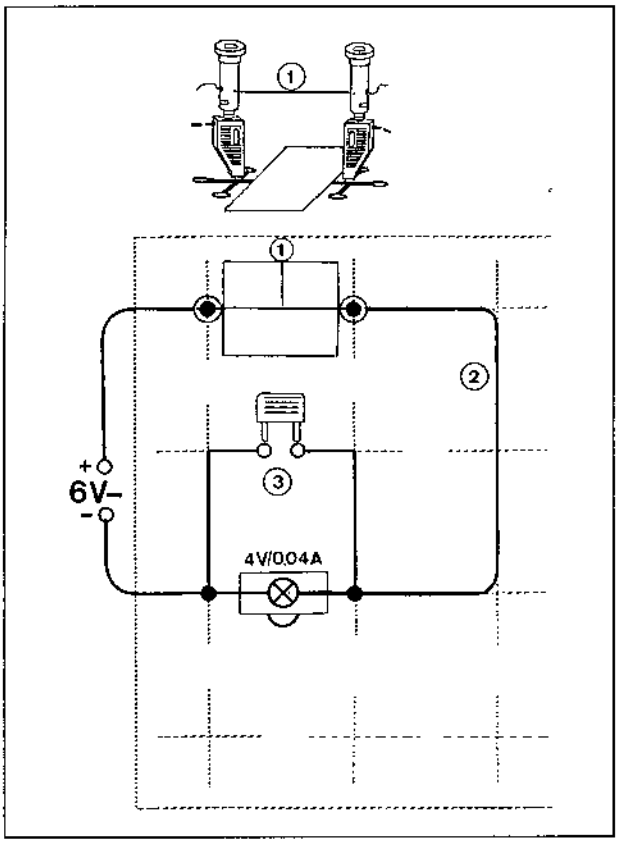

Fig. 1 Experiment setup: Model of a fuse
(1) iron wire; **(2)** lead; **(3)** jumper plug

Carrying out the experiment:

Experiment 1: short-circuit

2. Select a voltage of 6 V–.
3. Insert a jumper plug **(3)** in parallel to the lamp. This will cause a short circuit. We talk about a short circuit when the electrical current finds a way of bypassing all the electrical appliances.
4. What do you observe?

___

5. What can you say about the size of the short-circuit current?

___

___

___

Student's Sheet 3

Experiment 2: model of a fuse (fusible cutout)

6. We are going to use a thin piece of steel thread as a model of a fusible cutout (fuse). Use sellotape to stick it to the two plug-in clamps, as shown in fig. 3.
7. Does the lamp in the circuit shown in fig. 2 light up?

8. Draw the circuit diagram for this experiment.
   ▶ *Fig. 3.1.*
9. Now we must demonstrate:
   Even when paper which burns easily is placed over the bare conducting wire, there is no risk of a short circuit. Now insert a jumper plug at position **(3)**.

   Observe:

Experiment 3: dangers of repairing fuses

10. In an experiment using the model shown in fig. 2, we demonstrate how foolish it is to make repairs to a fuse by replacing the thin fuse wire with a contact strip.

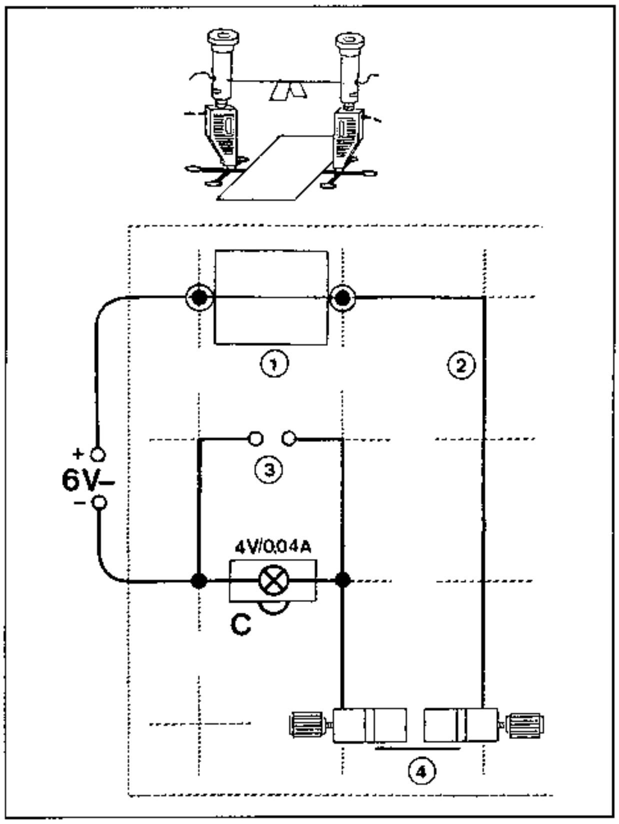

Fig. 2 Experiment setup: Model of a fuse (danger of making improvements)
(1) Iron wire with paper laid on top and cardboard underneath
(2) Lead
(3) Position at which a jumper plug should be inserted to short-circuit the lamp C
(4) Steel wool thread, fastened in place as shown in fig. 3

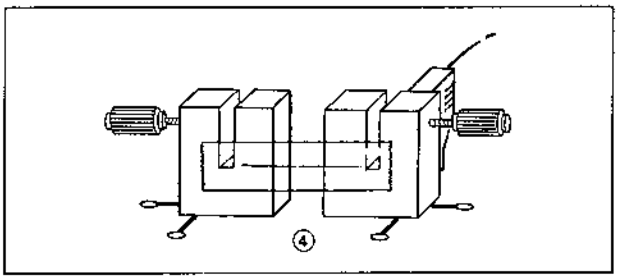

Fig. 3 Model of a fuse: steel wool thread **(4)** stuck to plug-in clamps by sellotape

Fig. 3.1 Circuit diagram for fig. 2

Experiment 4: overloading

Does the fuse wire only melt if there is a short circuit?

11. Construct a circuit as shown in fig. 4. The toggle switch is open. (Position 0).
12. What happens when you close the toggle switch?

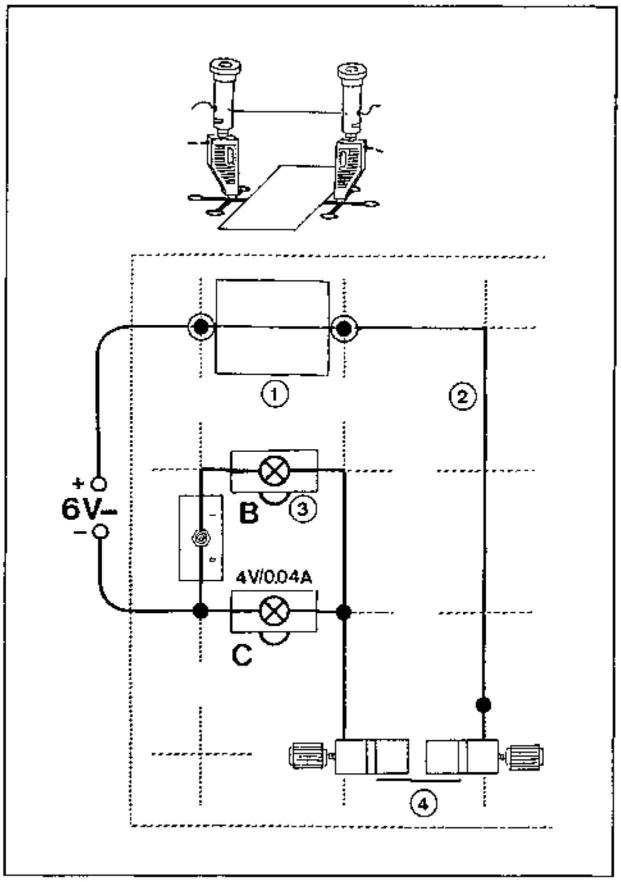

Fig. 4 Experiment setup:
Fuse reacting to overload
(1) Iron wire, with cardboard underneath
(2) Lead
(3) Bulb B, 12 V/3 W
(4) Fuse ▶ fig. 3

Student's Sheet 1

Bimetallic-element switches (model of a fire alarm)

Assignment: To construct a model fire alarm with the help of a bimetal strip.

Apparatus:

1 layout plug-in board, DIN A4
1 pair of board holders
1 lamp holder (screw-in holder, E10, lateral)
1 bulb, type B (12 V/3 W)
1 bimetal strip
1 contact strip
1 pair of plug-in clamps
2 jumper plugs
1 lead, red, 50 cm
1 lead, blue, 50 cm
matches
1 voltage source, 12 V~

Student's Sheet 2

Setup: ▶ fig. 1.

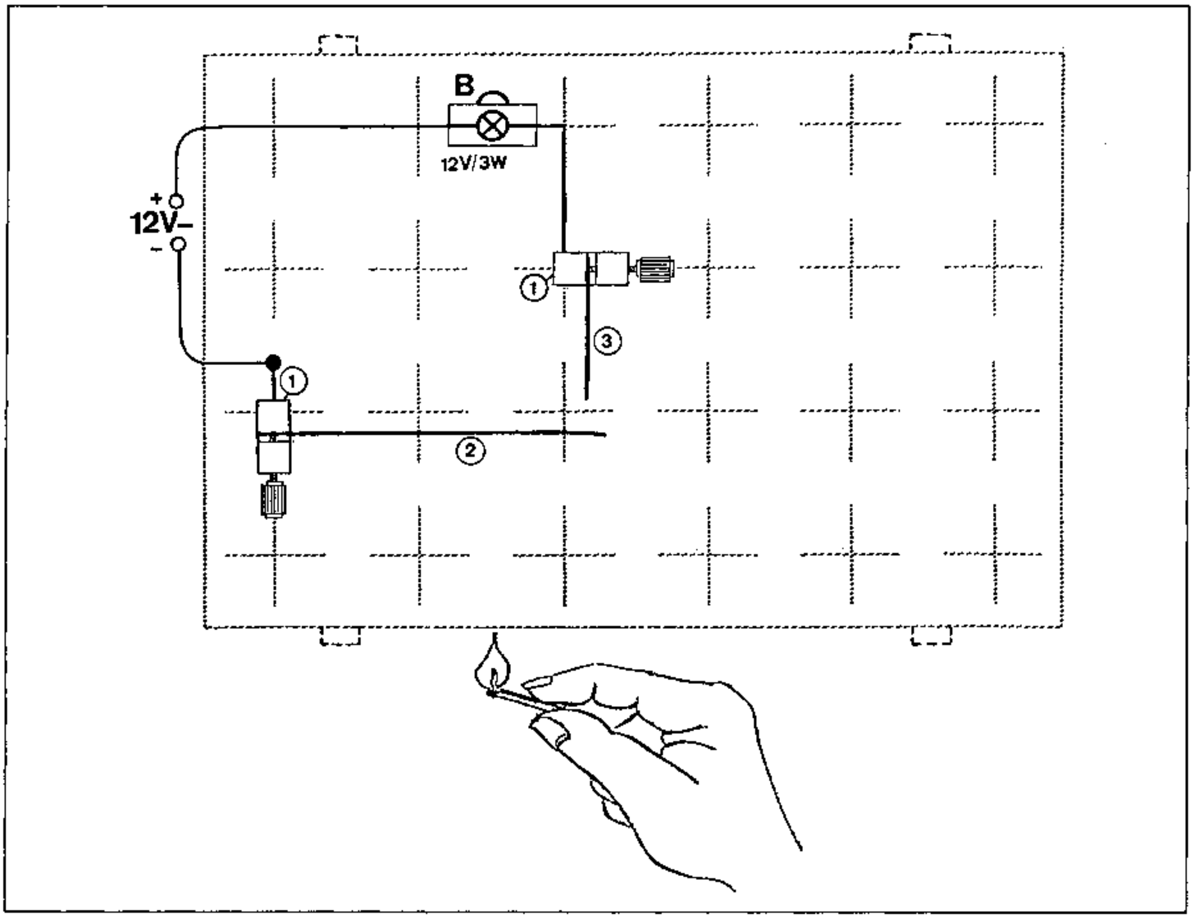

Fig. 1 Experiment setup: Bimetallic-element switch, held upright by board holders
(1) Plug-in clamps **(2)** Bimetal strip **(3)** Contact strip

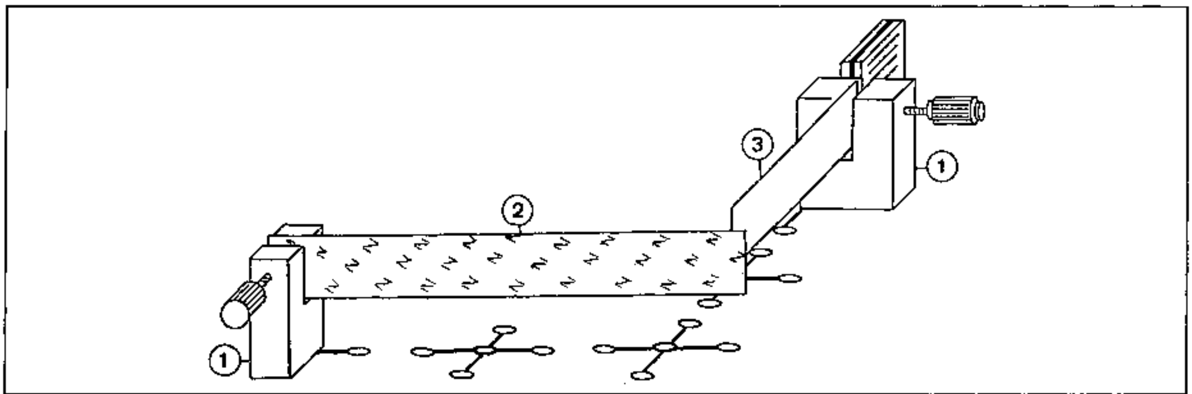

Fig. 2 Sideways view of the bimetal strip **(2)** shown in fig. 1; **(1)** plug-in holder **(3)** contact strip
The side with "N" printed on it should face downwards in the circuit shown in fig. 1.

1. Fit the bimetal strip as shown in fig. 2; the side with "N" printed on it should be facing forward while the board is horizontal (downwards when it is vertical). Fit the contact strip **(3)** in such a way that it does not touch the bimetal strip **(2)**. You should leave a gap of ca. 3 mm between them.

⚠ **Caution!**
Use board holders to position the layout plug-in board vertically. This will allow you to heat up the bimetal strip using a naked flame without damaging the heat-sensitive layout plug-in board.

Student's Sheet 3

Carrying out the experiment:

2. Strike a match and heat the middle part of the bimetal strip. What do you observe?

___

3. Blow out the flame as soon as the bimetal strip touches the contact plate. What happens?

___

4. Change the circuit round, so that the lamp lights up at room temperature and goes out when the bimetal strip is heated up.

Evaluation:

The bimetal strip consists of two different metals. They are fixed firmly together in a rolling process.

5. How does the bimetal strip behave when the temperature changes?

___

6. The bimetal strip is printed on one side with the letter "N" (repeatedly). Which side of the strip is composed of a metal which expands more quickly when heated; the printed side, or on the other side?

___

Student's Sheet 1

Model of a thermostat

Assignment: To build a model of an automatic temperature controller (a thermostat).

Apparatus:
- 1 layout plug-in board
- 1 pair of board holders
- 1 wire winding board
- 1 pair of plug-in clamps
- 1 contact strip
- 1 bimetal strip
- 2 clamping plugs
- 1 on/off switch (toggle switch, single-pole)
- 1 constantan wire, 0.35 mm ⌀, 60 cm long
- 2 leads, red, 25 cm
- 1 lead, blue, 25 cm
- 1 ammeter, 3 A
- 1 DC voltage source, 12 V

Setup:

▶ Fig. 1.

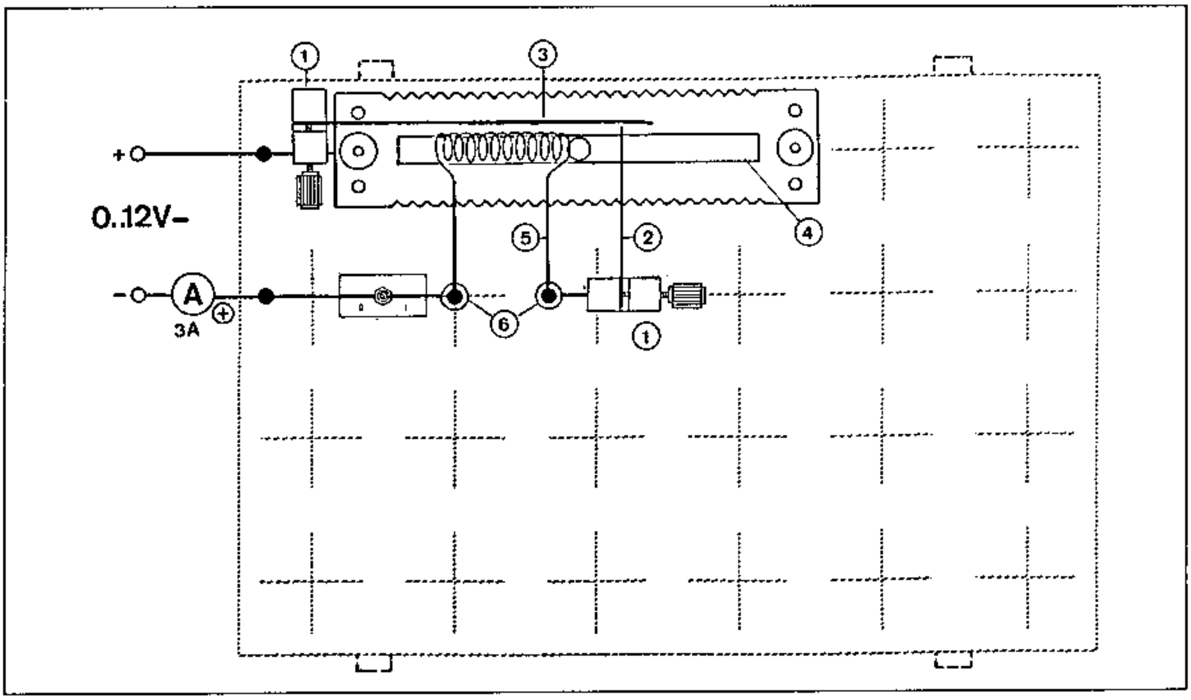

Fig. 1 Model of a thermostat, held in a vertical position by board holders
(1) Plug-in clamps (2) Contact strip (3) Bimetal strip
(4) Wire winding board (5) Chrome nickel wire (6) Clamping plugs

Student's Sheet 2

1. First set up the wire winding board **(4).** It is intended to protect the heat-sensitive layout plug-in board from the glowing wire filament **(5).**
2. Do not switch on the voltage source to start with.
3. Fasten one end of the bimetal strip **(3)** in the plug-in clamp **(1)**. The contact strip **(2)** and the bimetal strip **(3)** should be touching. The printed side of the bimetal strip identifies the material which expands more strongly when heated. When the strip is heated up, the contact between **(3)** and the contact strip **(2)** should be broken.

   Which way round should you fasten the bimetal strip?

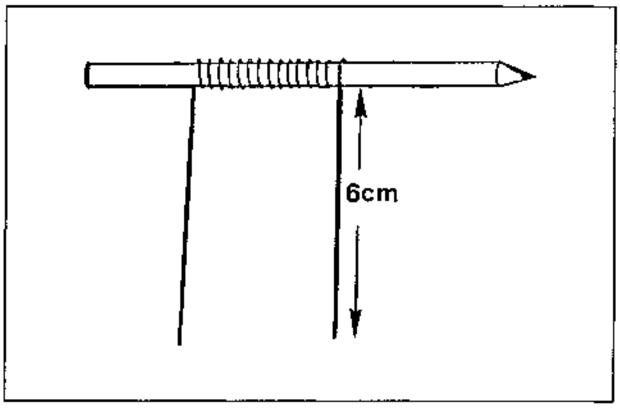

Fig. 2 Creating a heater coil using a thin rod, e.g. a pencil

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4. To create the wire filament, use a thin rod such as a pencil.

   ▶ Fig. 2.

   Do not wind the ends of the 60 cm long chrome nickel wire (ø 0.35 mm); leave a straight length of about 6 cm at either end.
5. Clamp the ends of the wire using the clamping plugs **(6).**

   Make sure the wire filament does not touch the bimetal strip.

6. To start with, the switch is open (position 0).
7. Position the layout plug-in board vertically, using the board holders.

Carrying out the experiment:

8. Apply a voltage of 12 V–. Close the switch.
9. Watch the ammeter and bimetal strip.

   Observation:

Student's Sheet 3

Evaluation:

10. What is the job of a thermostat?

____

____

11. Name some appliances which contain thermostats.

____

____

Student's Sheet 1

Power of and work done by an electrical current

Assignment: To determine the electrical output of and work performed by a bulb and a resistance wire by measuring voltage and current intensity.
To determine the time required by a heater coil to heat up 1 kg of water by 1 K (1 °C).

Apparatus:

1 layout plug-in board
9 jumper plugs
1 lamp holder (screw-in holder, E10, lateral)
1 on/off switch (toggle switch, single-pole)
1 wire winding board
2 clamping plugs
1 constantan wire, 0.35 mm ⌀, 204 cm long
2 leads, red, 25 cm
2 leads, blue, 25 cm
1 lead, blue, 50 cm
1 bulb, 12 V/3 W (type B)
1 voltage source, adjustable from 0 to 12 V–
1 voltmeter for 12 V–
1 ammeter, 0.3 A–

Experiment part 1: power consumption of a bulb

Setup: ▶ Fig. 1.

1. Keep the switch open. Set a current measuring range of 0.3 A–. Set the voltage of the power supply unit to 12 V–.

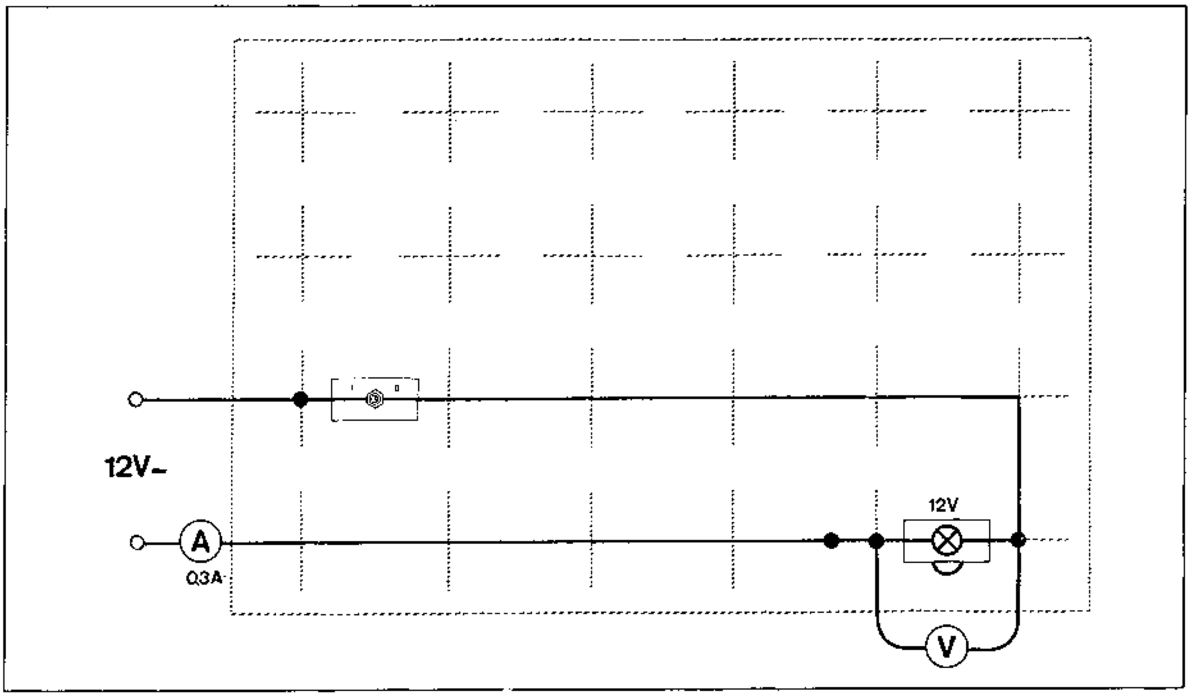

Fig. 1 Determining the power consumption of a bulb by measuring current and voltage

Student's Sheet 2

Carrying out the experiment:

2. Check that the bulb is indeed rated at 12 V, 3 W.

3. Close the switch. Read off the voltage *U* and current *I*.

Voltage *U* = _____
Current *I* = _____

Evaluation:

The electrical power *P* is the product of the voltage *U* and the current *I*:
$P = U \cdot I$.
It is measured in Watts. 1 W = 1 V · 1 A.

4. Calculate the power *P* of the bulb from the measured voltage *U* and current *I*.

____

____

____

5. Why is the power we have calculated less than 3 W?

____

____

6. What must you do in order to achieve maximum power?

____

7. What connection is there between the power of a bulb and its luminous intensity?

____

Student's Sheet 3

Experiment part 2: power consumption of a wire filament

▶ Fig. 2.

The switch is open. Voltage at the power supply unit: 12 V. Current measuring range: 3 A.

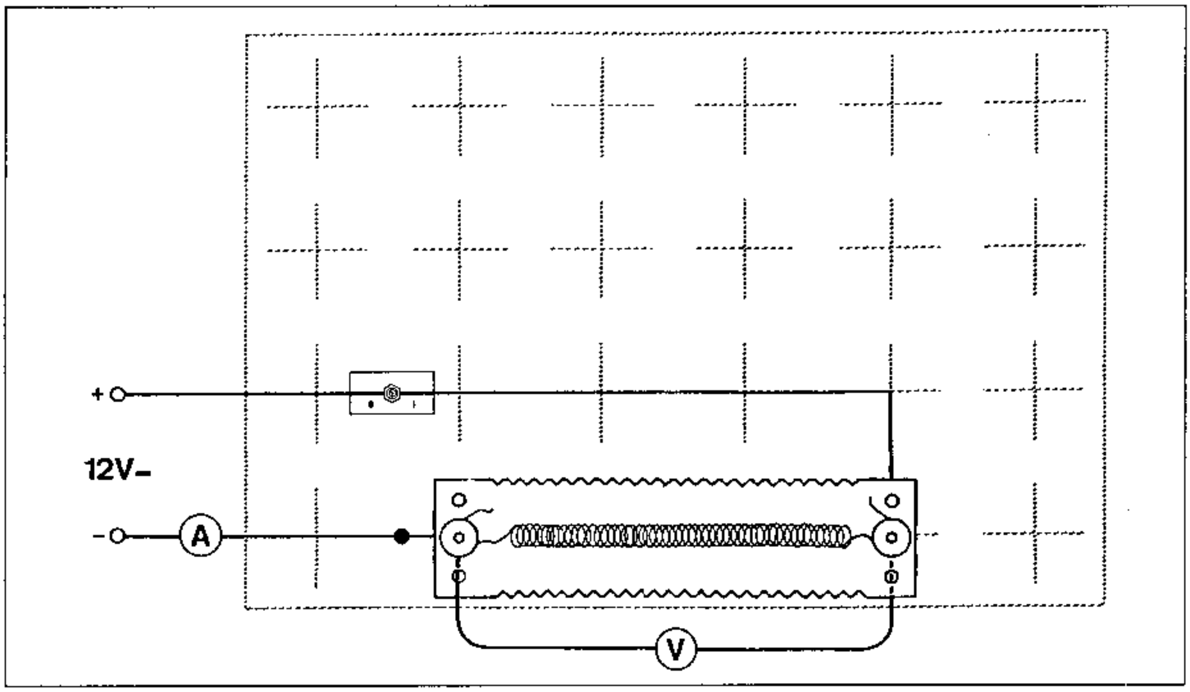

Fig. 2 Experiment setup: Determining the power consumption of a wire filament by measuring current and voltage

8. Clamp the wire winding board in place using clamping plugs.
9. Wind a 200 cm length of constantan wire into a filament with the help of a thin rod (e.g. a ball-point pen refill or a felt tip pen) and clamp the ends firmly to the wire winding board using the screw clamps.
   ▶ figs. 3 and 4.

⚠ **Caution!**

Do not touch the filament during the following experiment, as it becomes very hot.

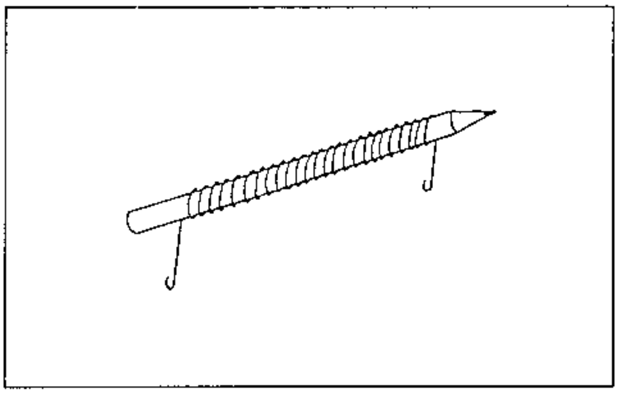

Fig. 3 Winding a wire to form a filament, e.g. with the help of a pencil

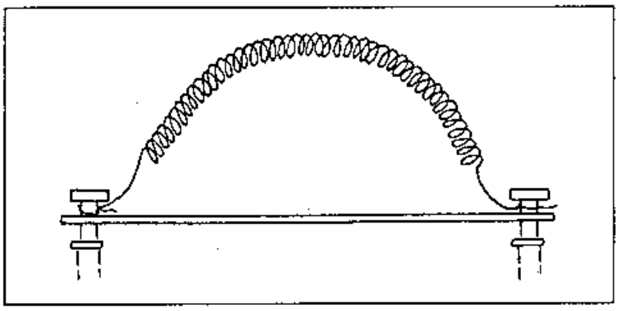

Fig. 4 Fastening the wire filament to the wire winding board

Student's Sheet 4

Carrying out the experiment:

10. Close the switch. Read off the voltage U and the current I at the different voltage levels listed in the table. Enter the values in the table.

Table

Voltage Level	Voltage	U	I	$P = U \cdot I$
1	3 V–			
2	6 V–			
3	9 V–			
4	12 V–			

Evaluation:

11. How does the electrical power consumption of the heater coil change if you double the applied voltage?

12. What relationship exists as a general rule between the power consumption P of a heater coil and the applied voltage U?

You can deduce the relationship very quickly if you know that Ohm's law applies to constantan ($U = R \cdot I$).

13. Calculate the power of the heater coil. ▶ Table, last column.
14. The work performed by the current is the product of electrical power *P* and time worked *t*;

    $W = P \cdot t$

    The unit of work is 1 watt-second or 1 joule

    1 Ws = 1 J

    To heat up 1 kg of water by 1 K (1 °C), you need 4187 J.

    How long should the heater coil be connected (at a level of 12 V) in order to perform this amount of work?

    ____

    ____

List of apparatus

Maximum Number	Description	Cat.-No.	Apparatus required in the experiment (number of units or length in cm)																			Number in the SVN apparatus set	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	El 1	El 2
1	Layout plug-in board, DIN A4	576 74	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	Jumper plug, Packof 10	501 48	3	3	1	1	3	6	4	1	2	–	–	5	9	–	1	4	2	–	9	1	
1	Pair of boardholders	576 77	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	(2)	2	–	(2)	
2	Leads, red, 25 cm	500 411	–	1	1	2	1	2	2	2	2	2	2	2	1	2	1	1	–	2	2	1	
2	Leads, blue, 25 cm	500 412	–	1	1	2	1	2	2	2	2	2	2	2	1	2	2	2	–	1	2	1	
2	Leads, black, 25 cm	500 414	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	
1	Lead, red, 50 cm	500 421	1	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	1	–	–	1	
1	Lead, blue, 50 cm	500 422	–	–	–	–	–	–	1	1	1	–	–	1	–	–	–	–	1	–	1		
2	Screw-in holders, E10, lateral	579 05	1	1	2	1	1	2	2	–	–	–	–	–	2	–	–	2	1	–	1	2	
1	Lamp 2.8 V/0.1 A (type A) from	505 11	1	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	1	
1	Lamp 12 V/3 W (type B) from	505 08	1	1	2	1	1	2	1	–	–	–	–	–	–	–	–	1	1	–	1	1	
1	Lamp 4 V/0.04 A (type C)	505 07	–	–	–	–	–	1	1	–	–	–	–	–	1	–	–	1	–	–	–	1	
1	Monocell holder	576 86	1	–	–	–	–	–	–	–	–	–	–	–	2	1	–	–	–	–	–	1	
2	Plug-in clams from	579 33	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	2	2	2	–	1	2
1	Toggle switch	579 13	1	1	–	–	–	1	1	1	1	–	1	1	1	–	1	1	–	1	1	1	
1	Contact strip from	579 332	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–		1
2	Changeover switches	582 81	–	–	1	2	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–		2
1	Wire winding board	567 18	–	–	–	–	–	–	–	1	1	1	–	–	–	1	1	–	–	1	1		1
1	Cr-Ni wire, 0.25 mm ⌀	550 46	–	–	–	–	–	–	–	204	204	204	–	–	–	–	–	–	–	–	–		$1/10$
1	Cr-Ni wire, 0.35 mm ⌀	550 47	–	–	–	–	–	–	–	–	204	–	–	–	–	20	–	–	–	–	–		$1/10$
1	Constantan wire, 0.35 mm ⌀	550 42	–	–	–	–	–	–	–	–	–	204	–	–	20	–	90	–	–	–	204		$1/10$
1	Fe wire, 0.2 mm ⌀	550 51	–	–	–	–	–	–	–	–	–	–	–	–	–	–	120	7	–	–	–		$1/10$
1	Bimetal strip	381 311	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–		1
1	Clamping plug	590 01	–	–	–	–	–	–	–	2	2	2	–	–	2	–	2	2	–	2	2	1	
1	Crocodile clips, Pair of	501 861	–	–	–	–	–	–	–	–	1	1	–	–	–	1	–	–	–	–	–		1
1	Setof 6 conductors/insulators	567 06	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		1
1	Potentiometer	577 90	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		
1	Resistor 47 Ω	577 28	–	1	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	1	
1	Resistor 100 Ω	577 32	–	1	–	–	–	–	–	–	1	–	2	2	–	–	–	–	–	–	–	1	
	U-measuring ranges in V–		–	–	–	–	–	–	15	15	15	1.5	15	15	1.5	1.5	–	–	–	15	15		
	I-measuring ranges in A–		–	–	–	–	–	0.03 0.3	–	0.3	0.3	–	0.3	0.3	3	3	3	–	–	3	0.3		
	Voltage source in V–		1.5	12	12	12	12	12	12	12	12	12	12	12	3.0	1.5	12	6	12	12	12		

Voltage sources

2 monocells, 1.5 V, from a pack of 20 . . . . 503 11
1 low-voltage power supply unit, 3 A
supply voltage 220 V~ 522 16

Measuring instruments

1 voltmeter, 1.5/3/15 V– DC
zero point at centre of scale, moving-coil type 531 68
1 ammeter 0.03/0.3/3 A–DC,
zero point at centre of scale, moving-coil type 531 69

Accessories

- Some steel wool threads
- Sellotape, ca. 10 cm
- Thin paper

1 pair of pincers, e.g. universal pliers (301 10)
1 pencil