B6 Renewable energies – Sun, water, wind, hydrogen, and fuel cell

1 Electrical energy from the radiant energy of light

Four groups of students can conduct this experiment simultaneously.

1.1 Apparatus and materials

- 5 connecting cables, alligator clip to alligator clip
- 1 digital multimeter
- Lamp with halogen light bulb, optional
- 1 measuring cable assembly, banana plug to alligator clip, red and black for each
- 2 solar cells, 0.5 V/150 mA
- 1 solar motor, large, iron armature, 0.4 V/25 mA
- 1 solar motor, small, bell-type armature, 0.1 V/2 mA*

*Since only one motor is available, you must pass it around to the other groups after you have used it.

Attention: After you have completed the experiment, return the apparatus and materials or dispose of them properly as instructed by your teacher.

1.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

1.3 Conducting the experiment

- Connect a solar cell to the multimeter using the measuring cable (pay attention to positive pole and negative pole). Turn the solar cell so that it is facing the light source (sunlight or artificial light) and you can determine the highest measurable voltage (in mV) and the highest measurable current (in mA).
- Then try to connect both available solar cells such that you achieve the highest voltage or the highest current. Keep in mind that for a series circuit, you must connect the positive pole of one solar cell with the negative pole of the other solar cell and, for a parallel circuit, you must connect the positive pole with the positive pole and the negative pole with the negative pole. Use the circuit diagrams and wiring tips shown in the figures as a guide.

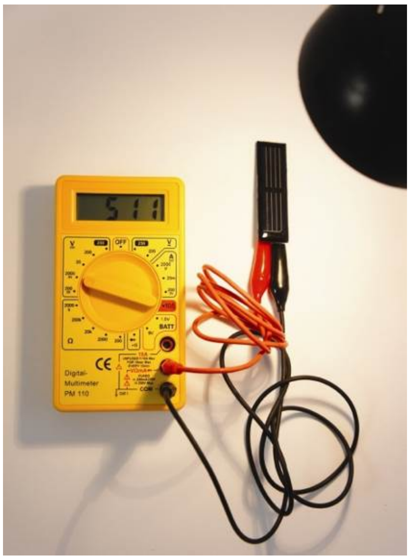

Fig. 1: Measuring with a solar cell.

- To ensure that the light conditions are identical for both solar cells, you should mount them next to each other on a strip of cardboard, as shown (Fig. 4).

- Depending on the lighting conditions, attach one solar cell to the large solar motor. If the motor does not start to rotate yet, then attach two solar cells connected in series.
- When the motor starts to rotate, measure the voltage and current values that are necessary for this to happen.
- If very little light is available, repeat the experiment with the small, more sensitive solar motor.

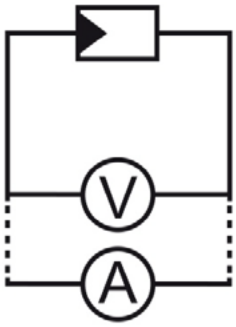

Fig. 2: Circuit diagram for measuring the voltage and current of a solar cell using one multimeter by switching the measurement range from voltage (V) to current (A).

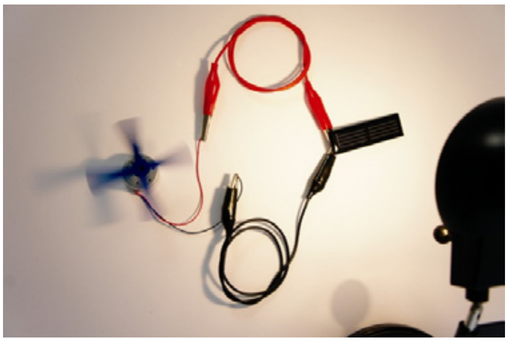

Fig. 3: Operating the large solar motor on one solar cell.

Fig. 4: Mounting the solar cells on a cardboard strip using rubber bands.

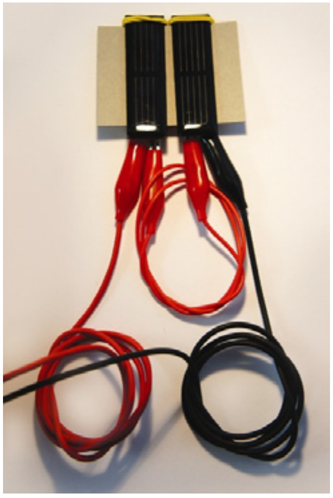

Fig. 5: Wiring the solar cell for a series circuit.

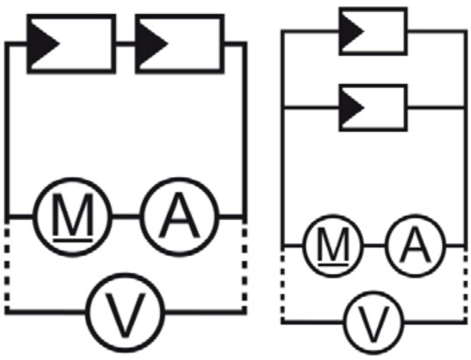

Fig. 6: Circuit diagrams for series (left) and parallel (right) circuits.

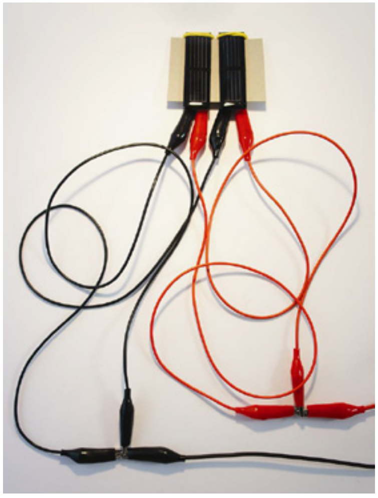

Fig. 7: Wiring for a parallel circuit. Do not connect the second solar cell directly to the first (risk of loose connection and short circuit). Instead, connect it using a cable junction.

1.4 Observation

For each setup, determine the highest values measured for the voltage and current, convert them to volts (V) and amperes (A), and record them in a table.

1.5 Analysis

Power (P) is calculated from the measured voltage (V) and the current (I):

Power P = voltage V · current I

Example for 0.3 V and 0.05 A $\Rightarrow$ P = 0.3 V · 0.05 A = 0.015 W

Calculate the power output from the measured values:

Number of cells	Circuit	Voltage [V]	Current [A]	Power output [W]
1	-			
2	Series circuit			
2	Parallel circuit			

1.6 Questions

a) What kind of circuit is best for reaching the highest voltage or the highest current?
b) How does the calculated power output differ for the same number of cells but different kind of circuit (series circuit or parallel circuit)? Compare and explain.

2 Electrical energy from hydropower

Four groups of students can conduct this experiment simultaneously.

2.1 Apparatus and materials

- Bucket or large bowl for collecting the water
- 1 digital multimeter
- 1 measuring cable assembly, banana plug to alligator clip, red and black for each
- 1 plant clip or similar item as motor holder
- 1 propeller (for large solar motor)
- 1 ruler
- 1 solar motor, large, iron armature, 0.4 V/25 mA
- 1 syringe (conical tip), 100 ml
- Tap water
- Tape
- Tea light (optional)
- 1 watch

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

2.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

2.3 Conducting the experiment

- If nobody has conducted the experiment yet, convert the propeller to a waterwheel. Hold the propeller above the flame of the tea light for approx. ten seconds. Hold the base of the blade to be deformed approx. 3 cm above the flame. Use the plant clip to bend the hot propeller from 45 degrees to 90 degrees. Repeat this process until all four blades are positioned at 90 degrees.

Fig. 8: Deforming the propeller into a waterwheel.

- Use the tape to seal the openings of the solar motor so that it is splash-proof.
- Place the waterwheel on the solar motor, which should now work as a generator. Connect the solar motor to the multimeter.

- Remove the plunger from the 100-ml syringe, and fill the syringe with 100 ml of water while blocking the opening with your finger.
- Have your partner use the plant clip to hold the generator with the waterwheel above a collecting container. From a height of approx. 30 cm, allow the water to flow from the syringe onto the waterwheel. (Remember: Precisely measure the distance from the waterwheel's blade to the tip of the syringe's cylinder at the beginning of the experiment, and maintain this same distance throughout the experiment.)
- Use the watch to measure the motor's operating time.

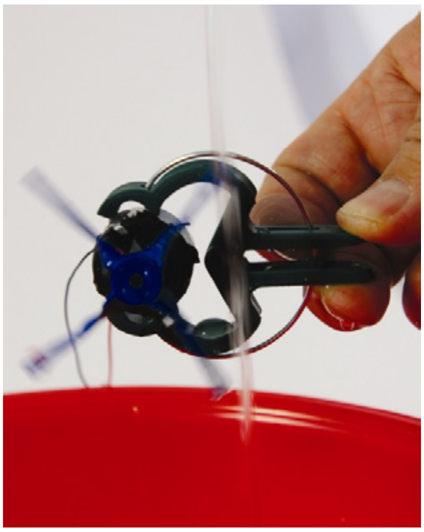

Fig. 9: The waterwheel turns in the stream of water.

- Repeat the test as often as necessary from different heights until you have determined the maximum values for the voltage (in mV), the current (in mA), and the motor's operating time (in seconds).
- If two tripods are available, you can clamp the motor and the syringe and align the stream of water so that it hits the waterwheel.

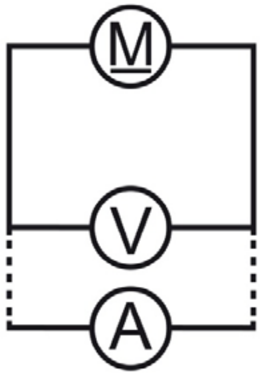

Fig. 10: Circuit diagram for measuring current and voltage.

2.4 Observation

- Record the maximum values you determined for the voltage (in mV), the current (in mA), and the motor's operating time (in s).
- Convert the measured values to volts (V) and amperes (A), and enter the values in a table based on the following template:

Height [cm]	Voltage [V]	Current [A]	Time [s]	Power [W]	Energy [Ws]

2.5 Analysis

The converted electrical energy is calculated from the power P and the time t:

$$\text{Energy } E = \text{Power } P \cdot \text{Time } t$$

Example for 0.03 W and 5.5 s $\Rightarrow$ $E = 0.03\ W \cdot 5.5\ s = 0.165\ Ws = 0.165\ J$

a) What influence does the height of the water's drop have on the energy given off by the water and thus on the power of the waterwheel?
b) Calculate the power and energy generated by the waterwheel from the values you measured and enter them in the table.
c) What experiment setups would you choose to generate the greatest amount of electrical energy with the waterwheel? Explain your reason.

2.6 Questions

Power plants generate surplus electrical power overnight that should be stored for consumption during the day. How would you develop a technical facility using water turbines to build a functional storage system?

3 Electrical energy from wind power

Two groups of students can conduct this experiment simultaneously.

3.1 Apparatus and materials

- 5 connecting cables, alligator clip to alligator clip
- 1 digital multimeter
- 1 dual propeller for small solar motor
- 1 LED, red (clear case), 1.7 V
- 1 measuring cable assembly, banana plug to alligator clip, red and black for each
- 1 plant clip as motor holder
- 1 propeller (for large solar motor)
- 1 solar motor, large, iron armature, 0.4 V/25 mA
- 1 solar motor, small, bell-type armature, 0.1 V/2 mA*

*Since only one motor is available, you must pass it around to the other groups after you have used it.

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

3.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

3.3 Conducting the experiment

- Connect the large solar motor (25 mA) to the small, highly sensitive solar motor (2 mA) and try to get the large motor to run by blowing on the small motor's dual propeller.
- Attach an LED to the small, highly sensitive solar motor (2 mA) (pay attention to the poles; the long terminal pin of the LED is the positive pole) and blow hard until the LED illuminates briefly. Determine the voltage by attaching the alligator clips of the multimeter to the pins of the LED.

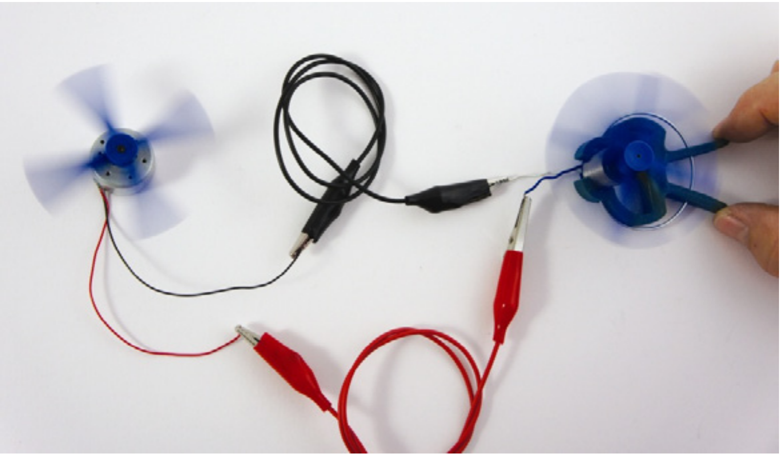

Fig. 11: Experiment setup for operating the large motor by using the small motor as a wind turbine. It's best to hold the small motor using the plant clip.

- Attach the measuring cables of the multimeter to the small, highly sensitive solar motor (2 mA) with two propellers stacked on top of each other (“dual propeller”); pay attention to positive pole and negative pole. Determine the highest voltage (in mV) and the highest current (in mA) you can reach by blowing on the dual propeller.
Repeat the experiment and have your partners blow on the propeller. Enter your partners’ results in the table.

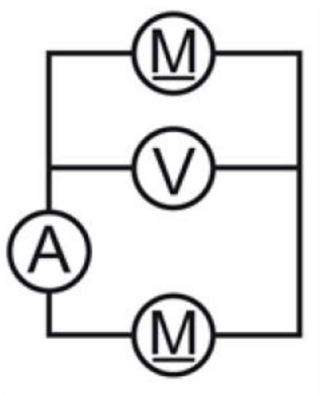

Fig. 12: Circuit diagram for measuring current and voltage.

3.4 Observation

- Record the maximum voltage (in mV) and maximum current (in mA) you reached.
- Convert the values to volts (V) and amperes (A), and enter the values in a table based on the following template:

Test	Voltage [V]	Current [A]	Power [W]
1			
2			
3			

- How high must the voltage (in mV) be roughly so that the LED visibly illuminates?

3.5 Analysis

a) Calculate the achieved power of the wind turbine.
b) What influence does the wind force, thus the force of your blowing, have on the power of a wind turbine?

3.6 Questions

What simple changes would you make to the wind turbine to increase its power output?

4 Conversion of electrical energy into chemical energy and vice versa

Two groups of students can conduct this experiment simultaneously.

4.1 Apparatus and materials

- 1 accumulator, 9 V
- 4 connecting cables, alligator clip to alligator clip
- 1 electrolytic cell
- 1 lighter or matches
- 2 one-way cocks
- 1 pair of safety goggles for each student
- 1 piece of silicone tube 7/4 mm, approx. 3.5 cm long
- Saturated soda solution **
- Solar motor, small, bell-type armature, 0.1 V/2 mA*
- 3 syringes, Luer lock, 10 ml
- 2 test tubes, plastic (polypropylene), mini

*Since only one motor is available, you must pass it around to the other groups after you have used it.
**If soda solution is not yet available, you must prepare it. Your teacher will tell you how.

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

4.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.

- Wear safety goggles during the entire experiment! If soda solution splashes into your eye or onto your skin, immediately rinse your eye or skin thoroughly with clear water.
- Take care when working with a flame that you don’t burn yourself or start a fire.
- The gas mixture may be carefully ignited only in the mini test tubes made of plastic (PP).
- Do not ever short-circuit the accumulator! This results in a risk of explosion and fire.

4.3 Conducting the experiment

If no other group has conducted this experiment yet, you must first set up the electrolytic cell from the supplied parts (see Fig. 13). Remove the insulation (about 2 cm) from the ends of the supplied copper cables and bend the cables according to the accompanying figure (see Fig. 14). Connect each bent copper cable to a graphite electrode using a piece of tube (see Fig. 15) and mount the two electrodes on the rim of the cup. Now the electrodes are upright in the cup, and you can place the syringe cylinders over them (see Fig. 16).

Fig. 13: Parts for the electrolytic cells.

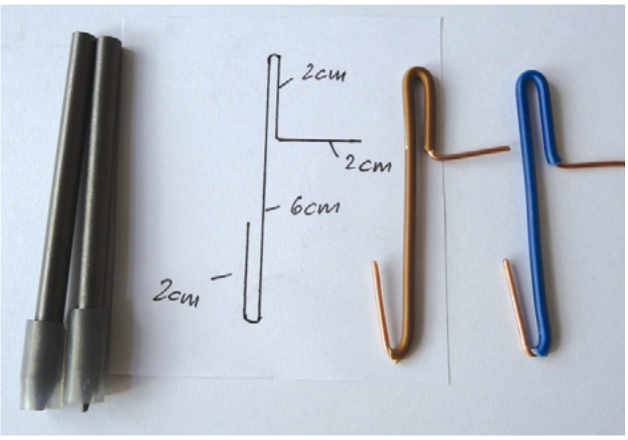

Fig. 14: Copper cables bent into shape.

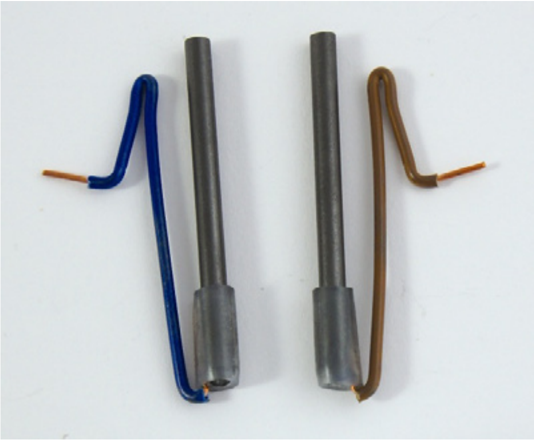

Fig. 15: The ends of the copper cables are positioned between the tube and electrode.

Fig. 16: Final assembly of the cell.

- Remove the plungers from two 10-ml syringes and screw a one-way cock on each syringe.
- With the cocks open, place the syringe cylinders on the graphite electrodes.
- Pour about 100 ml of saturated soda solution into the electrolytic chamber.
- Attach a piece of tube to a 10-ml syringe. Suction the remaining air from the two syringes of the cell and close the cocks (see Fig. 17).
- Attach the 9-volt accumulator to the electrodes (pay attention to positive pole and negative pole) and observe the formation of gas (see Fig. 18).
- When the graphite electrodes are surrounded by gas, attach the small solar motor (2 mA) to the electrodes in place of the 9-volt accumulator (see Fig. 19).


Fig. 17: Suctioning the remaining air; the cylinders fill with soda solution.

Fig. 18: Generating the gas after attaching the accumulator.


Fig. 19: The cell charged with electrolytic gas can also generate a current.

- Remove 6 ml of gas at the negative pole using a syringe. Hold a PP test tube upside-down and fill it with the gas. Ignite the gas with a flame.
- Repeat the test with a mixture of 4 ml of gas from the negative pole and 2 ml of gas from the positive pole.
- If the sunlight is sufficient, or by means of a bright light source, you can also use the solar cells provided in the experimentation set as a source of energy. Ask the other groups how the solar cells must be connected to achieve the highest possible voltage.

4.4 Observation

- Roughly determine the ratio of gas produced at the positive and negative poles.
- Record, if applicable, how many solar cells are necessary to start the formation of gas in the electrolytic cell.
- Record how long the connected solar motor rotated.
- Write down a summary of your perceptions from when you ignited the gas and gas mixture.

4.5 Analysis

a) What gases were produced at the negative/positive poles?
b) Record the ratio of volume of the gases produced. Explain this volume ratio based on the composition of water.
c) Indicate the voltage at which gas starts to form in the electrolytic cell if you assume a voltage of 0.5 volts per solar cell.
d) Into what form of energy was the electrical energy of the 9-volt accumulator or the solar cells mainly converted to in the electrolytic cell?
e) Explain why an electrolytic cell becomes a fuel cell when it is operated as a power supply.
f) In a fuel cell, electric current is generated from hydrogen and oxygen. Describe the chemical processes that occur.

4.6 Questions

a) If you have Internet access: Why is a soda solution used in this experiment instead of pure water? Search online for your answer.
b) In your view, how could an energy concept based on hydrogen technology be developed? Draw and label a sketch.