Leybold Physik Physics Physique

Elektrik
Electricity
Electricité

Electromagnetism and Induction

588 342
Students' work sheets
(Masters for copying)

Schülerversuche Naturwissenschaften

SVN

STM

Science Teaching Modules

STM-Physics
Electricity
Electromagnetism and Induction

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Table of Contents

General instructions on use of the 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 ring folder contains introductory experiment descriptions on electricity as part of the series "**S**cience **T**eaching **M**odules" (STM).

All experiments can be carried out using the equipment sets EL1 and EL3 together with a few additional devices (voltage sources, measuring instruments).

Energy supply and power supply units; using the equipment correctly

The power supply and measuring instruments are not included in the equipment sets.

Power supplies other than those described here can be used for supplying the adjustable experiment voltages of up to 12 V DC and 12 V AC.

Similarly, measurement instruments other than those described here can also be used in the experiments.

For this reason, these devices are represented in the students' worksheets using the standard international symbols.

In order prevent any misunderstandings due to this usage, the experiment descriptions are preceded by teacher's and students' worksheets describing the proper use of the recommended extra-low voltage power supply and the measuring instruments.

This allows the teacher wishing to use equipment already available to carry out the experiments using these devices with a minimum of difficulty.

Experiment times

The experiments have been designed so that all experiment phases – preparatory talk, issuing of apparatus, setting up, performing the experiment and evaluating the results – can generally be completed within a single two-hour lesson block.

You can also save time by omitting some experiment steps or an experiment section, as well as by sharing tasks when recording extensive measurement logs. Thus, the experiments can always be matched to the specific needs of each individual class.

The objectives of each experiment topic are given in the teacher's section. The teacher can thus obtain an overview of the material to be dealt with just by reading these sections in advance.

About the apparatus

1. **Low-voltage power supply (522 15/16) (voltage source)**

The low-voltage power supply provides the electrical circuits with voltage.

It does not generate the voltage itself, but transforms the dangerously high mains voltage available at the socket into a safe extra-low voltage.

Control elements:

1.1 Power lead with mains plug **(1)**

In order to obtain the required input voltage, the mains plug must be plugged into the socket before the device can be used.

1.2 Step switch **(2)**

When you are not observing or measuring, the step switch should be set to 0. The voltage can be set in four increasing steps, 1 to 4 (each step corresponds to approx. 3 V). The voltage you have selected is available at the outputs labeled "DC" (direct current) and "AC" (alternating current).

1.3 DC (direct current) output

Red socket = ⊕ pole
Blue socket = ⊖ pole

In the experiments, always connect the red socket to the circuit using a red connecting lead, and the blue socket using a blue connecting lead. This helps to prevent errors in connecting the circuit.

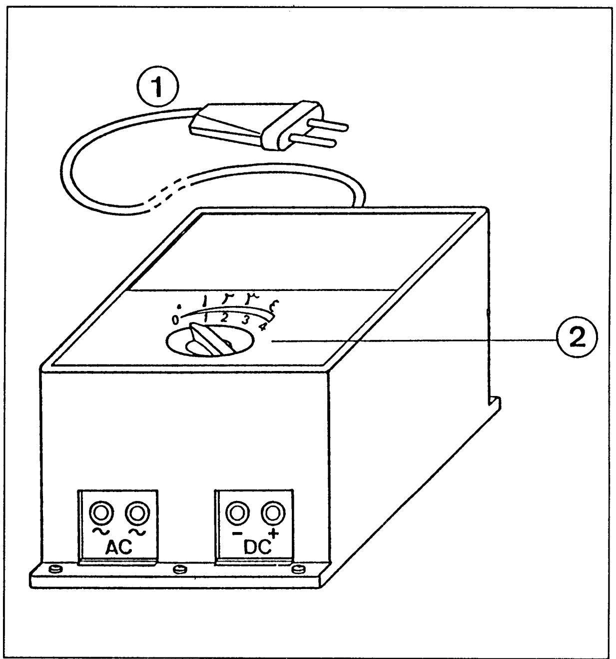

Fig. 1 Low-voltage power supply 522 15/16

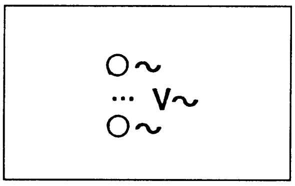

Fig. 2 AC voltage source

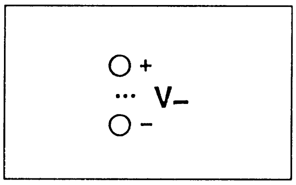

Fig. 3 DC voltage source

1.4 AC (alternating current) output

This output consists of two black sockets marked with the symbol ~. AC voltage at this output means that the ⊕ pole and ⊖ pole constantly change or "alternate" (a frequency of 50 Hz means that they change 50 times a second). As the two sockets are of equal importance, they have the same color. This means that you do not have to use different-colored connecting leads here.

1.5 Thermal protection

The low-voltage power supply becomes warm when it is connected. It heats up even when the step switch is set to 0. If too much current flows for too long at a particular voltage step, the interior of the device becomes hot and a thermal protection switch (a bimetal switch) switches off the outputs, so that the voltages are no longer available. When this happens, the power supply is *not defective*. However, it takes a while until the bimetal switch cools off and the voltage switches on again.

1.6 Symbol for power supply

The power supply is not drawn in complete form in the experiment descriptions. Only the socket symbols and the designation for the type of voltage are shown.

▶ Fig. 2 and Fig. 3

1.7 Technical data

522 16 for 220 V mains connection
522 15 for 110 V mains connection

Outputs: 3/6/9/12 V AC
3/6/9/12 V DC
Total load capacity: 3 A

2. Recommended voltage sources

2.1 Variable low-voltage transformer SE (522 20)

Outputs

0 to 25 V DC; 6 A, continuous
0 to 25 V AC; 6 A, continuous
6 V AC; 1.8 A
12 V AC; 1.8 A
± 5 V; 0.5 A stabilized

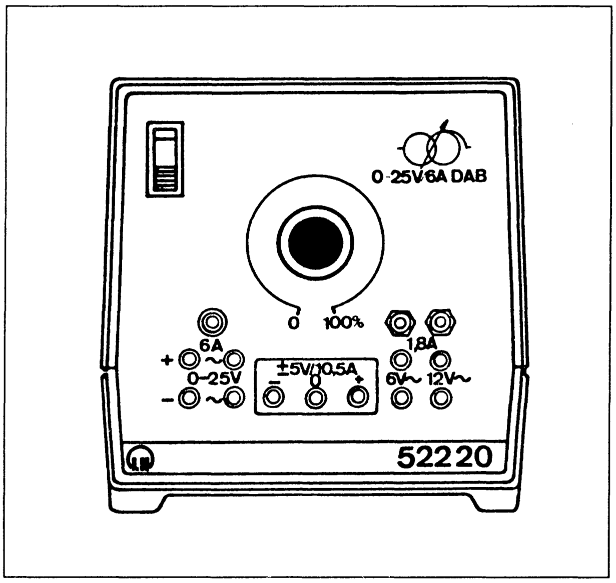

Fig. 4 Variable low-voltage transformer SE (522 20)

2.2 Variable low-voltage transformer S (591 09)

Outputs:

0 to 20 V DC; 6 A, continuous
0 to 20 V AC; 6 A, continuous
12 V AC; 1.8 A

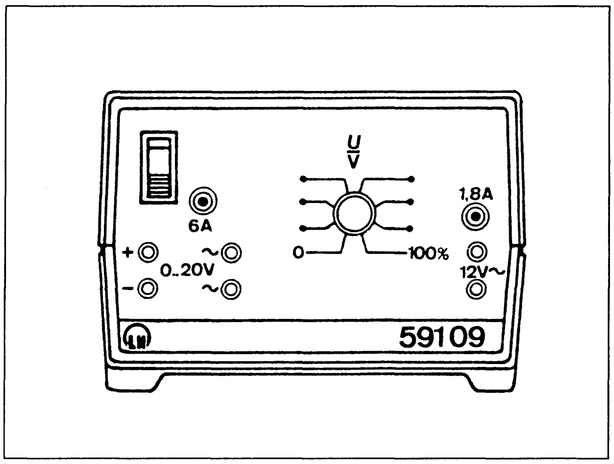

Fig. 5 Variable low-voltage transformer S (591 09)

2.3 Stabilized DC power supply (522 30)
0 to ±15 V

Outputs:

+ 0.1 to + 15 V DC; 1 A continuous
– 0.1 to – 15 V DC; 1 A continuous
Can be connected in series

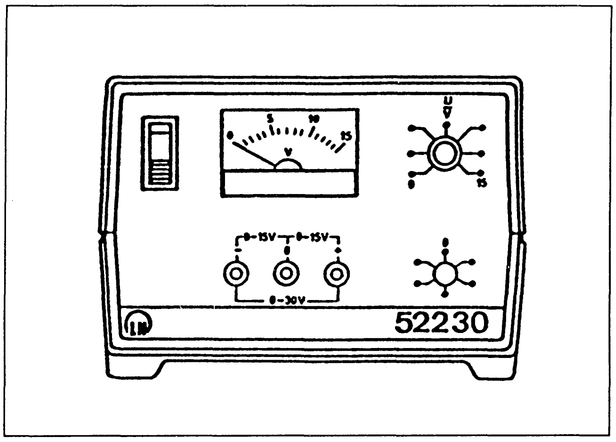

Fig. 6 Stabilized DC power supply (522 30)

2.4 Battery case 2 x 4.5 V DC (576 89)
Set of 20 batteries 1.5 V DC
(6 per group required) (503 11)

3. Multimeter M1 LH (531 50)

The multimeter (Fig. 8) can be used to measure both AC and DC currents and voltages, hence the name.

3.1 Selecting the measurement quantity and measuring range

On the front of the multimeter is a change-over switch surrounded by four fields. Each field is labelled with the unit of measure which the device measures when the switch points to one of the lines in this field. A stands for "Ampere" and V for "Volt". The type of current or voltage is designated by "–" for DC and "~" for AC. The measuring range is selected at the same time as the measurement quantity.

The measuring range shows the value at which the needle points to the last scale division (full scale deflection).

Attention!
When selecting a new measurement quantity, always set the largest measuring range first!

▶ Exercise 1

3.2 Scale

As you can see in the illustration, the zero point is in the middle of the scale. This means that you can measure DC currents and voltages which reverse their polarity without having to reconnect the leads.
Unlike measuring instruments with the zero point to the left of the scale, this multimeter cannot be damaged by connecting the leads with the wrong polarity (mixing up (+) and (–) during connection). Let us now take a closer look at the scales, the scale divisions and their designations.
The top scale is for current measurements and the bottom scale is for voltage measurements. You can only read the measured value from the meter correctly when you know the measurement quantity (A DC, A AC, V DC, V AC) and the measuring range.
It is easy to make a mistake when reading measured values from the scale. Before reading a measured value from the scale, you should ask yourself the following questions:

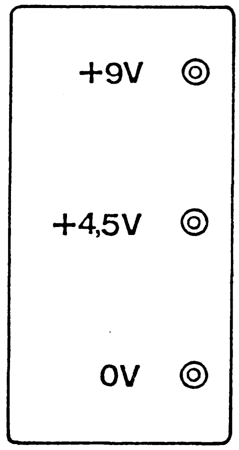

Abb. 7 Battery case (576 89)

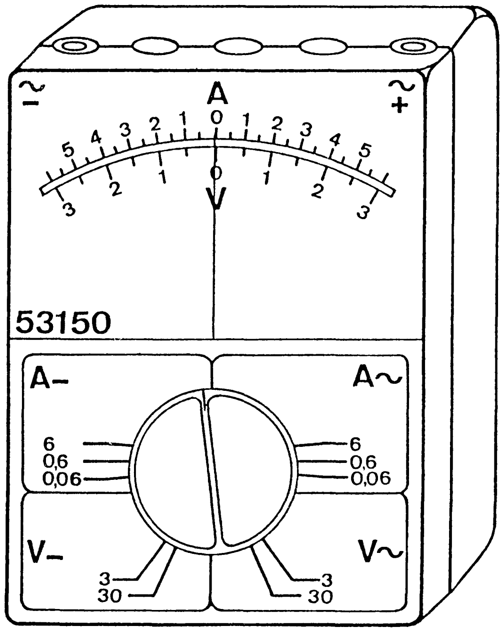

Abb. 8 Multimeter M1 LH (531 50)

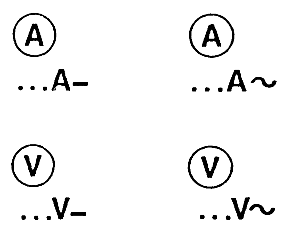

Abb. 9

a) What electrical quantity do I want to measure: direct current (DC), alternating current (AC), DC voltage or AC voltage?
b) What scale designations are possible for the selected measuring range?
c) What measured value corresponds to the scale division for number 1?
d) How much does the measured value change for each of the smallest scale divisions?

Another common mistake occurs when the eye is not directly over the needle. This type of mistake is called a “parallax error”.

To help prevent such errors, the meter has a mirror surface under the arc of the scale. When viewed at an angle, the reflection of the needle appears to be next to the needle itself. So, before reading a value from the scale, make sure that the needle covers its reflection.

You should also use this method to check that the zero point of the meter is set correctly. If it is not, ask your teacher. He or she will adjust the meter or instruct you how to do it.

3.3 Input sockets

The multimeter has two sockets for connecting it to the circuit; these are marked with + and – (at the top of the scale, above the sockets).

When measuring AC currents or voltages, the two sockets are of equal importance. The needle always deflects to the right, even when the sockets are exchanged. When you measure a DC current or voltage, the needle deflects to the right when the socket marked “+” is connected to the ⊕ pole of the voltage source, either directly or via other equipment, and the input marked “–” is connected to the ⊖ pole.

Note:

If you are using a meter with the zero point on the left of the scale, you must always make sure that the meter is connected as described.
In order to avoid mistakes in connection it is a good idea to always connect the socket marked “+” using a red connecting lead and the socket marked “–” using a blue connecting lead.

3.4 Symbols for the multimeter

In the experiment descriptions, the multimeter is represented by one of the symbols shown in Fig. 9. The selector switch of the multimeter should always be set to the measuring range given with the symbol.

4. Multimeter M2 LH (531 52)

Multimeter with high overload capacity and special built-in features for protection against damage due to improper use; for students' experiments.

Internal impedance:
30 kΩ V^{-1} (DC)
3 kΩ V^{-1} (AC)

Measuring ranges:
3/6/30/60/300/600 V AC/DC
0.006/0.06/0.6/6 A AC/DC
0 to 500 kΩ

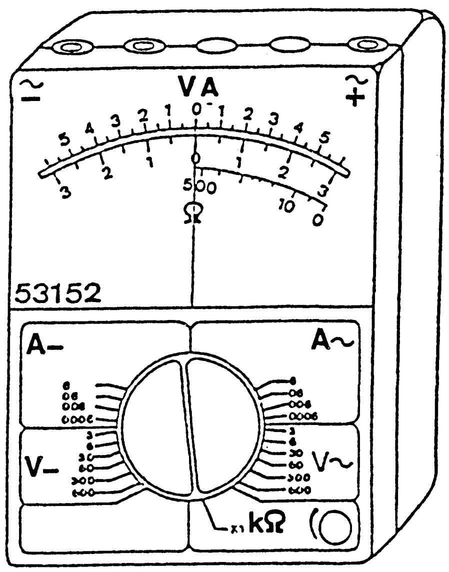

Fig. 10 Multimeter M2 LH (531 52)

5. Moving coil galvanometer (531 67)

The moving coil galvanometer is a sensitive instrument for measuring current or voltage; it has a scale with the zero point in the middle.

The needle deflects to the end of the scale when a voltage of about 0.07 V DC is connected between the two input sockets. This is the case when a current of about 0.0001 A DC flows through the meter mechanism.

The device measures the current when it is connected in a circuit as an ammeter.
Measuring range: 0.15 mA

The device measures voltage when it is connected as a voltmeter parallel to an element.
Measuring range: 0.15 V.

In the experiment examples, the moving coil galvanometer is used to measure voltages and show their polarity.
Fig. 12 shows the device symbol used in the experiment descriptions.

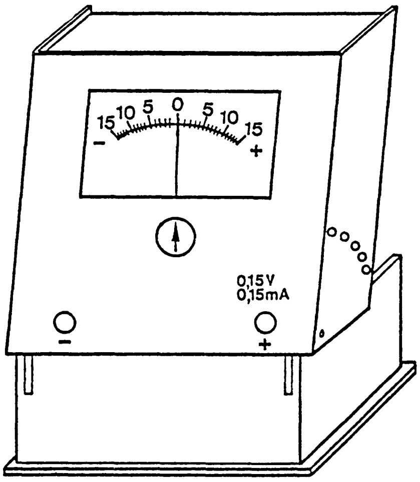

Fig. 11 Moving coil galvanometer (531 67)

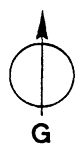

Fig. 12 Symbol for moving coil galvanometer

Student's Sheet 1

Practice exercises

Exercise 1

Name the measuring ranges of the multimeter M1 LH and write them in table 1.

Table 1

	Measuring ranges			Top scale	Bottom scale
DC current	6 A DC				
AC current	6 A AC				
DC voltage	3 V DC				
AC voltage	3 V AC				

Exercise 2

The meter has two scales. In table 1, mark with an x each range for which the top scale is used and each range for which the bottom scale is used.

Exercise 3

In table 2, the measuring range and the scale division number are given. Write in the measured value for each line.

Table 2

Measuring range	Scale division number	Measured value
6 A DC	1.6	1.6 A DC
0.6 A DC	0.3	
0.06 A DC	2.1	
6 A AC	0.9	
0.6 A AC	1.2	
0.06 A AC	0.7	
3 V DC	0.5	
30 V DC	1.5	
3 V AC	0.8	
30 V AC	2.6	

Student's Sheet 2

Note:

You can calculate the measured values for this multimeter quickly and easily by using the following formula:

a) **Current measurement**

$\frac{1}{6}$ x current range x scale division number

b) **Voltage measurement**

$\frac{1}{3}$ x voltage range x scale division number

Examples

Range	Scale division number	Measured value
6 A	1.6	$\frac{1}{6}$ x 6 A x 1.6 = 1.6 A
0.6 A	0.5	$\frac{1}{6}$ x 0.6 A x 0.5 = 0.05 A
3 V	0.3	$\frac{1}{3}$ x 3 V x 0.3 = 0,3 V
30 V	1.5	$\frac{1}{3}$ x 30 V x 1.5 = 15 V

Use these formulas to calculate the values for exercise 3.

Student's Sheet 1

The magnetic effect of electric current

Assignment: Using a compass, test whether magnetic forces act on a magnetized needle when placed close to a conductor carrying direct current (DC) (experiment after Oersted, 1820).

Apparatus:
1 rastered socket panel
1 bridging plug
1 plotting compass
1 STE toggle switch (on-off switch)
2 connecting leads, red, 25 cm
1 connecting lead, blue, 25 cm
1 low-voltage power supply, 3 V DC

Setup:

1. Assemble the circuit as shown in Fig. 1. Make sure that the switch is open. Connect points A and B on the rastered socket panel using a connecting lead.
2. Place the plotting compass between A and B under the connecting lead.

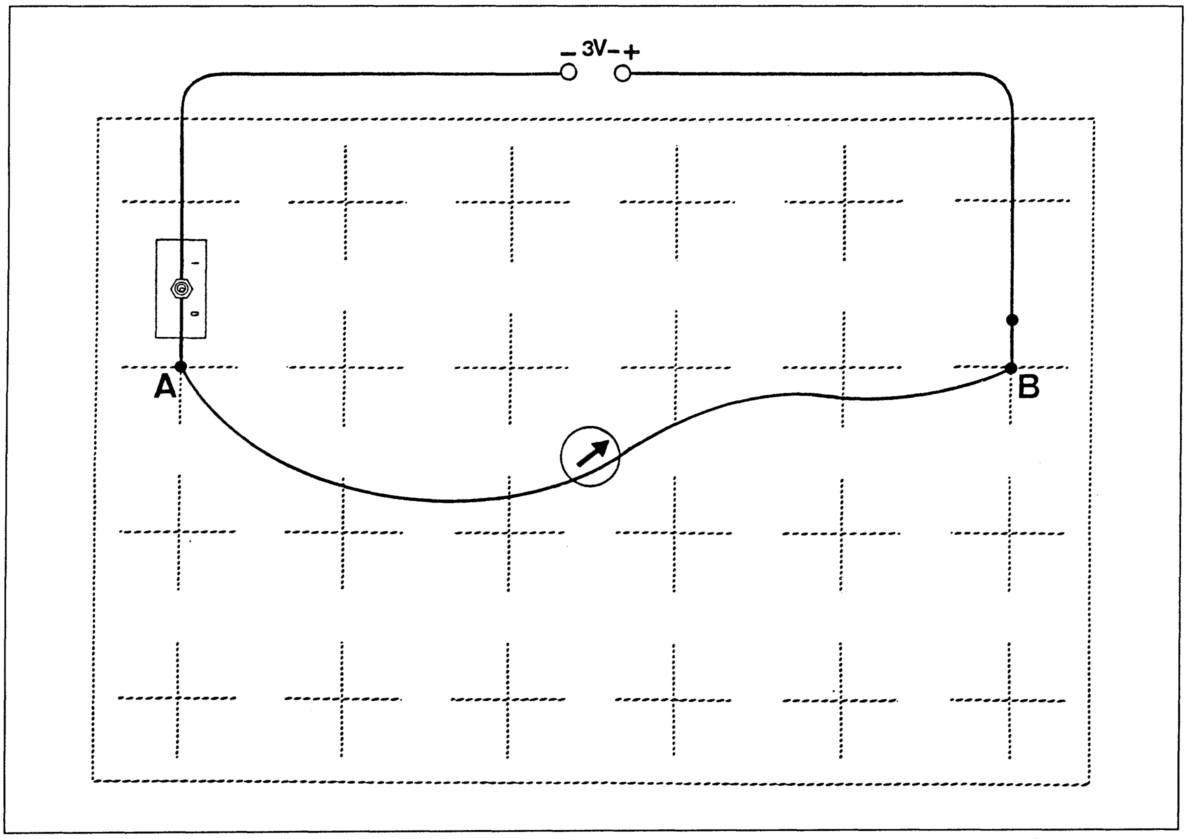

Fig. 1 Experiment setup after Oersted: demonstrating the magnetic effect of electric current

Student's Sheet 2

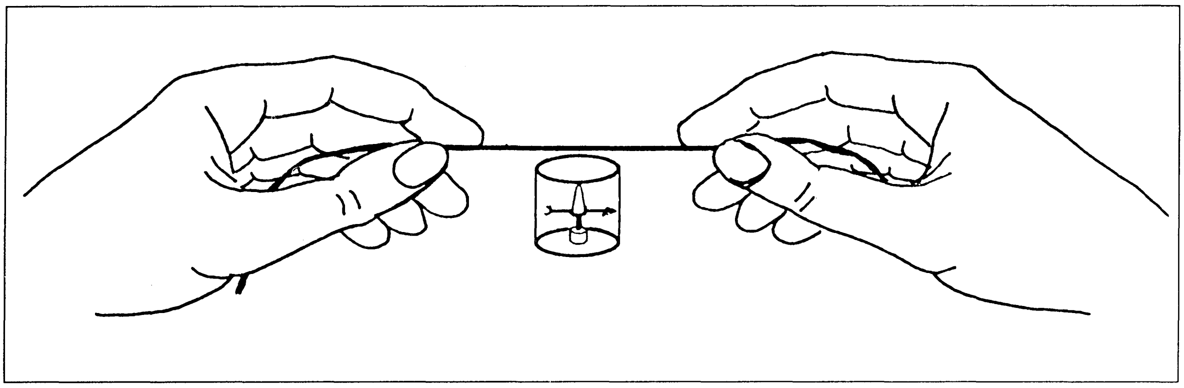

Fig. 2 Aligning a conductor (before connecting current) in the direction of a magnetized needle.

3. Turn the rastered socket panel so that the connecting lead is more or less aligned with the direction of the magnetized needle. Straighten the lead.
(▶ Fig. 2)

Performing the experiment:

4. Briefly close the switch and open it immediately. (Strong "short-circuit" current).

Attention!

If the switch is left closed for too long, the thermal protection switch in the power supply will switch the device off.

How does the magnetized needle react?

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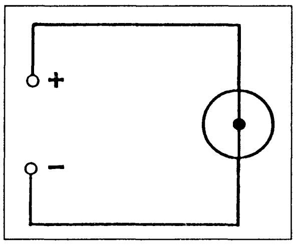

Fig. 3.1

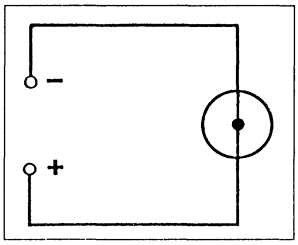

Fig. 4.1

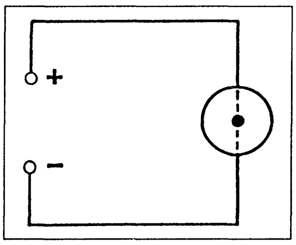

Fig. 5.1

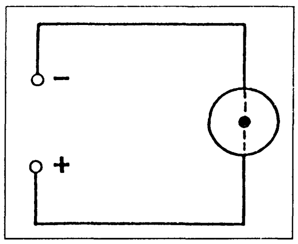

Fig. 6.1

5. Draw an arrow in the sketch in Fig. 3 to show the direction of the magnetized needle.

6. Use the plotting compass to show that the conductors are not magnetic when no current is flowing.

7. When the switch is open, reverse the connections at the voltage source and repeat step 5.
8. Draw an arrow in the sketch in Fig. 4 to show the direction of the magnetized needle.

9. Place the plotting compass *on top of* the connecting lead and repeat step 5.
10. Draw an arrow in the sketch in Fig. 6 to show the direction of the magnetized needle.

11. Reverse the connections at the voltage source and repeat step 5.
12. Draw an arrow in the sketch in Fig. 5 to show the direction of the magnetized needle.

Evaluation:

13. What is the relationship between electricity and magnetism?

____

____

14. Technically, we speak of current as flowing from + to –. How does the magnetized needle react to the direction of the current?

____

Current-carrying conductors in a magnetic field

Assignment: Test whether a magnet acts on a current-carrying conductor.
Arrangement over the pole of a bar magnet:
1. A freely swinging conductor carrying a direct current.
2. A wire carrying an alternating current (AC).

Apparatus:
1 rastered socket panel
1 pair of holders for rastered socket panel
1 STE toggle switch (on-off switch)
1 bar magnet
1 connecting lead, red, 25 cm
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 pair plug-in holders
1 constantan wire, 0.35 mm dia., 40 cm long
1 low-voltage power supply, 3 V AC/DC, 3 A

Student's Sheet 2

Experiment part 1: A DC-carrying freely swinging conductor in a magnetic field

Setup:

▶ Fig. 1

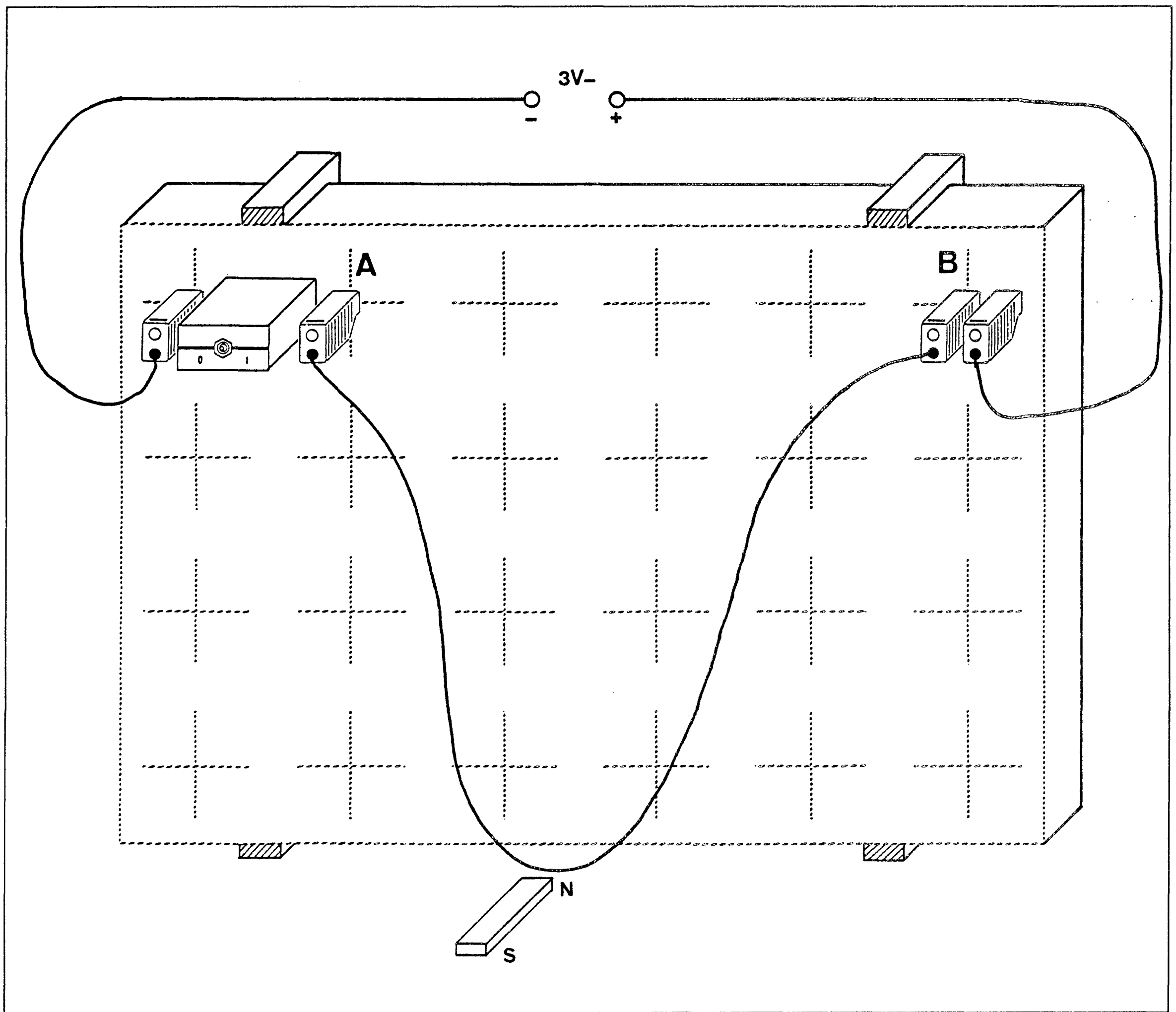

Fig. 1 Experiment setup: current-carrying freely swinging conductor in a magnetic field

1. Set up the rastered socket panel vertically using the pair of holders.
2. Insert the switch in the open position (switch position 0).
3. Select the connection points for the 25 cm connecting lead so that the middle of the lead hangs downward until it almost touches the bar magnet lying below it. Start with the marked end of the bar magnet (north pole) under the freely swinging conductor.

Student's Sheet 3

Performing the experiment:

4. Briefly close the switch and open it immediately. (Strong "short-circuit" current).

Attention!

⚠ If the switch is left closed for too long, the thermal protection switch in the power supply will switch the voltage supply off. You will then have to shut the device off and wait a while.

What do you observe when the current flows?

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___

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5. Turn the bar magnet around so that the poles are in the opposite positions. Close the switch and open it immediately! What do you observe now?

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___

___

Evaluation:

6. How does a conductor carrying direct current behave in a magnetic field?

___

___

How can you explain this behavior in physics terms?

___

Student's Sheet 4

Experiment part 2: wire carrying alternating current in a magnetic field

Setup:

▶ Fig. 2

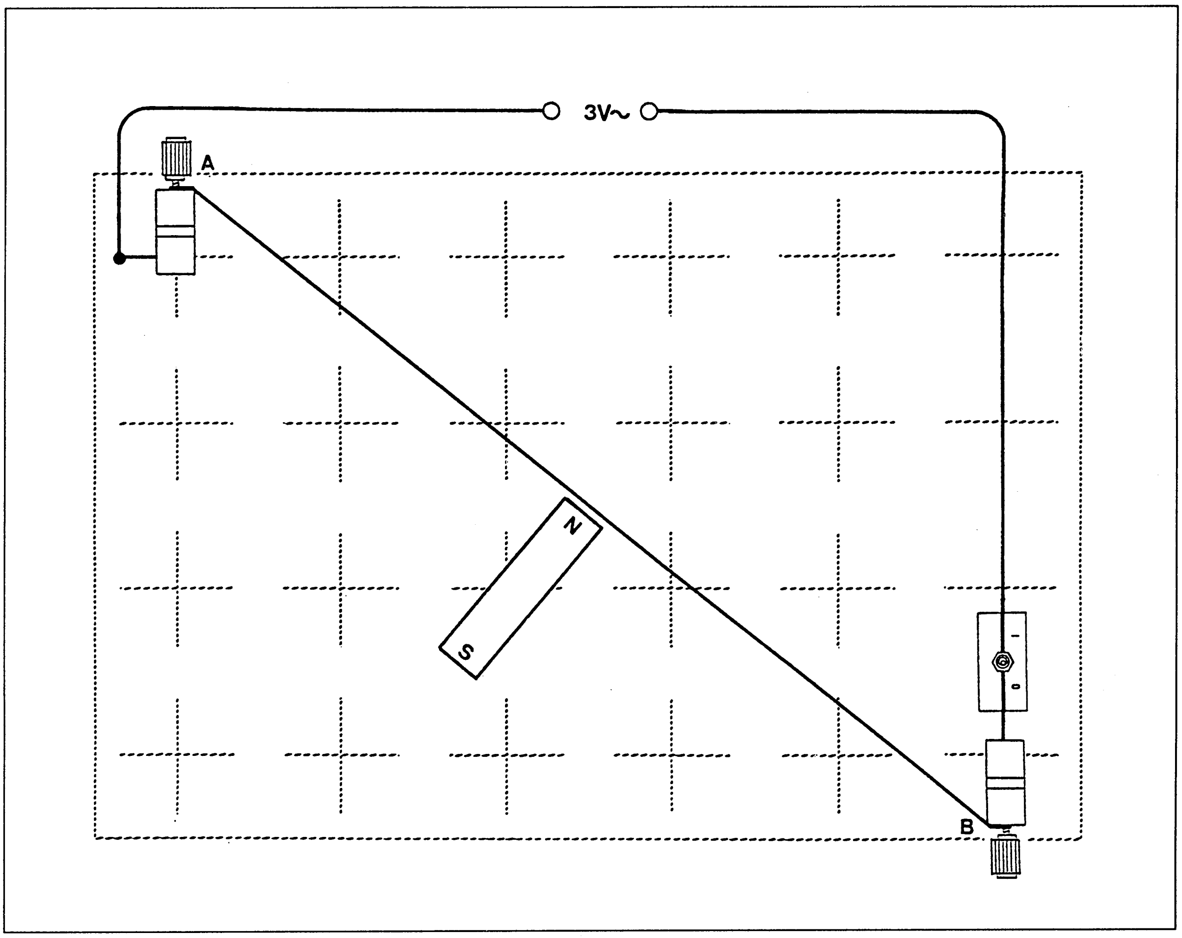

Fig. 2 A wire carrying alternating current in a magnetic field
A and B: screws of plug-in holders

7. Attach the constantan wire to the screws of two plug-in holders so that there is a little slack in the wire (▶ A and B in Fig. 2)
   Switch position: 0
8. Move the bar magnet to a distance of 1 mm from the middle of the wire, as shown in Fig. 2.

Student's Sheet 5

Performing the experiment:

9. Close the switch and open it immediately. High short-circuit current!
   What do you observe?

   ____

Attention!

⚠ If the switch is left closed for too long, the thermal protection switch in the power supply will switch the voltage off. You must then turn the device off and wait a while.

Evaluation:

10. What causes the action of the alternating current-carrying wire in the magnetic field which you observed?

    ____

    ____

    ____

Magnetic field of a coil

Assignment: To investigate the area surrounding a coil carrying direct current using a plotting compass.

Apparatus:
1 rastered socket panel
1 coil with 500 turns
1 transformer I-core (yoke)
1 plotting compass
2 connecting leads, red, 25 cm
2 connecting leads, blue, 25 cm
1 low-voltage power supply, 6 V DC
Material:
Sheet of paper, DIN A4
Pen or pencil

Student's Sheet 2

Experiment part 1: investigating the surroundings of a coil using a plotting compass

Setup:

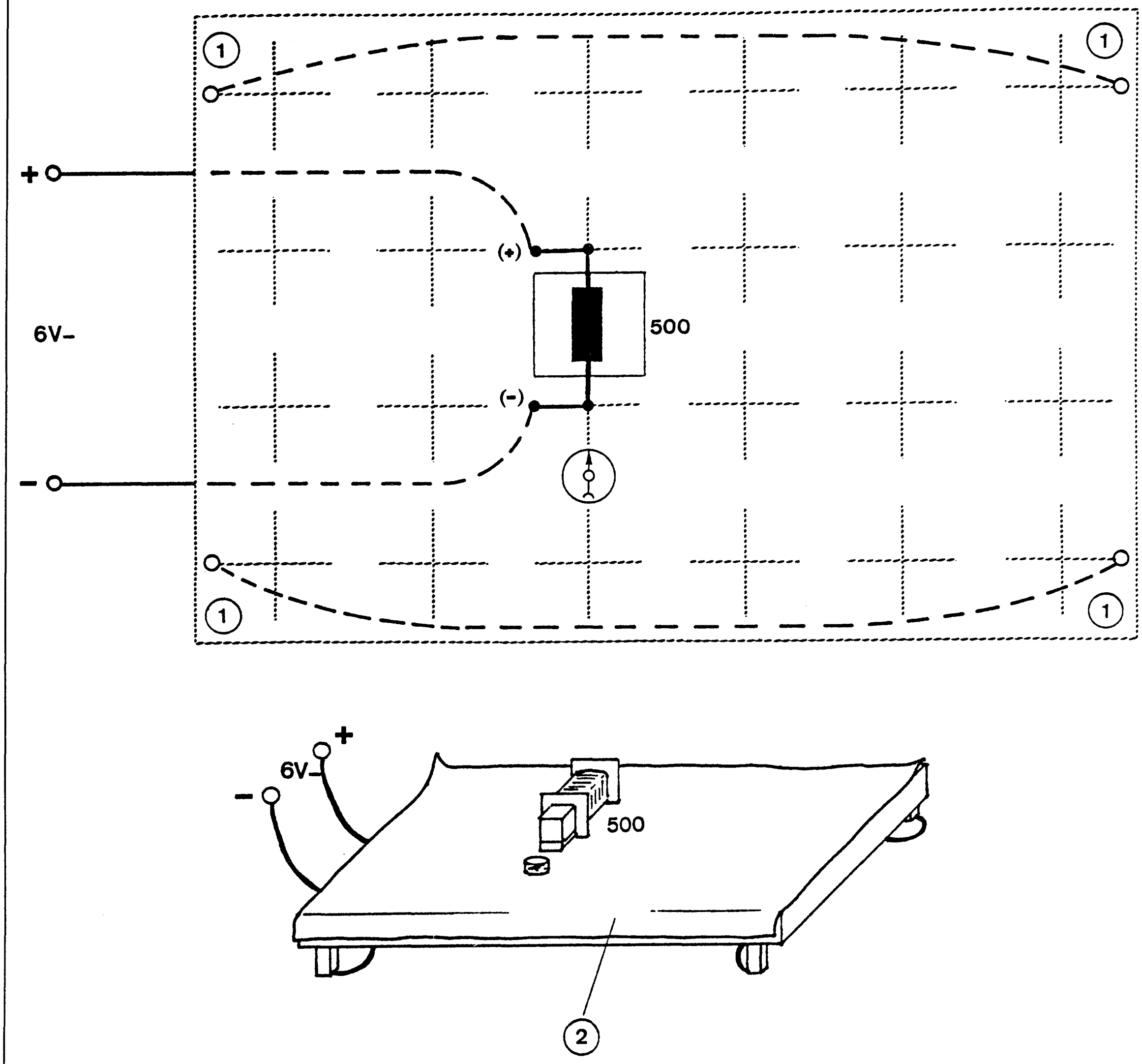

Fig. 1 Experiment setup: magnetic field of a coil
Top: top view
(**1**) Points for inserting 4 plugs
coil without I-core
Bottom: side view
(**2**) sheet of paper, DIN A4
coil with I-core

1. Insert the plugs of two cables on the back of the rastered socket panel at the points marked **(1)** in Fig. 1. The plugs serve as feet to allow access to the rear of the rastered socket panel.
2. Place a sheet of paper (DIN A4) on the rastered socket panel. Fold the edge of the paper sticking out on the long side downward (▶ Fig. 1).

Student's Sheet 3

3. Insert the coil (500 turns) through the paper at the point on the rastered socket panel shown in Fig. 1 and connect it to the voltage source (6 V DC) at the rear of the panel.
Do the first part of the experiment without the I-core!

Performing the experiment:

4. Slowly move the plotting compass around the coil.
What do you observe?

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5. Exchange the connections at the power supply.
What effect does this have?

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6. Push the I-core into the coil (▶ Fig. 1, bottom) and repeat step 4.
What effect does the I-core have?

____

Evaluation 1:

7. How can you use the compass to find the north and south poles of the electromagnet?

____

8. How does the magnetic needle of the plotting compass near the coil react when the direction of the current changes?

____

9. What effect does an iron core have inside the current-carrying coil?

____

Student's Sheet 4

Experiment part 2: drawing the lines of force of an electromagnet

Setup:

10. Use the same setup as in Fig. 1, but with the I-core in the coil

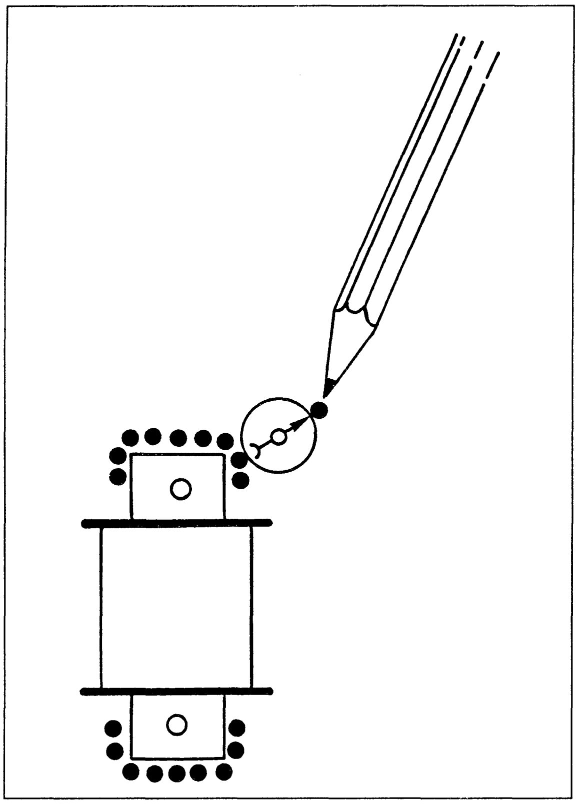

Fig. 2 Drawing the lines of magnetic force (first step)

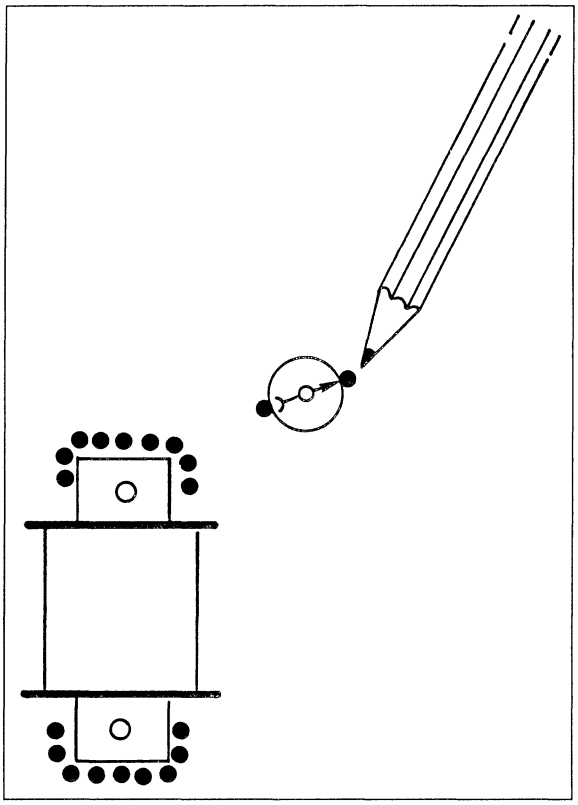

Fig. 3 Drawing the lines of magnetic force (second step)

Performing the experiment:

11. Set the plotting compass at a marked point next to the coil.
▶ Fig. 2
12. Mark the position of the needle tip on the paper with a pencil.
13. Shift the plotting compass so that the end of the needle is over the marked point.
Mark the new position of the needle tip. ▶ Fig. 3
14. Repeat this procedure until you come to either the edge of the paper or back to the coil.
15. When working in the direction opposite that in which the compass needle is pointing, shift the plotting compass so that the tip of the magnetized needle is on the point which you last drew. Then mark the position of the end of the magnetized needle on the paper.
16. Join the points with lines.
17. Draw arrows to show the direction in which the magnetized needle pointed each time.
18. Place the plotting compass at the other positions as described in step 11 (and shown in Fig. 2) and repeat the above procedure.

Evaluation 2:

19. What pattern of lines of force do the lines you have drawn look like?

____

____

Student's Sheet 1

Electromagnet

Assignment: Assemble a simple electromagnet. Find out what determines the position of the magnetic poles.

Apparatus:
1 rastered socket panel
1 pair of holders for rastered socket panel
2 bridging plugs
1 coil with 500 turns
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
1 plotting compass
1 connecting lead, red, 25 cm
1 connecting lead, blue, 25 cm
1 low-voltage power supply, 0 ... 6 V DC
Material:
Various iron or steel parts such as paper clips, nails, etc.

Setup:

1. Connect the coil as shown in Fig. 1 (connect the ⊕ pole of the voltage source to input **(1)** of the coil). Insert the I-core in the coil. Make sure that the voltage level is set to 0 and the switch is open.

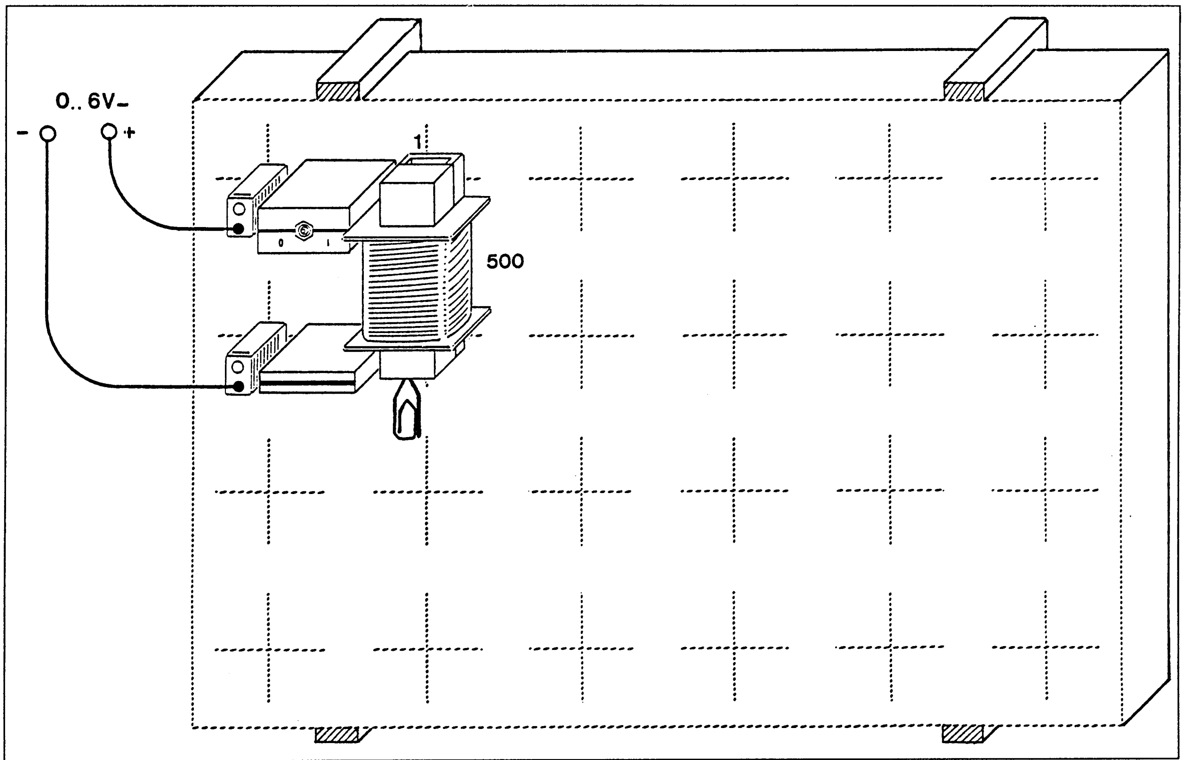

Fig. 1 Experiment setup: electromagnet

Student's Sheet 2

2. Fig. 2 and 3 show the symbol of a coil and the two possible connections to a DC voltage source.

Performing the experiment:

3. Select voltage level 1 (about 3 V DC).
   Close the switch and show that the coil attracts objects which contain iron.
4. Select voltage level 2 (about 6 V DC).
   What happens when you increase the voltage?

   ____

5. Open the switch while the iron parts are attached to the magnet.
   What do you observe?

   ____

6. Where are the poles of this electromagnet?

   Remember that the compass needle always points to the magnetic south pole.
   In Fig. 2, write in the letters N and S to show where the north and south poles are.

7. Exchange the connections at the voltage source.
   In Fig. 3, write in the letters N and S to show where the north and south poles are.

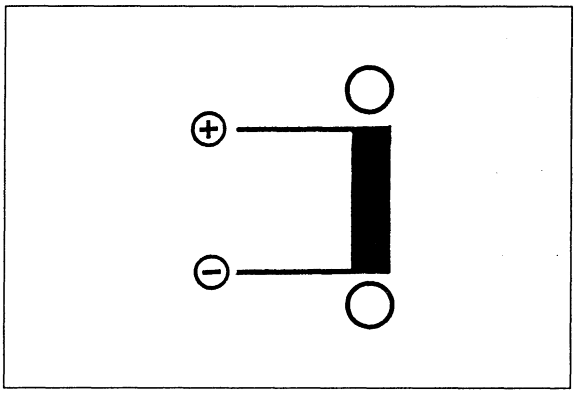

Fig. 2 Symbol for a coil with connection option 1

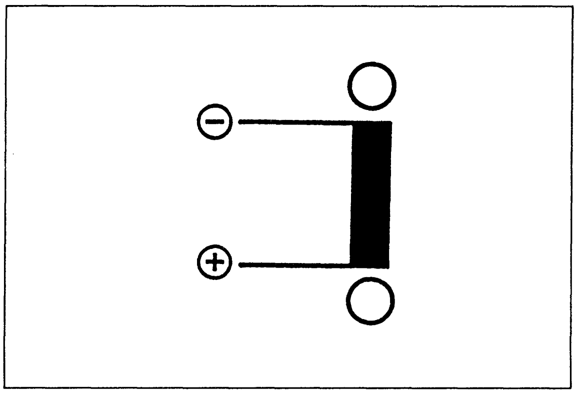

Fig. 3 Symbol for a coil with connection option 2

Evaluation:

8. What is the advantage of an electromagnet over a permanent magnet?

____

9. All coils in the equipment set are wound the same way, that is, clockwise from one connection to the other. An arrow on the end of the coil shows the direction in which the coil is wound. Check this. The arrow is on only **one** end of the coil. In which direction would an arrow on the other end of the coil point?

____

10. Which magnetic pole is on the side of the coil connected to the ⊕ terminal when the coil is wound clockwise? To find the answer, just look at Fig. 2 and 3 in the experiment log.

____

____

Model of a magnetic circuit breaker

Assignment: Build and investigate the magnetic circuit breaker model.

Apparatus:

1 rastered socket panel
1 coil with 500 turns
1 transformer I-core (yoke)
1 pair of plug-in holders
1 contact strip
1 leaf spring
1 STE toggle switch (on-off switch)
1 STE lamp holder E10, lateral
1 lamp, 4 V DC; 0.04 A (type C)
3 bridging plugs
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 connecting lead, red, 25 cm
1 low-voltage power supply, 9 V DC

Attention!
⚠ Do not touch the leaf spring, plug-in holders or contact strip during the experiment!

Student's Sheet 2

Setup:

▶ Fig. 1

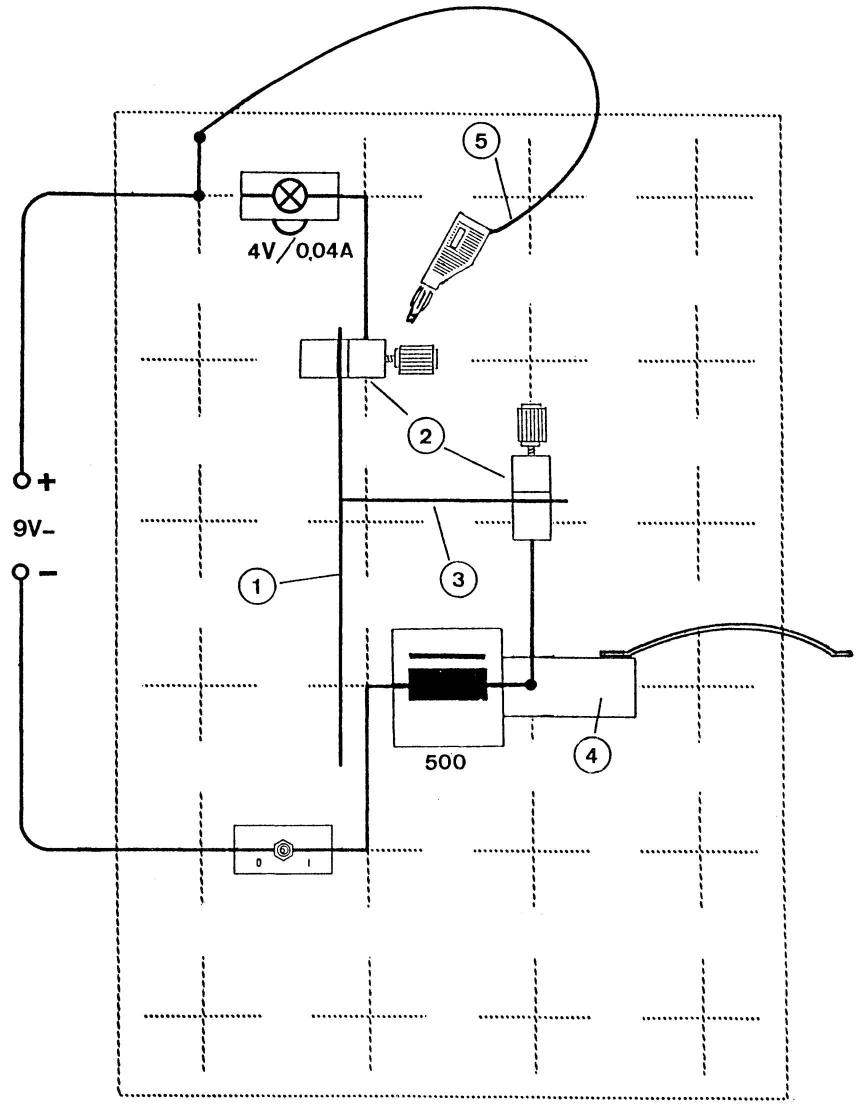

Fig. 1 Experiment setup:
model of a magnetic circuit breaker
(1) leaf spring; **(2)** plug-in holders; **(3)** contact strip;
(4) I-core (yoke) with arresting spring turned outwards (▶ Fig. 2);
(5) connecting lead for bridging the lamp

1. Connect the 9 V DC voltage to the circuit while the switch is open (switch position 0). The I-core **(4)** should slide easily in and out of the core. For this purpose, you must turn the arresting spring around 180°.
   ▶ Fig. 2.
2. The contact strip **(3)** should be attached in the plug-in holder so that it lightly touches the leaf spring **(1)**.

Performing the experiment:

3. Close the switch. The lamp should light up. What elements of the circuit are now carrying current?

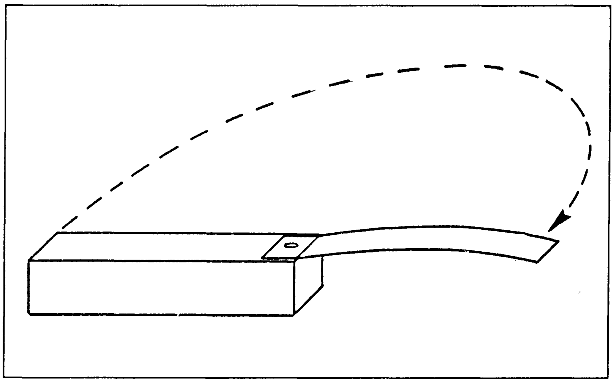

Fig. 2 I-core (yoke) with arresting spring; in this experiment, the spring is turned around 180° so that the core can move easily in the coil.

4. Bridge the lamp with the connecting lead **(5)**. You can do this by touching one of the plug-in holders **(2)** with the free plug of the connecting lead **(5)**.
What do you observe?

Evaluation:

5. Explain your observations.

Model of a moving-iron instrument

Assignment: Build a model of a moving-iron instrument and study its functional principle.

Apparatus:

1 rastered socket panel
1 pair of holders for rastered socket panel
1 coil with 500 turns
1 STE lamp holder E10, lateral
1 lamp, 12 V/3 W (type C)
1 STE toggle switch (on-off switch)
4 magnetizable rods (1 set)
2 bridging plugs
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 low-voltage power supply, 9 V DC
1 low-voltage power supply, 9 V AC

Student's Sheet 2

Setup:

1. Using the panel holders, set up the rastered socket panel in a tilted (console-type) position.
   ▶ Fig. 1

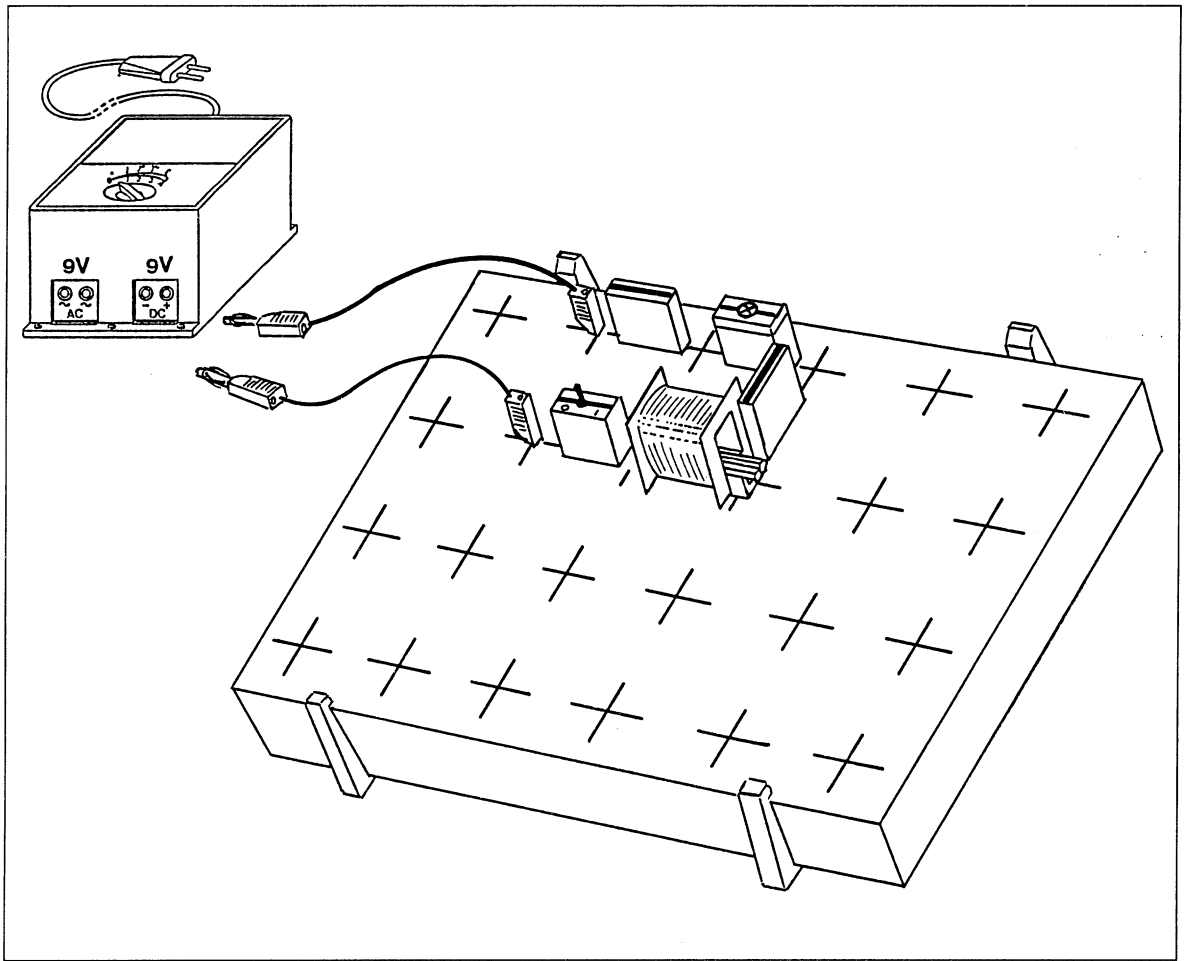

Fig. 1 Experiment setup (side view): model of a moving-iron instrument

2. Assemble the circuit as shown in Fig. 1 and Fig. 2. Make sure the switch is in the 0 position.
3. Screw the iron rods together so that you have two longer iron rods, and place these in the coil parallel to each other.

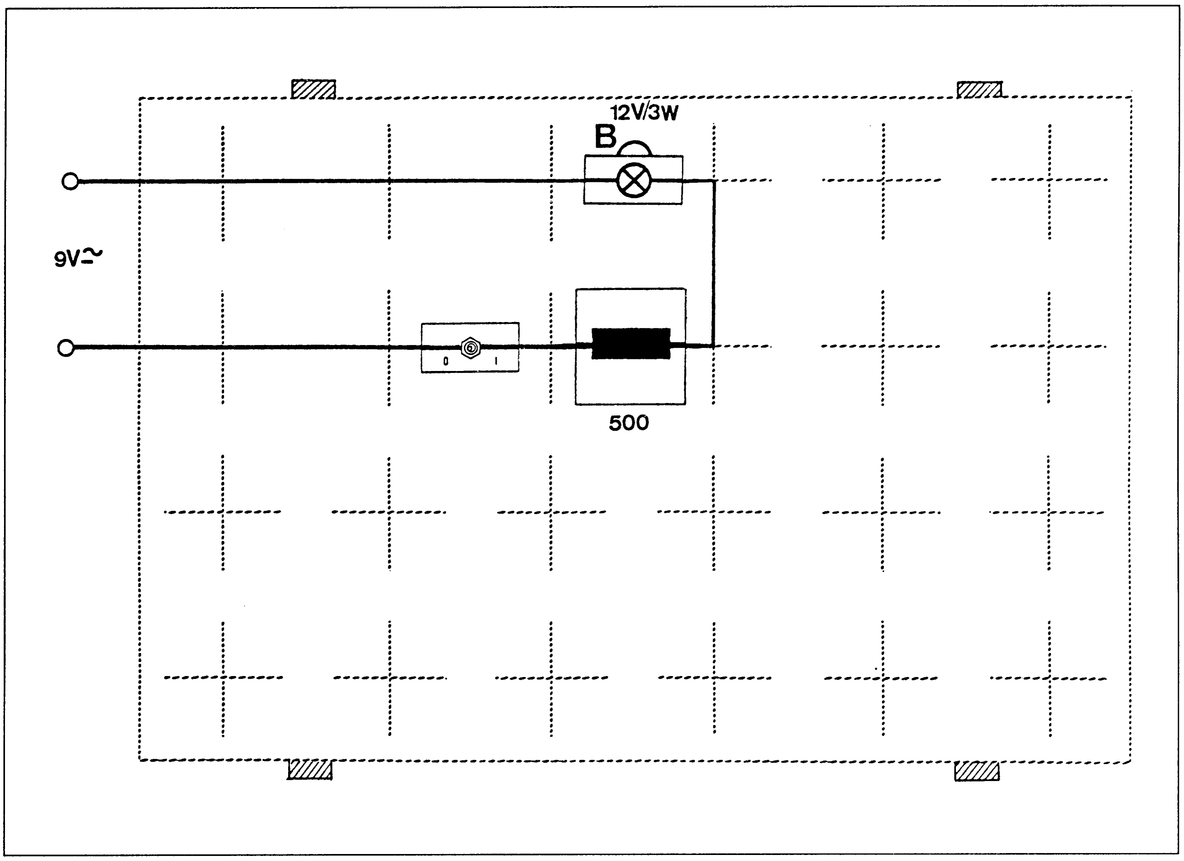

Fig. 2 Experiment setup from Fig. 1 (top view)

Performing the experiment:

4. Connect a voltage of 9 V DC. Turn the switch on and off several times. Observe the iron rods.

____

____

5. Reverse the direction of current by changing the connections at the voltage source. What do you observe?

____

6. Close the switch and then reduce the voltage to 6 V DC and then 3 V DC. What do you observe?

____

7. Open the switch and connect a voltage of 9 V AC to the circuit. Turn the switch on and off several times. What do you observe?

____

Evaluation:

8. How does the direct current flowing through the coil effect the iron rods?
Explain your answer in physics terms.

___

___

___

9. What is the effect of different current levels?

___

___

10. Is it possible to find out the direction of the current in a coil using a moving-iron instrument? Give reasons for your answer.

___

___

___

11. Can alternating current be measured with a moving-iron instrument?

___

___

Model of an electromagnetic relay

Assignment: Build a closing relay and a tripping relay.

Apparatus:

1 rastered socket panel
1 coil with 500 turns
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
1 pair of plug-in holders
1 contact strip
1 leaf spring
1 STE lamp holder E10, lateral
1 lamp, 4 V DC; 0.04 A (type C)
1 bridging plug
1 connecting lead, red, 25 cm
1 connecting lead, blue, 25 cm
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 low-voltage power supply, 6 V DC
1 low-voltage power supply, 6 V AC (or 6 V DC)

Attention!
⚠ Do not touch the leaf spring, plug-in holders or contact strip during the experiment!

Student's Sheet 2

Experiment part 1: building a closing relay

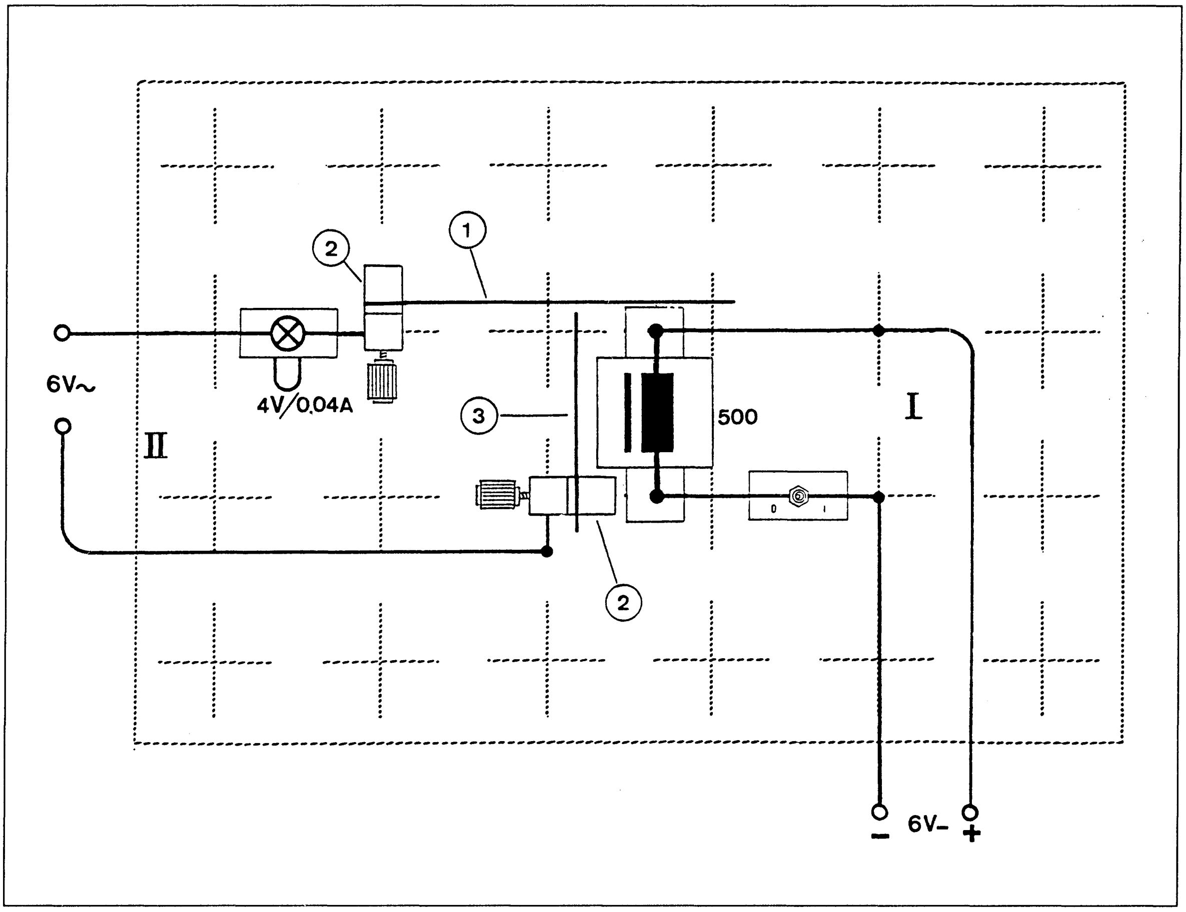

Fig. 1 Experiment setup (top view):
Model of a closing relay
(1) leaf spring; **(2)** plug-in holders; **(3)** contact strip

Setup:

1. Set up the circuit as shown in Fig. 1. The switch should be in the open position (switch position 0).
2. How can you set up the circuit so that the lamp lights up only when the switch is closed?

Student's Sheet 3

Performing the experiment:

3. The setup shown in Fig. 1 contains two circuits which are independent of each other:
   a) a DC circuit I and
   b) an AC circuit II.
   Name:
   a) the elements of DC circuit I
   b) the elements of AC circuit II
   a) ______________________
   ____
   ____
   ____
   b) ______________________
   ____
   ____
   ____

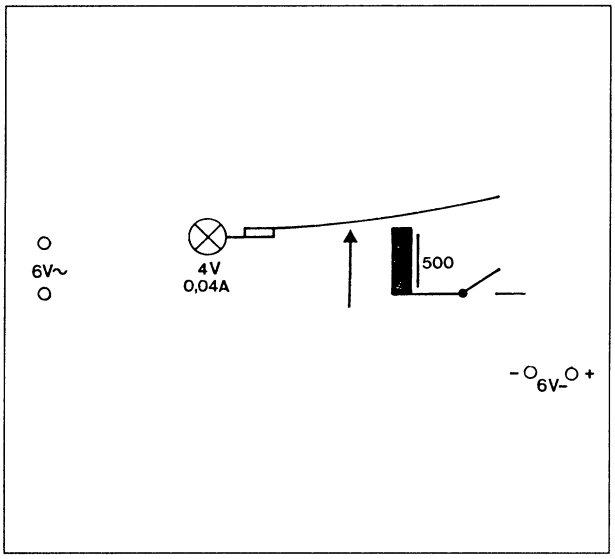

Fig. 2 Circuit symbols for the elements of the closing relay shown in Fig. 1.

4. In this setup, we see that turning the switch in circuit I opens and closes circuit II without touching it physically. The contact at the contact strip **(3)** is closed or interrupted. This kind of contact is called a **break contact** (or n.c. contact) when it is closed while no current is flowing through the coil. A contact which is closed while the coil is carrying a current is called a **make contact** (or n.o. contact).
   What kind of contact does the closing relay in Fig. 1 have?
   ____

5. Draw the circuit diagram for the closing relay shown in Fig. 1.
   Fig. 2 shows the elements of the diagram according to the setup on the rastered socket panel.

Evaluation:

6. How does the closing relay work when you close the switch and open it again?

____

____

____

Student's Sheet 5

Experiment part 2: building a tripping relay

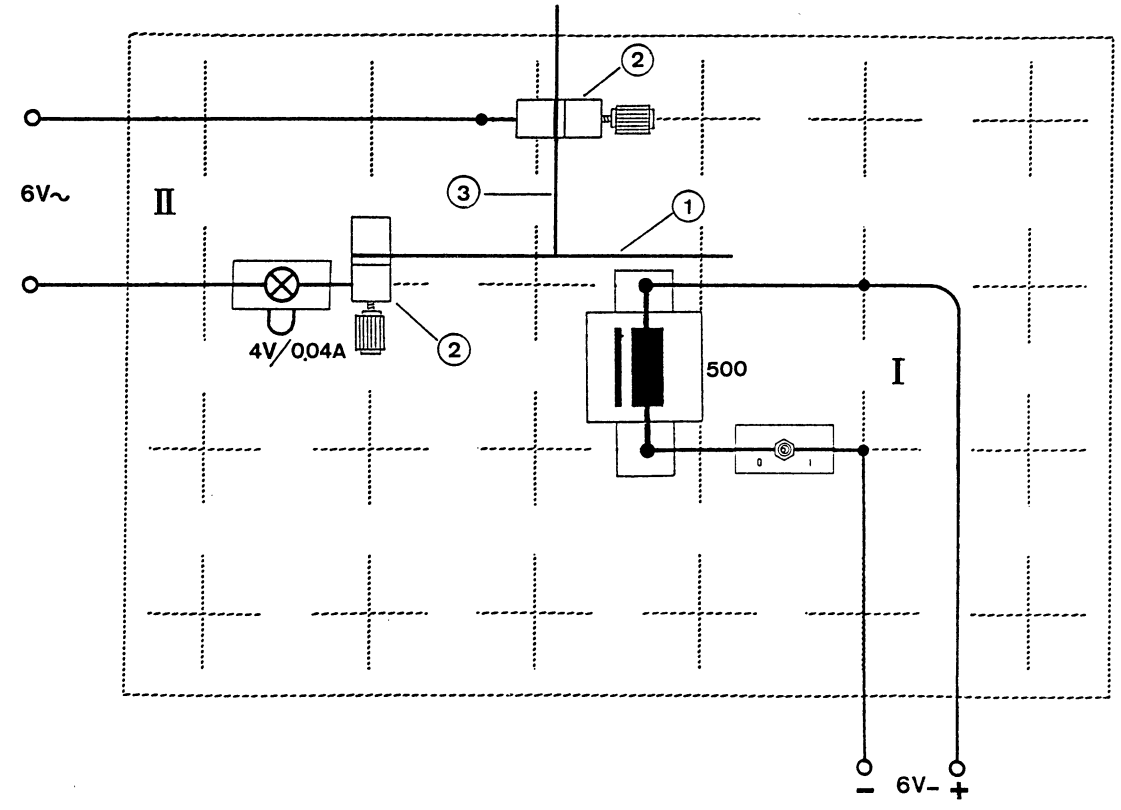

Fig. 3 Experiment setup (top view): model of a tripping relay
(1) leaf spring; **(2)** plug-in holders; **(3)** contact strip

Setup:

7. Set up the circuit as shown in Fig. 3. Make sure the switch is set to position 0.
8. How do you set up the circuit so that the lamp **does not** light up when the switch is closed?

___

Performing the experiment:

9. Place the contact strip **(3)** so that the lamp can be switched on and off using the switch.
Does the tripping relay have a **break contact** or a **make contact**?

___

10. Draw the circuit diagram of the tripping relay from Fig. 3. For comparison ▶ Fig. 2.

Fig. 3.1 Circuit diagram of a tripping relay according to Fig. 3.

Evaluation:

11. How does the tripping relay work when you open the switch and close it again?

___

___

___

Model of a buzzer (doorbell)

Assignment: Build a buzzer and study how it works.

Apparatus:

1 rastered socket panel
1 coil with 1000 turns
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
1 pair of plug-in holders
1 contact strip
1 leaf spring
1 croc-clip
3 bridging plugs
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 low-voltage power supply, 6 V DC

Student's Sheet 2

Attention!
Do not touch the leaf spring, plug-in holders or contact strip during the experiment!

Setup:

1. Set up the circuit as shown in Fig. 1. The switch should be in the open position (position 0).

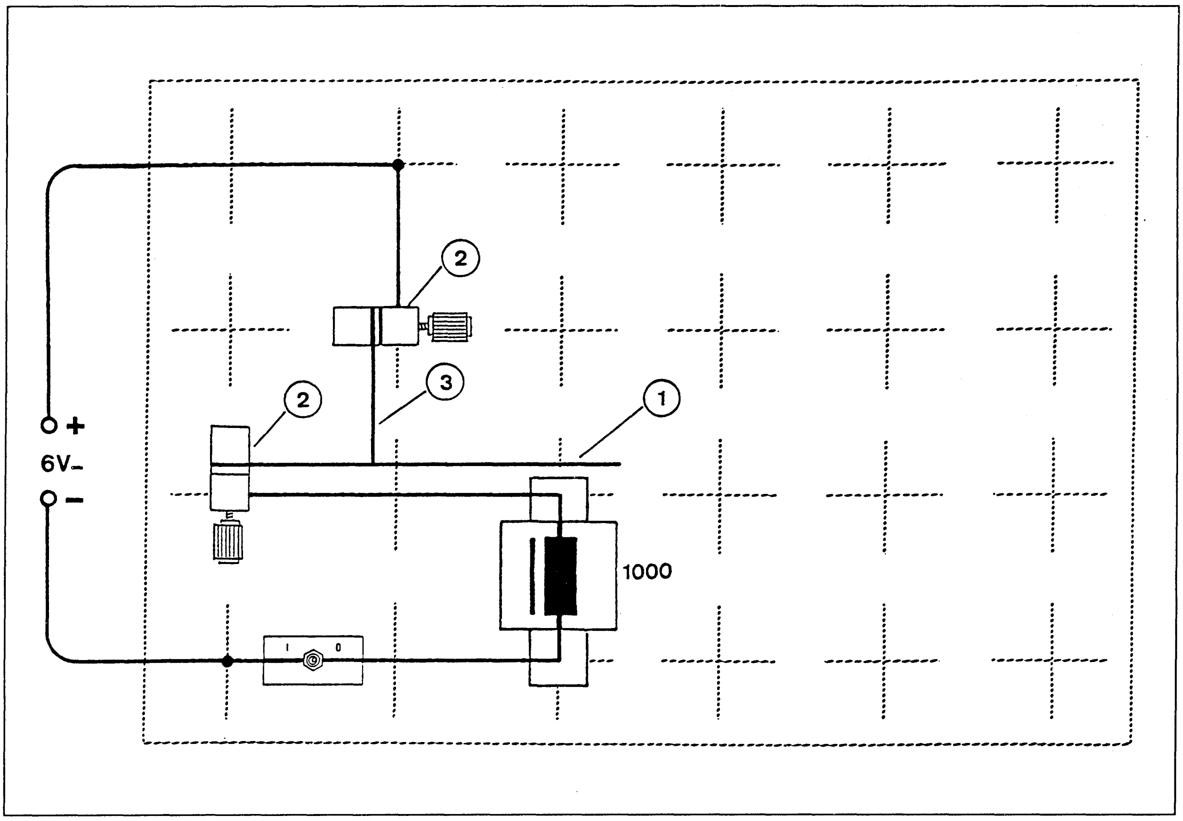

Fig. 1 Experiment setup (top view): model of a buzzer
(1) leaf spring;
(2) plug-in holders;
(3) contact strip

2. Place the leaf spring **(1)** in the left-hand plug-in holder **(2)** so that the left-hand end of the leaf spring is flush with the side of the plug-in holder.
3. The contact strip **(3)** should rest against the leaf spring **(1)** with a slight pressure.
4. Insert the I-core into the coil until it is about 3 mm away from the leaf spring.

Student's Sheet 3

Performing the experiment:

5. Close the switch, and then open it again after a few seconds. Then close and open the switch several times.

6. Attach a crocodile clip to the end of the leaf spring as shown in Fig. 2. What happens now when you close the switch?

____

____

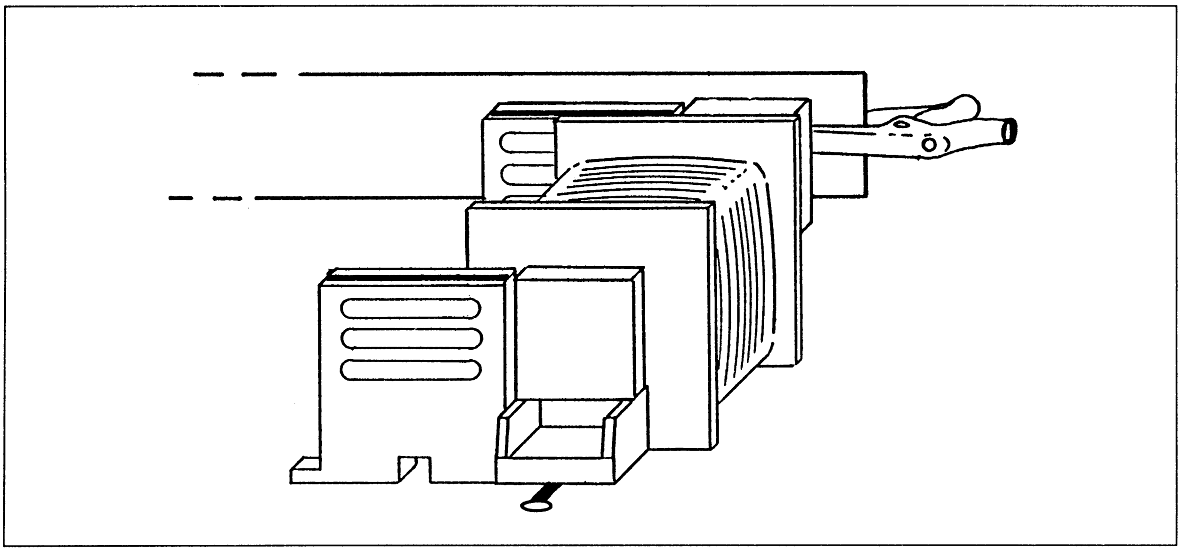

Fig. 2 Attaching a crocodile clip to the end of the leaf spring.

Evaluation:

7. Fig. 3 is a schematic drawing of the circuit, but without the connections which must be made using connecting leads. If you compare this drawing with Fig. 1, you can see which points must be connected with each other.
What are these points?

____

____

____

3. Draw the missing connections in Fig. 3.

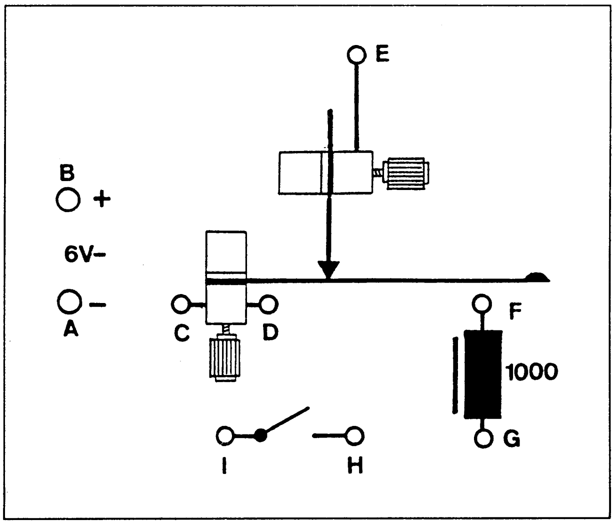

Fig. 3 Schematic drawing of the elements of a buzzer as shown in Fig. 1. The connection points are labelled with capital letters.

9. We can think of the leaf spring of the buzzer as the clapper of a bell. Where would we put the bell dome? Draw the position of the bell dome as a dashed circle in the circuit diagram in Fig. 3.

10. Can you exchange the connections at the voltage source?
Give reasons for your answer.

____

____

____

____

____

____

11. Describe, in a few sentences, how a buzzer or an electric doorbell works.
At what point does the circuit interrupt itself?

____

____

____

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____

____

____

Student's Sheet 5

Additional exercise:

12. Place the buzzer elements on the rastered socket panel as shown in Fig. 4.

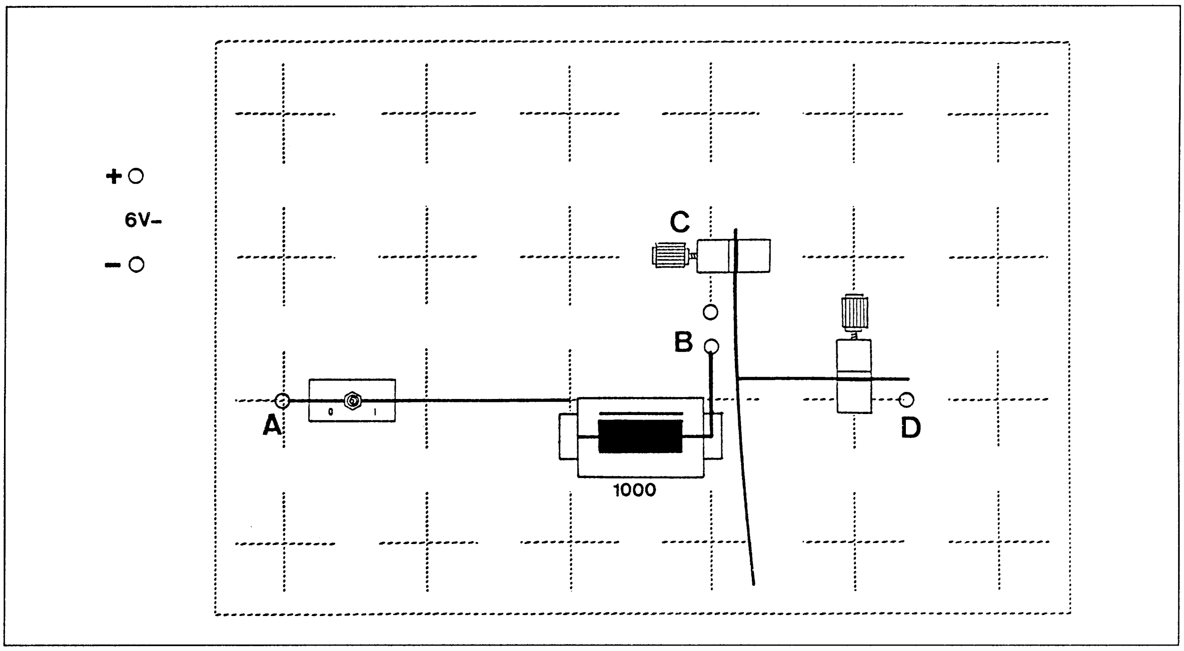

Fig. 4 Elements of a buzzer of the rastered socket panel, arrangement for ▶ 12.

13. What points (⊖ pole, ⊕ pole, A,B,C,D) must be connected with each other?

Note:

The arrangement for the automatic opening and closing of the circuit in the buzzer is called a **hammer break** or **"Wagner's interrupter"**.

Student's Sheet 1

Model of a loudspeaker

Assignment: Using a coil and a leaf spring, build a model of a loudspeaker.

Apparatus:
1 rastered socket panel
1 bridging plug
1 coil with 500 turns
1 transformer I-core (yoke)
1 pair of plug-in holders
1 leaf spring
1 connecting lead, red, 25 cm
1 connecting lead, blue, 25 cm
1 sheet of paper, approx. 30 cm x 8 cm
1 scissors (for cutting paper)
1 low-voltage power supply, 9 V AC

Setup:

▶ Fig. 1

1. Make sure the switch is set to position 0 (open).
2. Set the voltage supply to voltage level 3 (approx. 9 V AC) and switch it on.

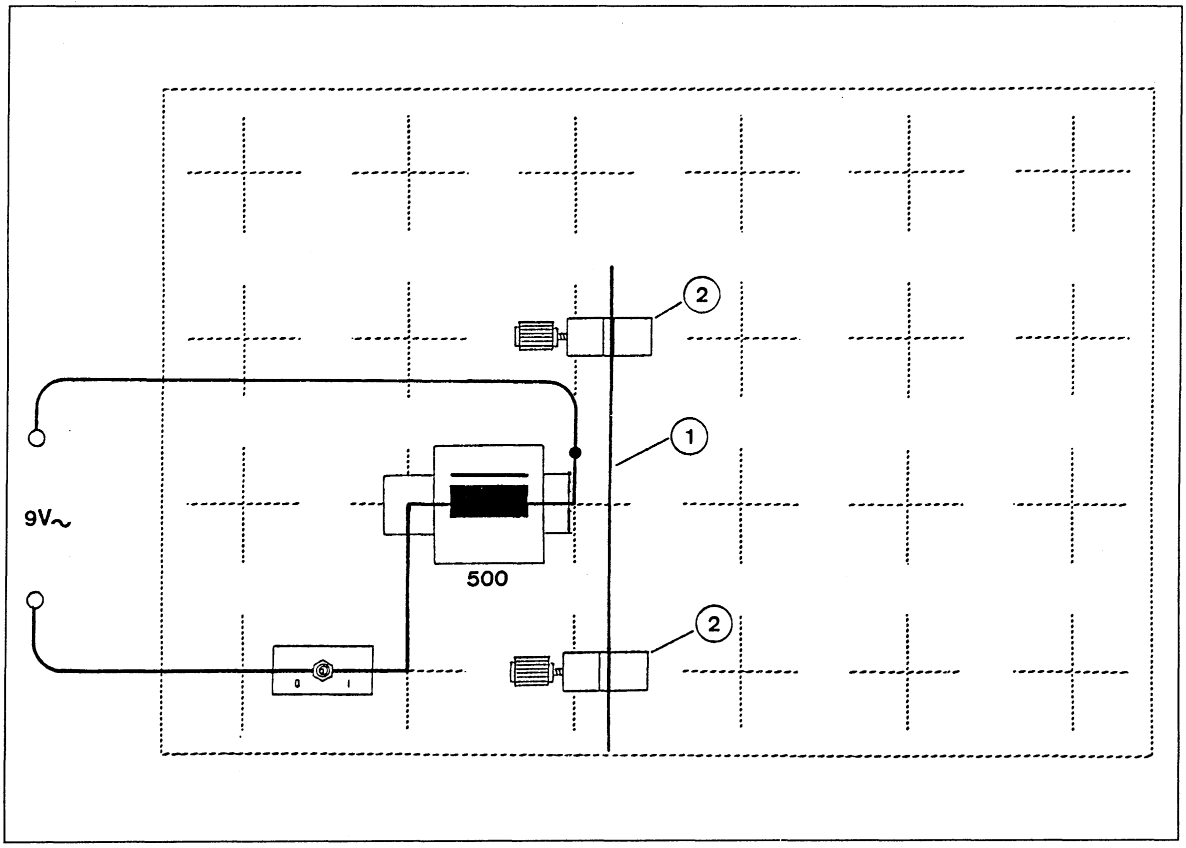

Fig. 1 Experiment setup: model of a loudspeaker
(1) leaf spring; **(2)** plug-in holders

Student's Sheet 2

3. Use the piece of paper as a membrane.
   ▶ Fig. 2.
4. Insert the I-core so that it is about 1 mm from the membrane.

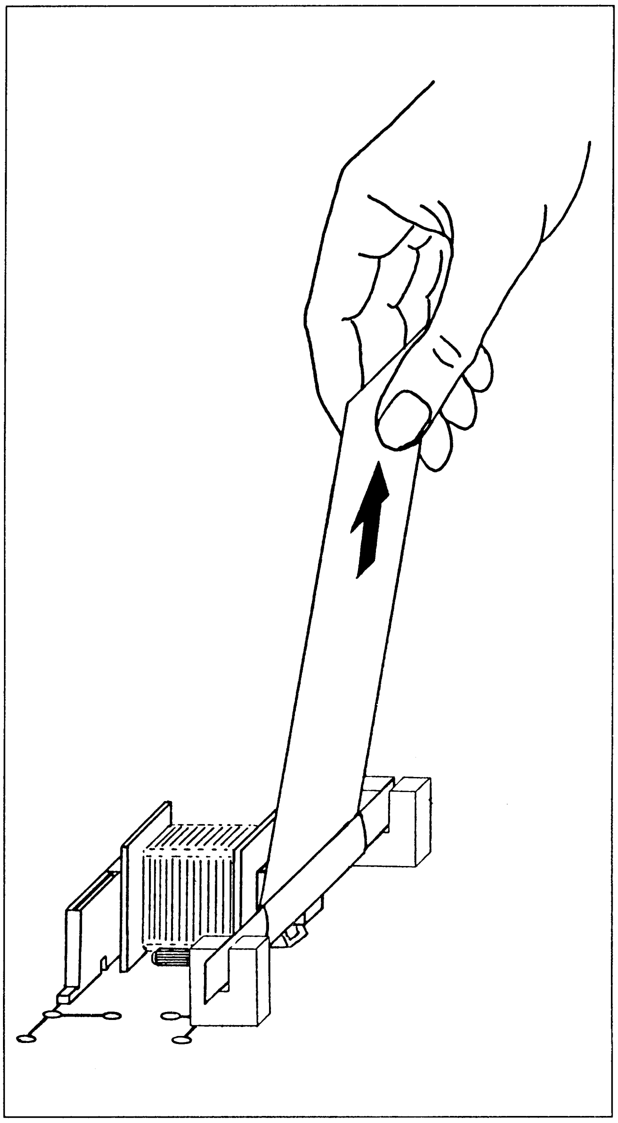

Fig. 2 Strip of paper as loudspeaker membrane. The bottom end is wrapped around the leaf spring twice.

Performing the experiment:

5. Tension the strip of paper as shown in Fig. 2.
6. Close the switch (position I).
7. Put your ear close to the surface of the paper. Vary the tension of the paper. What do you hear?

____

Evaluation:

8. What determines the pitch of the tone?

9. What must be changed if you want to produce other tones?

Student's Sheet 1

Electromagnetic induction with a bar magnet and a coil

Assignment: To investigate how to generate a voltage using a bar magnet and a coil.

Apparatus:

1 rastered socket panel
1 coil with 1000 turns
1 coil with 500 turns
1 bar magnet
3 bridging plugs
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 moving coil galvanometer (0.15 V/0.15 mA)
1 multimeter 3 V AC/0.06 A AC
(or 1.5 V AC/0.5 mA AC)

Student's Sheet 2

Setup:

1. Place the coil with 1000 turns on the rastered socket panel as shown in Fig. 1.
2. Connect the galvanometer. Make sure that the ⊕-connection (red socket) is connected with the right-hand coil input.

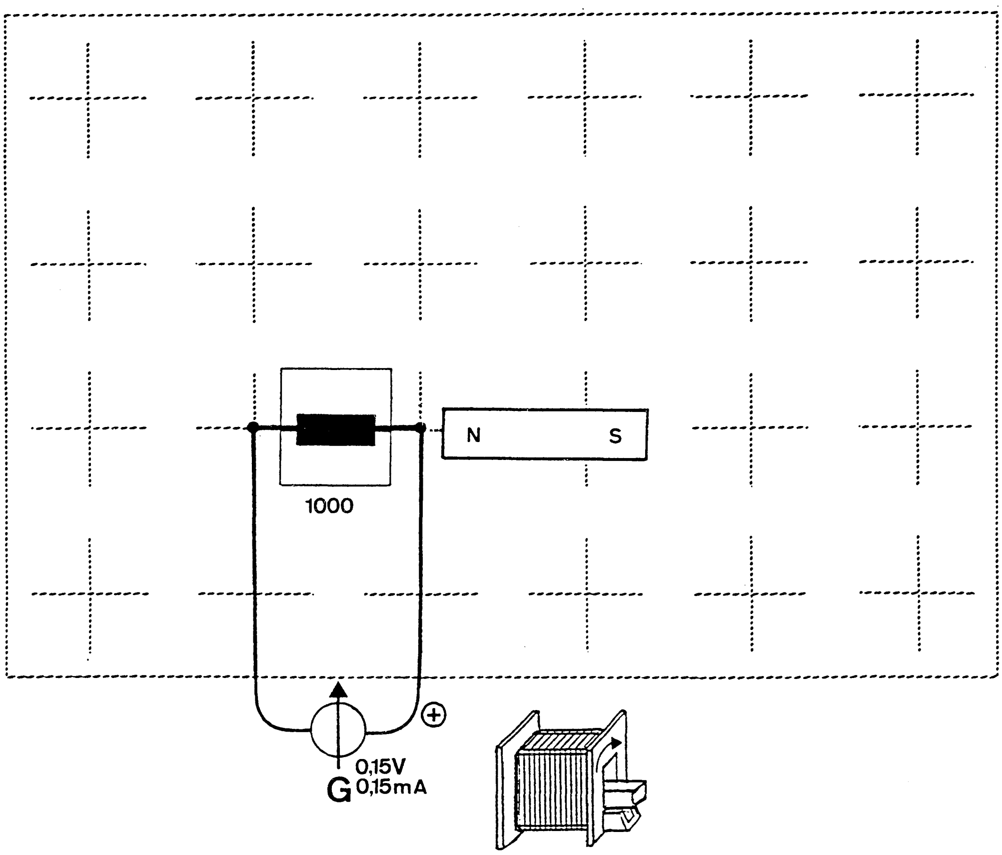

Fig. 1 Experiment setup: electromagnetic induction with bar magnet and coil
Detail sketch bottom: coil, with arrow showing the direction of the turns

Performing the experiment:
Experiment part 1: polarity and direction of motion of the bar magnet

3. Does a bar magnet generate an electrical voltage in the coil when it is placed motionless in front of the coil? Observe the galvanometer display.
   Result ▶ table.
4. Does the motion of the bar magnet generate a voltage? Insert the bar magnet in the coil with the north pole first.
   Write your observation ▶ table.
5. Quickly remove the north pole of the bar magnet from the coil.
   Write your observation ▶ table.

Student's Sheet 3

6. Quickly insert the bar magnet into the coil with the south pole first.
   Write your observation ▶ table.
7. Quickly remove the south pole of the bar magnet from the coil.
   Write your observation ▶ table.

Table 1

Step	Motion of bar magnet	Deflection of galvanometer
3	none	
4	North pole to left	
5	North pole to right	
6	South pole to left	
7	South pole to right	

Experiment part 2: speed of motion of the bar magnet

8. Connect the AC voltmeter to the circuit as shown in Fig. 2 and set the measuring range to 3 V AC.
9. Push the magnet halfway into the coil. It does not matter which pole you put in.

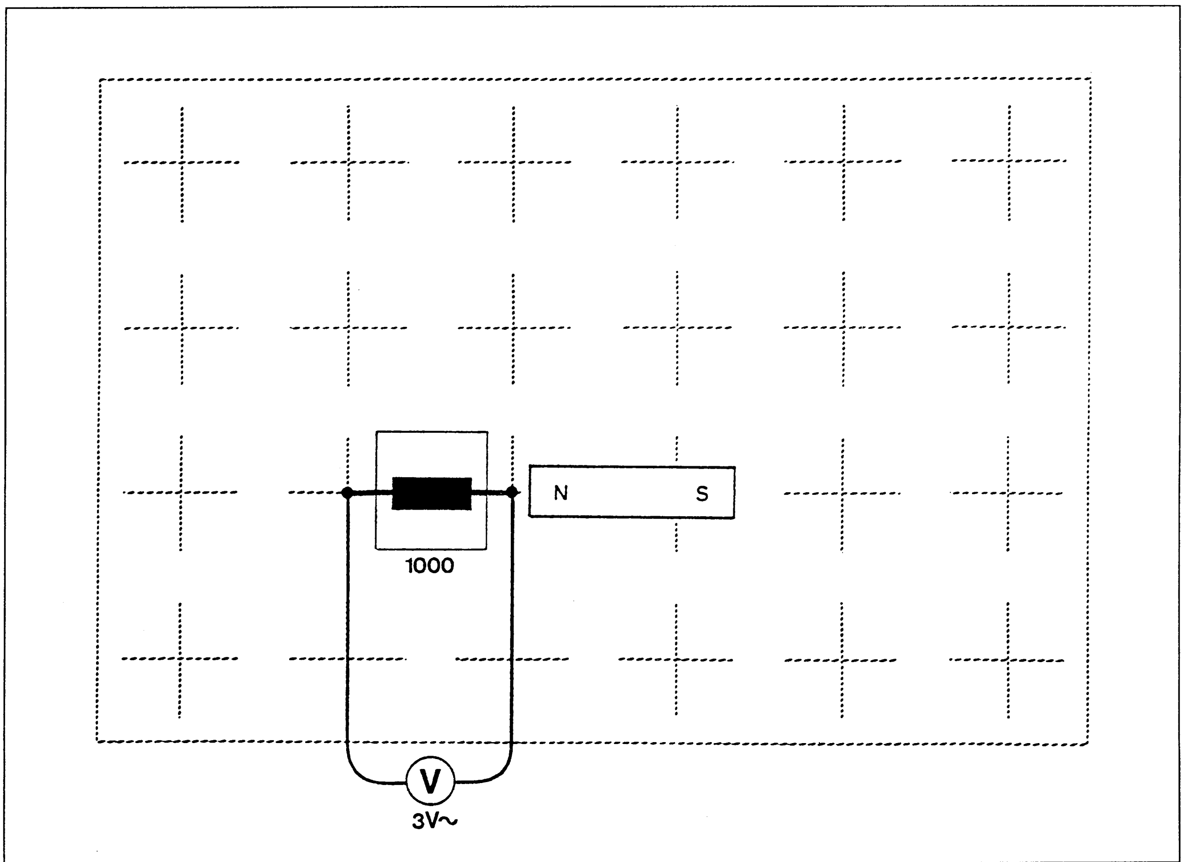

Fig. 2 Experiment setup: electromagnetic induction with bar magnet and coil and AC voltmeter

Student's Sheet 4

10. Move the magnet in the coil quickly back and forth. Does the voltmeter show a voltage?
    Write down your measuring result ▶ table 2.
11. Now move the magnet back and forth more slowly than in the last step (▶ 10).
    Write down your measuring result ▶ table 2.

Table 2

Step	Motion of bar magnet	Voltmeter display (approx.)
10	fast	
11	slow	

Experiment part 3: number of coil turns

12. Is there a relationship between the size of the AC voltage generated with a magnet in a coil and the number of turns of the coil?
    To answer this question, assemble the circuit in Fig. 3.

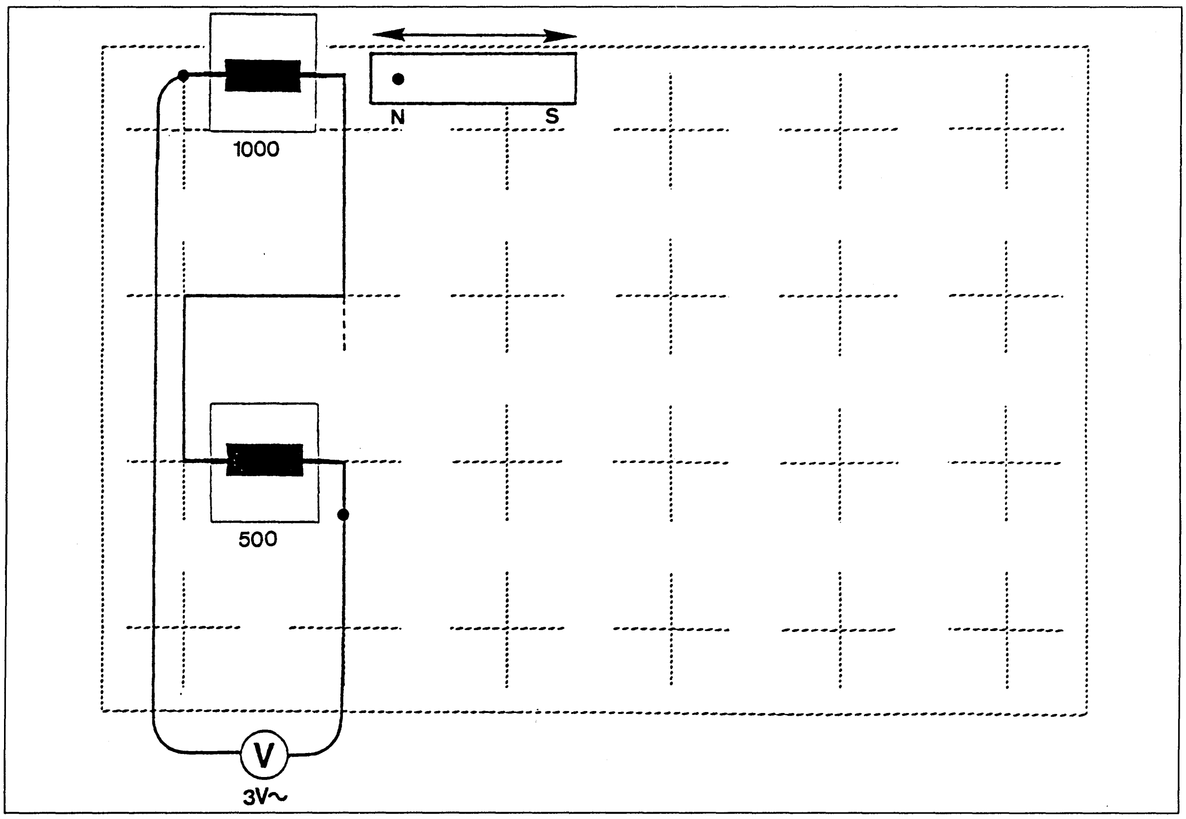

Fig. 3 Experiment setup: investigating the induction voltage as a function of the number of turns of the induction coil

13. Move the magnet quickly back and forth in each of the coils; try to move the magnet at the same speed in both coils. In which coil is the higher AC voltage generated?

____

____

Evaluation:

14. How is AC voltage generated with a coil and a bar magnet?

____

____

15. Fill in the blanks in the following sentence:
The AC voltage generated is higher when the number of turns of the coil is ______ and the bar magnet is moved ________.

Electromagnetic induction with two coils

Assignment: Test whether induction voltages can also be generated without moving a magnet.

Apparatus:
1 rastered socket panel
1 coil with 500 turns
1 coil with 1000 turns
1 transformer U-core
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
3 bridging plugs
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 connecting lead, red, 25 cm
1 connecting lead, blue, 25 cm
1 multimeter, zero-point middle, 3 V DC
1 low-voltage power supply, 3 V DC/3 A

Setup:

1. Set up the circuit as shown in Fig. 1. Make sure the switch is in position 0 (open).

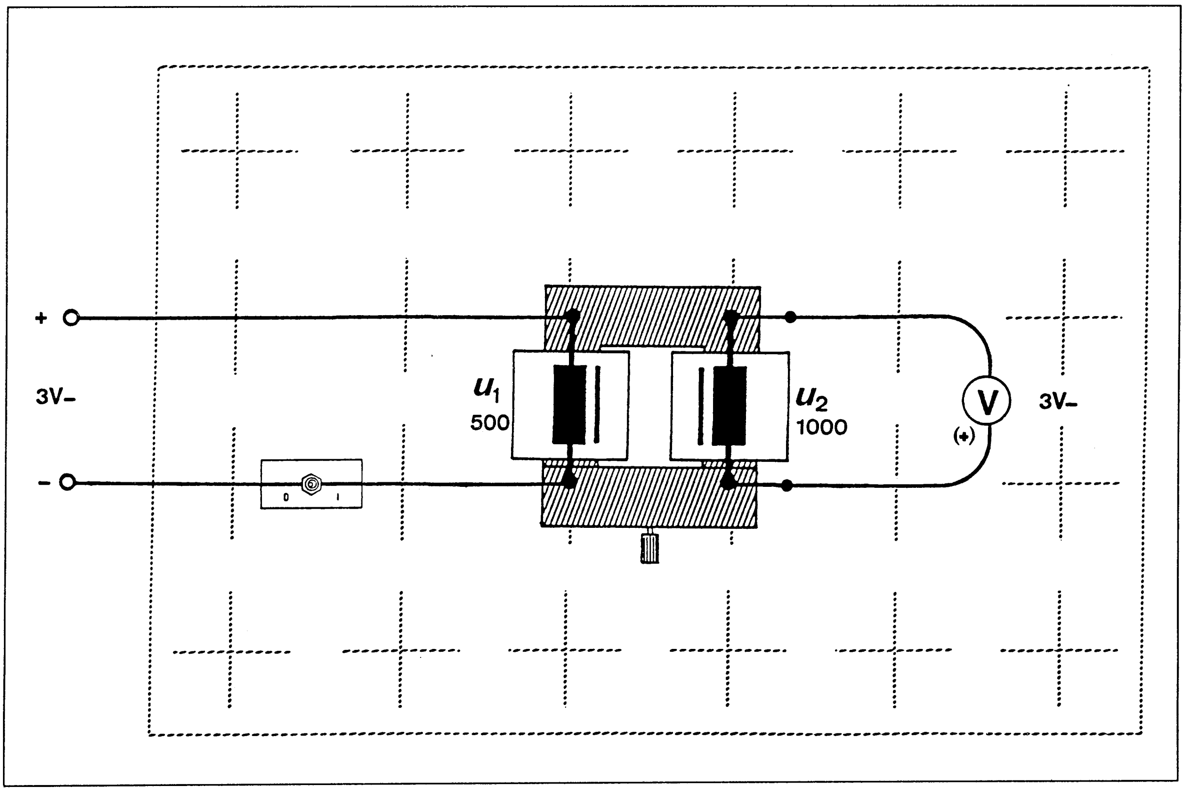

Fig. 1 Experiment setup: electromagnetic induction with two coils

Student's Sheet 2

2. Connect the front terminal of the right-hand coil (n_2 = 1000 turns) with the (+)-input (red socket) of the voltmeter.

3. Make sure that the I-core and the U-core are securely screwed together.

Performing the experiment:

4. Select voltage level 1 (3 V AC).
5. Close the switch.
   What do you observe? ▶ table.
6. Open the switch.
   Write down your observations in the table. ▶ table.
7. Unscrew the I-core from the U-core. Close the switch.
   Write down your observation ▶ table.
8. Open the switch.
   Write down your observation ▶ table.

Table

Step	U-core with and without I-core	Needle deflection left/right	Voltage approx.
5	with I-core		
6	with I-core		
7	without I-core		
8	without I-core		

Evaluation:

9. Can induction voltages be generated without moving a magnet?

____

10. What is the function of the closed U-core?

____

____

Student's Sheet 1

Voltage transformation

Assignment: Build simple transformers and measure their voltages.

Apparatus:

1 rastered socket panel
1 coil with 500 turns
1 coil with 1000 turns
1 transformer U-core
1 transformer I-core (yoke)
2 bridging plugs
2 connecting leads, red, 25 cm
2 connecting leads, blue, 25 cm
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
2 multimeters (30 V AC)
(if necessary, a single meter is sufficient)
1 low-voltage power supply, 0 … 12 V AC/3 A

Setup:

1. Set up the circuit as shown in Fig. 1. Screw the yoke securely to the U-coil (with the bare side inward).

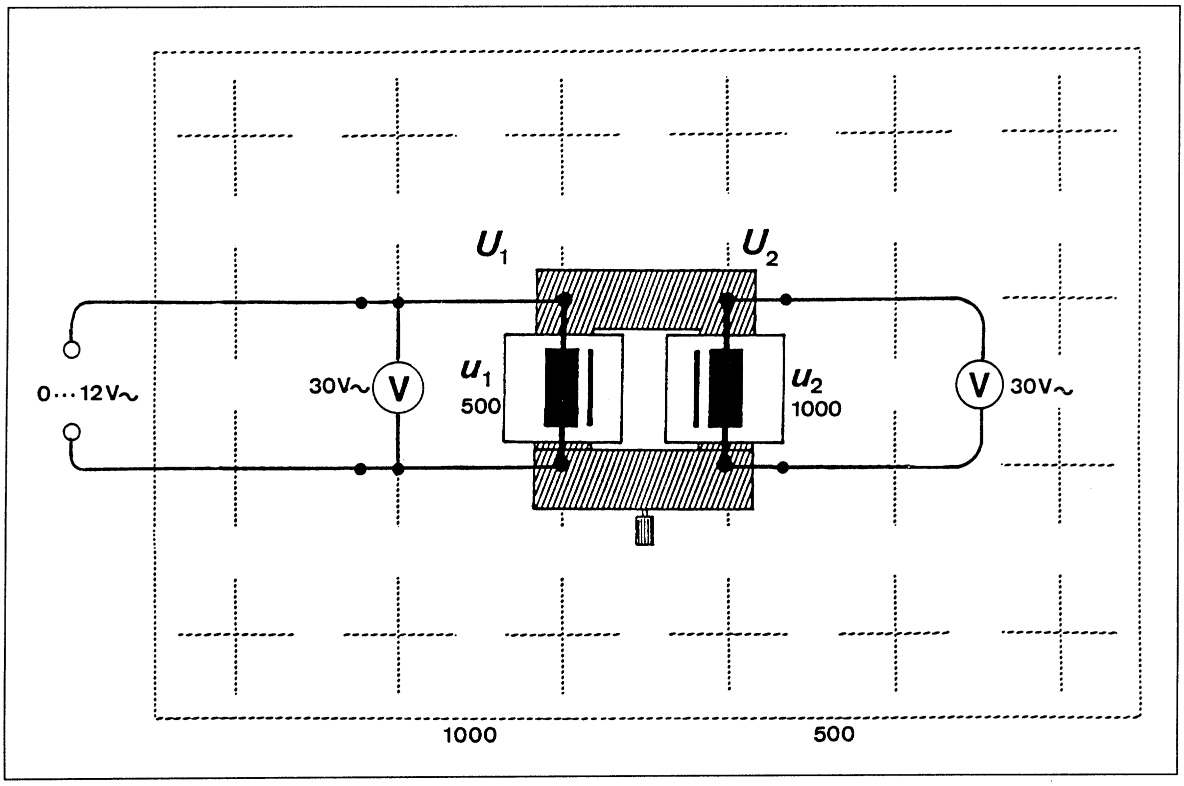

Fig. 1 Experiment setup: voltage transformation

Student's Sheet 2

Performing the experiment:

Experiment part 1:

2. Select voltage level 1 (3 V AC). Measure voltage U_1 and write down the value. ▶ Table 1 (turns: $n_1 = 500/n_2 = 1000$)
3. Continue measuring voltage U_1 for voltage levels 2 (6 V AC), 3 (9 V AC) and 4 (12 V AC). Write down the values. ▶ Table 1.
4. Now measure the voltage values for U_2 for voltage steps 1, 2, 3 and 4 in the same way. Write down the values. ▶ Table 1.

Experiment part 2:

5. Exchange the two coils. Why is it not necessary to unscrew the I-core?

____

____

6. Repeat steps 2 to 4 with this circuit. Write down your values. ▶ Table 2 (turns: $n_1 = 1000/n_2 = 500$)

Table 1 (experiment section 1)

Voltage level	U_1	U_2	$\frac{U_2}{U_1}$
1			
2			
3			
4			

Table 2 (experiment section 2)

Voltage level	U_1	U_2	$\frac{U_2}{U_1}$
1			
2			
3			
4			

Evaluation:

7. ▶ Table 1: calculate $\frac{U_2}{U_1}$ for each line and write it in the table.

8. ▶ Table 2: calculate $\frac{U_2}{U_1}$ for each line and write it in the table.

9. Compare the quotients $\frac{U_2}{U_1}$ with the ratio of the turns $\frac{n_2}{n_1}$

   Complete the following sentence: The ratio of the voltages of a transformer corresponds to

   ____

10. Complete the following formula: $\frac{U_2}{U_1} \approx$

Current transformation

Assignment: Build simple transformers and measure the currents flowing through the coils.

Apparatus:

1 rastered socket panel
1 coil with 1000 turns
1 coil with 500 turns
1 transformer U-core
1 transformer I-core (yoke)
1 STE lamp holder E10, lateral
1 lamp, 12 V /3 W (type B)
5 bridging plugs
2 connecting leads, red, 25 cm
1 connecting lead, blue, 25 cm
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
2 multimeters,1 A AC/0.6 A AC
1 low-voltage power supply, 0 ... 12 V AC/3 A

Setup:

1. Set up the circuit as shown in Fig. 1. Screw the yoke securely to the U-coil (with the bare side inward).

   Note: The experiment can be carried out with one ammeter with the given ranges if you measure I_1 and I_2 one after another.

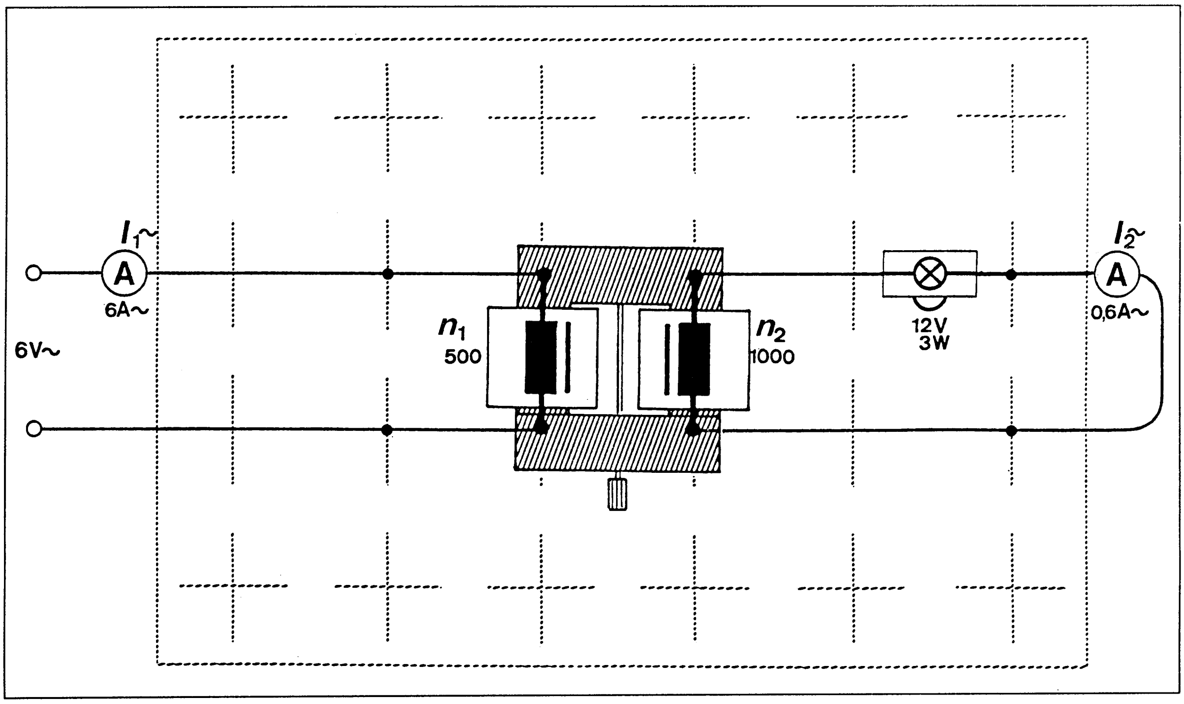

Fig. 1 Experiment setup: current transformation, $n_1 : n_2 = 0.5$

Performing the experiment:

Experiment part 1:

2. Select voltage level 1 (3 V AC) and measure current I_1;
write down the value. ▶ Table 1
3. Measure current I_2 in the same way and write down your measured value. ▶ Table 1.
4. Repeat steps 2 and 3 for voltage levels 2 (6 V AC), 3 (9 V AC) and 4 (12 V AC).
Write down the values. ▶ Table 1.

Experiment part 2:

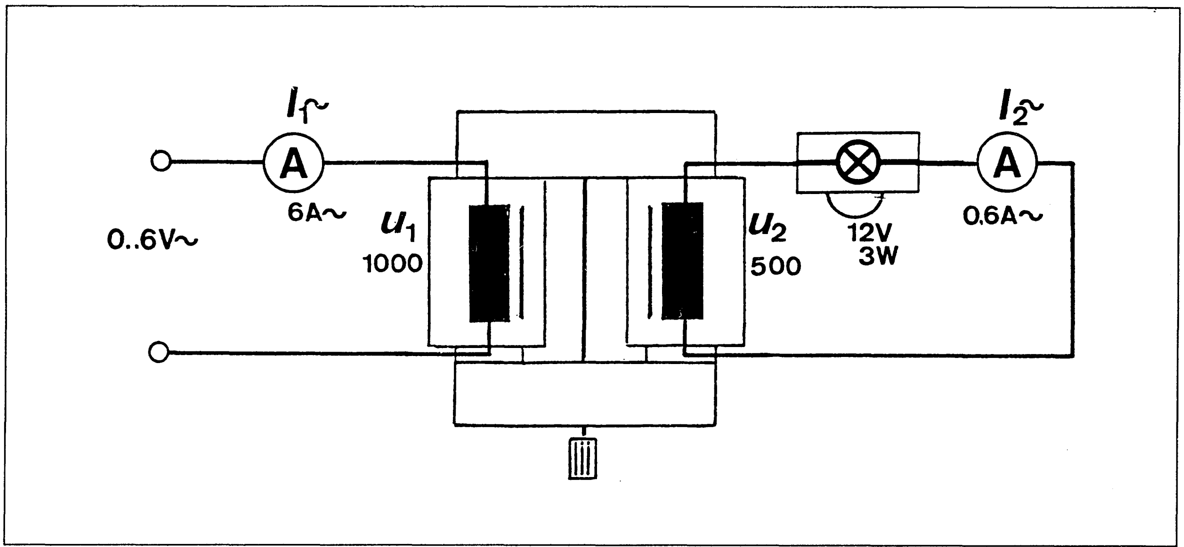

Fig. 2 Experiment setup: current transformation, $n_1 : n_2 = 2$

5. Exchange the two coils. ▶ Fig. 2.
Why is it not necessary to unscrew the I-core?

____

____

6. Repeat steps 2 to 4 from experiment part 1 with this circuit.
Write down your values. ▶ Table 2

Table 1 (turns: $n_1 = 500/n_2 = 1000$) – experiment section 1

Voltage level	I_1 AC	I_2 AC	$\frac{I_2}{I_1}$
1	mA	mA	
2	mA	mA	
3	mA	mA	
4	mA	mA	

Student's Sheet 3

Table 2 (turns: n_1 = 1000/n_2 = 500) – experiment section 2

Voltage level	I_1 AC	I_2 AC	$\frac{I_2}{I_1}$
1	mA	mA	
2	mA	mA	
3	mA	mA	
4	mA	mA	

Evaluation:

7. ▶ Table 1:
calculate $\frac{I_2}{I_1}$ for each line and write it in the table.

8. ▶ Table 2:
calculate $\frac{I_2}{I_1}$ for each line and write it in the table.

9. Compare the values for $\frac{I_2}{I_1}$ with the ratio of the turns, in other words, with the numerical value $\frac{n_2}{n_1}$.
Complete the following sentence: The ratio of the currents of a transformer corresponds to

____

10. Complete the formula for current transformation: $\frac{I_2}{I_1} \approx$

Self-induction of a coil (model of an induction coil)

Assignment: Test whether induction voltage occurs in the same coil in which a pre-existing magnetic field decays.

Apparatus:

1 rastered socket panel
1 coil with 1000 turns
1 transformer U-core
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
1 STE lamp holder E10, lateral
1 lamp, 4 V/0.04 A (type C)
1 glow lamp
5 bridging plugs
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 low-voltage power supply, 3 V DC/3 A

Setup:

Experiment part 1: self-induction, indicator: incandescent lamp

1. Set up the circuit as shown in Fig. 1. Make sure the switch is in the 0 position (open).

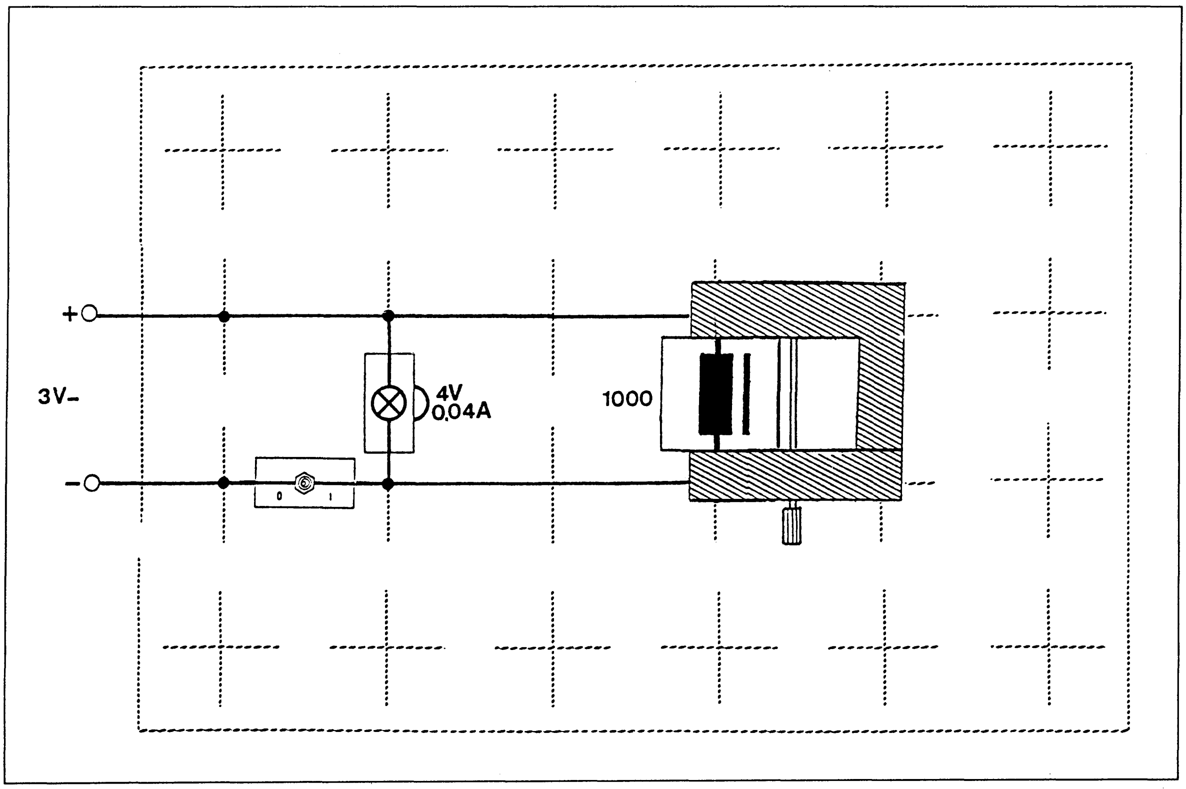

Fig. 1 Experiment setup: self-induction of a coil

2. Attach the U-core as shown in Fig. 2. Screw the I-core (yoke) securely to the U-coil (with the bare side inward).

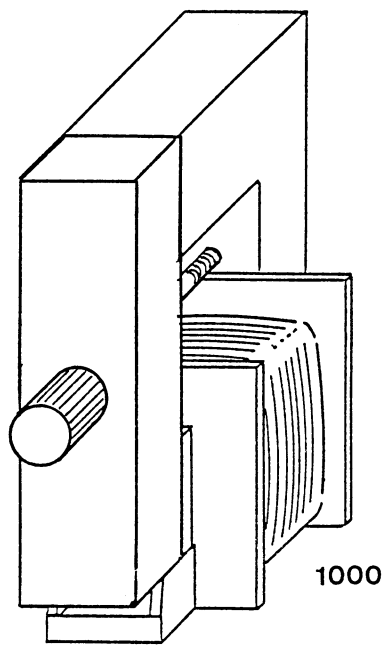

Fig. 2 Supplement to Fig. 1: attaching the U-core with the yoke (I-core)

Performing the experiment:

3. Close the switch.
   What do you observe?

   ____

4. Open the switch.
   What do you observe now?

   ____

5. Examine the conductors when the switch is open and when it is closed. What elements are connected in a closed circuit when the switch is open?

   ____

Experiment part 2:
Self induction, indicator: glow lamp

Setup:

6. Use a glow lamp (▶ Fig. 3) instead of the incandescent lamp (▶ Fig. 1).

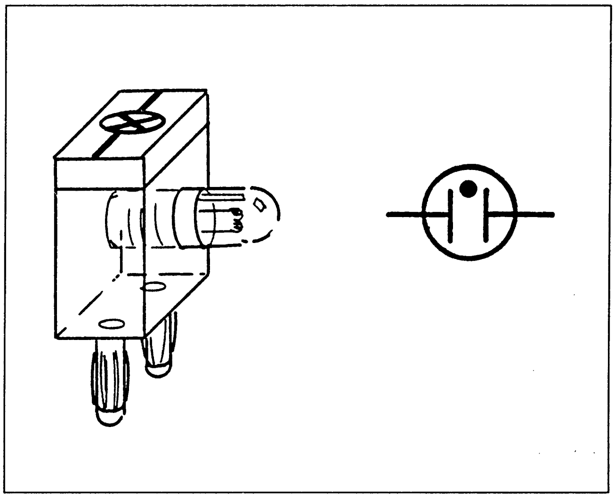

Fig. 3 Left: screw socket with glow lamp
Right: symbol of a glow lamp

Performing the experiment:

7. Close the switch and open it again. What do you observe?

____

____

Evaluation:

Experiment part 1

8. Explain your observations for the experiment with the incandescent lamp.

____

____

____

____

____

____

____

____

Student's Sheet 4

Experiment part 2:

9. The glow lamp gives us information on
the level of the induction voltage
and the direction of the induction current.
What can we say about these on the basis of the results?

Notes:

Glow lamp starting voltage: 110 V.

The glowing light indicates the negative electrode (cathode).

The law which we can derive for the direction of the induction voltage or the induction current is called "Lenz's law".

Supplementary exercise:

10. If we replace the toggle switch in experiment section 2 with a "hammer break" (Wagner's interrupter, ▶ experiment 8), we have a model of a so-called **induction coil.**
What is the purpose of such a device?

Model of an AC generator

Assignment: Discover whether a rotating magnet can generate voltages in a coil.

Apparatus:

1 rastered socket panel
1 coil with 1000 turns
1 coil with 500 turns
1 transformer U-core
1 transformer I-core (yoke)
1 bar magnet
1 rotary support for bar magnet
8 bridging plugs
1 connecting lead, red, 25 cm
2 connecting leads, blue, 25 cm
1 moving coil galvanometer (0.15 V/0.15 mA)
1 multimeter 3 V DC/3 V AC

Student's Sheet 2

Experiment part 1: model of a generator with one coil

Setup:

1. Place the magnet in the rotary support and assemble the circuit as shown in Fig. 1.

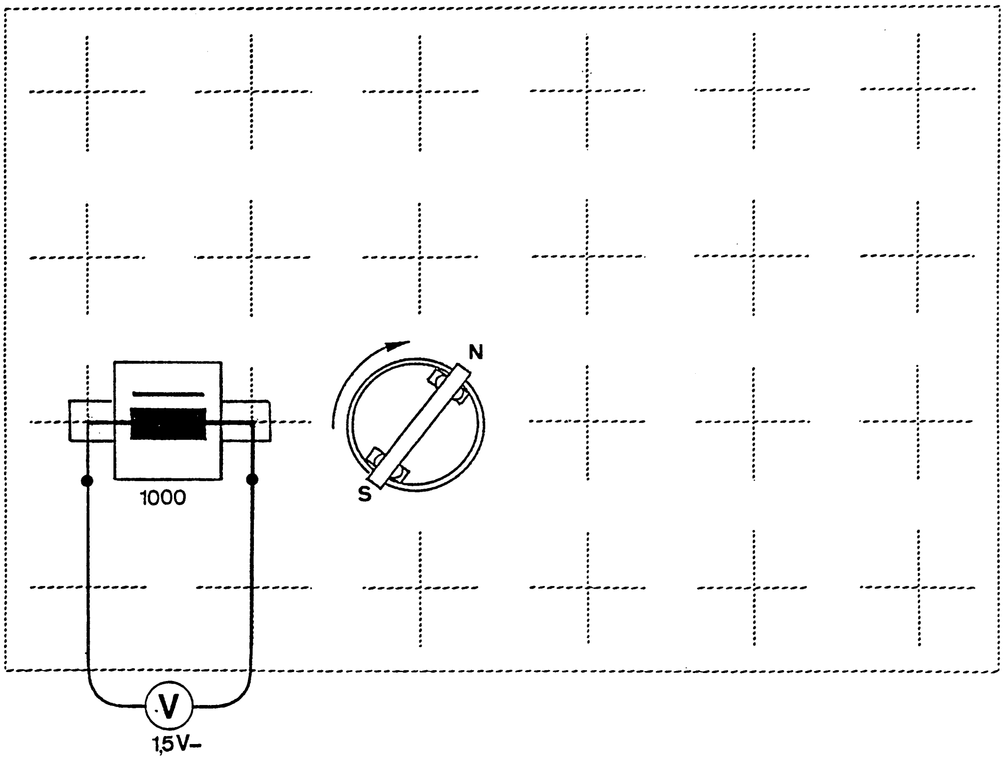

Fig. 1 Model of an AC generator

Performing the experiment:

2. Set the voltmeter to the range 3 V DC.
3. Turn the rotor slowly and observe the needle of the instrument. How does it move?

____

4. Replace the voltmeter with the moving coil galvanometer. Turn the rotor slowly.
   How does the needle move?

____

5. Turn the rotor quickly.
   What does the needle of the meter do now?
   Explain your observation:

____

____

Student's Sheet 3

6. Connect the multimeter and set it to the 3 V AC measuring range.
7. Turn the rotor as fast as you can.
   What AC voltage does the meter show?

   ____

   ____

8. How must you turn the magnet rotor to generate the greatest AC voltage: quickly or slowly?

   ____

9. Pull the core halfway out of the coil and turn the magnet rotor as fast as you can.
   What effect does the core of the coil have on the induction voltage?

   ____

   Maximum possible meter reading: _____ V AC.
10. Pull the core all the way out of the coil and turn the magnet as fast as in the last step.
    What is the maximum possible AC voltage now?

    ____

    Maximum possible meter reading: _____ V AC.
11. Remove the coil with 1000 turns and put in the coil with 500 turns. Push the core all the way into the coil. Maximum possible AC voltage: _____ V AC.

    What is the effect of the number of turns *n* of the generator coil on the size of the generated AC voltage?

    ____

12. **Evaluation 1:**

    Fill in the blanks:
    A rotating bar magnet generates a(n) ______ in a coil.
    This voltage is much _____ when the coil has a(n) ______. In addition, the voltage is higher the ______ the coil's number of turns is and the ______ the bar magnet rotates.

Student's Sheet 4

Experiment part 2: model of a generator with two coils

13. Set up the circuit as shown in Fig. 2. Insert the I-core in the coil with 1000 turns. Slide one arm of the U-core into the coil with 500 turns.

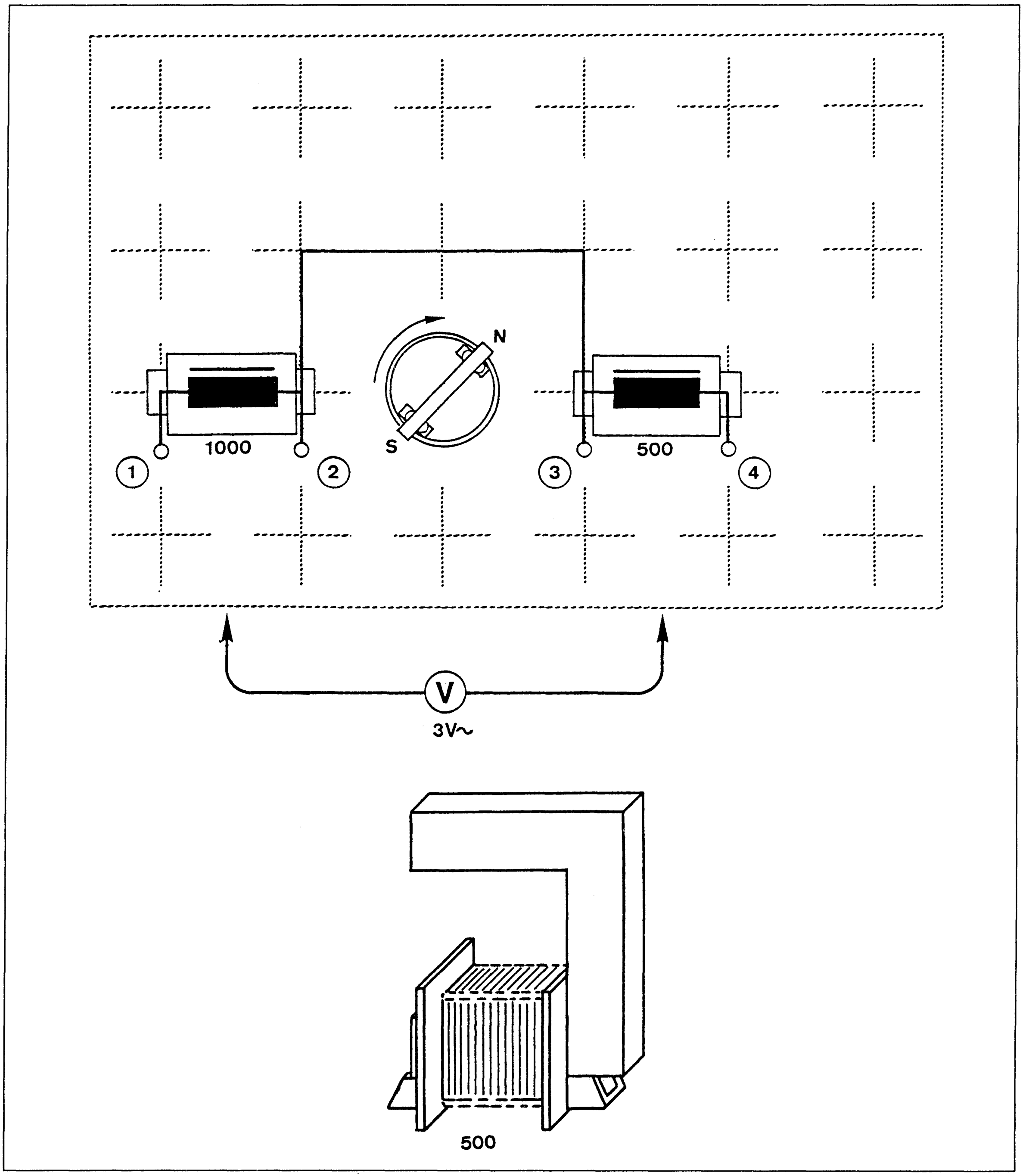

Fig. 2 Experiment setup for the model of an AC generator with two coils

Performing the experiment:

14. Connect the voltmeter between **(1)** and **(2)**, between **(3)** and **(4)** and between **(1)** and **(4)**. Turn the rotor as fast as you can each time.

Evaluation 2:

15. Between which connection points in the circuit from Fig. 2 is the voltage greatest?
How can you explain this?

____

____

____

____

Model of a synchronous motor

Assignment: Demonstrate the principle of a synchronous motor using a coil and a plotting compass.

Apparatus:

1 rastered socket panel
1 coil with 500 turns
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
1 bridging plug
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 plotting compass
1 low-voltage power supply, 6 V AC

Student's Sheet 2

Setup:

1. Set up the circuit as shown in Fig. 1. Make sure the switch is set to position 0 (open).
2. Select the AC output of the power supply.
   Set the power supply to voltage level 2 (6 V AC).
3. Place the plotting compass on the I-core (the yoke) as shown in the detail drawing in Fig. 1.

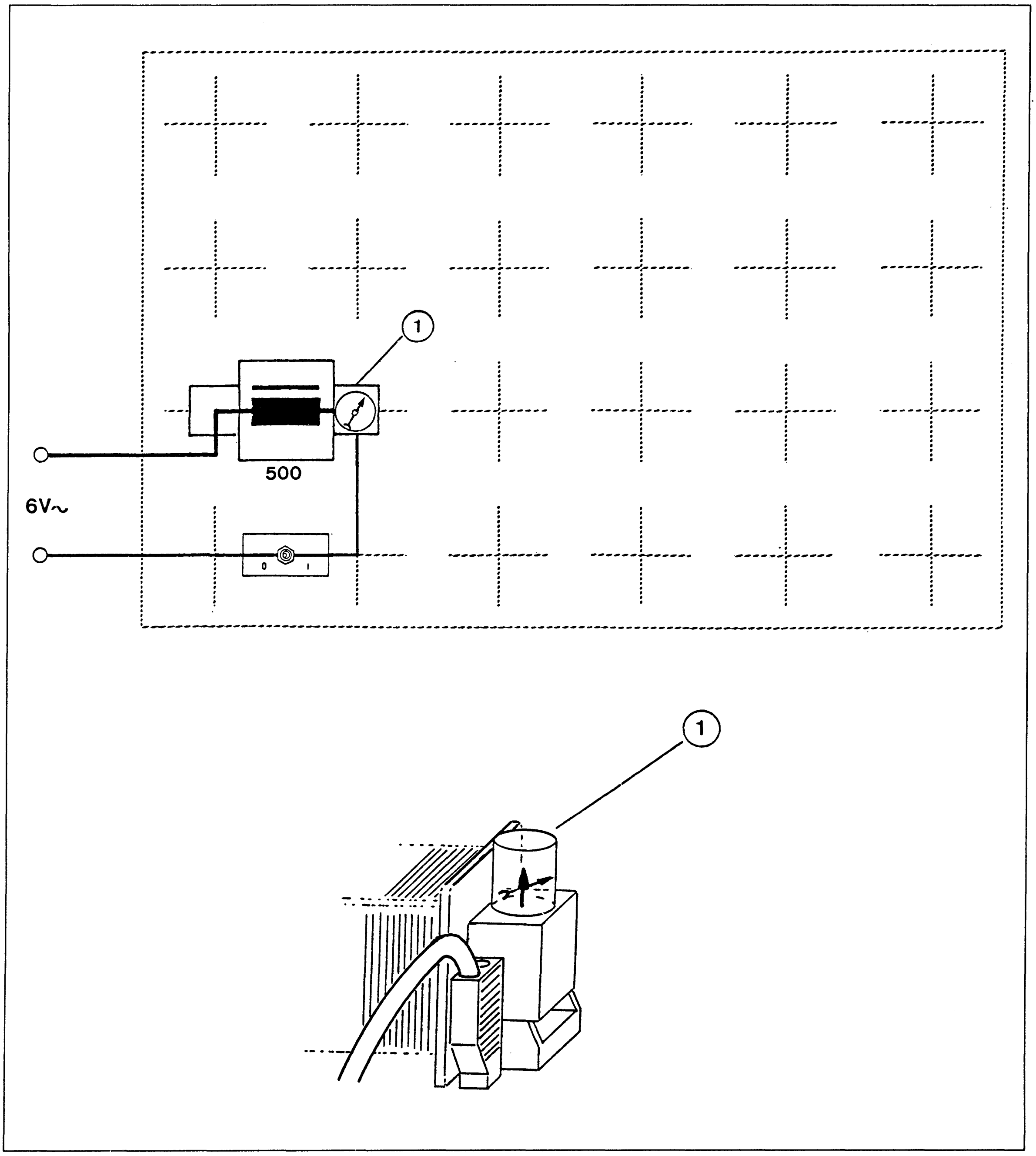

Fig. 1 Experiment setup: model of a synchronous motor
(1) plotting compass

Performing the experiment:

4. Close the switch and then open it after a while.
   What do you observe?

Evaluation:

5. The plotting compass together with a coil carrying an alternating current forms the model of a synchronous motor.
   What elements are moving synchronously?

DC and AC resistance of a coil I (observation experiment)

Assignment: Investigate the resistance of a coil in a DC circuit and an AC circuit.

Apparatus:
1 rastered socket panel
1 coil with 1000 turns
1 transformer U-core
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
1 STE lamp holder E10, lateral
1 lamp, 12 V DC/3 W (type B)
1 lamp, 4 V DC; 0.04 A (type C)
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
1 low-voltage power supply, 0 … 12 V AC/3 A

Experiment part 1: coil in a DC circuit

Setup: ▶ Fig. 1

1. Select the DC output of the power supply.
2. Assemble the circuit with the switch open (switch in position 0).

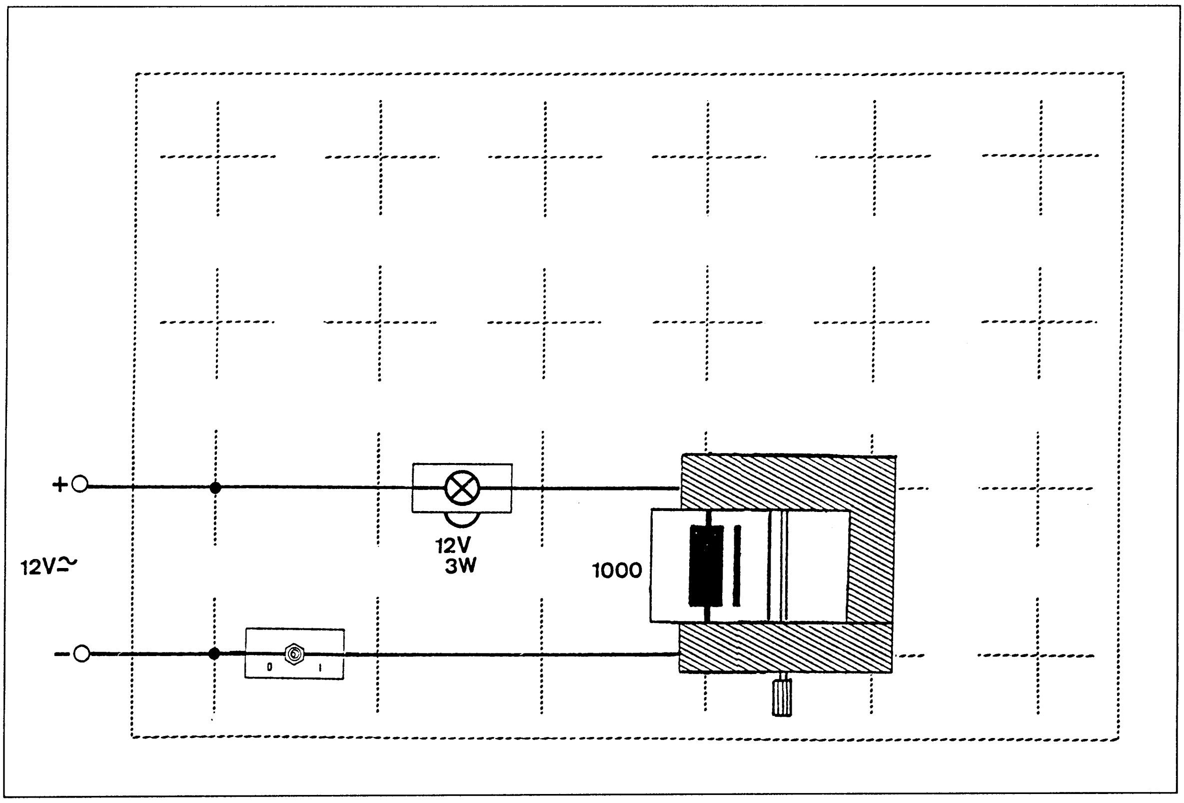

Fig. 1 Experiment setup: DC and AC resistance of a coil, with lamp as indicator

Student's Sheet 2

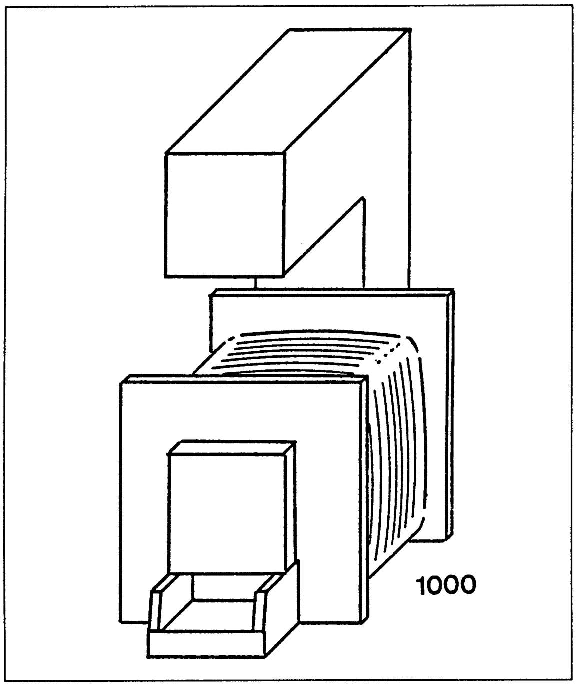

Fig. 2 Coil with U-core (vertical arrangement)

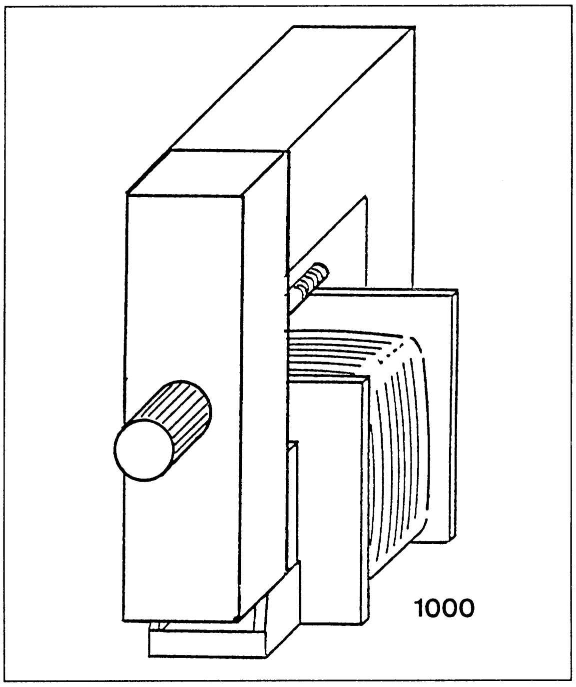

Fig. 3 Coil with U-core (vertical arrangement) and I-core mounted as yoke

3. Slide the U-core into the coil as shown in Fig. 2.
   Screw the I-core to the U-core as a yoke with the bare side inward.

Performing the experiment:

4. Select voltage level 1 (approx. 3 V DC).
   Close the switch.
   Does the lamp light up? If so, how bright is it?
   Write down your observations. ▶ table
5. With the switch closed, set the voltage source to voltage level 4 (approx. 12 V DC). Observe the lamp and write down your observations. ▶ table.
6. Open the switch and remove the I-core from the U-core.
7. Close the switch.
   Write down your observations. ▶ table

___

___

___

8. Open the switch.
   Set the voltage supply to voltage level 0.

Student's Sheet 3

Experiment part 2: coil in an AC circuit

Setup:

▶ Fig. 1

9. Mount the I-core as a yoke with the bare side inward – as shown in Fig. 2 and Fig. 3 – and screw it securely to the U-core.
10. Select the AC output of the power supply.
11. Select voltage level 1 and close the switch.
    Observe the lamp and write down your observations. ▶ table
12. Set the voltage source to voltage level 4. Observe the lamp and write down your observations. ▶ table.
13. Open the switch and remove the I-core from the U-core.
14. Close the switch.
    Write down your observations. ▶ table

Table

Step	Voltage type		level	Coil with U-core		Lamp lights up		
	DC	AC		closed	open	no	dim	bright
4	x		1	x				
5								
7								
11								
12								
14								

Evaluation:

Fill in the blanks in the following sentences.

15. Steps 5 and 7 show that:
    When a DC voltage is connected, the lamp lights up brightly at voltage level__regardless of whether the U-core of the coil is open or closed.
16. Steps 4 and 11 show that:
    When the voltage is set to level 1 and the U-core is closed, the lamp lights up dimly when ________ flows through the coil and ____________________________________
17. Steps 12 and 14 show that:
    The lamp lights up____for AC voltage level 4 when the U-core is open.
    It does not light up at all when________________

Student's Sheet 4

Experiment part 3: choke

Setup:

▶ Circuit diagram Fig. 4 and Fig. 3.

18. Set up the circuit on the rastered socket panel as shown in the circuit diagram. Attach the U-core and the I-core to the coil as shown in Fig. 3.

    Make sure that the bare side of the I-core is facing the U-core. Do not tighten the screw too tightly, because the yoke must turn easily.

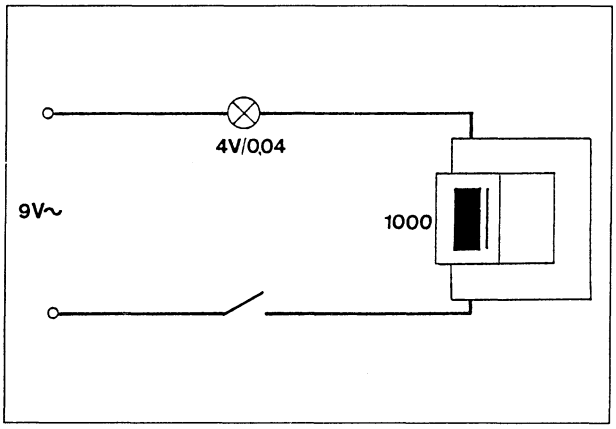

Fig. 4 Circuit diagram: choke

Performing the experiment:

19. Close the switch.
    Turn the yoke slightly (counterclockwise).

    What do you observe?

    ____

    ____

Evaluation:

20. What function does the coil with the U-core and yoke have in the circuit shown in Fig. 4?

    ____

    ____

    ____

Student's Sheet 1

DC and AC resistance of a coil II (measuring experiment)

Assignment: Find the DC and AC resistance of a coil without a core and a coil with a core. In addition, find out how suitable a coil is for limiting alternating current (i.e., as a choke).

Apparatus:

1 rastered socket panel
1 coil with 1000 turns
1 transformer U-core
1 transformer I-core (yoke)
1 STE toggle switch (on-off switch)
1 STE lamp holder E10, lateral
1 lamp, 12 V DC/3 W (type B)
4 bridging plugs
2 connecting leads, red, 25 cm
1 connecting lead, blue, 25 cm
1 connecting lead, red, 50 cm
1 connecting lead, blue, 50 cm
2 multimeters 30 V AC, 0.6 A DC/0.06 A AC
1 low-voltage power supply, 0 … 12 V AC/3 A
1 low-voltage power supply, 0 … 12 V DC
1 DC power supply, 0 … 12 V DC
(preferably smoothed)

Student's Sheet 2

Experiment part 1: coil in a DC circuit

Setup:

▶ Fig. 1

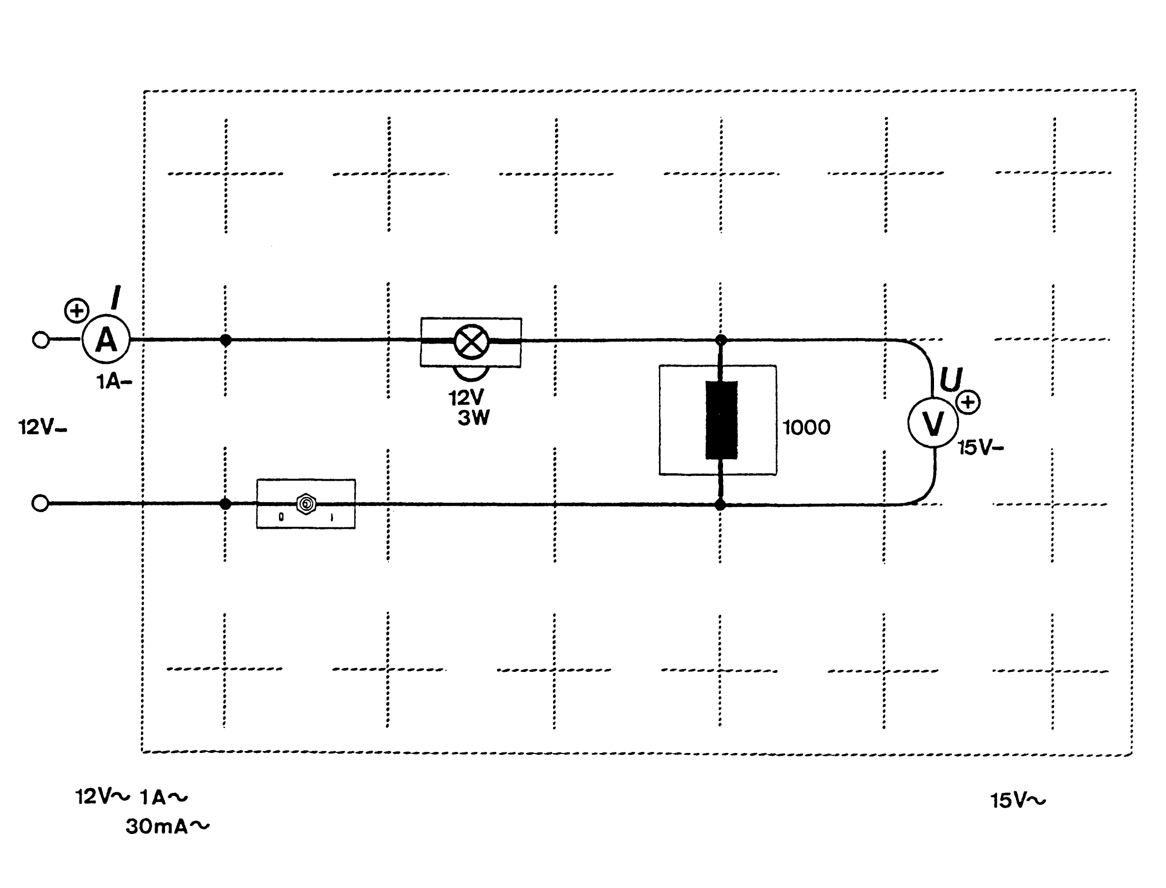

Fig. 1 Experiment setup: DC and AC resistance of a coil

1. Select the DC output of the power supply.
2. Plug the switch into the rastered socket panel (make sure the switch is set to position 0).
3. Set the following measuring ranges on the meters and check these very carefully!
   Voltmeter: 30 V DC
   Ammeter: 0.6 A DC

   Note:
   If you do not have two multimeters, you can measure current and voltage separately, one after the other.

Performing the experiment:

4. Close the switch. Select voltage level 4 (approx. 12 V DC).
5. Measure the values for DC voltage U and direct current I and write these down.
   ▶ table 1, a)

Student's Sheet 3

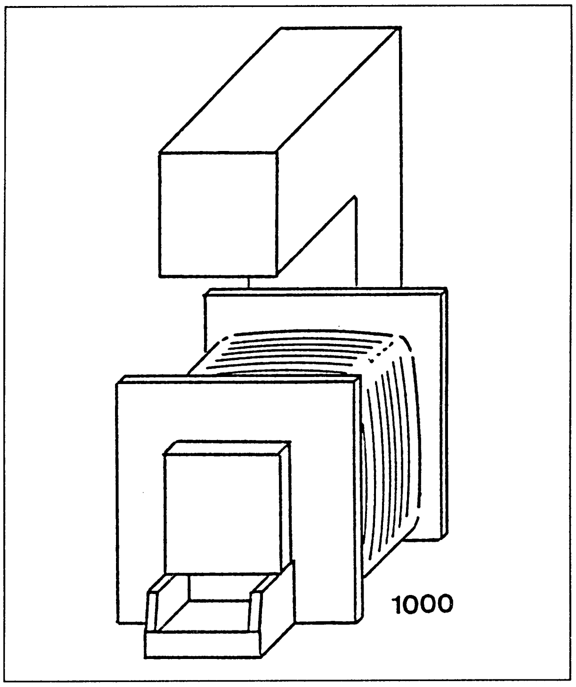

Fig. 2 Coil with U-core (vertical arrangement)

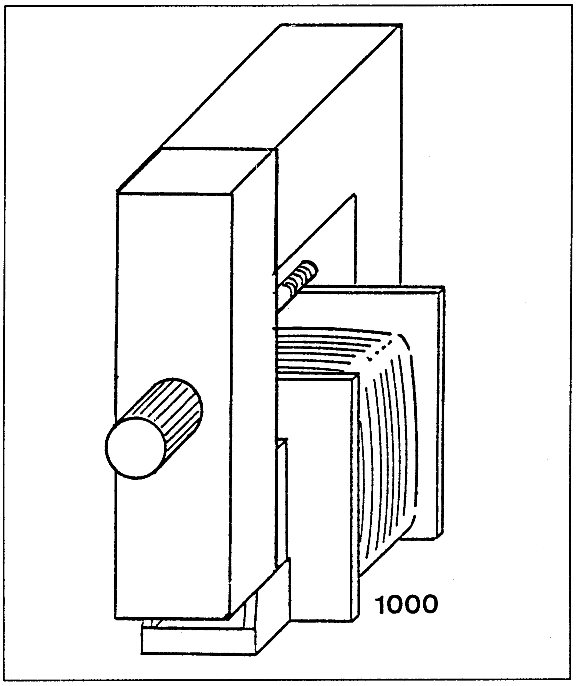

Fig. 3 Coil with U-core (vertical arrangement) and I-core mounted as yoke

6. Slide the U-core into the coil as shown in Fig. 2.
   Measure *U* and *I* and write down the values. ▶ table 1, b)
7. Screw the I-core to the U-core as a yoke with the bare side inward.
   ▶ Fig. 3.
   Measure *U* and *I* and write down the values. ▶ table 1, c).

Experiment part 2: coil in an AC circuit

Setup:

▶ Fig. 1

8. Open the switch. Set the power supply to voltage level 0.
9. Unscrew the I-core from the U-core and remove the U-core from the coil.
10. Select the AC output on the power supply.
11. Set the following measuring ranges on the meters and check these very carefully!
    Voltmeter: 30 V AC
    Ammeter: 0.6 A AC
12. Close the switch. Select voltage level 4 (approx. 12 V AC).
13. Measure the values for voltage *U* and current *I* and write these down.
    ▶ table 2, a
14. Slide the U-core into the coil as shown in Fig. 2.
    Measure *U* and *I* and write down the values. ▶ table 2, b)
15. Screw the I-core to the U-core as a yoke. ▶ Fig. 3.
16. Switch to the lower measuring range 0.06 A. Measure *I* and *U* again and write down the values.
    ▶ Table 2, c).

Table 1: Coil with n = 1000 turns in a DC circuit

	a) Coil without core	b) Coil with U-core but without yoke	c) Coil with U-core and yoke
U	V	V	V
I	A	A	A
$R = \frac{U}{I}$	Ω	Ω	Ω
$P = U \cdot I$	W	W	W

Note:
If you are using a power supply which does not supply a smoothed DC voltage, the AC voltage component will cause differences in a), b) and c).

Table 2: Coil with n = 1000 turns in an AC circuit

	a) Coil without core	b) Coil with U-core but without yoke	c) Coil with U-core and yoke
U	V AC	V AC	V AC
I	A AC	A AC	A AC
$R = \frac{U}{I}$	Ω	Ω	Ω
$P = U \cdot I$	W	W	W

Evaluation:

17. Calculate the coil resistances R for each set of measured values for U and I.
Write down your results: ▶ table 1 and table 2

How does the core of the coil influence the electrical resistance of the coil

a) in a DC circuit?

b) in an AC circuit?

____

a) ______________________________

b) ______________________________

____

Student's Sheet 5

18. Does the resistance of the coil depend on the type of current? What can you say about this in general?

____

____

19. Calculate the coil power values P from each set of measured values U and I.
Write down your results. ▶ table 1 and table 2.

How does the core of the coil influence the power of the coil

a) in a DC circuit?

b) in an AC circuit?

____

a) ______________________________

b) ______________________________

20. Does the power of the coil depend on the type of current?
What can you say about this in general?

____

____

21. An electrical component is needed which can reduce (choke) the alternating current in a circuit as much as possible at the lowest possible power value.
What component meets these requirements?

____

____

Capacitor in a DC circuit

Assignment: Study the behavior of a capacitor connected in a circuit with and without a DC voltage source.

Apparatus:

1 rastered socket panel
1 STE electrolytic capacitor, 470 µF
1 STE lamp holder E10, lateral
1 lamp, 4 V, 0.04 A (type C)
8 bridging plugs
2 connecting leads, red, 25 cm
2 connecting leads, blue, 25 cm
1 low-voltage power supply, 3,6,9,12 V DC, adjustable
1 voltmeter, 15 V DC

Student's Sheet 2

Setup:

1. Set up the circuit as shown in Fig. 1. Do not connect the voltmeter yet. Set the power supply to voltage level 0.

   Connect the ⊕ pole of the capacitor with the ⊕ pole of the voltage source.

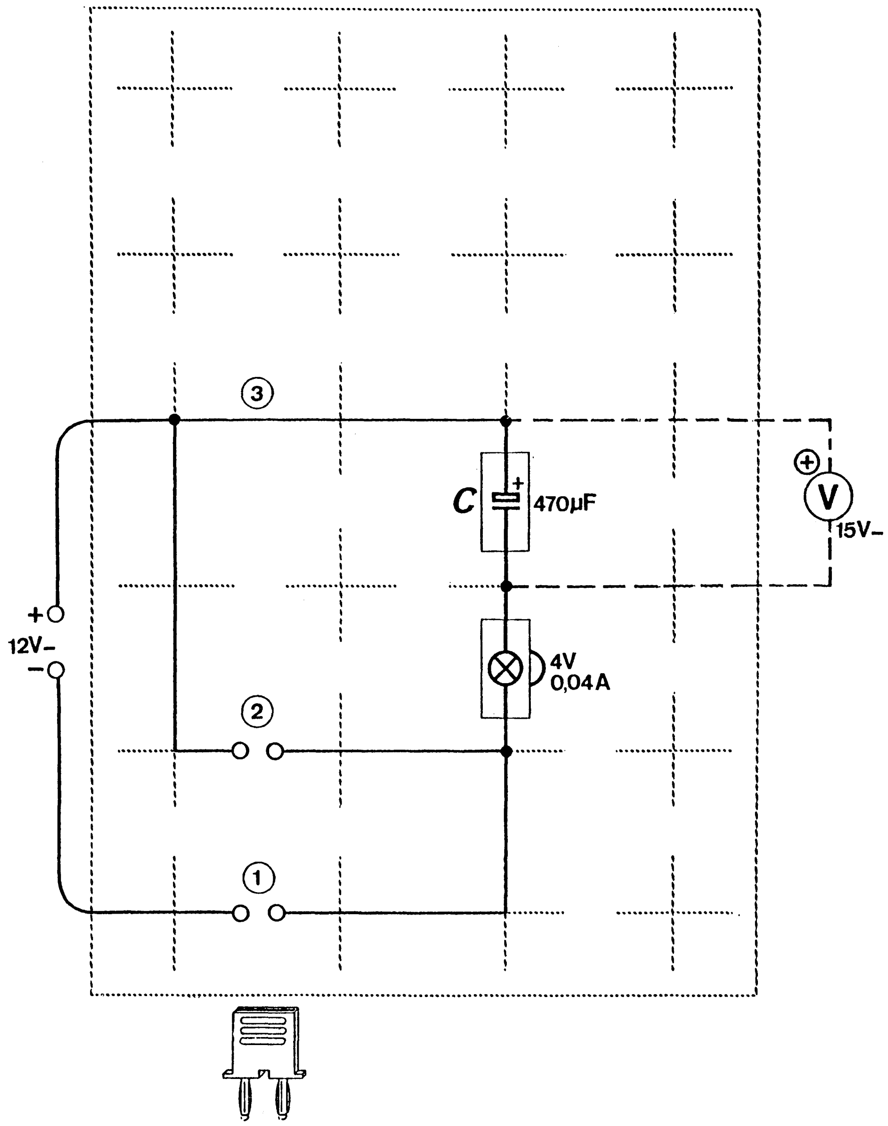

Fig. 1 Experiment setup: capacitor in a DC circuit
(1), **(2)** and **(3)**: plug-in points for bridging plug.

2. What elements are in a closed circuit when you plug in a bridging plug at **(1)**?

3. What elements are in a closed circuit when you remove the bridging plug from position **(1)** and plug it in at position **(2)**?

4. Select the voltage 12 V DC (voltage level 4).

Performing the experiment:

Experiment part 1: connecting a voltage source to the circuit (charging the capacitor)

5. Plug in a bridging plug at position **(1)**. What do you observe?
What conclusion can you draw from your observation?

Student's Sheet 4

Experiment part 2: closing the circuit without a voltage source (discharging of a capacitor)

6. Remove the bridging plug from position **(1)** and plug it in at position **(2)**. What do you observe, and how do you explain this?

Experiment part 3: measuring voltage at the capacitor

7. Connect a voltmeter to the capacitor.
Make sure the polarity is correct!
What voltage does the meter show?

8. Remove the bridging plug from position **(2)** and plug it in at position **(1)**.
Observe the voltage meter.

9. Remove the bridging plug from position **(3)** so that the connection to the voltage source is interrupted.
Does the voltmeter display change?

10. Plug the bridging plug in at position **(3)** again.

Experiment part 4: changing the voltage at the voltage source

11. Switch the voltage source to voltage level 1 (3 V DC). Remove the bridging plug from position **(1)** and plug it in at position **(2)**, and then return it to position **(1)**. Repeat this step for 6 V DC, 9 V DC and 12 V DC (voltage steps 2, 3 and 4).
What changes when you repeat this experiment with higher voltages?

Experiment part 5: increasing the voltage at the capacitor step by step

12. Switch the voltage source to voltage level 0. Leave the bridging plug at position **(1)** in place. Increase the voltage at the voltage source in steps of 3 V DC.
What can you observe for each voltage increase?

13. Remove the bridging plug from position **(1)** and plug it in at position **(2)** again.
    Compare your observations here with those from the last step.

Evaluation:

14. When we imagine that electric current is made up of a flow of electrical charge, it becomes easy to interpret the behavior of the capacitor.
    a) What happens when a capacitor is connected to a DC voltage source?
    b) Why does current flow for only a short time?
    c) What happens when we connect the terminals of a capacitor together which were previously connected to a DC voltage source?
    d) How does the voltage at the capacitor behave? How large is it in the beginning?

15. Where must we plug in the bridging plug when we want to
    a) charge the capacitor?
    b) discharge the capacitor?
    a)
    b)

16. How can we add more charge to a charged capacitor?

Capacitor in an AC circuit

Assignment: Find the resistance of capacitors in an AC circuit in relation to the voltage.

Apparatus:

1 rastered socket panel
1 STE electrolytic capacitor, 470 µF
1 STE electrolytic capacitor, 100 µF
1 bridging plug
1 STE toggle switch (on-off switch)
1 connecting lead, blue, 50 cm
2 connecting leads, blue, 25 cm
1 low-voltage power supply, 3,6,9,12 V DC, adjustable
1 voltmeter, 30 V AC
1 ammeter, 6 A AC

Setup:

1. Assemble the circuit as shown in Fig. 1. At the start, the switch should be in the open position (position 0). Set the voltage at the power supply to voltage level 0.

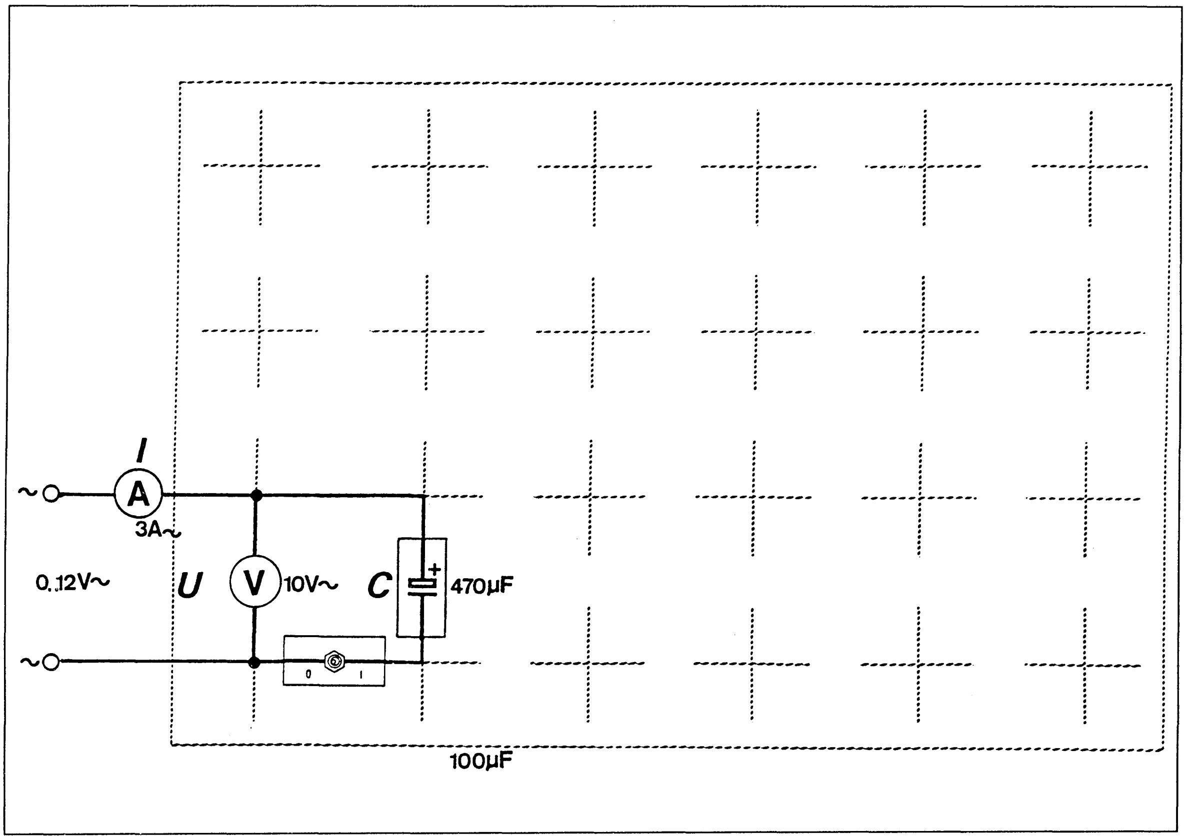

Fig. 1 Experiment setup: capacitor in an AC circuit

Student's Sheet 2

Performing the experiment:

2. Select the voltage levels 1 through 3 (3 V AC, 6 V AC, 9 V AC) at the voltage source one after another. Measure the AC voltage *U* AC and the alternating current *I* AC for each voltage level and write these down. ▶ table 1.

Table 1: capacitor *C* = 470 µF

Voltage level	$\frac{U\,AC}{V}$	$\frac{I\,AC}{A}$	$R = \frac{U\,AC}{I\,AC}$
1			
2			
3			

____

3. Replace the capacitor 470 µF with the capacitor 100 µF.
4. Measure and write down the values for *U* AC and *I* AC as before (▶ 2). ▶ table 2.

Table 2: capacitor *C* = 100 µF

Voltage level	$\frac{U\,AC}{V}$	$\frac{I\,AC}{A}$	$R = \frac{U\,AC}{I\,AC}$
1			
2			
3			

____

Evaluation:

5. Calculate the value of *R* for every value pair *U* AC and *I* AC. ▶ tables 1 and 2.
6. On the basis of your measurements, what can you say about the AC resistance (impedance) of a capacitor?

a) Does *R* depend on *U* AC?

b) Does *R* depend on the size of the capacitor (capacitance *C*)?

a) ____

____

b) ____

____

List of apparatus

Maximum Quantity	Description	Cat.-No.	Apparatus required in experiment (No. of items/lengths in cm)																				Number supplied in STM apparatus set	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	EI 1	EI 3
1	Rastered socket panel, 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	Pair of holders for rastered socket panel	576 77		1		1		1																
1	Bridging plugs, set of 10 from	501 48	1			1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1		
2	Connecting lead, red, 25 cm	500 411	1	1	2	1	1		1		1		1	2	2		1			2	2			
2	Connecting lead, blue, 25 cm	500 412	1		2	1			1		1		1	2	1		2			1	2	2		
1	Connecting lead, red, 50 cm	500 421		1			1	1	1	1		1	1	1	1	1		1	1	1				
1	Connecting lead, blue, 50 cm	500 422		1			1	1	1	1		1	1	1	1	1		1	1	1		1		
1	STE toggle switch (on-off switch)	579 13	1	1		1	1	1	1	1			1			1		1	1	1		1		
2	STE lamp holder E10, lateral	579 05					1	1	1						1	1			1	1	1			
1	Lamp, 12 V/3 W (type B)	505 08						1							1				1	1				
1	Lamp, 4 V DC; 0.04 A (type C)	505 07					1		1							1			1		1			
1	Glow lamp, E10/110 V	505 36														1								
1	Pair plug-in holders	579 331		1			1		1	1	1													
1	Contact strip from	579 332					1		1	1														
1	Leaf spring from	579 332					1		1	1	1													
1	Constantan wire, 0.35 mm dia.	550 42		1																				
1	Croc-clip, pair from	501 861								1														
1	Bar magnet	510 50		1								1					1							
1	Rotary support for bar magnet	510 51															1							
1	Plotting compass, pair from	510 53	1		1	1												1						
1	Coil with 500 turns	590 83			1	1	1	1	1		1	1	1	1	1		1	1						
1	Coil with 1000 turns	590 84								1		1	1	1	1	1	1		1	1				
1	Transformer U-core from	593 21				1							1	1	1	1	1		1	1				
1	Transformer I-core (yoke) from	593 21			1		1		1	1	1		1	1	1	1	1	1	1	1				
1	Set of 4 magnetizable rods	510 541						1																
1	STE electrolytic capacitor, 100 µF	578 39																				1		
1	STE electrolytic capacitor, 470 µF	578 40																			1	1		
	Voltage measuring ranges in V DC											0.15	3				0.15 3				15			
	Voltage measuring ranges in V AC											3		2x30			3			15		15		
	Current measuring ranges in mA DC											0.15					0.15			600				
	Current measuring ranges in mA AC											0.06			1/0.6					60		3000		
	Voltage source U DC in V		3	3	6	6	9	9	6	6			3			3				12	0-12			
	Voltage source U AC in V			3				9	6		9			0-12	0-12			6	0-12	12		0-12		

Measuring instruments

1 Multimeter M1 LH 531 50
1 Multimeter 1H 531 51
1 Moving coil galvanometer 531 67

Voltage sources

1 Low-voltage power supply 522 16
or
1 Variable low-voltage transformer S 591 09

recommended:
1 Stabilized DC power supply 522 30

Measurement instruments and voltage sources other than those described here and having comparable specifications can also be used in the experiments.