B7 Capacitor, hydrogen, redox flow – We store renewable energy

Energy stores are always necessary when electricity is generated at a location or time that differs from the location where or time when electricity is used. Energy stores are extremely important, especially as the use of renewable energies increases. Not all forms of energy are suitable for storage and must therefore be converted to other energy forms at a “loss”. For instance, surplus electrical energy can be stored in pumped storage power plants and converted back into electrical energy at a “loss” of only approx. 15%.
The following experiments will introduce some energy storage systems that are suitable for renewable energies.

1 Storage of electrical energy as chemical energy (hydrogen)

The electrical energy produced by wind or solar power plants can be stored in the form of hydrogen resulting from the electrolysis of water. This hydrogen is then available as an energy source for fuel cells or combustion engines. The principle of this hydrogen technology is covered in the following experiment.

1.1 Apparatus and materials

- 1 accumulator, 9 V
- Cardboard strip for mounting the solar cells
- 5 connecting cables, alligator clip to alligator clip
- 1 digital multimeter
- 1 dual propeller for small solar motor
- 1 electrolytic cell
- 1 lighter or matches
- 1 measuring cable assembly, banana plug to alligator clip, red and black for each
- 2 one-way cocks (to fit 7/4 mm tube and Luer lock)
- 1 pair of safety goggles for each student
- 1 piece of silicone tube 7/4 mm (to fit Luer lock), approx. 3.5 cm long
- 4 rubber bands for mounting the solar cells
- Saturated soda solution**
- 1 solar motor, small, bell-type armature, 0.1 V/2 mA*
- 3 syringes, Luer lock, 10 ml
- 2 test tubes, plastic (polypropylene), mini

*This motor must be shared with the other groups.
**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.

1.2 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.

1.3 Conducting the experiment

Preparation:
If no other group has conducted this experiment yet, you must first set up the electrolytic cell from the supplied parts (see Fig. 1). 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. 2). Connect each bent copper cable to a graphite electrode using a piece of tube (see Fig. 3) 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. 4).

Fig. 1: Parts for the electrolytic cell.

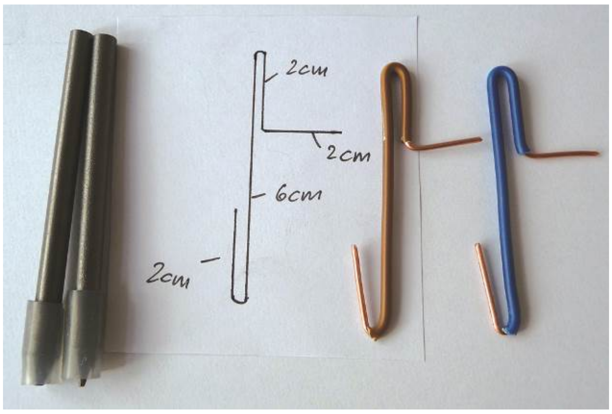

Fig. 2: Copper cables bent into shape.

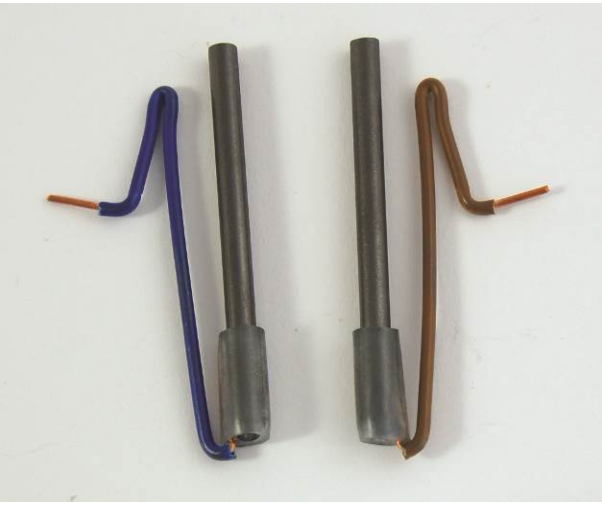

Fig. 3: The ends of the copper cables are inserted between the tube and electrode.

Fig. 4: 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. 5).

1.3.1 Step 1: Electrolysis of water

- Attach the 9-volt accumulator to the electrodes (pay attention to positive pole and negative pole) and observe the formation of gas (see Fig. 6).

Fig. 5: Suctioning the remaining air; the cylinders fill with soda solution.

Fig. 6: Generating the gas after attaching the accumulator.

Fig. 7: The cell charged with electrolytic gas can also generate a current.

1.3.2 Step 2: Oxyhydrogen test

- Remove 4 ml of gas at the negative pole and 2 ml of gas at the positive pole using a syringe. Hold a PP test tube upside-down and fill it with the gas.
- Ignite the gas with a flame. Don't be startled by the noise!

1.3.3 Step 3: Wind generator

- Attach the electric motor to the multimeter (measurement range 2,000 mV) and make the propeller rotate by blowing on it hard. If the multimeter indicates a negative value, you must reverse the connections.
- Connect the solar motor to the electrolytic cell (pay attention to polarity) and blow hard on the dual propeller about ten times.
- Briefly hold the propeller still after you blow on it the last time, let it go again, and count the number of seconds that the propeller continues to rotate (see Fig. 7).

Fig. 8: Measurement setup for determining the minimum voltage generated during electrolysis by means of solar cells.

Fig. 9: Make sure that the alligator clips do not touch when you hook them up, or a short circuit will occur.

Fig. 10: Mounting the solar cells on a cardboard strip using rubber bands.

1.3.4 Step 4: Solar cells

- Remove the two syringes over the graphite electrodes.
- Connect one solar cell after another in series to the electrolytic chamber until you detect the first gas bubbles at the electrodes. (If you need more than two solar cells, the other groups must lend you their solar cells).
- Mount the solar cells on a cardboard strip using the rubber bands. Make sure when you attach the wires that you do not cause a short circuit (see Fig. 9).
- Using the multimeter, determine the voltage at which gas begins to form.

1.4 Observation

- Describe the volume ratio of the gases produced at the negative and positive poles.
- Note how long the attached solar motor rotated in step 1.3.3 (in seconds). Also note the measured voltages.
- Describe what happens when you ignite the gas mixture.

1.5 Analysis

a) What gases were produced at the negative and positive poles?
Explain how you can verify them.
b) Write the reaction equation for the electrolysis of water (see Section 1.3.1) and explain whether the reaction is endothermic or exothermic.
c) In the fuel cell, electrical energy is produced by the reaction of the available gases (see Sections 1.3.3 and 1.3.4). Write the corresponding reaction equation and explain whether the reaction is endothermic or exothermic.
d) Note how many solar cells (0.5 volts) are necessary to split the water into hydrogen and oxygen electrolytically. Determine the decomposition voltage of the water.
e) Explain what happens when you blow on the propeller in the electrolytic cell and why the propeller continues to rotate after you stop it briefly.
f) What type of technical facility using an electrolytic cell would be suitable to store electrical energy, for example, from wind power plants? Draw and label a sketch.

1.6 Questions

What concept would you develop for transporting the energy-rich hydrogen over long distances to consumers and converting it back into electrical energy there?

Note: It is not necessary to transport oxygen, since it is available worldwide in the air (the oxygen content of air is about 21%).

2 Direct storage of electrical energy in capacitors

2.1 Apparatus and materials

- 5 connecting cables, alligator clip to alligator clip
- 1 Gold Cap capacitor, 0.22 F
- 1 lamp with halogen light bulb, optional
- 1 LED, red (red case), 5 V
- 2 plant clips (as test tube holders)
- 4 solar cells, 0.5 V/150 mA
- 1 solar motor, small, bell-type armature, 0.1 V/2 mA*
- 1 test tube, plastic (polypropylene), mini
- 1 watch

*Since the kit includes only one motor, the students will need to take turns using it.

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

In all experiments with the capacitor, do not short-circuit the capacitor. This means do not make any direct connection between the positive pole and the negative pole without placing a load in-between. Pay attention to correct polarity! We recommend that you insert the capacitor into the opening of the mini test tube and mark the polarity. The holder in the plant clip makes the experiment setup clearer.

Fig. 11: Gold Cap capacitor in holder.

2.3.1 Step 1

- Connect four solar cells (0.5 volts) in series (positive pole-negative pole-positive pole-negative pole) and connect them to the capacitor (positive pole to positive pole and negative pole to negative pole).
- Charge the capacitor for one minute.
- Ensure that the solar cells are well illuminated. If bright direct sunlight is not available, a halogen light bulb, for example, is perfectly suitable (approx. 5 – 10 cm distance from the solar cells).

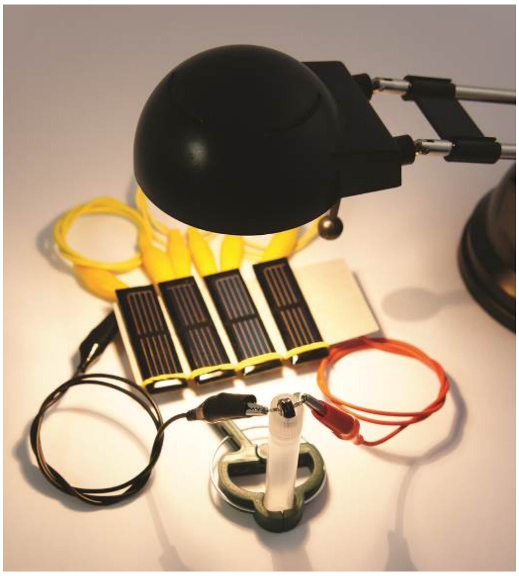

Fig. 12: Charging the capacitor.

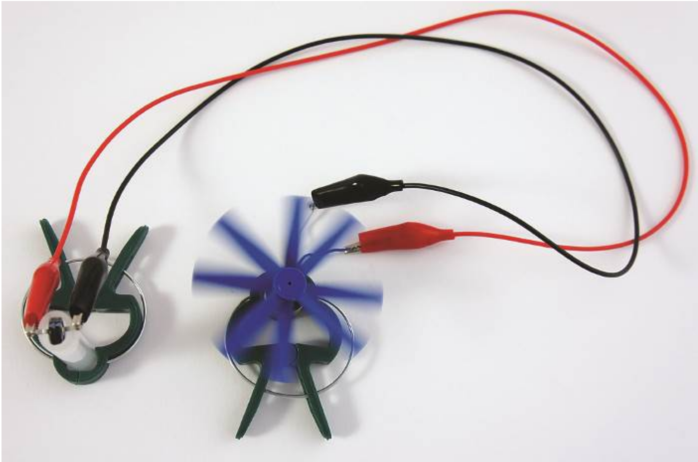

Fig. 13: Motor being operated with the capacitor. The same setup also applies to charging the capacitor with the “wind turbine generator“.

2.3.2 Step 2

Connect the small solar motor (2 mA) to the capacitor in place of the solar cells.
Determine the propeller’s operating time (in minutes) and record it.

2.3.3 Step 3

- Charge the capacitor again for one minute as described in 2.3.1 and then connect a light-emitting diode as the load (pay attention to polarity: long terminal pin = positive pole, short terminal pin = negative pole).
- Determine how long the LED is powered in minutes and record the time.

2.3.4 Step 4

- Attach the electric motor to the multimeter (measurement range 2,000 mV) and make the propeller rotate by blowing on it hard. If the multimeter indicates a negative value, you must reverse the connections. You now know the positive and negative poles for properly connecting the motor to the capacitor.
- Connect the solar motor to the capacitor and make the propeller rotate by blowing on it hard ten times (pay attention to polarity).
- Briefly hold the propeller still after you blow on it the last time, let it go again, and determine the propeller’s operating time (in seconds).

2.4 Observation

Write down a summary of your observations.

2.5 Analysis

a) Name the component in Step 3 that is the power generator in a particular situation and which component is the load.
b) Compare the capacitor's charging time with the motor's operating time and explain the difference.
c) Compare the time the LED was powered with the motor's operating time and explain the difference.
d) Explain why the solar motor continues to rotate after you stop blowing, and even in the same direction.
e) Describe the processes in the Gold Cap capacitor during charging and discharging (use the figure as an aid). Keep in mind that direct current voltage is applied to the two electrodes of activated carbon and that the electrolyte is split into ions. Why is this called a double-layer capacitor?

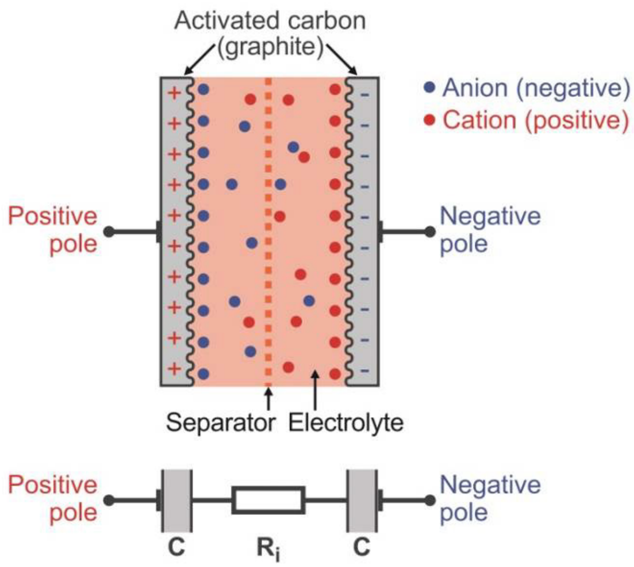

Fig. 14: Gold Cap capacitor

2.6 Questions

Capacitors, and especially Gold Cap capacitors, are used to temporarily store relatively large volumes of electrical energy. This isn't the case just for electric brakes in racecars, trucks, and trains. Cell phones also have Gold Cap capacitors to compensate for power fluctuations. Another example of application is solar watches, which normally no longer run on batteries, but the solar cells integrated into the watches charge a Gold Cap capacitor. How much capacity must a capacitor have for a watch to run for up to 48 hours without sunlight at a consumption of 0.2 mA and 3 volts?

3 Storage of electrical energy in a zinc-iodide cell (redox flow)

The principle of storing electrical energy in redox flow cells is to be described based on the example of a zinc-iodide cell. Large plants with this type of cell system can be used as energy buffers in modern power supply grids to balance out differences in power generation and power consumption. In redox flow cells, the substances generated during electrolysis (endothermic reaction) are stored in separate tanks in order to use them to produce electrical energy again when there is a demand for energy, according to the principle of the galvanic cell (exothermic reaction).

3.1 Apparatus and materials

- 4 connecting cables, alligator clip to alligator clip
- 4 solar cells, 0.5V/150mA
- 1 solar motor, small, bell-type armature, 0.1V/2mA ∅
- 1 zinc-iodide cell

3.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.
The zinc-iodide cell must not be disassembled, or it will no longer be functional and irritant chemicals could leak out.

3.3 Conducting the experiment

3.3.1 Step 1

- Use the alligator clips to connect the small solar motor to the graphite electrodes (pay attention to polarity) and make the propeller rotate by blowing on it hard ten times. Record approximately how long (in seconds) the propeller rotates after the charging by blowing.
- Briefly hold the propeller still after you blow on it the last time, and then let it rotate again independently.
- Have the other members of your group try the same thing. Which group member got the propeller to rotate for the longest amount of time during discharging after blowing on it?

3.3.2 Step 2

- Connect the four solar cells in series to the zinc-iodide cell. Pay attention to the polarity (positive pole to positive pole and negative pole to negative pole). Allow bright light to shine on the solar cells for approx. 1 minute.
- Then connect the solar motor to the cell. How long does the motor run?

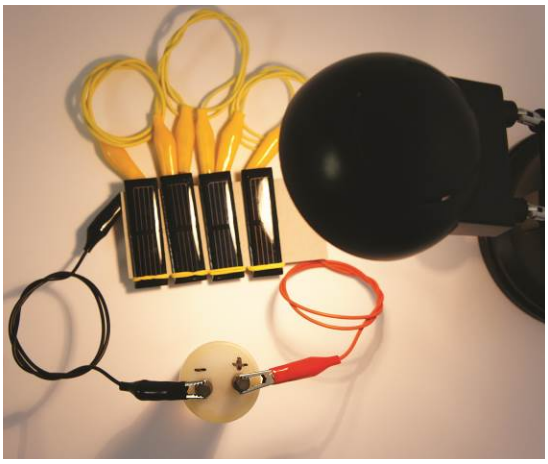

Fig. 15: Zinc-iodide cell during charging with four solar cells.

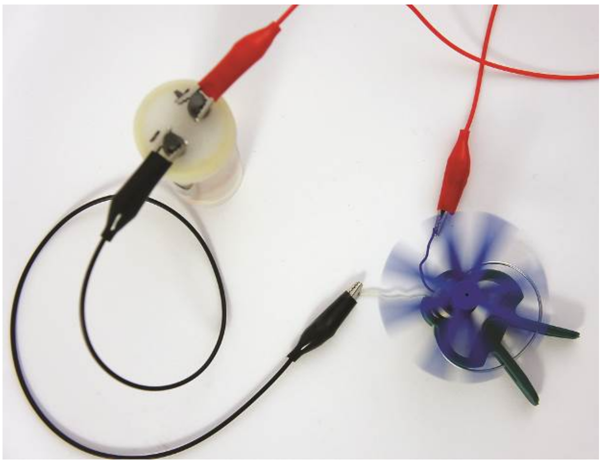

Fig. 16: Solar motor connected to the solar cell.

3.4 Observation

- Write down a summary of your observations.
- Did you detect a color change in the zinc-iodide cell's electrodes?

3.5 Analysis

a) Describe the changes after blowing on the propeller and after connecting the solar cells to the negative pole and positive pole.

b) Describe the chemical reactions that take place in the zinc-iodide cell when electrical energy is fed to it (charging process).

c) Describe the chemical reactions that take place in the zinc-iodide cell when a load is connected to the cell (discharging process).

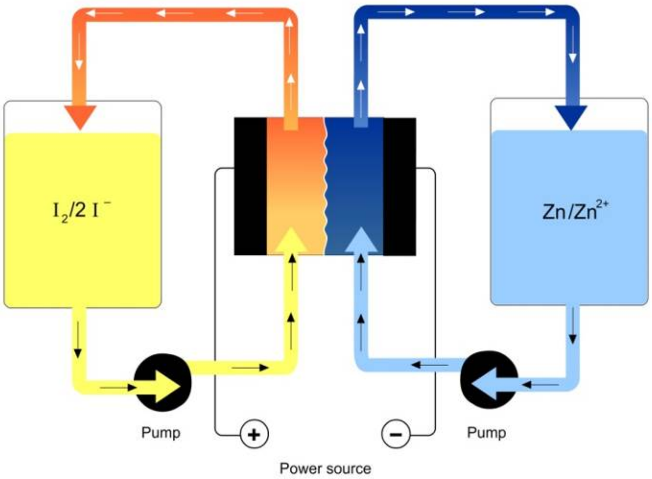

Fig. 17: Redox flow cell.

d) What changes should be made to the zinc-iodide cell used to more closely correspond to the model of a redox flow cell? Make a suggestion.

3.6 Questions

Where could energy storage systems based on the principle of the redox flow cell be used most effectively?