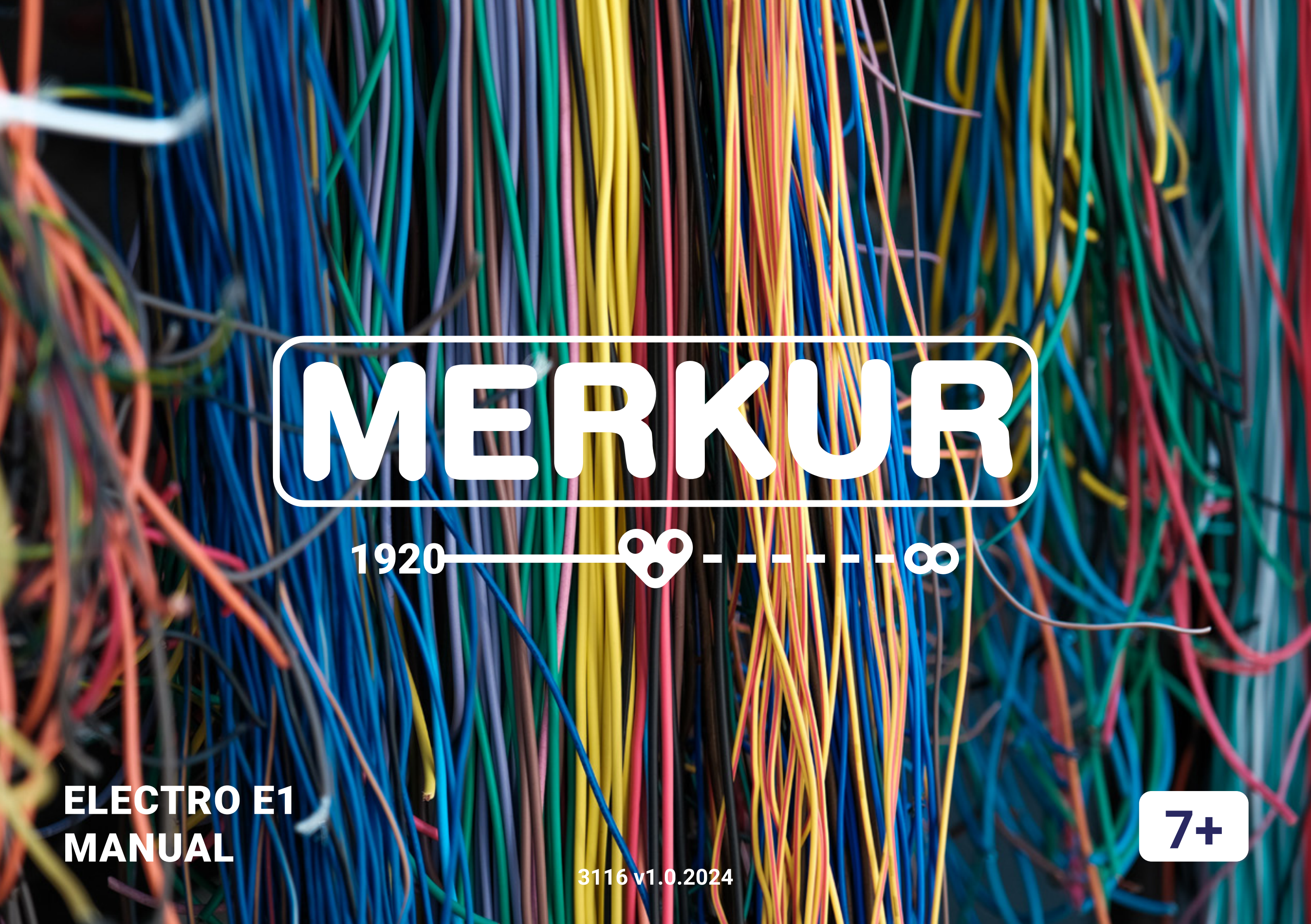


MERKUR

1920 – ∞

ELECTRO E1 MANUAL

7+

3116 v1.0.2024

TABLE OF CONTENTS

INTRODUCTION

Dear boys and girls, you have received a new Merkur Elektro E1 construction set, which is another extension of the Merkur series of metal construction sets. However, this set differs from the others in its content. You can use it to construct 88 experiments in the fields of electrostatics, electricity, magnetism, electromagnetism, electric machines, measuring instruments and electrochemistry.

Without us always being aware of it, electricity has become an essential part of our daily lives. We encounter it everywhere – not only at home but also in all other sectors of human activity. You have probably pondered why a light bulb in a room lights up when you turn on a switch or why music or spoken word comes out of a radio receiver. You may wonder how come we can watch on TV what is happening far away from us, etc. We could thus list many mysteries that we probably still cannot explain properly today, just like people in the past. Our construction set may help you to clarify some of these phenomena; it may provide you with the essentials for further activities and motivate you to learn and study more. And if you want to penetrate the secrets of electronics as well after you have mastered this construction set, you can also get the Merkur Elektro E2 set, which will provide you with the basics of this field and give you the opportunity to create many interesting circuits from fun electronics.

You will see that electricity can help people a lot, make their life easier and their leisure time more enjoyable. But beware, it can also harm them or even cause death. Our construction set is designed only for low voltage from 4.5V flat batteries or from 1.5V batteries, or it is possible to use a voltage converter. The low voltages and small electric currents used in our experiments do not pose a danger to you. Nevertheless, always avoid any manipulation of the mains electricity. Do not plug any wires into a socket, do not disassemble the power supply and only follow the directions in the instructions. Observe all safety instructions and warnings. Then you will be pleased to find that things previously incomprehensible to you are no longer a mystery.

Each experiment in this manual is accompanied by a brief description and explanation of some basic physical phenomena that you encounter in everyday life, that you have learnt about in school, and that will help you to gain a lot of new knowledge.

The construction set consists of numerous components and parts, which are listed and depicted on pages 4–7. For some experiments, you can use commonly available items that you have at home or at school. Most of the experiments are assembled on a perforated plastic base plate. On this plate, you are going to mount the individual parts of the construction set according to the instructions, pictures and diagrams. This should make the experiment functional and explain some laws of physics. Especially in the beginning, follow the instructions carefully when assembling the experiments. Later on, you can use your own imagination to construct other, new experiments.

Before you start building the experiments, prepare the base plate according to the instructions by bolting the basic Merkur plates, strips and angles to it as shown in the respective picture. Also use the pictures to prepare a model of a light bulb, resistor and switch so that you can then quickly create individual circuits as depicted.

We wish you great success in making experiments using this construction set!

CONSTRUCTION-SET PARTS

1095
Rubber locking ring
5×

1268
Cylindrical magnet
16×6
2×

1051
Zn nut M3.5
68×

1052
Zn bolt M3.5×6
30×

2053
Zn bolt M3.5×10
4×

1054
Zn bolt M3.5×16
5×

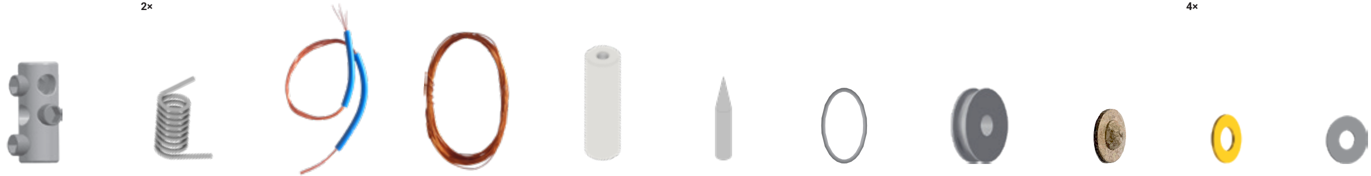
1055
Zn bolt M3.5×20
20×

1311
Iron nuggets
1 package

1228
Motor pulley
1×

1050
Adjusting ring
ID 4 mm
4×

3050
Zn adjusting ring
4×



1049
Sleeve coupling 6×6
2×

1294
Spiral resistance wire
1×

1293
Fine copper litz wire
1×

1291
Enamelled mounting wire
1×

1247
Coil core
1×

1267
Compass-needle pivot
1 package

2309
Rubber band
2×

1048
Pulley wheel
1×

1296
Insulation washer with fraying
5×

1295
Insulation washer
5×

1098
Steel washer
5×

1227
Six-tooth commutator
2×

1001
2-hole Zn angle
6×

1033
3-hole double-angle Zn strip
1×

1030
5-hole double-angle Zn strip
1×

1034
5-hole U-shaped Zn connector
2×

1315
Dull razor blade
2×

1301
Switch and push-button combination
1×

1203
Strip with 3 holes (ø 4 and 5 mm)
2×

1204
Insulation strip with 3 holes (ø 4 and 5 mm)
1×

1205
Insulation strip with 5 holes (ø 4 and 5 mm)
2×

1003
3-hole Zn strip
1×

1004
4-hole Zn strip
2×

1006
6-hole Zn strip
2×

1007
7-hole Zn strip
2×

1009
9-hole Zn strip
2×

1015
15-hole Zn strip
2×

1002
2-hole Zn strip
6×

2002
Thin 2-hole strip
2×

1038
Small joining plate
1×

2038
Small plastic joining plate
1×

1028
15-hole angle girder
4×

1029
25-hole angle girder
2×

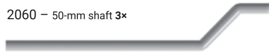
2031
9-hole double-angle
Zn strip
1×

1039
7-hole angle bracket
3×

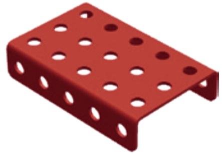
2130
Zn steering piece
1×

2061 – 90-mm shaft **2×**

2060 – 50-mm shaft **3×**

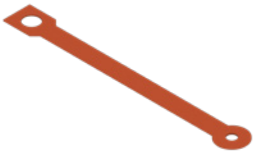


1068
Crank
1×

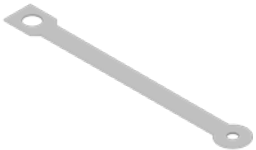


1024
Flanged plate
(30×50 mm)
4×

1271
Stator arm
2×



1213
2-hole bronze strip (61 mm)
narrowed in the middle
1×



1212
2-hole tin-plated strip (61 mm)
narrowed in the middle
1×

1222
Interrupting contact brush
with a bent tip
1×

1221
Straight contact brush
1×

1304
Insulation sleeve
(4 mm)
1×

1319
Magnetically hard rod
1×

1265
Magnetic compass
needle
1×

1266
Compass rose
1×

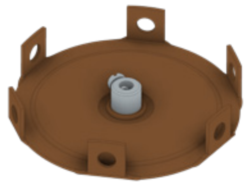
1223
E10 light-bulb socket
3×

1226
2.5V 200mA E10
light bulb
1×

1226-1
6V 100mA E10
light bulb
2×

1229
Bell cap
1×

1279
Aluminium disc
(62 mm)
1×



1230
Rotor plate
1×

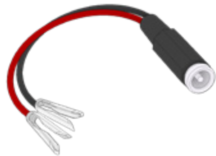
CONSTRUCTION-SET PARTS

1317
Crocodile-clip / socket cable
2×

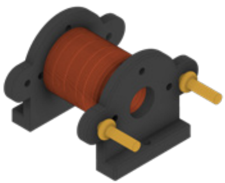
1321
Socket / socket cable (10 cm)
2×

1287
Socket / socket cable (16 cm)
4×

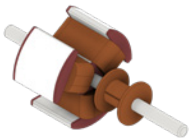
1286
Socket / socket cable (8 cm)
2×



1288
Power-supply cable
1×



1246
Induction coil
1×



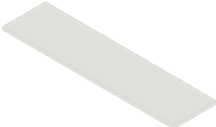
1270
Rotor with a shaft and a commutator
1×

1310
Iron filings
1 package

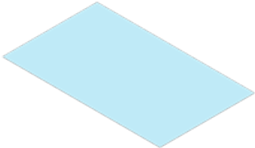
1306
Table salt
1 package

1308
Blue vitriol
1 package

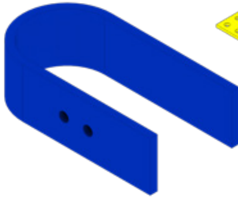
1235
Cu electrode
1×



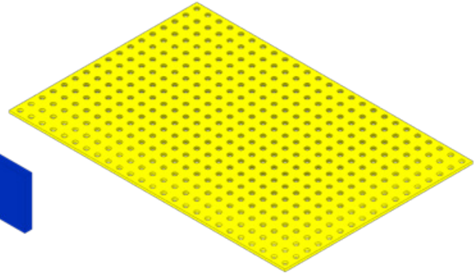
1236
Zn electrode
1×



1307
Phenolphthalein paper
1×



1269
Horseshoe magnet
1×



1274
Insulation plate
1×

1273
Longer motor bearing
1×

1272
Shorter motor bearing
1×

1275
Bronze motor contact brush
2×

1702
Carbon resistor (470 ohm)
1×

1701
Carbon resistor (100 ohm)
1×

1713
Green LED
1×

1090
String (1×1.3 m)
1×

1088
Nut holder
1×

2085
Offset wrench
1×

1085
Straight wrench
1×

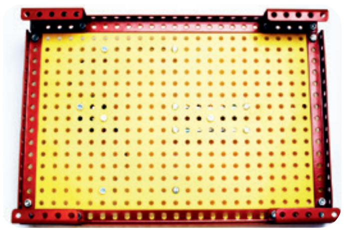
-
Hex key (Inbus, 2 mm)
1×

4081
Merkur screwdriver (135×3 mm)
1×

The colour, size and appearance of the product may differ from the photographs shown. The bolt type is subject to change.

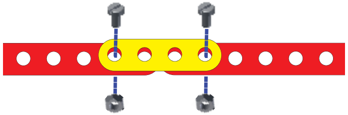
MOUNTING BASES

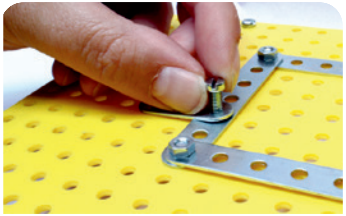
BASE-PLATE ASSEMBLY

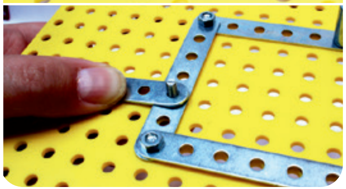


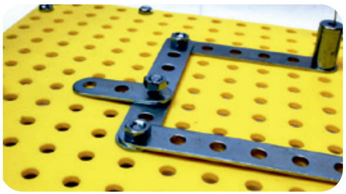
CABLE COILING

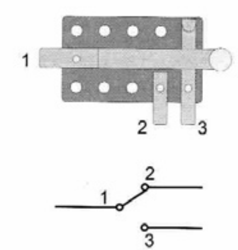
STRIP MOUNTING AND CABLE CONNECTION

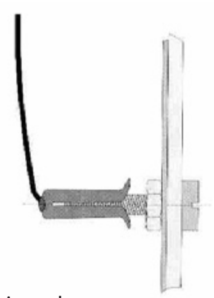






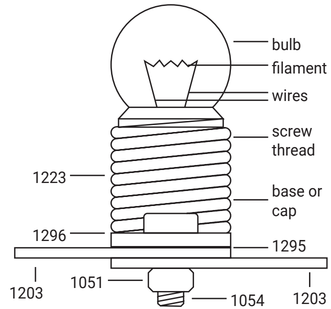






into the power-supply socket

LIGHT BULB



ELECTRONIC-COMPONENT DESCRIPTION

Electronic components are used to make electrical circuits. If you want to build a real electrical circuit, first draw a circuit diagram and then build the actual circuit based on it. A circuit consists of a power supply and various electronic components that are connected together by wires. The circuit diagram should be clear and include all the components, represented by electronic symbols.

Individual components have various technical designs depending on the manufacturer and the application. They have different technical parameters, which are usually indicated on these components by letter or colour codes; resistors are marked with colour bands. The value indicated by each colour is listed in the respective table. These rated values determine such quantities as voltage, current, power, frequency, resistance, capacitance, etc., including their permissible deviations given in %. This manual lists the basic parameters next to the schematic symbol of each electronic component.

RESISTOR

A resistor is a fundamental electronic component that provides resistance to the flow of current passing through it. Most types of resistors have a special electrical porcelain body suitably coated with a functional layer that provides the desired resistance to the flow of electric current. The surface of the resistors is protected by varnish coating or casting in epoxy resin.

These resistors have a constant resistance value. Nevertheless, the resistance value may be changed by using a different type of component, namely a wirewound resistor with a tap, a potentiometer or a trimmer.

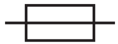
The basic unit of electrical resistance is 1 ohm (Ω). Resistors are manufactured with nominal resistance values ranging from about 0 Ω to 100 ΩM and with various values of the possible power load in watts (W). The resistance value of a resistor is indicated on the component by a number or by a colour-band code.

COLOUR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER (Ω)	TOLERANCE
Black	0	0	0	1	
Brown	1	1	1	10	±1% (F)
Red	2	2	2	100	±2% (G)
Orange	3	3	3	1,000	
Yellow	4	4	4	10,000	
Green	5	5	5	100,000	±0.5% (D)
Blue	6	6	6	1,000,000	±0.25% (C)
Purple	7	7	7	10,000,000	±0.10% (B)
Grey	8	8	8	100,000,000	±0.05% (B)
White	9	9	9	1,000,000,000	
Gold				0.1	±5%
Silver				0.01	±10%

4-band code

5-band code

FUSE



A fuse is an electrical component used to protect electrical equipment from overload and short-circuit currents. In the event of a device failure and short circuit, the fuse blows, thus disconnecting the device from the power supply. Therefore, the fuse is placed in the circuit before the load. A blown fuse must always be replaced by a new fuse of the same type and ampere rating. It cannot be repaired. It is intended for a single use only. Fuses come in several different designs: glass fuses for currents from 50 mA to 6 A, porcelain fuses for 2 A–63 A, and blade fuses for the currents ranging from 10 A to hundreds of amperes.

BATTERY AND POWER SUPPLY

Experiments with the construction set can be performed using the following direct-current (DC) power supplies. One of the possibilities is a 1.5V battery, or you can connect two or

ELECTRONIC-COMPONENT DESCRIPTION

more 1.5V batteries in series (always connecting the positive terminal of one battery with the negative terminal of another), thus obtaining a voltage multiple depending on the number of the batteries, i.e. 3 V, 4.5 V (flat battery), 6 V, etc. These power supplies, especially at higher loads, have a limited lifetime (they discharge). It is possible to use nickel–cadmium batteries, which can be recharged with a special charger. Another source of DC voltage is provided by various adapters (voltage converters), which are plugged into the mains socket. The 230V voltage is converted by a transformer to low voltage, e.g. 1.5–12 V. In addition, the alternating-current (AC) voltage must be rectified and sometimes also stabilised.

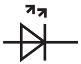
The power supply in the construction set is a universal power source that is designed for a maximum load current of 500 mA with DC output voltages of 1.5 V, 3 V, 4.5 V, 6 V, 7.5 V, 9 V and 12 V.

Caution: Do not subject the power supply to continuous high loads! Use the device only in a dry environment! The device has been approved by a state testing laboratory for continuous safe operation. Always connect the power supply to the construction set as the last part of the experiments!

CAPACITOR

A capacitor is an electrical component consisting of two conducting plates separated by an insulating layer called a dielectric. Depending on the surface area, thickness and the type of material of the dielectric as well as on the voltage, the capacitor is able to store electrical charge. The ratio of the free charge (Q), expressed in coulombs, to the voltage (U) in volts determines the capacitance of the capacitor (C), whose unit is 1 farad (F). A capacitor has a capacitance of 1 F when it can store 1 coulomb (C) of charge at a voltage of 1 volt (V). The capacitor is theoretically capable of maintaining its charge indefinitely. In practice, however, the ability is not unlimited because the insulating material – the dielectric – is not completely non-conducting.

LED

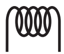


A light-emitting diode (LED) is a special type of diode. All LEDs only allow current to pass through them in one, forward direction. A LED differs from other diodes in that it emits light when current flows through it in the forward direction – it glows. The best-known diodes include: rectifier diodes, LEDs, Zener (stabiliser) diodes, varicaps (variable-capacitance) diodes, and photodiodes. The last of them have been used, for example, in TV remote controls.

LIGHT BULB

The light bulb is one of the most famous inventions of the American inventor Thomas Alva Edison. In contemporary design, it comprises a tungsten filament twisted into a spiral placed in an airless glass bulb (in the case of bulbs up to 25 watts) or a bulb filled with an inert gas (nitrogen or a noble gas) at low pressure. A glowing incandescent light bulb also radiates heat into its surroundings (92% of electrical energy is converted to heat, only less than 8% to light).

INDUCTOR



Every conductor (wire through which electricity flows) is surrounded by a magnetic field. An inductor is an electrical component consisting of a coil of wire that converts electrical energy into magnetic energy and vice versa. The magnetic properties of a coil are enhanced by the insertion of a steel core.

RELAY

A relay is an electrical component working as a controlled switch. It can have normally-open, normally-closed and change-over (double-throw) contacts. Current flowing through a coil wound around a steel core generates a strong magnetic field, attracting the relay armature (a movable contact), which closes or opens the contacts. Relays are produced in various designs with different parameters. They can be divided according to:

1. operating coil voltage (6V, 12V, 24V, 48V etc.)
   a) AC
   b) DC
2. the rated voltages and currents of the contacts (e.g. 600V/10A)
3. the number and type of contacts (normally-open, normally-closed and double-throw)
4. operating environment (suitable for dry, humid, explosive environments, etc.)
5. mounting (onto a printed circuit board – PCB, with screws on DIN rail, etc.)

I. ELECTROSTATICS

I. ELECTROSTATICS

In ancient times, people already noticed the special properties of amber (‘electron’ in Greek). When rubbed, it acquired the ability to attract some light bodies. In the Middle Ages, these phenomena were assumed to be the Devil’s work. However, we know that there are no devils or other supernatural beings. We are trying to explain and understand these phenomena on the basis of scientific knowledge. The science of these natural phenomena was later called **electrostatics**.

Everything around us is made of the basic building blocks – **atoms**. Each atom is composed of a nucleus and a shell. The nucleus further consists of positively charged elementary particles (**protons**) and neutral particles (**neutrons**). What we will be primarily interested in is the shell, in which the negatively charged particles (**electrons**) orbit the nucleus. An electron is a particle that carries one negative elementary charge. The **electric charge** cannot be destroyed, it is impossible to make it appear or disappear instantaneously, and it is always bound to some particle. In reactions between charged particles, the total electric charge before and after the reaction must always be the same. The law of conservation of electric charge was proved experimentally by Michael Faraday in 1843.

The smallest electrically neutral particle is an atom. Under certain circumstances, electrons are able to move from the shell of one atom to the shell of another atom, which creates an imbalance of charges. We say that a substance has been **electrified**. A body with a deficiency of electrons is positively charged, whereas a body with an excess of electrons is negatively charged. The more electrons that pass from one body to another, the greater the charge.

Equally charged bodies repel each other, while oppositely charged bodies attract each other. The unit of electric charge is one **coulomb** (C). The charges occurring in our experiments are about a million times smaller than 1 C.

In 1785, C. A. Coulomb discovered that two point charges attract each other with an electric force that is inversely proportional to the square of the distance between them. This is analogous to Newton’s law of gravitation, where two material points are also attracted with a force inversely proportional to the square of the distance between their centres of mass.

1. ELECTRIC-CHARGE GENERATION

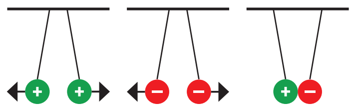
The generation of an electric charge is the separation of positive and negative charges. The charge itself can neither be created nor destroyed.

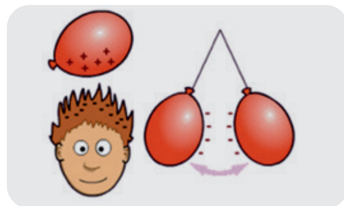
The construction set includes a large plastic base plate. Take it and rub it against your clothes. When you bring this plate close to your hair, your hair seems to have come to life and is being pulled towards the plate because you have electrified it by rubbing it. Other materials (e.g. a comb, a file folder, a ballpoint pen) will behave similarly. We are going to use this observation to study the source of electrostatic energy further.

You may have noticed that when you take off a synthetic pullover, you can hear a crackling sound, and if it is dark, you can see tiny sparks. This electrostatic phenomenon is caused by parts of the garment rubbing against each other – when you take the garment off, the accumulated charges become balanced again, creating the sparks.

2. ELECTRIC FIELD

Take the iron filings that are included in the construction set and sprinkle them on a piece of paper. Electrify the plastic base plate and bring it closer to the iron filings. These suddenly seem to have gone wild, jumping and flying until they stick to the electrified plate. Why? The base plate is surrounded by an electric field, in which the iron filings become charged, apparently with the same charge. You already know that particles with the same charge repel each other. Therefore, the iron filings in the electric field cannot remain in the pile for long and they begin to jump and fly. Unless you remove the charged plate quickly enough, the filings will stick to it.





I. ELECTROSTATICS

3. PAPER DANCERS

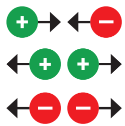
Cut fine paper into small pieces (6–8 mm). Borrow a small translucent plastic box from your mum and put the cut pieces of paper in it. Make sure your hand is dry and rub it against the lid of the box. Instead of your hand, you can also use a piece of cloth. Being attracted by the electrified lid, the pieces of paper start to dance. If you want to improve the experiment, you can cut out figures and colour them. Similarly, you can perform this experiment by electrifying e.g. a comb, which, when approached, will attract pieces of paper with its electrostatic charge.

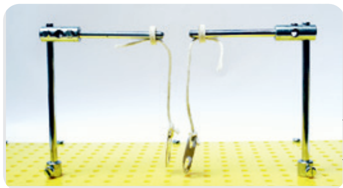
Why are the pieces of paper attracted to the comb? It is strange – they are not electrically charged, they are non-conductors! In the electric field around the plastic base plate, the pieces of paper become polarised. The electrons in them move towards the edge closer to a positively charged object or away from a negative object. It depends on which field they are in. This creates an electric dipole, which means that positive charges are concentrated at one end and negative charges at the other. Closer pieces are affected by a greater force than more distant pieces.

4. CHARGE INTERACTIONS

You have already learnt to create an **electric charge** and have discovered its effect on the surroundings. You can electrify various objects, but will it always produce the same charge? In the introduction, you read about **positive** and **negative charges**. Which charge have you made? Electrify a plastic file folder and use it to charge two pieces of paper on a stand built on the plastic base plate. The pieces jump apart. This means that both pieces of paper are equally charged. It has been agreed that this charge is negative. A positive charge would be obtained by rubbing a glass rod. An experiment will show you that even two electrified glass rods repel each other. If you take positively and negatively charged objects, you will see that they attract each other, which is similar to hair combing (with individual hair strands sticking to the comb).

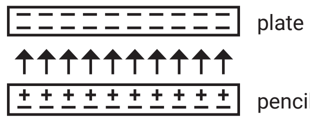
Construct two stands as shown in the picture. They must be isolated from each other. Tie one strip No. 2002 to the end of each of them. Charge one strip with one charge using the plastic base plate. Charge the other strip on the other stand with aluminium foil. Since the strips have different charges, they start to attract each other. If you charge both strips with the same charge, they will repel each other.





5. RESTLESS WAND

Put a pencil on the table and place another one crosswise on top of it. Make sure to place it exactly in the middle, balancing it so that neither end touches the top of the table. Now take the plastic base plate and charge it by rubbing it. Without touching anything with the plate, slowly bring it towards one end of the pencil. At a certain distance, you will notice that the pencil starts to be attracted to the plate. If you move the plate away, the pencil will rotate until it falls. You already know that objects with different charges attract each other. Nevertheless, you have only charged the basic plate. How come they attract each other? It is because they are in an electric field, where, as you know from previous chapters, a dielectric (the pencil) becomes polarised. The charge in the pencil opposite to that on the charged plate is thus transferred to the side of the pencil that is closer to the charged plate.



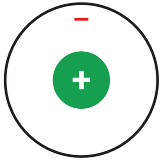
I. ELECTROSTATICS

6. BENDING WATER

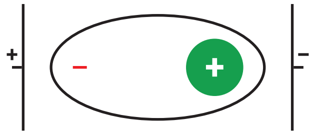
You know that if you turn on the water at the sink and let it run slowly, it falls vertically downwards due to the Earth's gravity. When you bring the plastic base plate close to the flow of running water, you will not notice any change. Then rub the plastic plate against your hair to create an electrostatic charge. When you bring it close to the trickle of water without actually touching it, you will see that the water suddenly changes direction and bends towards the plastic plate. Now touch something conductive, such as a central-heating radiator (whose pipes are grounded), with the plate. Allow the plate to discharge for a moment and bring it close to the water again. You can see that it is bent much less, if at all.

This phenomenon is based on the polarisation of water molecules in an electric field (water is a polar dielectric).

without an electric field



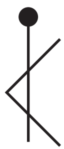
inside an electric field



7. SWING

Make a stand as shown in the picture so that you can insert a pin into the two holes. Fold a narrow strip of paper lengthwise to form a small angle bar (a V-shaped chute). Pierce it with a pin near the centre of its length. Place the created lever on the metal pieces attached to the stand.

Because the paper lever is not balanced, its heavier side goes down. Now charge the plastic base plate by rubbing it against your hair and bring it close to the strip of paper. It will move. At that point, quickly pull the plate back. The paper strip will return to its original position, but inertia will keep it moving and the strip will begin to swing. Try to approach the plate again in the oscillation rhythm in order to ensure oscillatory motion.



8. PENDULUM

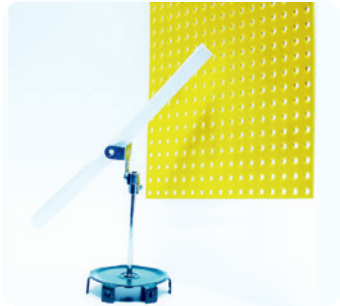
Construct another stand. Attach a small weight, e.g. the strip No. 2002, to the end of a thread and hang it on the stand. Bring the electrostatically charged base plate closer to the weight. Similarly to the previous experiment, the weight will move and then, after the plate is removed, it will begin to swing. If you manage to coordinate the approach of the charged plate with the motion of the weight, you will achieve large oscillations. You have constructed a pendulum.

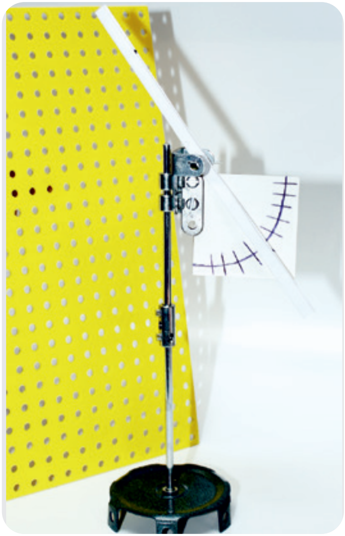
I. ELECTROSTATICS

9. ELECTROSCOPE

You are going to build a simple device to measure electrostatic charge. Such a device is called an **electroscope**. Construct a stand according to the picture. Again, use a strip of paper folded into an angle bar, pierce it with a needle or pin and place this lever on metal angles. Because of a slight imbalance, the paper angle bar will be in a vertical position.

When you approach it with the charged plate from the front, the paper angle bar will move. When you remove the plate, the paper strip will return to its original position. When you approach from behind and touch the stand with the charged plate, you will transfer the charge to the conductive stand. At that point, the stand and the paper angle bar will have the same charge, as a result of which the paper will move like when you approached with the plate from the front. Nevertheless, it will remain in this deflected position. In order to discharge the electroscope and return the paper strip to the zero position, touch the stand with your hand. The principle of the electroscope is based on the fact that like charges repel each other.



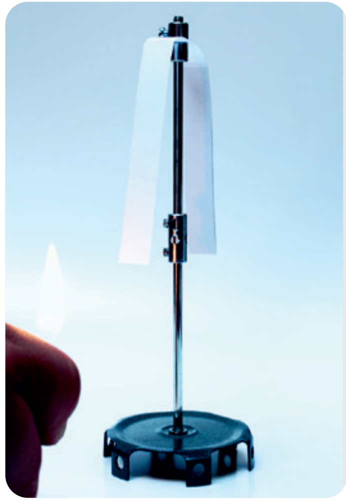


10. ELECTROMETER

In the previous experiment, you found out whether the plate was charged or not. If you want to measure the electric charge at least approximately or compare it, you can make a scale on your electroscope to measure the deflection. Such an instrument is called an **electrometer**. You can now transfer different charges to the discharged electroscope and compare them.

11. AIR IONISATION

Make a stand according to the picture and attach two narrow strips of fine tissue or toilet paper to the end of the rod. Transfer electrostatic charge to this module. It will deflect the two pieces of paper away from each other because they have the same charge. Two like charges repel each other. These pieces of paper remain in the deflected position. Now light a match and carefully approach it from the side to the two pieces of paper. They will return to their original vertical position. Why? The air around the paper is ionised by heating (it breaks down into positive and negative ions) and the charge on the pieces of paper is discharged.



12. FARADAY CAGE

Construct a stand as shown in the picture. Hang a string on it. Take a plastic, wooden or paper container and place the string hanging on the stand inside. Bring the electrified plastic base plate closer to the container and observe whether it affects the string inside the container. You can see that the string is deflected towards the charged plate.

Now repeat the whole experiment with a tin mug. The string does not move at all. The force of attraction of electrically charged bodies penetrates non-conductive materials, but it is blocked by a closed metal case. This phenomenon, which follows from Gauss's law, is called a **Faraday cage**. Airplanes or cars act as Faraday cages, protecting passengers from being struck by lightning.

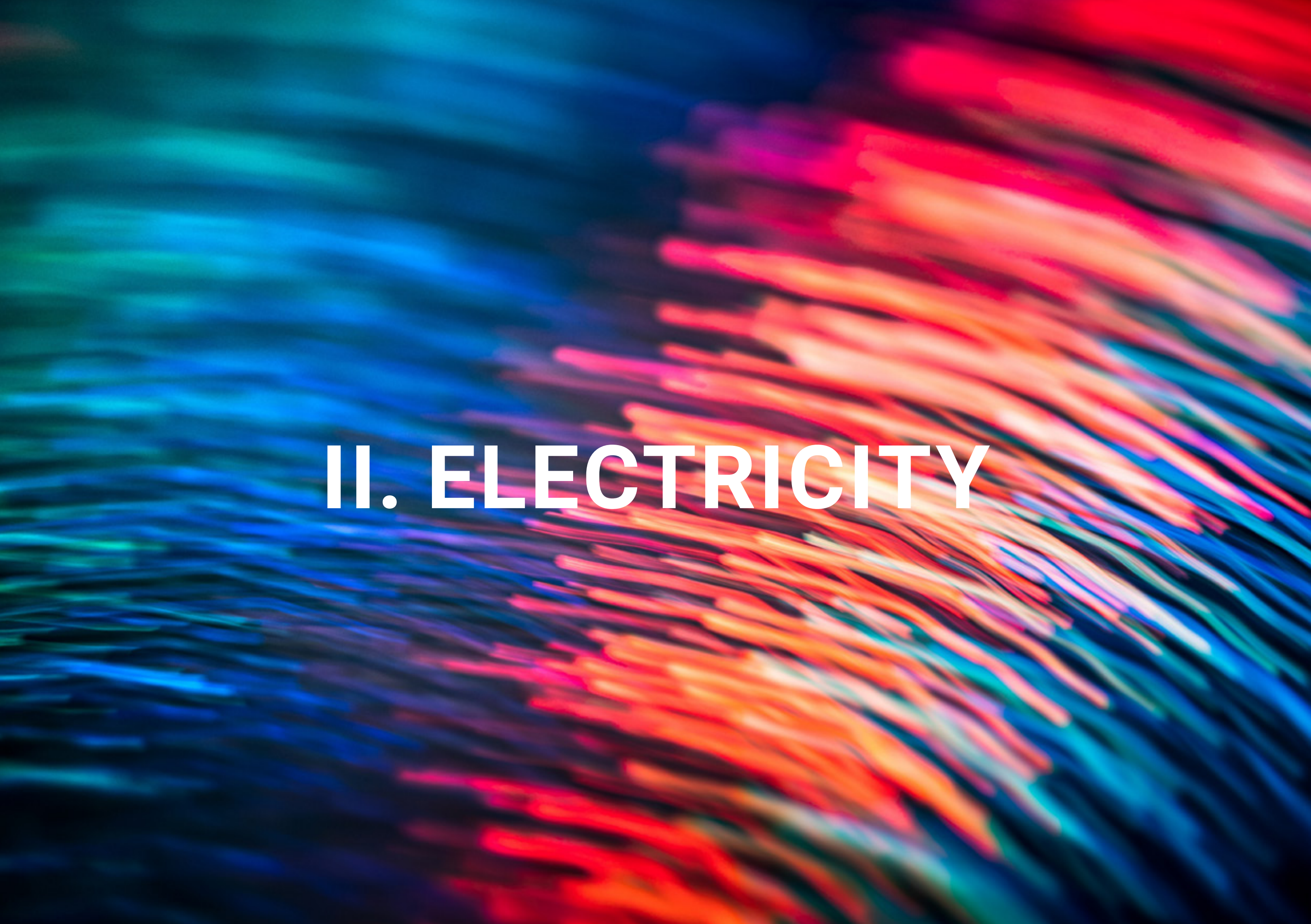
a metal container
The string does not move towards the charged plate. The cage blocks the external electric field.

a plastic container
The string is deflected towards the charged plate. The cage does not block the external electric field.

13. CAPACITOR

As you have seen, everything in nature tends to assume the lowest-energy state (a body falling towards the Earth, polarised particles attracting each other, etc.). Is there any way to conserve electrical energy? Yes, with a device called a **capacitor**. You are going to make one. Mount a shaft on the base plate using an adjusting ring. Attach strips of thin paper to the top end. Create an electric charge and touch the attached rod from below. The pieces of paper deflect to opposite sides and remain in that position. This enables you to preserve the electric charge. Although everything is insulated, the capacitor will discharge after some time because there is no such thing as a perfect conductor or insulator.

We encounter such a capacitor everywhere. The surface of the Earth and the ionosphere (a layer of the atmosphere) form two electrodes of a spherical capacitor. We walk on the inner electrode of this capacitor. The accumulated charge is discharged through lightning during a storm. About 100 lightning bolts strike the Earth's surface every second.



II. ELECTRICITY

Photographs of the assemblies are shown on pp. 53–56.

II. ELECTRICITY

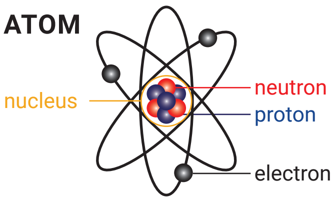
You have undoubtedly heard of electricity, **electric current** and **voltage**. What exactly is electric current? For a long time, people did not know. We will try to explain that to you.

You might have already thought about what the objects around us are composed of. You probably already know from school, your parents or older friends that they are composed of **matter**, which consists of extremely small particles, called **atoms**. Everything around us is made of these basic building blocks. After years of research, scientists have discovered that not even atoms are the smallest particles of matter. Each atom is composed of a **nucleus** and a **shell**. The nucleus further consists of **protons** and **neutrons**. However, we will primarily be interested in the shell, in which **electrons** orbit. These particles are depicted as spheres, but we have no idea what they actually look like.

You already know from electrostatics about the existence of an electric charge, which can be negative or positive. An electron is a particle that carries one negative elementary charge. If there is an excess of electrons in one place (which is negatively charged) and a deficiency in another (which is positively charged), the connection of the two places results in an ordered motion of free electrons from the negative pole to the positive pole – this movement is called **electric current**. **Voltage** is the potential difference between these points.

Before this was discovered and proved, it was a common misconception that electric current flows from the positive to the negative pole. In order to avoid confusion, because various diagrams and rules were based on this mistaken view, it was agreed that this established rule would be maintained and this would be the 'conventional direction of electric current'. You already know that the opposite is the case. All diagrams of electrical circuits, however, show the direction of the electric current from the positive pole to the negative pole. In most cases, this concerns the movement of electrons in the metal. Since metals contain a large number of free electrons, they are good **conductors** of electric current. Nevertheless, electric current may involve not only the movement of negative electrons. This will be discussed later.

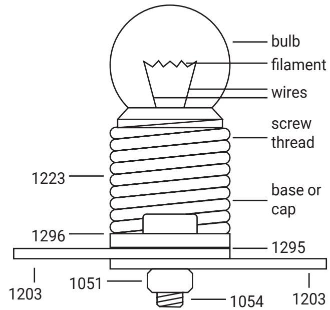
In order to be able to measure and compare it, we are introducing a new physical quantity – electric current. The unit of **electric current** (I) is one **ampere** (A). It is an SI base unit. The unit of **voltage** (U) is one **volt** (V). Sometimes, you may come across the term **electromotive force** (voltage), which means the voltage of a source when no current is flowing through it.



14. LIGHT BULB

You have undoubtedly seen a light bulb, one of the most famous inventions of the American inventor Thomas Alva Edison. Edison's original light bulb has been gradually improved. In contemporary design, it comprises a tungsten filament placed in an airless glass bulb or a bulb filled with an inert gas (nitrogen or a noble gas) at low pressure. The passage of an electric current through this filament, which is twisted into a spiral, makes it white-hot, as a result of which it emits **light energy** (it glows). There must be a vacuum or inert atmosphere in the bulb. Otherwise, the tungsten filament would quickly burn away – it would react with the oxygen in the air. Light bulbs have different designs depending on the application. They are classified according to the type of glass (clear, coloured, milk), shape (bulb, cylinder, spot), size, brightness, luminous intensity, and the type of fitting (Edison screw cap, bayonet cap). A glowing incandescent light bulb also radiates heat into its surroundings (92% of electrical energy is converted to heat, only less than 8% to light).

Our construction set contains one 2.5V and two 6V bulbs. You can test a 6V bulb using a flat battery or our power supply by touching the bulb cap (or base) and the metal tip with the contacts. The bulb will light up. Do not exceed the rated voltage!



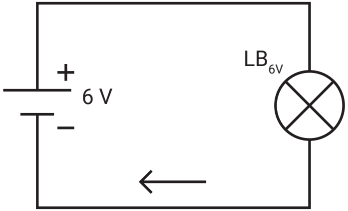
Photographs of the assemblies are shown on pp. 53–56.

15. LIGHT-BULB CIRCUIT

Now proceed to the construction of the first **electrical circuit**. An electrical circuit is a set of electrical components (light bulb, motor, inductor, etc.) connected by means of conductors (wires, strips) together in a loop with a power source (e.g. battery, transformer, etc.).

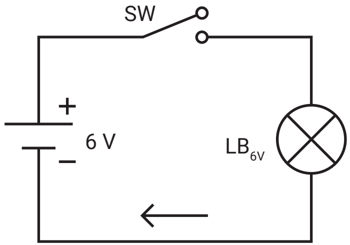
Create a light-bulb (LB) holder. Attach the light-bulb holder to the perforated plastic base plate according to the picture at the end of the previous page and connect this holder to the power supply by means of conductors according to the picture and the diagram. A **schematic-circuit diagram** is a graphical representation of an electrical circuit showing how the electrical components are connected.

In order to ensure that everyone can understand this schematic-circuit diagram, it is drawn according to certain conventions and individual components are depicted using the **electronic symbols** defined by the standard. When you connect a power supply to the ends of conductors (metal wires, Merkur galvanised strips), the light bulb will light up.



16. ELECTRICAL CIRCUIT WITH A SWITCH

An electrical circuit with a **switch** (SW) is a circuit that can be permanently **closed** (connected) or **opened** (disconnected), i.e. switched on or off, by means of a mechanical switch. It is possible to use several types of switches, including rotary, toggle, rocker, push-button, slide and other switches. They are manufactured for different rated voltages, currents and environments. There is a special component in the construction set that can be connected as a switch with normally-open (NO) or normally-closed (NC) contacts or as a change-over switch. On the plastic base plate, build a circuit with a universal switch, a 6V bulb, conductors and a power supply according to the diagram. You can also use another switch, such as a doorbell push-button switch. As a general rule, the switches in the 6V diagram are connected to the positive pole of the power supply.

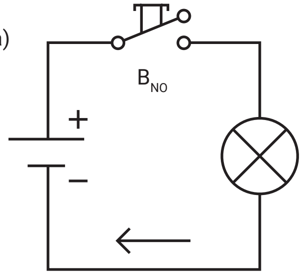


17. ELECTRICAL CIRCUIT WITH A PUSH BUTTON

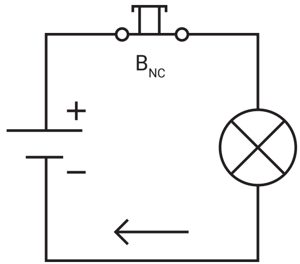
Instead of a switch, connect a **push button** (B) to the circuit. An electrical circuit with a push button is a circuit that can be mechanically closed, opened or switched by means of a **normally-open**, **normally-closed** or **change-over** push button, respectively, for as long as the push button is pressed (momentarily). In practice, it is possible to use several types of push buttons, differing in the shape of the head, the voltage and current values, or in the design for use in a particular environment.

In this experiment, use our special component again. This time, connect it as a normally-open button (B_{NO} in Fig. a) or as a normally-closed button (B_{NC} in Fig. b) or as a change-over button (B_{CO} in Fig. c). Make a circuit with each type of button and note the differences between the buttons and a switch.

a)

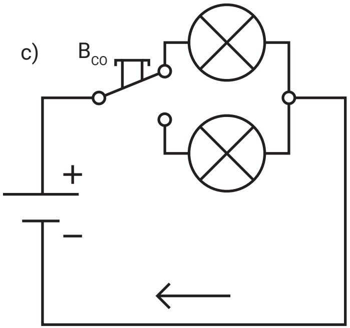


b)



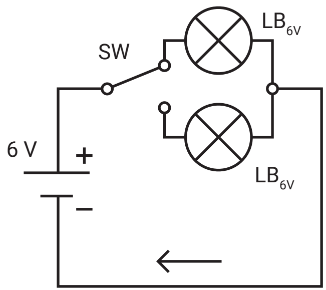
c) ⟶

Photographs of the assemblies are shown on pp. 53–56.



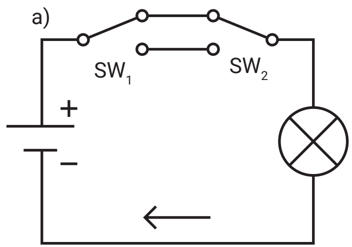
18. ELECTRICAL CIRCUIT WITH A CHANGE-OVER SWITCH

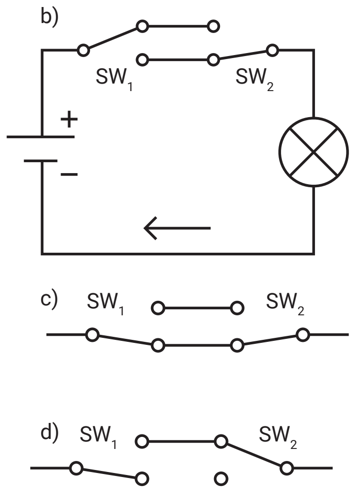
Extend the current circuit by connecting another 6V light bulb to the second and third contacts according to the diagram. Try connecting the switch lever first to one and then to the other contact. You can thus switch between lighting the two light bulbs.



19. THREE-WAY SWITCH

Now that you have understood the principle of the switch, you must be wondering how the light switch at the landing of a staircase works when you turn the light on downstairs and off upstairs. The explanation is simple. Study the diagram and make the wiring as shown. You will find out that in this wiring method, the switch SW1 can be in the ON state once in the position 1 and the second time in the position 2. The same is true for the switch SW2. This creates several combinations, but you can always use one or the other switch to turn the light bulb on or off. The bulb is on in the cases a) and c), off in the cases b) and d). Obviously, you need two switches for this experiment. Make the second one from the strips as shown in the picture.



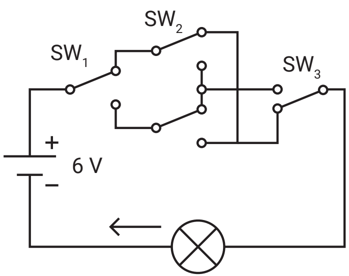


II. ELECTRICITY

Photographs of the assemblies are shown on pp. 53–56.

20. FOUR-WAY SWITCH CONTROLLED FROM THREE LOCATIONS

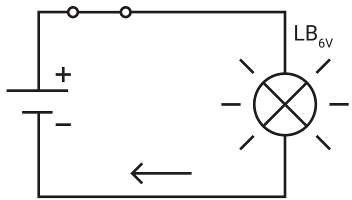
In practice, switching from two locations is often not enough. There are cases when you need to switch an appliance (a load) on or off from more than one place. This problem can be solved with a double, **four-way switch**. If you connect such a switch between two three-way switches, you can control the light from three locations. To control it from even more places, you can connect the necessary number of four-way switches to the circuit. The number is not limited. You just need to solve the technical problems. You can build a four-way switch using the 6V parts of the construction set as shown in the picture.

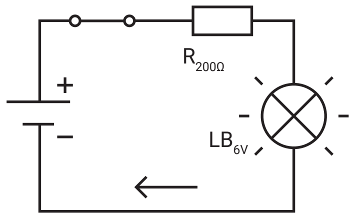


21. ELECTRICAL RESISTANCE

Materials are divided into **conductors** and **insulators**. Conductors conduct electric current. Each conductor puts some resistance to electric current. If you have two wires of the same length made of the same material but of different cross-sections, the thicker one conducts the current better – it has lower resistance. It is the other way round with the length. The longer the wire, the greater the resistance. However, if two wires have the same length and cross-section and each is made of a different material, then each has a different resistance. Good conductors of current include metals, especially silver, copper, gold and aluminium. The most commonly used conductors among them are copper and aluminium. For specific purposes (e.g. cooker, iron, electric-oven heating), it is necessary to use special alloys with high resistance. In practice, we need not only to have good conductors, but also, for example, to connect two places by a high-resistance conductor. For this, we cannot use ordinary conductors, because these would have to be many kilometres long. Therefore, we utilise components called resistors. To measure the magnitude of resistance, we are introducing the unit of 1 Ω (**ohm**).

The construction set includes one such resistor with a value of 430 Ω. Build a simple circuit with a light bulb. Then connect the resistor from the set into the circuit between the light bulb and the power supply. Notice the different brightness of the bulb. The light bulb with the resistor glows less because the resistor offers more resistance to the passing current than the Merkur strip.





22. SERIES CIRCUIT

A **series circuit** is the basic circuit in electronics, in which several loads (resistors, light bulbs, etc.) are connected in series. *The electric current has the same value at all points in the circuit; the sum of the voltages across all components is equal to the voltage of the power supply.* This means that, for example, a 12V power supply can power two identical 6V light bulbs connected in series. The voltage across each bulb is then half the voltage of the battery.

Build a circuit with two identical 6V light bulbs in series and a voltage source set to 6V. Now try to connect only one 6V bulb to the circuit with the voltage source set to 6V. Do not leave a light bulb connected to a higher voltage than the rated voltage on for a long time because the filament of the bulb may burn out. Compare the brightness of the bulbs. A single bulb glows more brightly than bulbs in series. You know that a bulb connected to a higher-than-rated voltage glows more brightly. This implies that the voltage across each bulb connected in series is lower than the voltage across a single bulb. If you had

Photographs of the assemblies are shown on pp. 53–56.

a voltmeter and an ammeter, you could measure the exact values of the voltage and current in the given circuit and verify this claim.

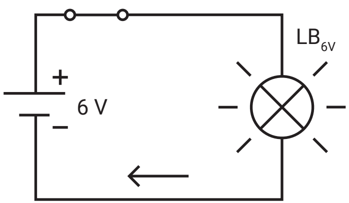
If one of the bulbs in a series circuit burns out, the other bulbs stop working too. The circuit is broken – no current flows through it.

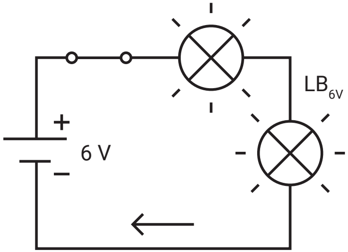
In practice, this circuit is used, for example, in Christmas-tree lights. Although the light bulbs are only 12V, they can be connected to the voltage of 230 V. How many bulbs must be connected in series so that they are not damaged?

Note: The following formula applies to a series circuit:

$R = R_1 + R_2 + ... + R_n$,

where R is the total load resistance and R_i are the individual load resistances i = 1, 2,... n.

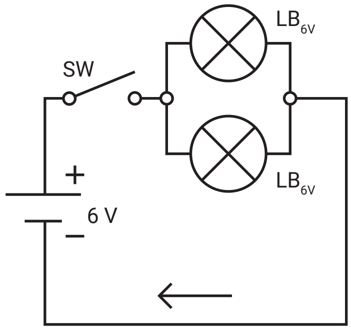




23. PARALLEL CIRCUIT

A parallel circuit is another basic circuit in electronics, in which several loads (resistors, light bulbs, etc.) are connected in parallel, on separate branches. The magnitude of the electric current in each branch depends on the resistance of the components in that branch. *The total current in the circuit is given by the sum of the currents in each branch. The voltage is the same across all components in the circuit.* Parallel bulb circuits are used for lights, for example in our homes. When you turn on all the lights in all rooms, the light bulbs will *glow as brightly* as when only one bulb is lit. However, more current will flow through the circuit, being the sum of the currents in the individual branches.

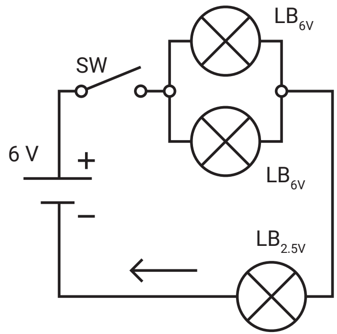
With the voltage source set to 6 V, build a circuit with two 6V light bulbs in parallel. Now try to connect only one 6V bulb to this circuit with the 6V voltage source. When you compare the brightness of the light bulbs, you can see that it is the same in both cases. The voltage is thus the same in each branch.



24. SERIES AND PARALLEL CIRCUITS

Now compare the brightness of the light bulbs in series and in parallel. When connected in series, the bulbs become dimmer than when connected in parallel. An example of a series circuit is a string of Christmas-tree lights. When one bulb burns out, the entire string goes dark because the electrical circuit is broken. An example of a parallel circuit is a household electrical system, where you can close the circuit (turn on a light bulb) in any branch.

If you turn on the lights in all the rooms at once, you can see that they all shine with full brightness, like when one bulb is lit. There is more current flowing through the whole circuit than in the individual branches. However, you can also build combined circuits with multiple bulbs. An example of a combined circuit is shown in the diagram. If you want to build even more complex circuits, you have to buy more bulbs.



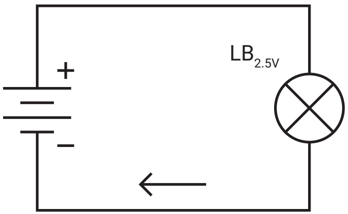
Photographs of the assemblies are shown on pp. 53–56.

II. ELECTRICITY

25. SERIES CONNECTION OF POWER SUPPLIES

The circuit can be powered by a 1.5V battery, which can light only small, low-voltage (e.g. 2.5V) bulbs. The bulb from the construction set will glow very dimly. *To increase the voltage, you can connect batteries in series*, i.e. connect the positive pole of one battery to the negative pole of another. The result will be a higher voltage equal to the sum of the voltages across each of them. This will create a flat battery, consisting of three small 1.5V batteries and thus having a voltage of 4.5 V.

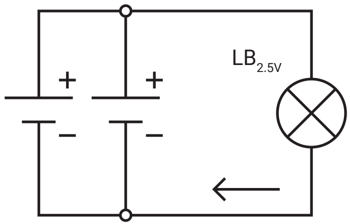
In practice, this connection is very common, e.g. in calculators, cameras, etc.



26. PARALLEL CONNECTION OF POWER SUPPLIES

The question is what happens when you connect the 1.5V batteries in **parallel** by connecting the positive pole of one battery to the positive pole of another and the negative pole of one to the negative pole of the other. When you connect a light bulb to this source, consisting of two or more batteries, you can see that the light bulb glows with the same brightness as when connected to a single battery. This means that the voltage is the same in all cases, namely 1.5 V. Again, use the 2.5V light bulb from the construction set. When you utilise the same sources, the bulb remains on longer.

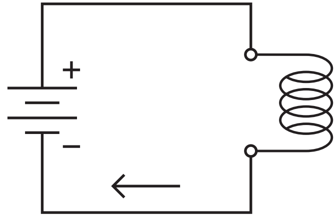
Unlike the series connection of power supplies, the parallel connection is little used in practice – it has no particular application.



27. ELECTRICITY AS A SOURCE OF HEAT

As already mentioned in the text about the incandescent light bulb, light emission is accompanied by **heat** formation. The heat generated by the passage of an electric current is called the **Joule heat**. It depends on the resistance of the conductor. In order to generate a large amount of heat, for example in a cooker, the heating coils have to be made of a material that has a high resistance to the passage of electric current. In other cases, e.g. in light bulbs, in electric-power lines, etc., this effect is undesirable. In a conventional incandescent light bulb, more than 90% of electrical energy is converted to heat, the rest is converted to light energy. The law of conservation of total energy applies, which means that energy can be converted from one form to another, but it cannot be created or destroyed.

The construction set contains a small spiral of resistance wire (No. 1294). Connect it into the circuit as shown in the diagram. When you close the circuit, you can notice that the spiral heats up considerably. As a source of current, you can use two 1.5V batteries connected in series. *Be careful not to burn yourself!*

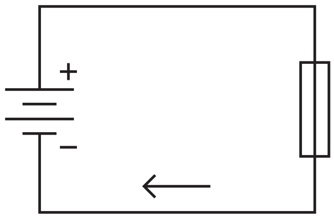


28. FUSE

An **electrical short circuit** occurs when the positive and negative poles of a DC power source come into direct contact. In the case of an AC power source, a short circuit is caused by direct contact between the phase and PEN conductors. During a short circuit, a large amount of current flows through the conductor, causing it to *heat up* and subsequently to *burn out*. If a thin wire is connected to the circuit, it heats up much more rapidly and burns out first. This is the principle of a **fuse**.

Take a very thin wire from the construction set. Use this wire to connect the positive and negative poles of the flat battery. You can see that this wire has been burned out.

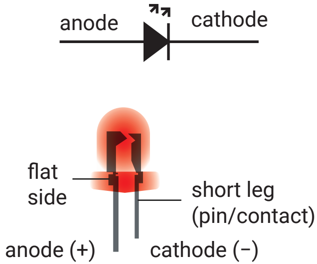
In homes, fuses are made for a certain current, e.g. 6 A, 10 A, etc. When this current is significantly exceeded, the fuse blows. The current can be exceeded in the case of a short circuit or when several appliances (loads) are connected at the same time. When a short circuit occurs, the current flowing through the circuit is so great that it blows every fuse. Nowadays, fuses are replaced by circuit breakers. However, the principle of the circuit breaker is based on a different physical process, which is discussed below.



29. LED IN THE FORWARD DIRECTION

A **light-emitting diode (LED)** is a semiconductor device with a p–n junction that emits visible light when an electric current passes through it. It thus works on an entirely different principle than an incandescent light bulb. A LED was formerly used mainly as an indicator light.

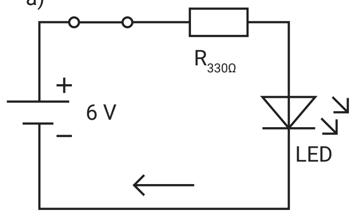
Build a LED circuit as shown in the diagram in Figure a. When you close the circuit (switch it on), current flows from the positive pole of the power supply through the switch, resistor and LED back to the power supply. The LED lights up. To limit the current flowing through the circuit, include a resistor with such a resistance that the current flowing through the circuit (LED) does not exceed 20 mA, which is the maximum allowable current through the LED. The LED in the circuit behaves like a conventional semiconductor diode. Current can only pass through it in one direction if you connect the cathode to the negative pole and the anode to the positive pole of the power supply.



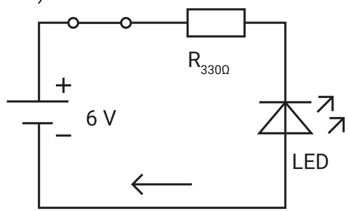
30. LED IN THE REVERSE DIRECTION

In the previous experiment, the LED was connected in the forward direction. Now try to connect the LED in the opposite way – the reverse direction (Figure b). However, when you close the circuit, no current flows through it. The LED does not light up. Its p–n semiconductor junction is polarised in the reverse direction. This is how a LED differs from a conventional light bulb.

a)



b)



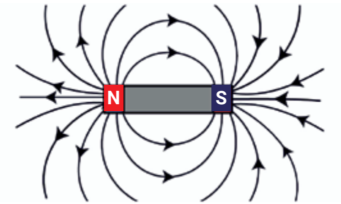
III. MAGNETISM

III. MAGNETISM

You have undoubtedly seen magnets or heard something about them. The effects of magnets were known long ago, but the essence of magnetism was not explained until much later. Magnetism is related to the structure of matter, especially the orbiting of electrons.

What exactly is a magnet? At first glance, it is a piece of iron, but it can do strange things – it attracts iron objects to itself while not interacting with some others at all. The construction set contains two types of magnet: two small round magnets, made of ferrite (a mixture of various iron oxides), and one large blue horseshoe magnet, made of steel.

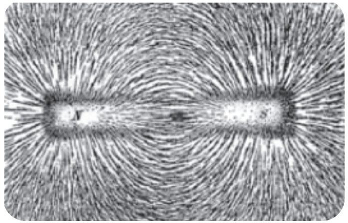
A magnet has **two poles – a north pole (N) and a south pole (S)**. The north pole is marked with red.



31. THE MAGNETIC FIELD AROUND A MAGNET

Every magnet has a **magnetic field** around it. It is referred to as a vortex or closed-loop field and can be represented by **magnetic field lines**. Take the bag of iron filings from the construction set and a clean white sheet of paper. Place the horseshoe magnet under this paper and lightly sprinkle the iron filings over it. Observe the arrangement of the iron filings. They align with the magnetic field lines and form a picture. Notice the distinct patterns created by the different magnets of various shapes, e.g. round, bar or horseshoe magnets.

The biggest magnet is the Earth. The north magnetic pole is located near the Geographic South Pole and vice versa – the south magnetic pole is located near the Geographic North Pole. To make things even more complicated, it has been observed that the position of the Earth's magnetic poles is not constant but shows an appreciable change. Several million years ago, the magnetic poles were even exactly the opposite. This means that there is a magnetic field around the Earth as well. Can we take advantage of the Earth's magnetic properties? Yes, the Chinese realised this about 2,000 years ago. This is discussed below.



32. MAGNETISATION

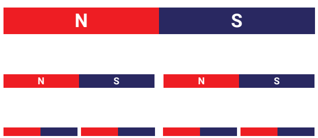
Most materials can be classified as diamagnetic, paramagnetic or ferromagnetic. **Diamagnetic materials**, such as gold and copper, *slightly weaken* the magnetic field of a magnet. No change is observed in the proximity of the magnet. **Paramagnetic materials**, such as aluminium, sodium, etc., on the other hand, *slightly intensify* the magnetic field. However, this change is too small to be observable when you approach the magnet. **Ferromagnetic materials**, such as iron, cobalt or nickel, *significantly increase* the magnetic-field strength.

If an object made of a ferromagnetic material is placed in a magnetic field, it becomes a magnet. If it is slightly magnetised when removed from the magnetic field, it is made of a **magnetically soft material**; otherwise, it is made of a **magnetically hard material** – it becomes a *permanent magnet*. You can test this by comparing e.g. a knitting needle, a screwdriver, a nail, a piece of common wire, a bolt, etc. Can you tell which objects are made of magnetically hard materials? If you magnetise a steel object, you will notice that objects made of magnetically hard materials retain their property permanently – they are magnetic. This property is sometimes useful. For example, a magnetised screwdriver can be utilised to tighten or screw a steel screw or bolt in an inaccessible place.

III. MAGNETISM

33. MAGNET CANNOT BE DESTROYED

Ask your mum for a steel knitting needle and magnetise it. Place it in the iron filings. You can see a spot in the middle of the magnet that does not attract the iron filings at all. Mark this spot with a marker. Now take this needle, put it in a vice and cut it with pliers at the exact spot marked. Well done! Now you have two magnets attracted at only one end. Nevertheless, the assumption needs to be verified. A theory that disagrees with observation is useless. Place both halves in the iron filings. What has happened? Each half of the needle behaves like the original needle – it attracts at both ends. It is obvious – we have already said that there are always two poles in a magnet. Now you can repeat the experiment with a half of a half of the needle and then again with its half. Each time, you will come to the same conclusion – *a magnet always has two poles.*



34. AND YET IT IS NOT INDESTRUCTIBLE

You have learnt that a magnetised object made of magnetically hard steel retains its magnetic properties permanently. What can you do with it if you do not want it to be a magnet anymore?

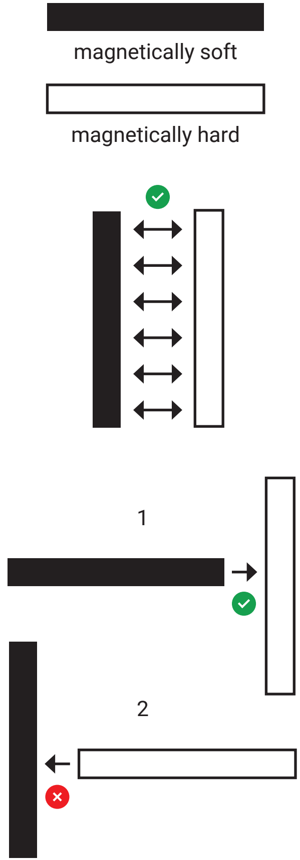
It is not completely indestructible. Place a magnetised needle or other object on a hot stove or cooker plate. The object becomes red-hot. After you let it cool, you can notice that it has lost its magnetic properties. However, do not try this on your own, only with your parents, because there is a risk of burns.

The temperature at which a magnet loses its magnetic properties is called the **Curie temperature**. The same happens if you hit a magnetised needle on an anvil with a heavy hammer. Soon it will lose its magnetic properties as well.

35. HOW TO RECOGNISE A MAGNET

The construction set contains two identical rods with a diameter of about 4 mm and a length of 50 mm. One is made of a magnetically hard material (No. 1319) and the other of a magnetically soft material (No. 2060). Magnetise both rods. The rod made of a magnetically hard material becomes a magnet. The magnetic properties of the other rod disappear after a while.

Imagine you are in a room where there is no metal or magnetic object and you are to determine which of the rods is a magnet. How to solve this puzzle? The solution is simple. If you put the rods parallel to each other, they are attracted to each other. Nevertheless, you still do not know which one has attracted the other. Therefore, place one rod perpendicular to the middle of the other. If the rods start to attract each other, you have the case 1 If they do not attract each other, you have the case 2 (see the figures). The experiment is based on the fact that there is a spot in the middle of the magnet that does not attract steel objects.

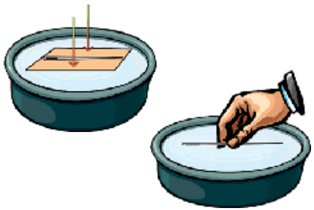


III. MAGNETISM

36. FLOATING NEEDLE

What is heavier? The same volume of water or iron? Everyone knows that an iron object immersed in water sinks to the bottom. **Archimedes' principle**, which applies here, states that any object, totally or partially immersed in a fluid or liquid, is buoyed up by a force equal to the weight of the fluid displaced by the object. Even though iron is being buoyed up, its weight is greater, as a result of which the iron sinks to the bottom.

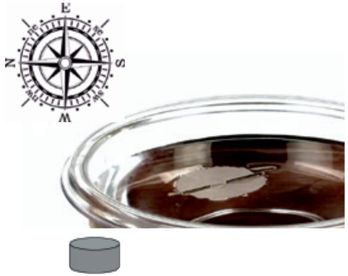
Try something that seems impossible. Place a piece of fine paper on the surface of water in a container and carefully lay a preferably slightly greasy sewing needle on the piece of paper. After a while, the paper soaks up the water and sinks, but the needle, strangely enough, stays afloat. With a little practice, you can manage to place the needle on the water surface without the paper, just between your fingers. Similarly, you can place a razor blade (component No. 1315) on the surface. So why does iron float on water although it is heavier than water? Because the needle is kept afloat by the **surface tension** of water. If you look at the floating needle with a magnifying glass, you can see that the water has created a depression under it – the water surface behaves like a thin elastic membrane. The needle is now very mobile and can be used for various interesting experiments.



37. FLOATING-NEEDLE COMPASS

Now magnetise the sewing needle first and then place it on the water surface. You can use this needle for many experiments. When it is magnetised, it assumes the same position every time. So where does the needle turn? You have probably guessed that it has something to do with the Earth's *magnetic field*. Yes, the needle always takes the north–south position. You have made a primitive **compass**, which shows you the north and south.

But beware! The needle reacts to any presence of a magnet, and even iron. When you bring a magnet closer to the water container from any direction, the needle immediately changes its position and moves towards the magnet. This is because the magnetic field of this magnet is greater in this location than that of the Earth, as a result of which the needle reacts to the new situation.



38. REAL COMPASS

The construction set contains a *magnetic needle* with a brass cap in the middle for mounting on a pivot. First check that the magnetic needle is sufficiently magnetised. If not, magnetise it properly. Screw a steel cylinder onto the perforated plastic base plate and screw the steel pivot into it. Pierce the compass rose with the pivot and mount the magnetised needle on it. After a while, the magnetic needle will show you the Geographical North Pole. Now turn the compass rose so that the red colour of the needle overlaps with the north (N) on the compass rose. You probably know approximately where the North Pole is. If you have magnetised the needle in the opposite direction, remagnetise it. Afterwards, you can use the compass rose to determine all the cardinal directions. When you place such a compass on a map, you can use it for outdoor navigation.

III. MAGNETISM

39. CONFUSED COMPASS

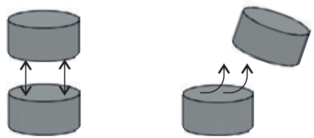
Bring an iron object close to the compass. The magnetic needle will turn towards the iron object. So where is the north? Obviously, the Geographical North Pole should remain in the same place. Is the compass thus pointing in the wrong direction? You know that the needle always turns towards the magnet in the direction of the magnetic field lines. Then why has the needle turned towards the iron? It is because the iron object intensifies the Earth's magnetic field and becomes a weak magnet. The needle reacts to the stronger magnetic field in its vicinity and turns. When you use a compass, you must be well away from iron objects.

This knowledge can be used and abused in various ways, like in Jules Verne's novel *Dick Sand. A Captain at Fifteen*, where an evil sailor deceives the young captain by placing a piece of iron under the ship's compass.

40. MAGICAL MAGNETS

In the box, find two small grey discs stuck together. These are two strong permanent magnets, with which you can repeat all the experiments you did before with the horseshoe magnet. Separate the discs from each other and flip one over. If you then try to place them on top of each other in this new position, you will feel a strong resistance, as if an invisible hand were pushing the disc away. Nevertheless, press them very firmly together and hold them between two fingers. Release the top disc in front of your friends. It will fly upwards. If you then hand the discs to someone as they were originally stuck together, no one will be able to repeat your experiment.

You can probably already guess the principle of this experiment. Of course – *the same poles repel each other and the opposite poles attract each other*. This magnet has no markings to indicate its poles. You will have to find that out for yourself, e.g. with a compass. You can see that even if you have two magnets alone, you cannot tell which pole is north and which is south. It is like with electric charge. You also cannot tell which is positive and which is negative.



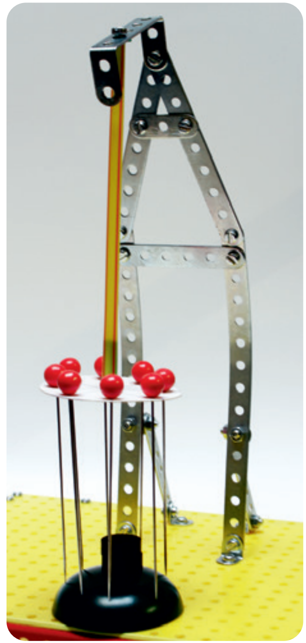
41. DISLIKE FOR EACH OTHER

So far, it has seemed that magnets attract any iron or steel object. However, an experiment with needles will show you that this is not entirely true. If you play with a pile of needles, especially if you magnetise several of them thoroughly, you will notice that some of the needles are repelled by the magnet.

After a few such experiments, you will figure it out. A needle, when magnetised, also becomes a magnet. It is made of magnetically hard steel. And you already know that *the opposite poles of two magnets attract each other*, i.e. the north pole attracts the south pole and vice versa – north repels north and south repels south. Yes, the principle of this experiment is the same as in the previous one.

42. MAGNETOSCOPE

Based on your experience from previous experiments, make a very simple device that can indicate a magnetic field. Construct a stand as shown in the picture.



III. MAGNETISM

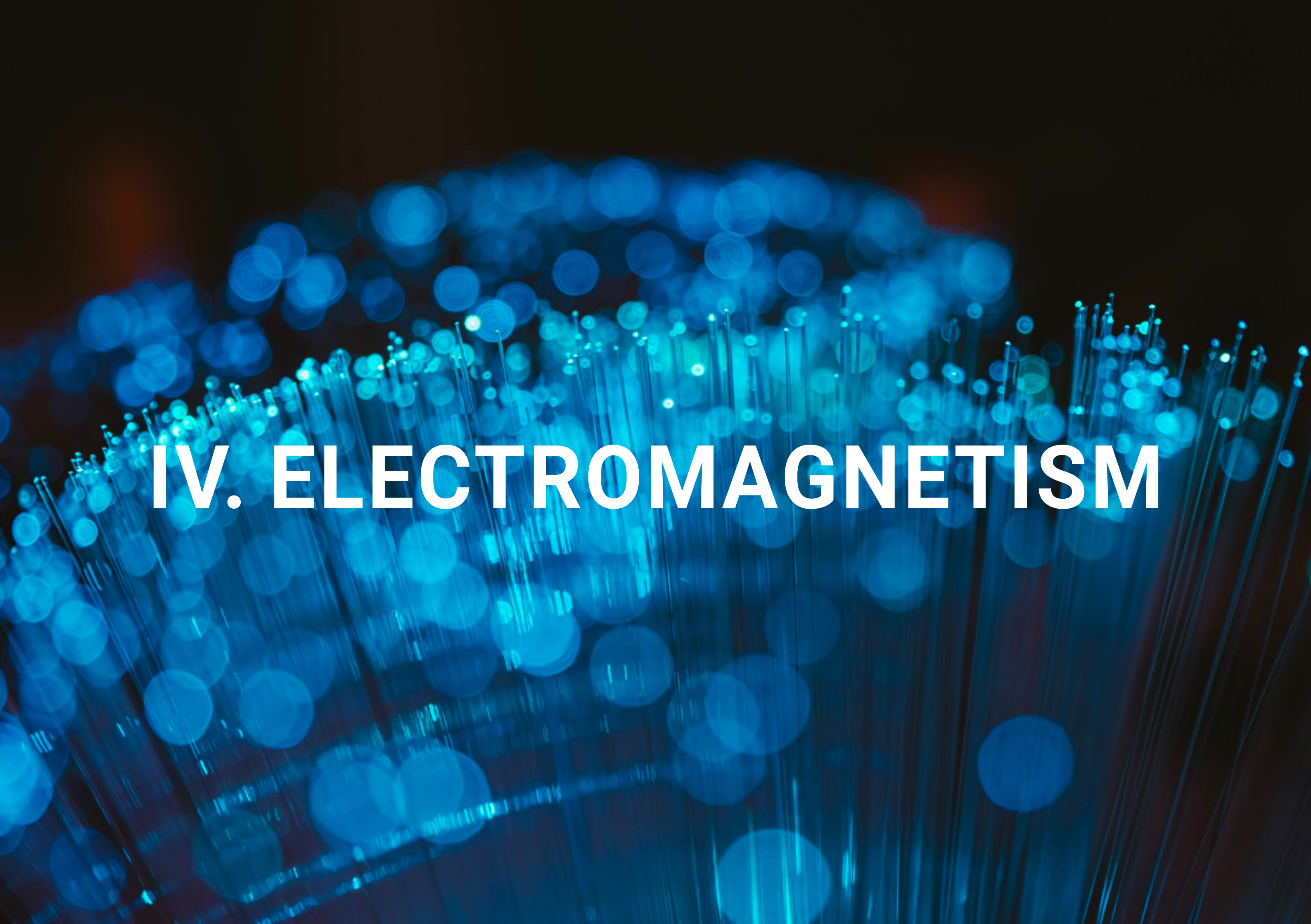
Cut a circle with a diameter of about 15 mm from cardstock or cardboard paper and prepare some long pins with large heads. Stick the pins into the disc, placing them at regular intervals along the circumference of the disc. Glue the disc to the unsharpened end of a pencil or to a wooden stick. You have made a **magnetoscope**. When you bring a magnet up to it from underneath, the tips of the pins will start to repel each other, because the pins have been magnetised in the same direction. The pin tips will remain spread apart even if you move the magnet away. The reason for this is that they are made of magnetically hard steel. Alternatively, you could also use, for example, needles.

43. MYSTERIOUS KEY HOLDER

You can use a **magnet** for various experiments. It makes it easier to find small iron objects etc. It would be hard to pick up scattered nails from the ground. With a magnet, however, you can do it easily. Just bring the magnet closer and the metal objects will jump onto it.

You can also use a magnet to make a hookless key holder. Construct a stand according to the picture and attach a magnet to the back. Cover the front of the stand with paper so that no one can see what is behind it. Now just take an iron object – it will stick to the key holder. Note: The key holder cannot be used for brass keys, because they are not attracted by the magnet.

IV. ELECTROMAGNETISM



IV. ELECTROMAGNETISM

Photographs of the assemblies are shown on pp. 53–56.

You are already familiar with electric current, voltage and magnetic field. These phenomena have been known since ancient times. However, it was not until 1820 that the relationship between magnetism and electric current was discovered. In that year, the Danish physicist H. C. Oersted noticed that a magnetic compass needle brought near a current-carrying wire was deflected when an electric current passed through the wire. The French physicist A. M. Ampère became acquainted with the experiment and began to study these phenomena in detail.

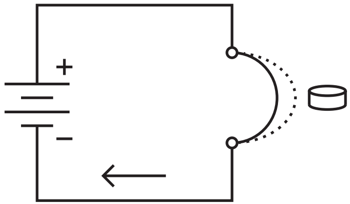
When two long straight wires are set parallel to each other, then it is important whether they carry currents in the same or opposite direction. In the first case, they attract each other; in the second, they repel each other. The direction of the magnetic field around a current-carrying wire is determined by the current flow. If the wires are not charged, they cannot interact electrically with each other.

Experiment shows that two wires with currents flowing in the same direction really attract each other, namely with such a force that can propel vehicles or lift heavy loads. *These experiments have proved the existence of a magnetic field around current-carrying wires.*

44. RESTLESS WIRE

According to the picture, make a simple structure. Hang a thin copper wire on it so that it can move freely (like a simple swing). Bring a permanent magnet close to the wire. Of course, nothing will happen. The magnet does not attract copper objects.

Now let electric current flow through the circuit. Suddenly, the wire slightly moves either towards or away from the magnet. How is this possible? The explanation is simple. A current-carrying wire is surrounded by an **electromagnetic field**, which is similar to the magnetic field around a permanent magnet. And you already know that two magnets can either attract or repel each other depending on their position. A current-carrying wire thus behaves like a small magnet.



45. CIRCUIT WITH AN INDUCTOR

As you already know, a current-carrying wire is surrounded by an **electromagnetic field**. When you wind the wire into a **coil** with several turns, this magnetic field increases. A long cylindrical coil of many tightly wound turns is called a **solenoid**. By inserting a steel core into the coil, you create an **electromagnet**, generating a much stronger magnetic field. This can be demonstrated by an experiment.

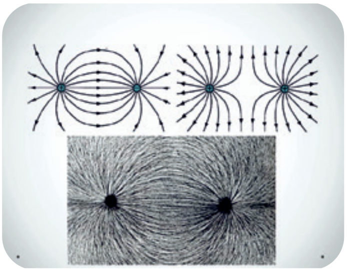
Build a simple electrical circuit as shown in the diagram. Connect the induction coil next to the switch. When you close the circuit, the current flowing through the inductor heats it. Do not leave the coil on for a long time; otherwise, it would become very hot and the battery would soon run down. Another interesting finding is that the coil begins to behave like a magnet. It starts to attract objects made of steel, e.g. a nail, a screwdriver, etc. The strength of the magnet can be enhanced by inserting a steel core (a small steel cylinder) into the coil. This greatly increases the attractive force acting on the steel objects. *You have thus made an electromagnet. With a direct current passing through it, it has the same properties as a permanent magnet*. When the current is switched off, the electromagnet stops attracting iron objects.

46. MAGNETIC FIELD LINES AROUND A COIL

This experiment verifies whether a **coil** through which a direct current flows really behaves like a permanent magnet. You already know that every magnet is surrounded by a magnetic field and that it must be a closed-loop (vortex) field. Of course, magnetic, electric or gravitational fields are invisible. Nevertheless, this does not matter – like in the previous cases, you can simply represent the field structure by means of iron filings.

IV. ELECTROMAGNETISM

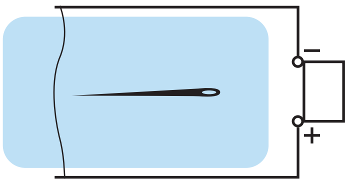
Build a circuit with an inductor like in the previous experiment. Place a sheet of white paper over the coil and keep it in a horizontal position. There is no current flowing through the circuit yet. Take the iron filings and sprinkle them lightly over the paper above the coil. Now close the circuit (switch in on). With the current flowing through the inductor, the iron filings align with the magnetic field lines. Alternatively, the circuit can be closed from the beginning. Notice how the iron filings fall as you lightly sprinkle them. What happens if you reverse the polarity of the power supply? The same as if you flipped a magnet.



47. MAGNETISED NEEDLE AND WIRE

Magnetise a sewing needle with a permanent magnet or electromagnet. Test whether it is magnetised enough by moving it closer to another needle. If they attract each other, the first needle is magnetised.

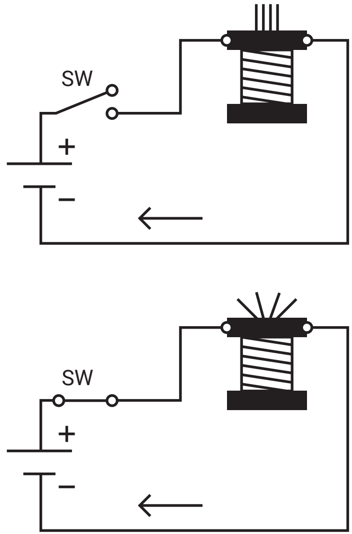
In the magnetic experiments, you learnt to place a needle on the water surface without it sinking. Fill a vessel with water to the brim. Place the needle on the water surface and stretch a wire just above the needle. Apply an electric current to this wire. The needle suddenly jerks and begins to assume a different position, perpendicular to the direction of the current. Notice where the tip or eye of the needle turns in relation to the wire. Now reverse the polarity of the power supply. The needle turns to the opposite side.



48. WHY ARE THE NEEDLES FLYING APART?

Connect the coil into the circuit in a vertical position. Insert several needles into it. Now close the circuit (switch in on). The needles start to repel each other. They bounce apart and spread out around the perimeter of the hole so that they are as far apart as possible. Why does this happen? The explanation is simple. The needles have been magnetised by the electric current passing through the coil. Having DC poles at the top and bottom, they repel each other and try to position themselves as far apart as possible.

Now open (interrupt) the circuit. The needles continue to repel each other and remain as far apart as possible, even with no magnetic field induced by the coil. This can be explained by the fact that the needles are made of a magnetically hard material. If you used small nails made of soft iron, they would stop repelling each other when the circuit is broken (open) and become disordered again.



Photographs of the assemblies are shown on pp. 53–56.

IV. ELECTROMAGNETISM

49. MAGNETISING WITHOUT MAGNETS

Magnetic experiments have shown you that steel objects (made of a magnetically hard material) can be **magnetised** by rubbing with a permanent magnet. You can then, for example, use a screwdriver to retrieve a pin, screw or bolt from an inaccessible place.

Since a coil through which a direct current flows behaves like a permanent magnet, you can also magnetise a steel object with an electromagnet. Insert the object to be magnetised into the coil. Pass current through the coil. After a while, the object is magnetised. Of course, the object must be made of magnetically hard steel.

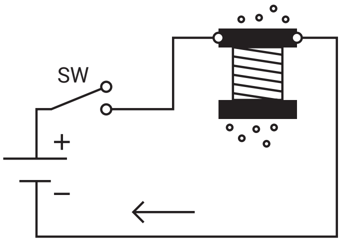
Actually, the title is somewhat misleading. The magnetisation is performed without a classical permanent magnet, but even an electromagnet is a magnet.

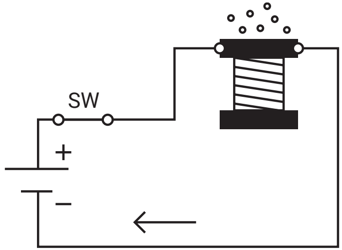
50. IRON FILINGS CANNOT FALL THROUGH

Build a simple structure for the coil about 100 mm above the ground. Place the coil there, connect it into a circuit with a switch and a voltage source and let the current flow through it. Place a bowl under the coil. Gradually insert objects of various materials (e.g. safety matches, pieces of paper, graphite lead refills, pins, iron filings) into the vertical hole of the coil and observe what happens.

The objects made of steel do not fall through the coil, whereas other (non-magnetic) materials fall into the bowl. You can try mixing, for example, iron filings with sand. Then drop a pinch of this mixture through the coil. The sand falls through, the sawdust does not. You have made a simple separator of different materials.

A strong magnetic field is created in the coil, as a result of which steel objects (nails, pellets or nuggets – component No. 1311, pins) do not fall through, but a brass screw or bolt does, because the magnet does not act on brass objects. Brass is an alloy of copper and zinc, which are not ferromagnetic.

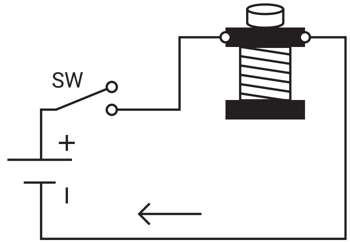


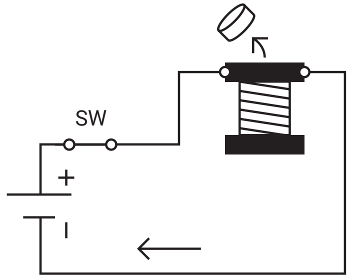


51. LONG JUMP

Previous experiments have shown you that a permanent magnet is surrounded by a magnetic field. You also know that there is a magnetic field around a coil through which an electric current passes. The coil is a magnet as well. Each magnet has two poles – north and south. Examine the interaction of a permanent magnet with an electromagnet.

Place a permanent magnet on the coil and let a direct current from a battery or a power supply flow through the coil. The permanent magnet quickly bounces off the field or it is attracted by an even greater force. This depends on whether the poles of the coil and the permanent magnet are the same or opposite. Try to change the polarity of the coil by reversing the polarity of the power supply (+ to – and vice versa). What happens? The magnet sticks to the coil and is hard to pull off.





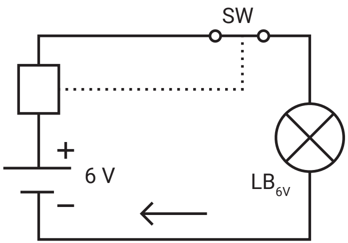
IV. ELECTROMAGNETISM

Photographs of the assemblies are shown on pp. 53–56.

52. MAGNETIC TRIP UNIT

Our first application concerns security. A **magnetic trip unit** can be encountered frequently, because it is part of the circuit breaker, where it provides protection against a short circuit. Another component of the circuit breaker, a bimetallic strip, ensures protection against overload. If there is a short circuit, the magnetic trip unit quickly breaks the electrical circuit. In our case, it has to be put back in manually after the cause of the short circuit has been removed.

Set up the experiment as shown in the figure. Now use the universal switch to open the circuit. This switch is operated by an electromagnet. The electromagnet is connected in series with the load (light bulb). If the load suddenly short-circuits, the large current flowing through the circuit induces such a strong magnetic field in the electromagnet that pulls the core into the coil. Since the core is connected to the strip of the switch, the switch opens and the circuit breaks. To restore the function, you must pull the core back out and set the switch to the ON state (close the circuit).



53. ELECTROMAGNETIC CRANE

According to the picture, construct a simple crane. Hang the coil with the core (electromagnet) on a string suspended from the crane boom. When you pass an electric current through the coil, the coil starts to attract iron objects. When the current is interrupted, the iron objects fall off the coil. You have constructed a model of an electromagnetic crane, which is used to load, for example, scrap iron, but also other iron objects. If you want to build a larger crane, you can use parts from other Merkur construction sets.

54. RAILWAY BARRIERS

According to the picture, construct a model of railway barriers controlled by an electromagnet. When current flows through the inductor, the metal core is pulled into the coil and the barrier is raised. When the current is interrupted, the barrier falls again. In a similar way, you can make a railway semaphore signal for a model railway. You can increase the effect if a light bulb is switched on when the signal arm is raised.

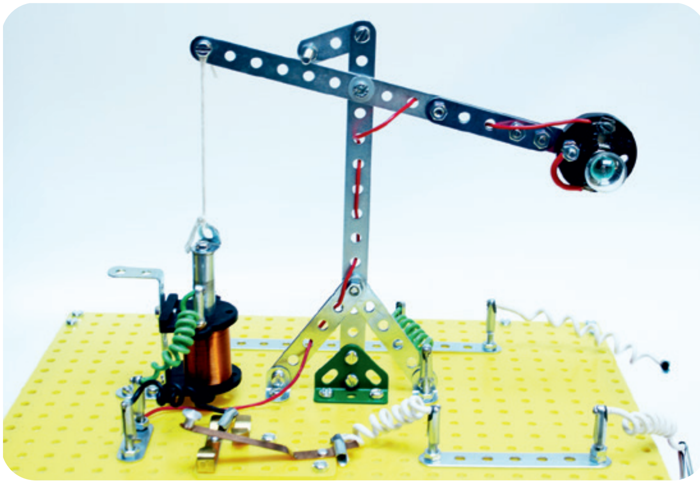
When constructing the railway-barrier and railway-semaphore-signal models, you must balance the arms so that only a little force is needed to lift the arm and the coil can thus pull the core with a force capable of lifting the arm.

IV. ELECTROMAGNETISM

55. RAILWAY SEMAPHORE SIGNAL

You have already constructed railway barriers. Now build a railway semaphore signal based on a similar principle. Make a simple semaphore according to the picture. When you pass an electric current through the inductor, the coil pulls the core inside, which then pulls the string attached to the shorter arm of the lever. This raises the longer arm, which allows the locomotive to pass. The lever must first be balanced so that it can move easily.

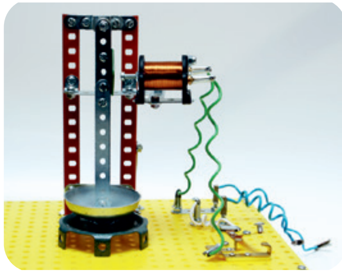
Remember that the movable arm contains a socket with a light bulb. The bulb can be powered from the same source as the coil or from another one. Do not connect the light bulb in series with the coil, because there is a risk of destroying the bulb when the circuit is switched off. When connecting wires to the light bulb, you can replace one of the wires with, for example, a construction of connected conductive strips.

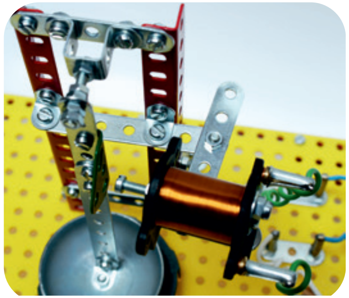


56. SWING

Construct a swing as shown in the picture. Attach the coil to the top of the structure and connect it and the switch to the electrical circuit. Once the circuit is closed, the electromagnet located at the top of the structure attracts the steel strip that has a bell cap attached to its end. The motion made by the cap is several times greater than the distance by which the electromagnetic coil has attracted the steel strip. The explanation is simple. It is actually a simple lever, where the distance from the fulcrum is directly proportional to the amount of deflection.

This swing is only one of many possible designs. Try to come up with other possible swing constructions from the pieces available in your construction set. It is important to remember that all of these pendulums and swings are based on the magnetic attraction of an electromagnet.





Photographs of the assemblies are shown on pp. 53–56.

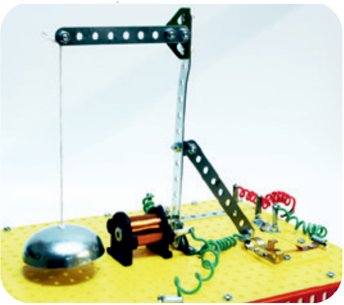
IV. ELECTROMAGNETISM

57. ELECTROMAGNETIC BELL

Build a simple structure with an electromagnetic coil as shown in the picture. Hang a bell cap about 15 mm away from the core of the coil. Pass an electric current through the inductor. The core of the coil pulls the suspended cap towards it. At this point, use the push button to interrupt the electric current. The cap tends to return to its original position, so it begins to oscillate. Repeat this periodically, switching the current off (opening the circuit) at the moment of impact and then switching it back on (closing the circuit). You have thus constructed a pendulum similar to the swing from the previous experiment. Every time the cap hits the core of the coil, you can hear a ding.

Large bells are set in motion by manipulating long ropes in the rhythm of the swinging bells. The force applied only for a certain amount of time to make the bells swing results in their ringing. You, however, are not going to pull a rope but to close and open the electrical circuit at a certain rate. Push the button repeatedly in the swinging rhythm. While swinging more and more, the bell will eventually strike the core of the electromagnet periodically and ring.

The phenomenon of applying a force to the pendulum with a frequency equal to the natural frequency of the pendulum is called resonance. It can be taken advantage of in many ways, but it often causes great problems – for instance, a small force can destroy bridges, houses, machines, etc. You also encounter **resonance** in electrical circuits, e.g. when tuning the radio, etc.



58. RELAY

A **relay** is an electrical component that allows one electrical circuit to control one or more other circuits by opening and closing its contacts. It is an electrically operated switch. Current flowing through a coil wound around a steel core generates a strong magnetic field, attracting the relay armature (a movable contact), which closes or opens the contacts to allow or interrupt the flow of electric current through a circuit.

According to the picture, construct a model of a relay, connecting an electromagnetic coil into one circuit. When the switch is in the ON state, the current flowing through the coil induces a strong magnetic field, which attracts the arm of the switch on the other circuit with a separate battery, where a light bulb is connected. When the first circuit is closed, the bulb is switched on.

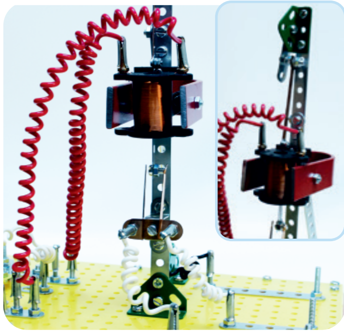
In practice, a small current applied to the relay closes another circuit with a much larger current, e.g. in water heaters, machine motors, etc.

59. POLARISED RELAY

Follow the picture to make a very responsive relay, which can be turned on even by a weak current and allows the flow of current in two directions. Connect the coil into the circuit in a vertical position.

A strip of non-magnetic iron, No. 1212, passes through the centre of the coil. It is attached to the bronze strip No. 1213 and has a brass bolt at the bottom end. The bolt is hanging in the middle between the two contacts. The bottom end of this strip is between the poles of the magnet. When a current passes through the coil, the iron becomes magnetised and, according to the direction of the current, it is pulled towards one or the other contact. This relay can thus be used to close as well as switch the circuit.

The relay is unusually responsive, but it is also sensitive, because it is difficult to maintain an ordinary iron strip in the centre when the current is not passing through. Therefore, you must adjust the magnetic field by moving the magnet to keep the connected strips in the zero position. The current here comes to the connected strips from above and leaves from below via one of the two contacts.



IV. ELECTROMAGNETISM

Photographs of the assemblies are shown on pp. 53–56.

60. WAGNER'S HAMMER

It is referred to as '**Wagner's hammer**', but it is not a hammer in the true sense of the word. It is a special circuit invented by J. P. Wagner from Frankfurt am Main in 1837.

The trick is that an electric current is conducted from a fixed terminal to a movable spring, which is attracted by an electromagnet. As soon as it is attracted, the current is interrupted and the spring returns to the terminal. This is the first experiment with this construction set where an electric current induces a continuous motion. But why is this experiment so interesting? On impact, the spring (in this case a Merkur strip) makes a sound. Since this impact is repeated many times a minute, you get a buzzer.

When connecting the circuit, you have to be patient with the adjustment of the oscillating strip. It needs to be tightened 'just right'. For this experiment, it is advisable to use a higher voltage – 9 V or 12 V. After the experiment, carefully check the contacts (spring, bolt). Notice how scorched they are. This is also one of the main disadvantages of mechanical switching.

61. BUZZER

The device described in the previous experiment is actually a **buzzer**, which you can use to give audible signals, telegraph from a distance and learn Morse code. For the learning, however, you need a louder sound that can be heard throughout the room. For tapping out the Morse code, connect a convenient telegraph key into the circuit. You can use the switch included in the construction set or make one according to instruction No. 16. To make the buzzer sound stronger and clearer, attach a metal or plastic box lid or something like that to the spring.

62. ELECTRIC BELL

In the construction of an electric bell, proceed from the previous experiment. Just bolt a bell cap to the end of the strip No. 1034 and make a clapper by attaching a larger bolt to the elongated oscillating lever. The bell is finished. The correct position of the spring and the appropriate length of the bolt require some construction skills. Nevertheless, you have already acquired these in previous experiments, so the bell will certainly ring properly when you press the button.

63. MORSE CODE

You have already built a buzzer. If you want to communicate with a friend, you can use **Morse code**. It is a character-encoding scheme that encodes text characters as standardised sequences of dots and dashes. For the communication, you must first learn all the letters. To make yourself understood, you must remember the respective letter and then quickly tap it out. Leave a longer space between letters.

a	• –	l	• – • •
b	– • • •	m	– –
c	– • – •	n	– •
d	– • •	o	– – –
e	•	p	• – – •
f	• • – •	q	– – • –
g	– – •	r	• – •
h	• • • •	s	• • •
i	• •	t	–
j	• – – –	u	• • –
k	– • –	v	• • • –

w	• – –	7	– – • • •
x	– • • –	8	– – – • •
y	– • – –	9	– – – – •
z	– – • •	0	– – – – –
1	• – – – –	.	• • • • • •
2	• • – – –	;	– • – • – •
3	• • • – –	,	• – • – • –
4	• • • • –	:	– – – • • •
5	• • • • •	?	• • – • •
6	– • • • •	!	– – • • – –

IV. ELECTROMAGNETISM

Photographs of the assemblies are shown on pp. 53–56.

64. TELEGRAPH

It is nice that you can communicate in Morse code using a buzzer, but if you were farther apart, you would not be able to hear anything. There is a device called a **telegraph**, which can be used to communicate in Morse code over long distances. There used to be a telegraph in every post office. It will take some effort and thought to build such a machine, but you can do it with the help of the picture shown.

The basic part is an inductor with a core. The coil attracts a lever, which has a piece of pencil inserted into its fourth hole. The telegraph paper roll is wound on a large wheel. If someone pushes a button at the transmitting station, an electric current passes through the coil and the electromagnet attracts the lever. The other end of the lever then presses the pencil against the paper and begins to write. The written paper is wound onto the crank, which must be turned steadily.

65. ELECTRIC WATCHDOG

Make a device that will monitor whether someone has opened the door and entered. Remove the two brass contacts from a dead flat battery (or you can use bronze motor contact brushes – No. 1275). Bend one of the strips twice at right angles as shown in the detailed picture. Screw or nail both strips according to the picture to the bottom of the door below the handle so that they touch and close the circuit when the door is open. Drive a nail into the threshold in such a way that when the door is closed, it touches the lower strip and prevents its contact with the upper strip. The circuit is interrupted and no current flows through it.

If someone opens the door, the strip is released and current starts to flow through the circuit. Of course, you must have some kind of indicator device connected in the circuit. It is best to use the electric bell that you have made or a light bulb. Such a device is usually installed at the top of the door, but the idea is the same. You can also install this security device at the top of the door, but the installation is slightly more complicated in the case of metal door frames.

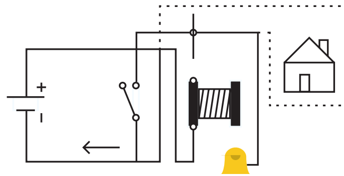
66. FIRE EMERGENCY

Storage areas of flammable materials and other rooms at risk of fire are equipped with high-temperature and direct-fire alarm systems. You are also going to build such a device. Fix two resilient strips over each other so that the top one presses against the bottom one. Then stretch a lightweight thread across the room above combustible items to make it pull away the springy contact element resting on the other contact. You can use, like in the previous experiment, the brass contacts from a dead flat battery or our universal switch. In this case, tie one end of the thread to the movable lever and fasten the other end firmly on the other side of the room so that when the thread is fully stretched, the lever is pressed against the bottom of the button. Remember that the lever must be positioned above the second contact. If you light a candle below the thread to simulate fire, the thread will burn, which will close the circuit. Again, you must have an electric bell or another indicating device connected in the circuit.

67. OUTWITTED BURGLAR

You have already built fire and burglar alarms. A burglar who wants to break into a house or flat, shop or storage area will certainly take a look around. Of course, he cannot miss the power lines. He will find a suitable spot and surreptitiously cut the wires, which will put the alarm system out of action. But do not give up! There is a defence against every attack.

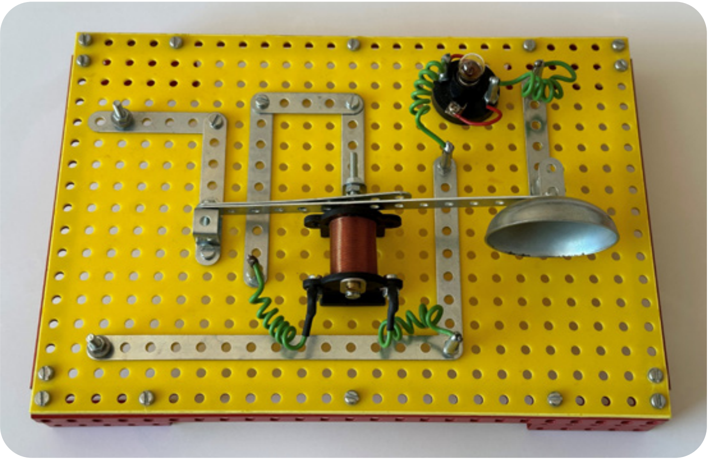
Modify the bell as shown in the picture so that it rings when someone cuts the wire and interrupts the flow of electric current. In the experiment, it is easy to do. Run another long wire to the bell from the battery directly to the coil without a breaker circuit. The coil now constantly attracts the armature and the bell cannot ring. If the burglar cuts the wire, thinking that he has disabled the alarm, the electromagnet activates the clapper and the bell rings. The burglar is caught.



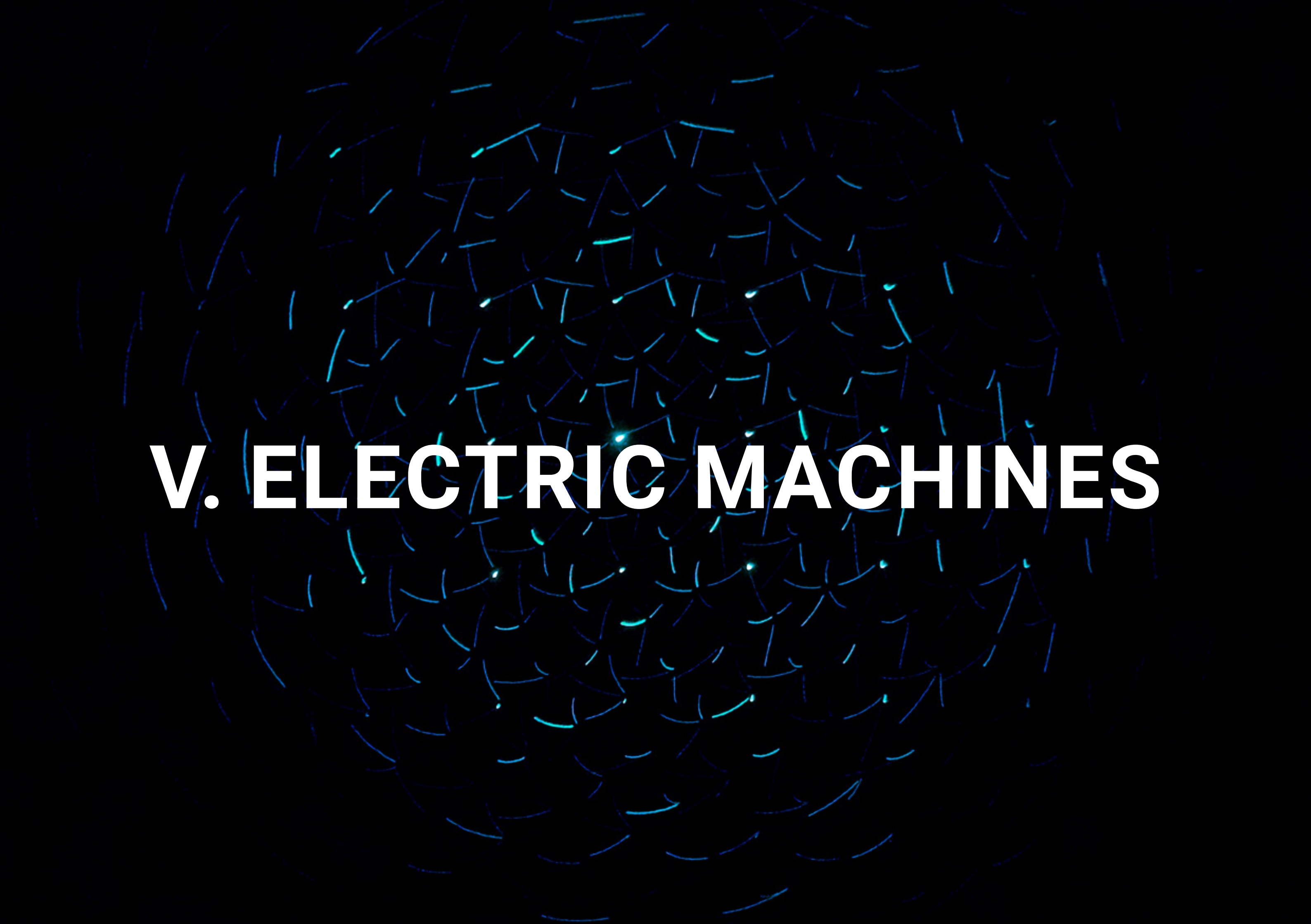
IV. ELECTROMAGNETISM

68. DIY FLASHER

Do you want to make a flasher from our construction set? Then go ahead! Like the previous experiments, also this one is based on Wagner's hammer. Extend the oscillating strip considerably so that is produces larger and longer oscillations. To increase the deflection of the strip, you can add a bell cap to the end of the lever. You can use a grub screw to adjust the flashing frequency as you wish. If you remove the bell cap and attach it next to the lever (like in the experiment No. 62), the flashing of the light bulb will be accompanied by the tinkling of the bell. Remember to connect a 6V light bulb, otherwise it may burn out. If that happens, the bell will keep ringing. Do you know why? The answer is simple. The light bulb is connected in parallel in the circuit.



V. ELECTRIC MACHINES



V. ELECTRIC MACHINES

Photographs of the assemblies are shown on pp. 53–56.

Electricity is mostly used to power electric machines. We can encounter them everywhere – for instance a food processor, an electric saw, a drill, a tram, etc. The main component of most electric machines is an electric motor. The principle of an electric motor is based on the interaction of two magnetic fields, at least one of which is created by an electric current.

You know from magnetic experiments that like poles repel each other and opposite poles attract each other. You also know that you can change the magnetic orientation of a coil by reversing the polarity of the power supply. For our experiment, you will need two magnets: one fixed in position and the other fixed nearby but free to rotate. The second magnet will turn the opposite pole towards the first magnet. If you change the polarity of the first magnet, the second will rotate again, and so on. This produces a turning motion. Obviously, the first magnet must be a coil. All you have to do is somehow make the magnetic field of the coil change. You do not necessarily have to change the polarity, just cut the power to the coil. The magnet will move by inertia. When you close the circuit again, the other end of the magnet will be attracted because it is closer to the core of the coil. And again, this produces a spinning motion. In the picture on page 44, you can see an actual motor.

69. ELECTRIC BRAKE

An electric brake consists of a non-magnetic metal disc (aluminium wheel) and an electromagnet (induction coil). The disc rotates in the magnetic field of the electromagnet. In this experiment, the non-magnetic disc is mounted on the shaft so that it rotates freely between the pole of the electromagnet and the iron adjusting ring, which represents the other pole.

Spin the disc by hand or with a string. It continues to spin freely for a long time. As soon as you pass an electric current through the coil, the disc quickly stops. According to the law of electromagnetic induction, electric eddy currents and thus also a magnetic field have been induced in the disc. The attractive force of the magnetic field stops the disc.

Some of us may still find a similar device at home in the transparent plastic case of an electricity meter, where the disc rotates between the poles of a permanent magnet. The magnet acts as an eddy-current brake controlling the speed of the disc so that the disc does not continue to rotate by inertia when electricity is no longer drawn. Because of their high efficiency, electric brakes are also used for braking trams, which is advantageous considering the weight of the trams. The higher the speed of the tram, the greater the braking effect.

70. SWING BRAKE

Now you are going to build a damped pendulum, whose motion is damped by a magnetic force like in the previous case. Build such a swing with a coil and a weight as shown in the picture. Set the swing in motion. All you have to do to damp the swing motion is to press a switch. As soon as the current starts flowing through the coil, the motion of the pendulum is damped. According to the law of electromagnetic induction, electric eddy currents and thus also a magnetic field have been induced in the bob like in the previous experiment. The attractive force of the magnetic field gradually brings the pendulum to a halt.

71. SIMPLE MOTOR

The construction of a simple motor will start an interesting series of experiments. First, notice how such a motor works. The large rotor with protruding armatures (component No. 1230) rotates freely above the electromagnet. When the current passes through the inductor, the magnet attracts the nearest armature. At this point, the rotor would stop rotating. However, there is a mechanism (components No. 1227 – six-tooth commutator, 1221 and 1222 – contact brushes) mounted on the same axis

Photographs of the assemblies are shown on pp. 53–56.

as the rotor. The mechanism interrupts the passing current and thus disables the electromagnet. The rotor continues to rotate by inertia. In a moment, the contact brush touches a tooth of the commutator, switching the current on again, which attracts another armature of the rotor. If everything is properly adjusted, your first motor that you have just built keeps rotating. However, it is better if the motor does not start the very first time. This gives you the opportunity to think about it further and look for a fault. You can encounter such a situation in the workshop, in the laboratory and in life in general.

The motor must usually be set in motion by a slight manual rotation of the shaft. Two contact brushes, one straight (No. 1221) and the other with a bent tip (No. 1222), touch the commutator, which is mounted on the wheel shaft with an insulation sleeve (No. 1304). The straight brush is in constant contact with the smooth part of the commutator, touching it only lightly (so as not to slow it down). When the commutator is rotating, the second brush touches the teeth of the commutator only lightly in such a way as to interrupt the current in the position between the teeth. The brushes must be mounted insulated on an insulation strip (No. 1204). The correct position of the commutator on the shaft and the correct positioning of the brushes are critical for ensuring optimal performance.

You have built your first motor. Its efficiency is negligible, because it can be stopped even by a small resistive force. Nevertheless, it is very important for you – you have learnt the principle of all electric motors on it. In practice, much more efficient types of electric motors are used.

72. PERMANENT-MAGNET MOTOR

A **permanent-magnet motor** consists of two basic parts, namely the **stator** (the stationary part), which in our case comprises a horseshoe **permanent magnet** (it could also be replaced by two disc magnets), and the **rotor** (the moving – rotating part, also referred to as the armature), which can have two or more poles (our armature has three poles).

An electric current is fed into the rotor (which is actually an electromagnet) via **brushes** (No. 1275) and the **commutator**, which ensures the changing polarity of the rotor electromagnet. With constantly changing polarity, the rotor pole is repelled by one pole of the permanent magnet and attracted by the other, which makes the rotor rotate.

The permanent-magnet motor must be assembled so that the rotor axis is horizontal and the rotor does not touch the magnet as it rotates. This is achieved by inserting a washer under the bearings (components Nos. 1272 and 1273) such that the rotor axis is in the correct position. The friction surfaces must be lubricated.

Small permanent-magnet motors are used to drive toys, models, etc. In practice, bronze contact brushes are replaced by carbon ones (carbon is a good conductor and reduces friction) and the permanent magnet is not horseshoe- but ring-shaped.

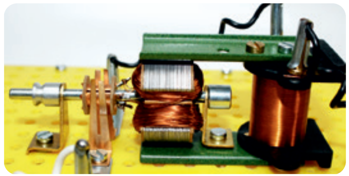
73. INDEPENDENT-EXCITATION MOTOR

In the case of an **independent-excitation motor**, the horseshoe permanent magnet is replaced by an electromagnet. The electromagnet (in our case a coil with a core and attached arms made of steel – component No. 1271) generates the necessary magnetic field, which alternately repels and attracts the rotor poles, thus creating a rotating motion. The rotor is powered from one source, the coil from another (independent) source (hence the name – independent-excitation motor). Independent-excitation motors have a high power output.

Also in this motor, it is necessary to lubricate the friction surfaces. Independent-excitation motors have the same application as permanent-magnet DC motors, but they have much better speed control.

74. SERIES MOTOR

A **series motor** is one in which the rotor and stator electromagnets are powered from the same source, so that current flows from the source to the rotor, from the rotor to the coil and back to the source.



75. SHUNT MOTOR

A **shunt motor** is one in which the stator and rotor electromagnets are connected in parallel (or shunt) – hence the name shunt motor. The

Photographs of the assemblies are shown on pp. 53–56.

motor is powered from a single source. The direction of rotation of the rotor cannot be reversed by simply switching the cables at the source, because this would reverse the poles of the stator and rotor without affecting the attraction and repulsion of the stator and rotor poles.

76. HOW TO CHANGE THE SENSE OF ROTATION

You have built several types of motors. Now you may be wondering how to make the motor turn the other way, i.e. to change its sense (direction) of rotation.

In the case of a permanent-magnet motor, you can change the sense of rotation by simply reversing the polarity of the power supply or the rotor commutator. This is logical – you cannot change the magnetic field around a permanent magnet. You can only change the magnetic field of the coil, which changes the sense of rotation.

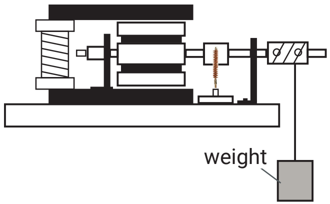
In the case of an independent-excitation motor, you achieve a change in the sense of rotation by reversing the polarity of either only the primary or only the secondary power supply.

In the case of series and shunt motors, the sense of rotation of the rotor can be changed by reversing the rotor polarity of the rotor only or by reversing the polarity of the coil only.

77. MOTOR WORK PERFORMANCE

Different types of motors have different parameters. In this experiment, you are going to calculate the work done and learn how to calculate the power and efficiency of the motor. **Mechanical work (W_m)** is calculated as the product of the force (F) and the displacement (d) if the force is constant and acts in the direction of the displacement. The unit of work is 1 joule (J). Also an electric motor performs work when, like in this experiment, it moves a weight from one location to another. **Output power (P_o)** is equal to the work done by the motor divided by the time (t) it takes to do that work. **Input power (P_i)** is equal to the product of the voltage (U) and the current (I). **Efficiency (η)** is the ratio of the output power to the input power. It is always less than 1 (or less than 100 if it is given in %).

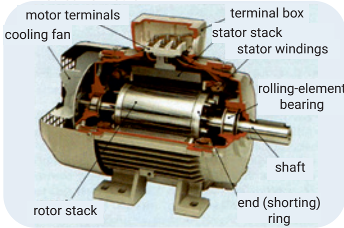
Build a circuit with a shunt motor and set the power supply to 6 V. Attach a small weight to the end of a longer string. Tie the string to the shaft. Switch the motor on and let it pull the weight up. Measure the distance and the time required to cover this distance. Calculate the mechanical work done.



78. ALTERNATING-CURRENT MOTORS

In the previous chapters, you have learnt about direct-current (DC) motors. In technical practice, however, you can encounter mainly alternating-current motors. Series and shunt motors rotate in exactly the same way as in a DC circuit.

Our power system uses alternating electric current with a frequency of 50 Hz, which means that a positive current flows through the line 50 times a second and a negative current flows through the line 50 times per second. The reason is probably clear to you from the preceding chapters. The alternating current changes its direction 100 times a second. The north pole of the armature becomes the south pole in one-fiftieth of a second. Nevertheless, the south pole of the coil becomes the north pole. Consequently, the two poles attract each other like in the previous experiments. The figure shows a three-phase squirrel-cage induction motor.



Photographs of the assemblies are shown on pp. 53–56.

V. ELECTRIC MACHINES

79. ALTERNATOR AND DYNAMO

A device that produces an electric current is called a power **generator**. An **alternator** is a generator that produces alternating current. Power plants use powerful three-phase alternating-current generators – three-phase alternators. A **dynamo** is a device that makes direct current.

Take the permanent-magnet motor from the construction set. Start turning the shaft. An alternating current is induced in the rotor windings and subsequently converted into a direct current through brushes. To be more specific, the rotor (armature) rotates in the magnetic field between the poles of the permanent magnet, and a voltage is induced in its windings. Since the rotor windings are connected to the commutator (a device whose circuit is divided into several segments isolated from each other), the direct current can be taken from the commutator by means of the brushes. The motor becomes a dynamo. When you turn the shaft in the opposite direction, the + and – polarity of the brushes is reversed. A magnetic field can be produced by an electromagnet instead of a permanent magnet. Depending on the winding, we can distinguish between an independent-excitation dynamo, a shunt dynamo or a compound dynamo (a combination of series and parallel, or shunt, excitation windings).

VI. MEASURING INSTRUMENTS

VI. MEASURING INSTRUMENTS

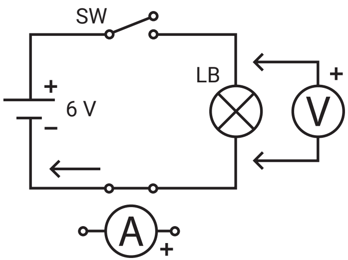
Photographs of the assemblies are shown on pp. 53–56.

The basic measurements of DC and AC quantities include voltage and current measurements. Both are usually performed using one universal measuring instrument, which is first connected as a voltmeter and then as an ammeter.

Voltage is measured using a voltmeter, which is connected in the circuit in parallel with the element being measured (see the diagram). This means that it is possible to measure the voltage at any point without having to break the circuit.

In the case of current measurement, the situation is different. Current is measured by an ammeter, which is connected in series with the circuit. This means that it is first necessary to turn off the circuit, connect the ammeter, and then turn the circuit back on to measure the required value. Since the ammeter has a small internal resistance, it must never be connected directly to a voltage source. Before connecting the measuring instrument to the circuit, always set it to measure the quantity required and select the highest possible range. This will prevent unintentional damage to the instrument.

Try to build some measuring instruments from the components of the construction set. These experiments should give you an idea of the principles on which such real measuring instruments work.



80. SIMPLE AMMETER

Try to build a measuring instrument. Like most measuring instruments, also this one is based on electromagnetic effects. The stronger the current through the coil, the more strongly the coil pulls iron objects into its centre. This property can be used to measure electric current. The easiest way to build such an ammeter is to follow the picture. Suspend the iron core just above the centre of the coil on a thin rubber band (component No. 2309). Attach a light paper pointer to the core. The pointer should move along the scale as the core is pulled in. The more current through the coil, the deeper inside the coil pulls the core. You can change the amount of current by connecting a light bulb between the power supply and the coil. You can also try two bulbs in parallel.

81. MILLIAMPERE MEASUREMENT

You can achieve an even more sensitive device by letting a **magnetic compass needle** (component No. 1265) rotate in a coil of insulated wire. However, there is one drawback – you have to position the device with the magnetic needle in the north–south direction. You can eliminate this problem and increase sensitivity by hanging two magnetic needles above each other with the opposite poles facing each other, so that the effect of the Earth's magnetism is cancelled out (astatic needles).

Take two dull blades from the construction set (No. 1315). Never use shop-bought sharp razor blades! Magnetise the two blades as much as possible and bolt them together as shown in the picture so that they are above each other with the opposite poles facing. Hang the two bolted-together blades on a long, thin string above the coil. Then a very weak current flowing through the coil is enough to make the system rotate. As you know, the current flowing through the coil produces a magnetic field. The more current that flows, the stronger the field around the coil and the more it affects the blades bolted together. With a carefully constructed instrument, you can easily achieve the sensitivity of even a few thousandths of an ampere (milliamperes).

VI. MEASURING INSTRUMENTS

Photographs of the assemblies are shown on pp. 53–56.

82. COIL GALVANOMETER

In the previous experiment, a permanent magnet was suspended while the electromagnet was bolted in place. In this experiment, it will be the other way round. Even an ordinary wire in a magnetic field through which electric current flows can indicate the current flowing. To increase the effect of the electric current, wind a coil of thin enamelled wire (component No. 1291) around a cork or plastic stopper or another similar plastic object. Hang the coil on two lead-in wires between the poles of a permanent magnet. From the bottom, you can attach it with a thread and a bolt to a metal plate.

Glue for example a piece of aluminium-foil chocolate wrapper to the front of the coil, on the thread. Apply two strips of duct tape along the sides of the aluminium foil to leave only a narrow line in the centre (a mirror). When you illuminate it with a light bulb, the light is reflected on the wall. The coil suspension must be very easy to move. If it is, a very small current flowing through the coil is sufficient to move the line on the wall. Draw a scale for it on a piece paper. You can roughly calibrate it.

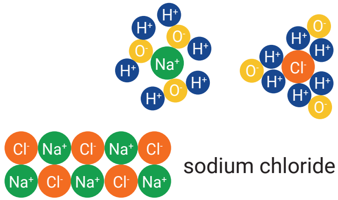
VII. ELECTROCHEMISTRY

VII. ELECTROCHEMISTRY

Pure **water** is not a conductor. However, perfectly pure water does not occur in nature. It always contains a variety of different contaminants and impurities. Various impurities are also present in tap water. *Nevertheless, water with impurities conducts electricity.* Relatively pure water can be obtained, for example, by distillation.

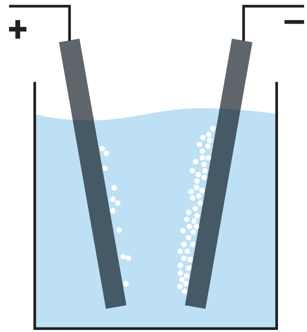
You have already learnt that everything around us is made of atoms. In nature, atoms usually combine into more complex units – molecules. A water molecule contains one oxygen and two hydrogen atoms. The chemical formula of water is H_20. The structure of water molecules makes water a **polar solvent**. A polar solvent dissolves ionic or polar compounds.

A typical ionic compound is **sodium chloride** (NaCl), known as salt. In water, NaCl molecules are dissociated into ions, which are then surrounded by water molecules. This is called **electrolytic dissociation**. And it is these ions that are responsible for the conductivity of water. *So never touch electrical wires or electrical appliances with wet hands!*



83. BUBBLES AT THE ELECTRODES

Take a glass of water, insert the electrodes (Nos. 1235 and 1236) into it and connect them to a circuit with an electric current. You can see bubbles forming on the electrodes. The electric current splits the water into hydrogen and oxygen. These gases are then released in the form of bubbles at the respective electrodes. If there are few bubbles, add some vinegar or salt to the water. You already know why more bubbles start to form after the addition of, for example, salt – you have increased the conductivity of the solution. More bubbles (hydrogen) are released at the negative electrode.



84. ELECTROLYSIS

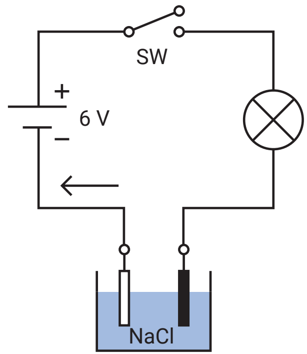
When an electric current is passed through an aqueous solution of NaCl, **electrolysis** occurs. Electrolysis is the decomposition of an electrolyte by the passage of an electric current. During the decomposition, the positively charged ion (**cation**) migrates to the negative electrode (**cathode**) and the negatively charged ion (**anion**) travels to the positive electrode (**anode**). An anion is an ion that has gained one or more electrons. A cation is an ion that has lost one or more electrons.

At the anode, chlorine anions lose electrons, which results in the release of chlorine, recognisable by its characteristic smell. At the cathode, water molecules accept electrons to produce hydrogen gas and an alkaline solution. The conduction of the electric current is thus caused by ions.

Take a glass of water and dissolve a teaspoon of salt in it. Salt is provided in the construction set (No. 1306), but you can use ordinary table salt. You have prepared a solution of salt. Take two electrodes, immerse them in the solution and connect them to the circuit as shown in the diagram. The construction set also includes a piece of white phenolphthalein paper (No. 1307), which turns pink in a basic (alkaline) solution. Test whether it turns pink in the alkaline environment of the cathode.

$2Cl^- - 2e^- \rightarrow Cl_2$

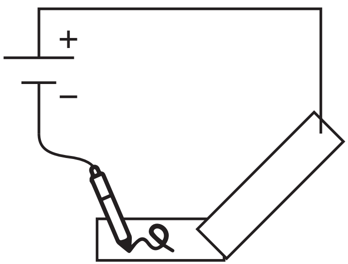
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$



VII. ELECTROCHEMISTRY

85. RED-WRITING NEGATIVE POLE

Moisten the phenolphthalein paper with water and put it on one electrode. Connect the electrode with a conductor to the positive terminal of the battery or power supply. Connect another conductor to the negative pole. Now you can use the conductor to write on the moistened paper in red. The conductor connected to the negative pole is actually the cathode, which means, as you know, that it is surrounded by an alkaline environment, where *phenolphthalein turns pink*. You can use this to determine the polarity of an unknown source.



86. ELECTROPLATING

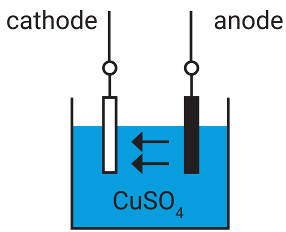
When electrodes connected to the poles of a battery or power supply are immersed in a solution, positively charged ions (cations) migrate to the negative electrode (cathode) and negatively charged ions (anions) migrate to the positive electrode (anode).

The construction set includes a small package of blue-vitriol crystals (No. 1308). Blue vitriol contains copper. How can you recover it from the crystals and use it?

Dissolve the blue vitriol in a small glass of water. Then use sandpaper or a file to clean a metal object, e.g. a nail, a key, etc. Do not touch the cleaned areas with your hands again. Sweat and grease would stick to them. Connect the object to be electroplated to a wire as the cathode (connect it to the negative pole of the battery). Connect the copper electrode (No. 1235) as the anode (connect it to the positive pole of the battery). Immerse both electrodes in the blue-vitriol solution and close the circuit. The object will soon begin to be covered with a red layer of copper.

What has happened? The **copper cations** in the blue-vitriol solution migrate to the negative pole (cathode), where they settle, as a result of which the amount of copper at the cathode gradually increases. The anions, on the other hand, migrate to the anode, where they begin to dissolve the copper, and the mass of copper at the anode thus decreases. You can utilise various salts to coat (electroplate) objects with copper, nickel, chrome, and even with silver or gold. This is also widely used in practice. Just look at 'silver' Merkur strips, adjusting rings, nuts and bolts, which are zinc-plated.

Why is **electroplating** used? Most metal objects are made of steel, which has good mechanical properties and is the cheapest metal, but it corrodes (rusts) in the air. On the other hand, noble metals are highly resistant to corrosion but are not as strong and are always more expensive than steel. An electroplated steel object retains the properties of steel but does not rust and looks nicer.



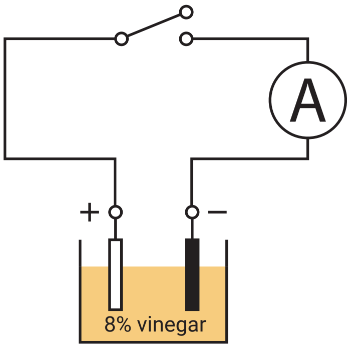
87. GALVANIC CELL

Usable **electricity** is not freely available in nature. Therefore, it must be created by converting other types of energy – mechanical, thermal or light energy, or by means of chemical processes. This is done in **galvanic cells**, either **wet** (used in the past) or **dry** (used today).

A Daniell cell is a type of wet galvanic cell consisting of an electrolyte (acid) and two electrodes: a positive one, made of copper (Cu), and a negative one, made of zinc (Zn). The zinc electrode dissolves in the electrolyte and its cations make the electrolyte positively charged; free electrons remain at the electrode, as a result of which it becomes negatively charged. The copper at the other electrode dissolves more slowly; consequently, there is a voltage of about 1 V between the positive and negative electrodes. If a pinch of blue vitriol is added near the copper electrode, an equilibrium state is created. However, if the terminals of the galvanic cell are connected by a conductor through a load, the equilibrium state is disturbed. Electrons flow through the appliance from the zinc electrode (where they are in an excess) to the copper electrode – an electric current flows through the conductor and the load.

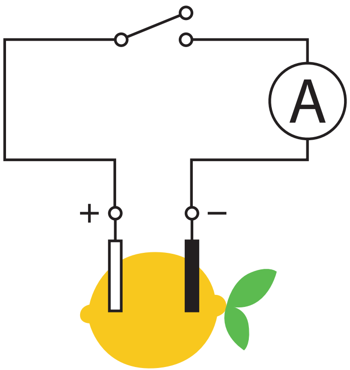
VII. ELECTROCHEMISTRY

Take the copper and zinc electrodes (Nos. 1235 and 1236) and place them in a glass. Now you need to find a suitable electrolyte. You can use vinegar, which is commonly an 8% solution of acetic acid in water. If you connect the electrodes together, current will start flowing through the circuit. But how can you detect such a small current? This should not be a problem for you – you can already build a sensitive ammeter. Connect the ammeter to the circuit and observe the deflection on the measuring instrument.

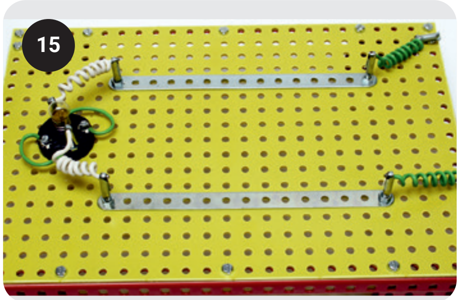


88. LEMON BATTERY

For this experiment, you need a lemon and the two electrodes, zinc and copper. Insert both electrodes into the lemon and connect an ammeter. Can the lemon produce current? Yes, the lemon flesh is the electrolyte. The electrolyte in a galvanic cell is an acid and a lemon is acidic – it contains citric acid.



PHOTOGRAPHS OF SELECTED ASSEMBLIES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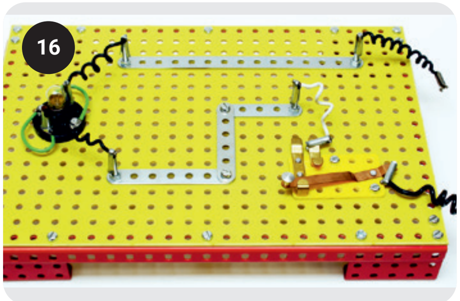
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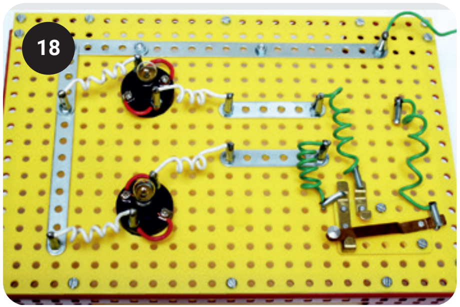
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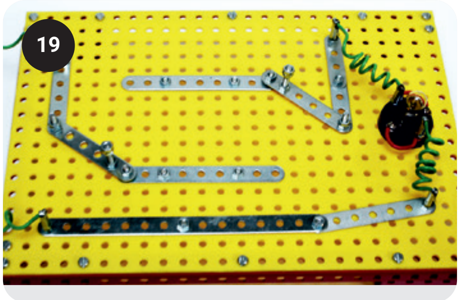
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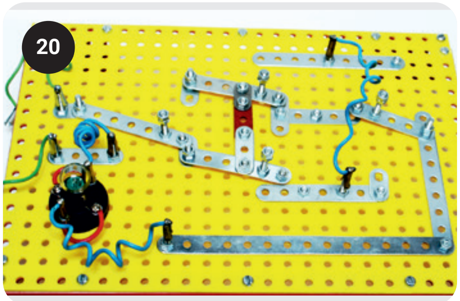
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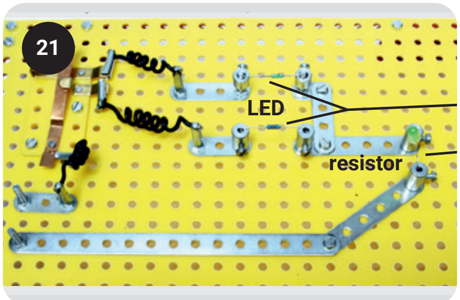
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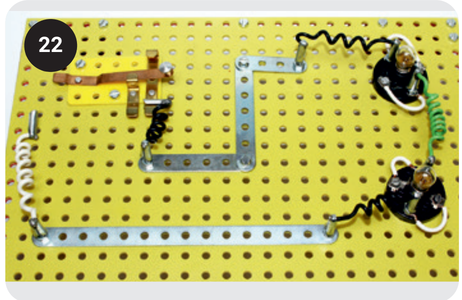
LED
resistor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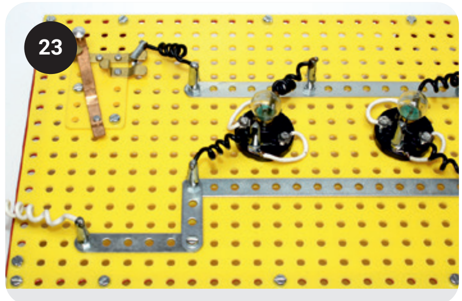
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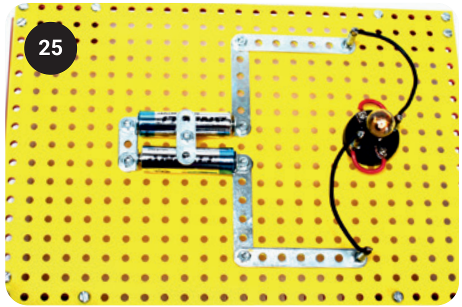
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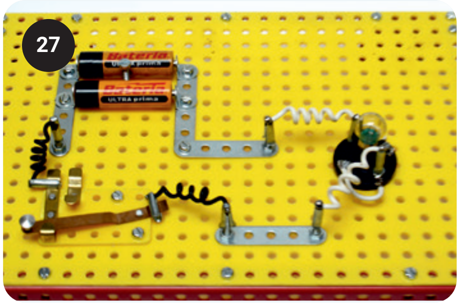
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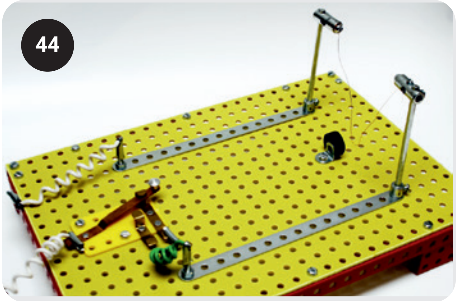
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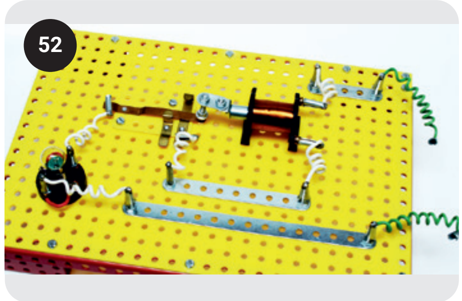
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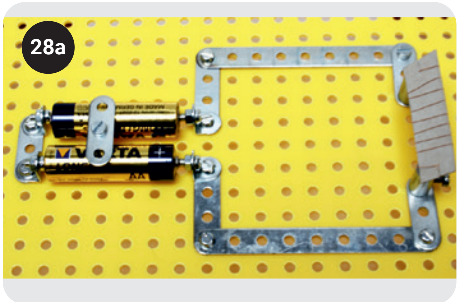
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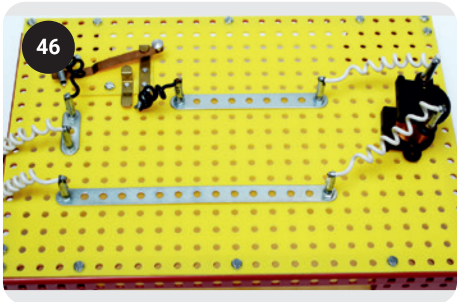
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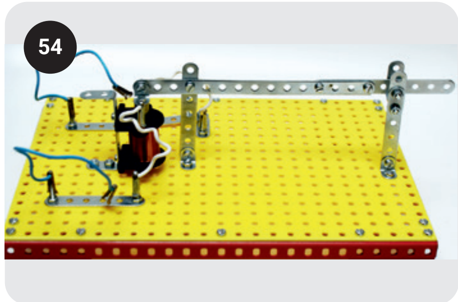
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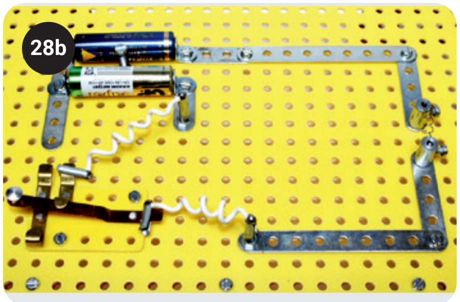
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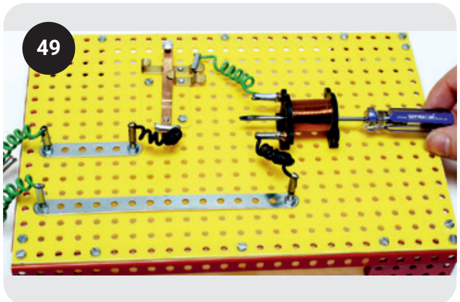
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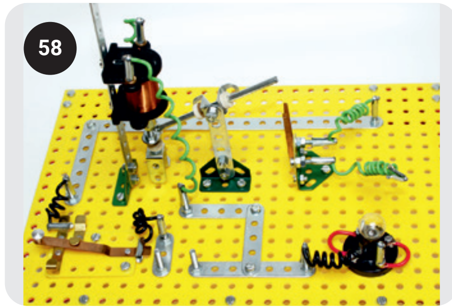
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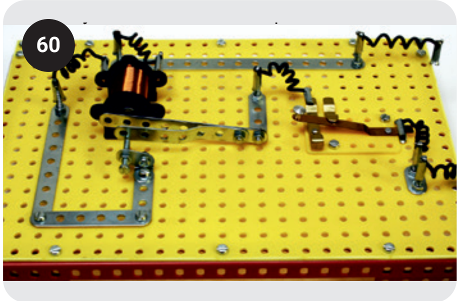

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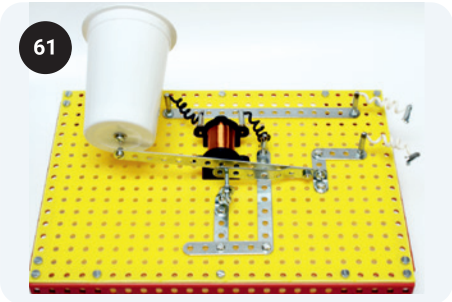

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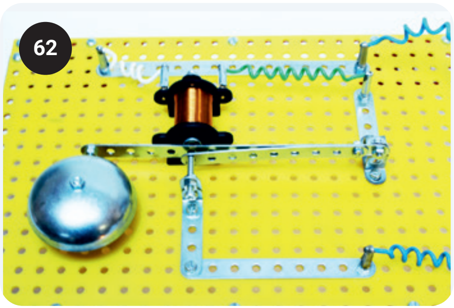

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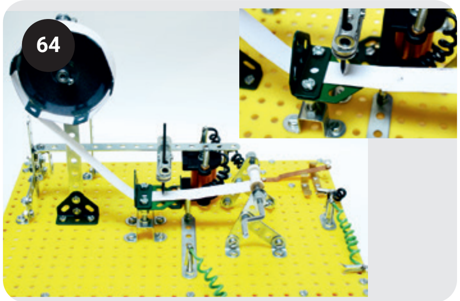

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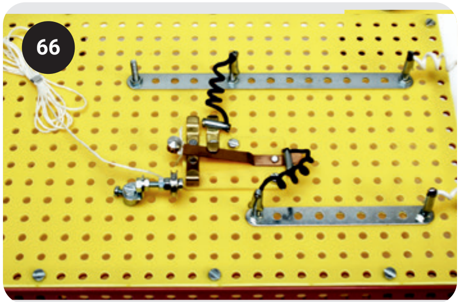

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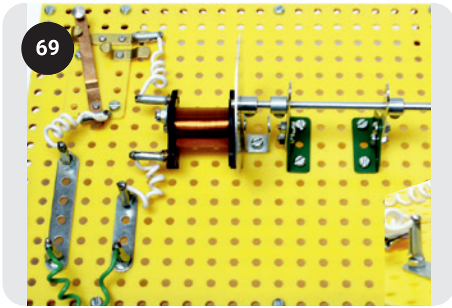

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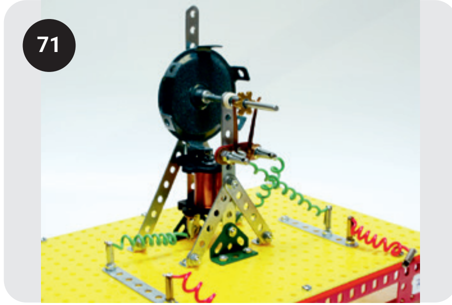

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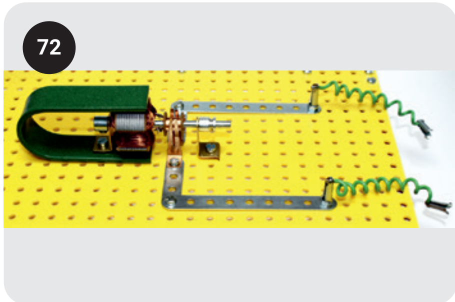

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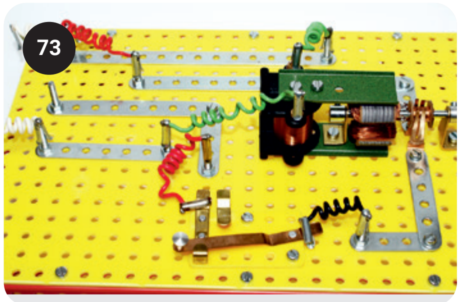

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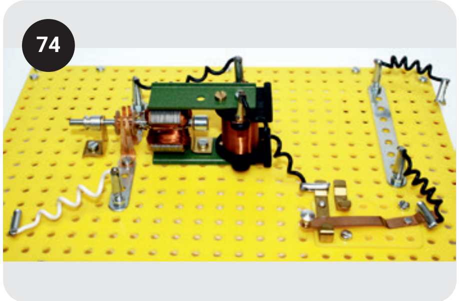

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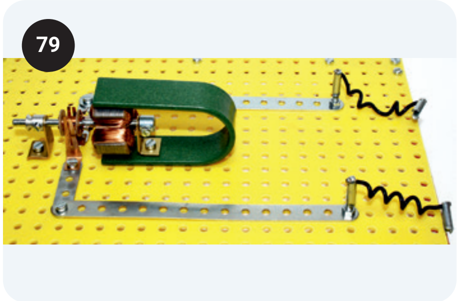

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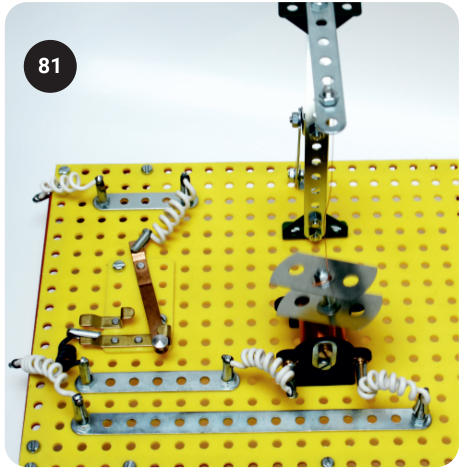

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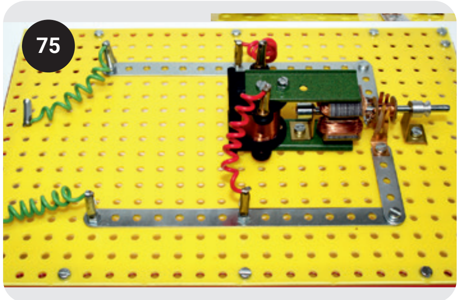

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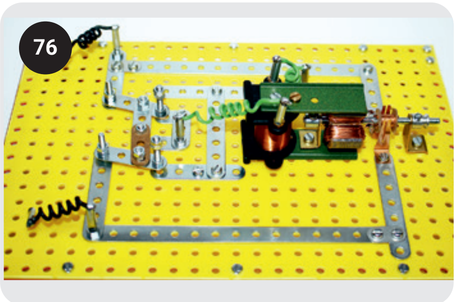

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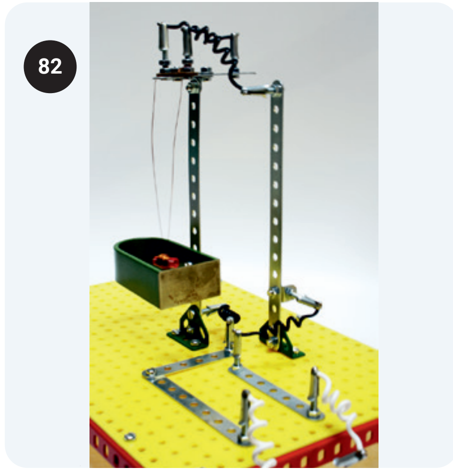

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age/věk: .... 6+
parts/díly: 210
weight/váha: .... 1.1 kg

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All construction sets are available in our eshop

Všechny stavebnice najdeš u nás na e-shopu. • Alle Kits sind in unserem E-Shop erhältlich • Tous les kits sont disponibles dans notre e-shop • Todos los kits están disponibles en nuestra e-shop • Tutti i kit sono disponibili nel nostro e-shop • Všetky súpravy sú k dispozícii v našom e-shope • Wszystkie zestawy są dostępne w naszym sklepie internetowym • Vsi kompleti so na voljo v naši e-trgovini • Minden készlet elérhető webáruházunkban • Alle kits zijn verkrijgbaar in onze e-shop • Svi kompleti dostupni su u našoj e-trgovini • Всички комплекти са налични в нашия електронен магазин • Toate kiturile sunt disponibile în e-shop-ul nostru • Все наборы можно приобрести в нашем интернет-магазине

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