Short basic course: Electrical measurements and circuits

In order to avoid misunderstandings, the topics covered here are dealt with only to the extent and in the detail necessary for working with the experiment kit.

1 Measuring with the digital multimeter

This section provides information and tips on using the digital multimeter. These are not the official operating instructions, which should be consulted in case of doubt.

1.1 Safety information

The digital multimeter may be used only as instructed by your teacher or as described in the experimentation instructions. Failure to observe the instructions may lead to damage to the device or have harmful effects on health. The following safety information must be observed specifically:

- Protect the device from moisture, splashes, and heat and use it only in clean, dry rooms.
- Do not drop the digital multimeter or subject it to strong mechanical pressure.
- Never open the digital multimeter on your own without being instructed to do so by a teacher.
- Voltage measurement: **Only extra-low voltages up to 25 volts** may be measured with the digital multimeter and the measuring cable assembly contained in the experiment kit.
- Current measurement: In the 200-mA and 10-A range, no currents higher than these may be measured in either case.

1.2 What's what on the digital multimeter?

1 LCD display for indicating the measured values.

2 Rotary switch: On/Off and selection of the test mode and measuring range.

3 Input jack for 10 A current (currents greater than 200 mA).

4 Connection jack for V (voltage), Ω (resistance), A (current up to 200 mA); corresponds to the **positive pole** (for connecting **red** measuring cable).

5 COM: Common connection jack; corresponds to the **negative pole** (for connecting **black** measuring cable).

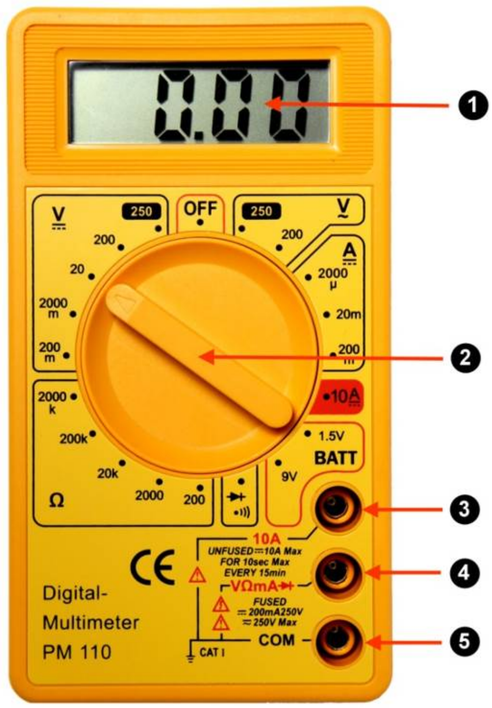


Fig. 1: PM110 digital multimeter.

1.3 Inserting the battery

- The battery provided must be inserted before using the multimeter for the first time.
- Open the rear panel with a Phillips screwdriver. Nothing may be connected to the device when you open it. The rotary switch should be in the "OFF" position.
- When you close the rear panel, make sure that the battery connection cable is not wedged in the casing. If it is, do not screw the panel shut with force, but first push the battery cable out of the way under the battery (see Fig. 2, b).

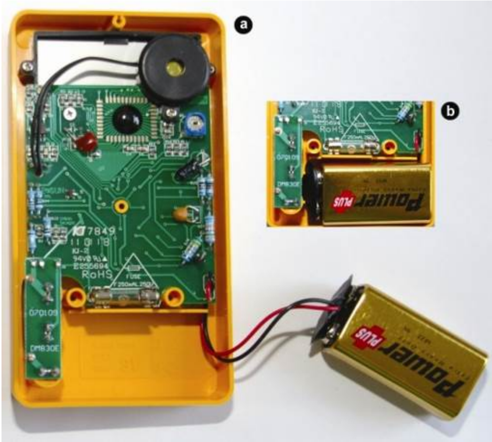


Fig. 2: Inserting the battery.

1.4 Switching the device on and off

To switch the multimeter on, turn the rotary switch from the "OFF" position to the desired test function. Turn the rotary switch back to "OFF" to switch the multimeter off. **Always switch the digital multimeter off again** after use; otherwise, the battery will be drained unnecessarily.

1.5 Selection of the measuring type and measuring function

The following electrical quantities can be measured (see Fig. 3):

a) DC voltage, set to 20-V range
b) AC voltage, set to 200-V range
c) Direct current (up to 200 mA), set to 200-mA range
d) Direct current (up to 10 A)
e) Resistance set to 2,000-ohm range. The display indicates "1" if the resistance is greater than the set measuring range.

If necessary, you will find explanations of the measuring functions "Diode test/Continuity test" and "Battery test" in the original device instructions.

Caution when switching the measuring function:
When you switch from one function to another, for example, from "resistance measurement" to "DC voltage measurement", you must **always remove the measuring cable from the test object first.** Otherwise, the multimeter or the test object could be damaged. Switching is safe only if you switch directly, for example, from "DC voltage" to "Direct current" via "OFF".

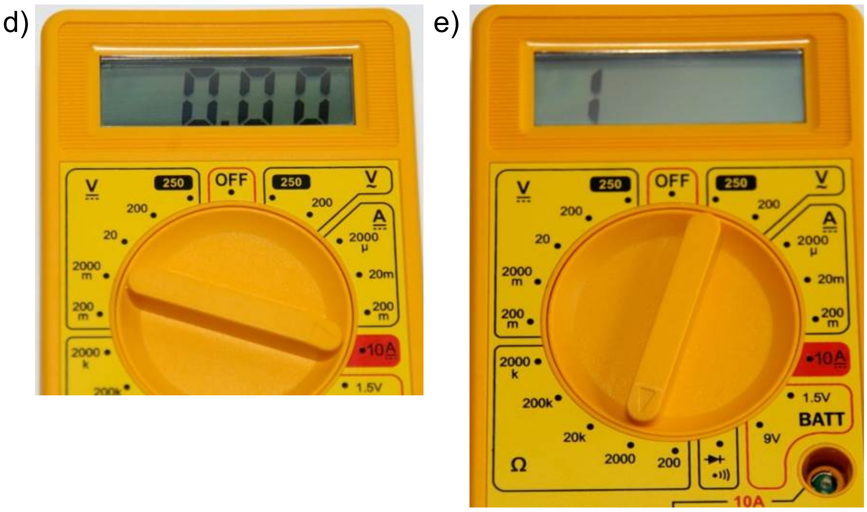


Fig. 3: Setting the measuring functions.

1.6 Connecting the measuring cables correctly

1.6.1 The rule is: Black always to COM

- The **COM jack** is the connection jack for the **black** test cable.
  Always connect it to the **negative pole** of the measuring circuit.
- The jack marked **"V Ω mA"** is the input jack for the red measuring cable for all voltage, resistance, and current measurements (except 10 A).
  Always connect it to the **positive pole** of the measuring circuit.
- The jack marked **"10A"** is the input jack for the red measuring cable for measuring high currents.
  Always connect it to the **positive pole** of the measuring circuit.

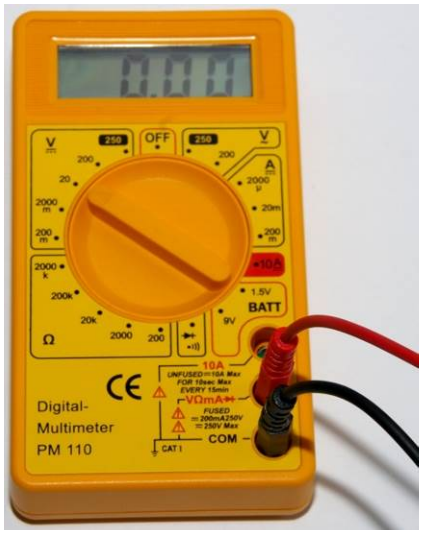


Fig. 4: Correct connection of the measuring cables to the digital multimeter.

Here again is a summary of the rules:

Jack	Cable	Polarity
COM	Black	Negative
V Ω mA	Red	Positive
10A	Red	Positive

1.6.2 Checking for correct connection

Check for yourself whether these rules are correct using a battery, an accumulator, or a solar cell. Set the measuring function to direct current and select the 20-volt range using a 9-volt accumulator. Connect the measuring cable to the digital multimeter correctly (black to “COM”, red to “V Ω mA”). Now connect the red measuring cable to the negative pole and the black cable to the positive pole of the accumulator. A negative voltage will be indicated. Now connect the black cable to the negative pole and the red cable to the positive pole of the accumulator. A positive voltage will be indicated. Even if you connect the positive pole of a solar cell to the red cable and the negative pole to the black cable, a positive voltage will be indicated.

a) Connection of the measuring cables to the digital multimeter is incorrect. A negative voltage is indicated.

b) Connection of the measuring cables to the digital multimeter and accumulator is correct. A positive voltage is indicated.

c) Connection to this solar cell with marked positive and negative poles is correct.

Fig. 5: Connecting the measuring cables to the digital multimeter.

1.7 What measuring range should you select?

If the value of the quantity to be measured is unknown, **always select the highest measuring range first**. In the case of a DC voltage measurement, for example, that would mean 250 volts. Then adjust the measuring range to a lower setting and find the magnitude of the measured value by trial and error. You will recognize the optimum setting from the **highest resolution of the measured value**. With a 9-volt accumulator, this resolution is least good when you set 250 volts (Fig. 6, a), better at 200 volts (Fig. 6, b), and best of all at 20 volts (Fig. 6, c). A setting of 2000 mV or 2 volts (Fig. 6, d) is totally unsuitable for a 9-volt accumulator. The display “1” indicates overflow (or overload). Using this method of setting by starting with the highest value, you will also make sure that you don’t blow the multimeter’s fuse.

a) b) c) d)

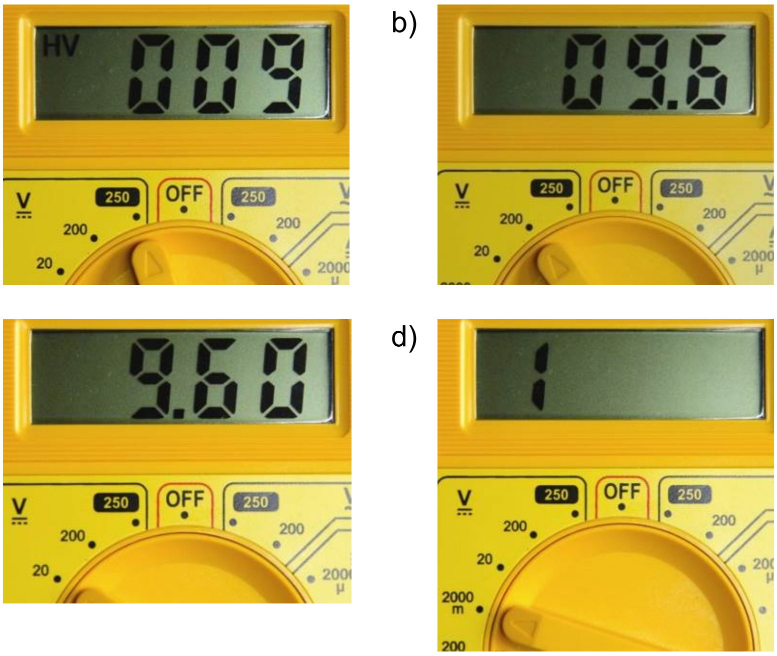


Fig. 6: Optimum choice of measuring range using the example of a 9-volt accumulator.

1.8 Determining the unknown polarity of current and voltage sources

The rules explained in section 1.6 for correctly connecting the measuring cables to the digital multimeter and test object appear arbitrary. Could you not equally well define them the other way round?
No, because when these rules are observed, we can determine the polarity of current and voltage sources when they are still unknown.

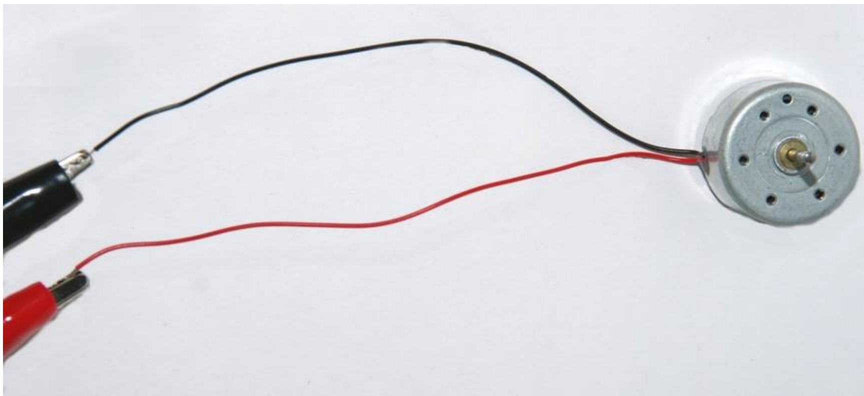


Fig. 7: We want to use the electric motor as a generator in the clockwise direction. To do so, we check whether it delivers a positive voltage with this connection.

Knowledge of the polarity of current and voltage sources is very important because many electrical components do not function if they are connected with incorrect polarity. LEDs, for instance, do not light up if the polarity is incorrect; accumulators and electrolytic capacitors are not charged if the polarity is incorrect or may even be destroyed.
If we want, for example, to use an electric motor as a generator in order to charge an electrolytic capacitor or an electrochemical cell, we need to know which connecting wire is the positive pole and which is the negative pole. In our example (see Fig. 7), if the multimeter indicated a positive voltage when the motor is rotated to the right, we would know that the red connecting wire of the motor is the positive pole in this direction of rotation.

2 Circuits for simple electrical measurements

The topic is dealt with only to the extent and in the detail necessary for working with the experiment kit.

2.1 Measuring the voltage in a circuit

As a general rule, the multimeter is always connected in **parallel with the voltage source** or to the test object: red cable to the positive pole and black to the negative pole of the test object.

2.1.1 Measuring the no-load voltage of a current source

In this case, the multimeter is the only load. The internal resistance of the device, that is, the load resistance, is extremely high when you are measuring voltage (in the case of digital multimeters, up to 20 Mohms).
The internal resistance of the voltage source (in our example, a battery or accumulator) is therefore extremely small in relation to the load resistance. Therefore, practically no load current flows through the digital multimeter in the circuit (no-load operation). The no-load voltage is therefore measured across the unloaded voltage source.

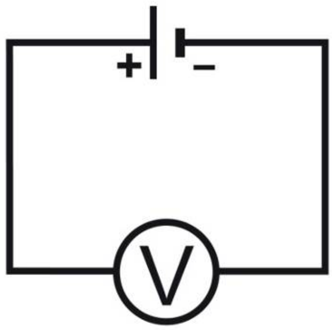


Fig. 8: Circuit diagram for measuring the no-load voltage.

2.1.2 Measuring the voltage under load

In this case, a load current flows via the load (in our example, an incandescent lamp) in the circuit. The measured voltage is less than the no-load voltage. Depending on how low the internal resistance of the voltage source is compared with the load resistance, the size of the voltage drop will vary compared with the no-load voltage.

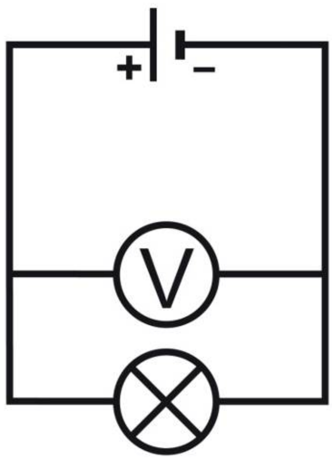


Fig. 9: Circuit diagram for measuring the voltage in a circuit with a load.

2.1.3 Measurement of the voltage in branched networks

If there are several loads connected in series in a circuit, the voltage is divided. The voltage can be measured as the total voltage parallel to the voltage source (shown here as V_1) or as a partial voltage at each load resistance (here V_2, V_3, V_4).

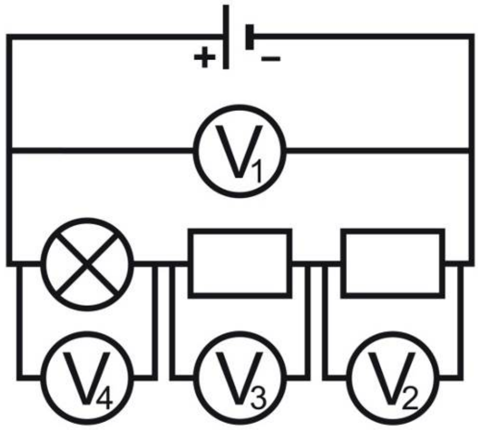


Fig. 10: Circuit diagram for measuring the voltage in a circuit with several loads.

2.2 Measuring the current in a circuit

As a general rule, the multimeter is always connected **in series with the load or the test object**: red cable to the positive pole of the test object and black to the negative pole.

2.2.1 Measuring the short-circuit current of a current source

The digital multimeter has an extremely low resistance in current measurement, which means the load resistance is therefore extremely small. In this case, the multimeter is the only load. The internal resistance of the current source (in our example, a battery or an accumulator) is therefore relatively large compared to the load resistance. Connecting the digital multimeter therefore acts practically as a short circuit. The current is usually greater than in the case of current flow through a normal load.

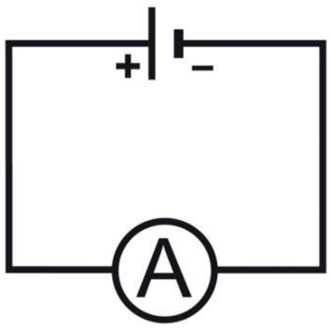


Fig. 11: Circuit diagram for measuring the short-circuit current.

Warning: The short-circuit current of batteries or accumulators must never be measured, since this can result in the destruction of the batteries, accumulators, and multimeter. For this reason, the charging state of a battery or accumulator may be determined only by measuring the voltage and not by measuring the current.

2.2.2 Measuring the current flow through a load

If you want to measure the current flowing through a load, the multimeter must be connected in series with the test object.

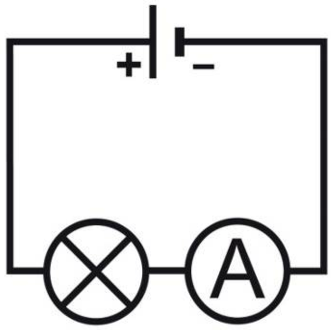


Fig. 12: Circuit diagram for measuring the current in a circuit with load.

2.2.3 Measuring the current flow in branched circuits

If you want to measure the current flowing through several loads, the multimeter must be connected in series with every test object connected in parallel with the current source. This is because a different current flows through them (in our example I_1, I_2, and I_3). The same current (here I_3) flows through series-connected test objects (in our example, the two incandescent lamps), so a common multimeter is adequate. The total current incidentally is the sum of currents I_1, I_2, and I_3.

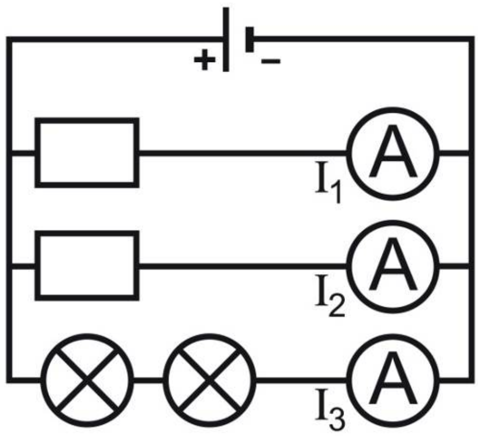


Fig. 13: Circuit diagram for measuring the current in a circuit with several loads.

2.3 Measuring resistances

2.3.1 Direct measurement of the resistance

As a general rule, the multimeter is connected in parallel with the resistance.

In order to determine the resistance, the digital multimeter applies a voltage across the resistance and measures the current flowing through it. The meter then automatically calculates the resistance from U/I and indicates this value.

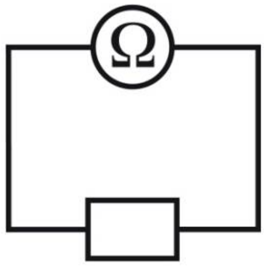


Fig. 14: Circuit diagram for measuring an individual resistance.

Caution: You should never measure individual resistances in complex circuits that are already set up. This is because if there are still voltages present anywhere in this complex circuit (for example, due to capacitors that are not fully discharged), this can lead to incorrect measurements or even damage to the multimeter. However, there is another reason why measuring the resistance in complex circuits is not advisable. This is because if other resistances are connected in parallel with the resistance you wish to measure, you will no longer measure the individual resistance, but the combined resistance value of several resistances.

2.3.2 Determining the resistance indirectly from voltage and current

To determine the resistance, connect the resistance to a voltage source (in this case, a battery or an accumulator) and measure the voltage applied and the current flowing through the resistance. You then calculate the resistance by dividing the voltage by the current (U/I).

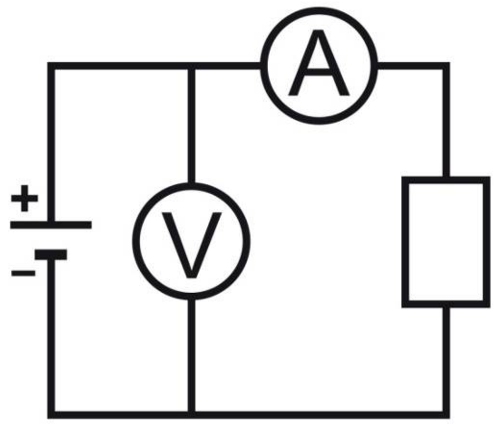


Fig. 15: Circuit diagram for indirect measurement of the resistance by measuring the current and voltage.

3 Avoiding short circuits when setting up circuits

Connecting circuits with alligator clips is a very quick method but prone to faults. It is therefore essential to work with the utmost care.

Caution: Risk of short circuits: If the connection points are close to each other, as for example in the solar cell, make sure that the alligator clips of the two connecting cables do not come into contact with each other.

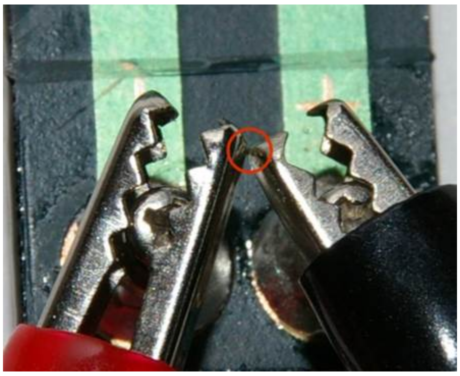


Fig. 16: Incorrect: The alligator clips are touching and so cause a short circuit.

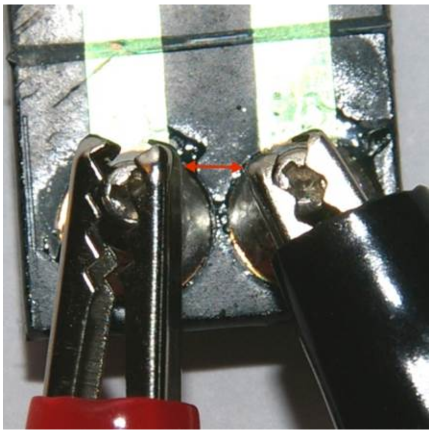


Fig. 17: Correct, safe distance: The alligator clips cannot touch, even if the cables are moved.

Neat cabling in parallel circuit: If too many alligator clips are attached to one connection point (for example, on solar cells), this will almost certainly cause a short circuit or a loose contact. In this case, it is advisable to connect each solar cell separately to a cable pair and to connect the other cables in parallel via junctions.

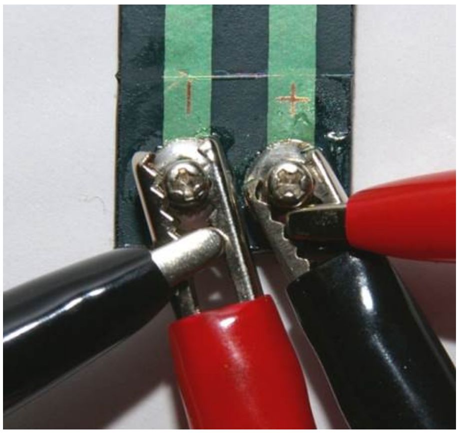


Fig. 18: Incorrect: Too many clips at one device terminal.

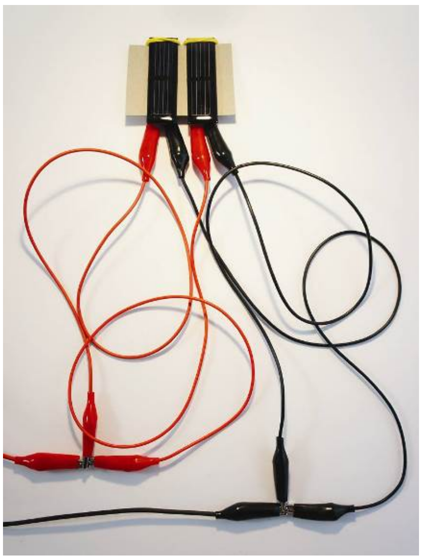


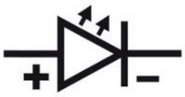
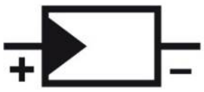
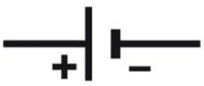
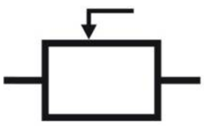
Fig. 19: Correct: Safe wiring with parallel circuit. The two solar cells are connected in parallel via cable junctions.

4 Handling of batteries and accumulators

Accumulators should be recharged immediately after use. This is also recommended if they have not been used for a long period.
Batteries and accumulators must never be short-circuited. In a short circuit, a current of several amperes flows (in alkaline manganese mignon batteries, for example, up to 80 A). At best, this can cause deep discharge and destruction of the battery or accumulator. In the worst case scenario, it can cause an explosion and fire. If an accumulator heats up, this can also cause an explosion.
Batteries and accumulators must not be disposed of in the normal trash, but should be taken to a recycling center.

5 Appendix: Circuit symbols

In order to be able to “read” circuit diagrams, you must be familiar with the most important circuit symbols used.

Device	Symbol	Special information
Voltmeter, voltage measurement		The digital multimeter becomes a voltmeter by switching on the DC or AC voltage measuring functions.
Amperemeter, measurement of current		The digital multimeter becomes an amperemeter by switching on the DC/AC milliampere or ampere measuring functions.
Light-emitting diode		Short pin = Negative pole Long pin = Positive pole
Motor		In the case of a motor, the positive pole is usually defined so that the motor runs in a clockwise direction when DC voltage is applied.
Solar cell		As a flat component, the solar cell has its own circuit symbol, which is different from that of the photodiode. Do not confuse them.
Accumulator, battery		None
Resistance		None
Potentiometer		Variable resistance. The resistance can be set by a sliding contact.
Capacitor		Capacitor with small capacitance. In this case, the polarity is irrelevant.
Electrolytic capacitor		Electrolytes are used in capacitors with large capacitance. Therefore, the polarity matters. Electrolytic capacitors can be destroyed if connected with incorrect polarity.
Incandescent lamp		None