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

Note: This answer sheet will go into the analyses for the individual subexperiments only if experience shows that there could be particular difficulties.

1 Electrical energy from the radiant energy of light

1.6 Questions

a) What kind of circuit is best for reaching the highest voltage or the highest current?

Answer: The voltages are added together in a series circuit, and the currents are added together in a parallel circuit. Students should be able to confirm this based on their results. Since we do not have 100% identical solar cells (they differ somewhat in terms of voltage, current, and internal resistance), we cannot confirm this precisely in the experiment.

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

Answer: The power output always remains the same for the two circuits. Only the division into current and voltage differ. As before, there can be the appearance of deviations from this principle (see above).

2 Electrical energy from hydropower

2.5 Analysis

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?

Note: The greater the height of the water's drop, the greater the water's potential energy and thus also the kinetic energy of the stream of water when it hits the blade. The amount of energy transferred is thus greater as the height of the drop increases, and the speed and the rotational energy of the waterwheel also increase. We can also say that the greater the height of the drop is, the longer the water is accelerated and the faster it is moving when it hits the waterwheel, which causes the waterwheel to rotate faster.

b) Calculate the power and energy generated by the waterwheel from the values you measured and enter them in the table.

Note: The calculation method is clear. However, the numerical results greatly depend on the values actually measured. See the teacher instructions for typical values.

c) What experiment setups would you choose to generate the greatest amount of electrical energy with the “water turbine”? Explain your reason.

Note: The problem with waterwheels is that much of the water flows around the blades or bounces off unused. For this reason, traditional mill wheels are usually less than 30% efficient. We could improve our experiment setup by using a hose and nozzle to spray the water exactly on the blades instead of allowing the water to flow freely. In addition, we would have to optimize the shape of the blades to minimize the amount of water that splashes away unused. This would then simulate the principle of the Pelton turbine. (But also by using a closed turbine housing with an optimized shape, additional rigid “guide blades,” and an optimized rotor blade shape, we can compel the water to release over 90% of its energy on the rotor, as occurs with the Francis and Kaplan turbines.)

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?

Note: Surplus energy is generated not only at night. Particularly when renewable energies such as wind and solar electricity are used, surpluses and shortages occur constantly in electricity production. The traditional solution for this is a “pumped storage hydroelectric plant.” This type of hydroelectric plant works between two water reservoirs: a higher-elevation lake (upper reservoir), usually artificial, and a lower-elevation lake (lower reservoir), which can also be a dammed river. The height of the drop must be as great as possible. Small pumped storage power plants begin at a drop height of approx. 80 m, and very powerful power plants have a drop of over 2,000 m. However, the power output depends not only on the height of the drop, but also on the volume of water available per second.

3 Electrical energy from wind power

3.6 Questions

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

Answer: Anything that does not serve to collect the wind energy should slow down the airflow as little as possible. This means that the generator must be integrated into an aerodynamically optimized housing and should be mounted on a support that is as thin as possible.
The main problem, however, is the propeller. The profiles of our propeller blades are rather flat. Our wind turbine therefore works primarily as a resistance force type turbine, because the airflow simply pushes the blades away. However, efficiency is maximized when the wind turbine works as a lift-type wind turbine. These propellers have a profile like airplane wings or airplane propellers. The air flowing around has to travel different distances on the two sides of the propeller. According to Bernouilli, the divided airflows

have different speeds, resulting in a pressure difference that pushes the blade away. The theoretically possible maximum efficiency for wind turbines of 59.3% can be achieved only with such propellers. Today's optimized three-bladed wind turbines achieve a solid 50% efficiency.

4 Conversion of electrical energy into chemical energy and vice versa

4.5 Analysis

a) What gases were produced at the negative/positive poles?

Note: Hydrogen is produced at the cathode (negative pole) and oxygen at the anode (positive pole). The following reactions take place in the process.

Cathode: $2\ H_3O^+ + 2\ e^- \rightarrow H_2 + 2\ H_2O$

Anode: $4\ OH^- \rightarrow O_2 + 2\ H_2O + 4\ e^-$

b) Record the ratio of volume of the gases produced. Explain this volume ratio based on the composition of water.

Note: The volume ratio is one oxygen atom for every two hydrogen atoms, because a water molecule consists of two hydrogen atoms and one oxygen atom.

c) Indicate the voltage at which gas starts to form in the electrolytic cell if you assume a voltage of 0.5 V per solar cell.

Note: Theoretically, the decomposition voltage of pure water with ideal electrodes is approx. 1.25 volts (platinized platinum). Due to so-called overvoltage effects, however, you need up to 16 volts. This overvoltage drops if the water is made acidic or basic. With our graphite electrodes in sodium carbonate solution, the voltage should be approx. 1.7 volts. We therefore need at least three, more likely four solar cells connected in series.

d) Into what form of energy was the electrical energy of the 9-V accumulator or the solar cells mainly converted in the electrolytic cell?

Note: In the electrolytic cell, electrical energy is converted into chemical energy.

e) Explain why an electrolytic cell becomes a fuel cell when it is operated as a power supply.

Note: Since water has less chemical energy than hydrogen and oxygen and since the electrolytic process is reversible, water can be produced again from hydrogen and oxygen. However, since gaseous hydrogen and oxygen make very poor contact with the graphite electrodes, the fuel cell in our experiment is very weak. Real fuel cells work with platinum electrodes, which adsorb both gas molecules atomically and can therefore receive or donate electrons extremely well.

f) In a fuel cell, electric current is generated from hydrogen and oxygen. Describe the chemical processes that occur during this process.

Note: The simulation “Fuel cell – operating principle” is available on the media portal of the Siemens Stiftung; see the media package for the experiment “Experimento | 10+: B6 Renewable energies.”

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.

Answer: A soda solution is used to reduce the electrolysis voltage required. With pure water, this voltage is very high. (See notes on the analyses.)

b) In your view, how could an energy concept based on hydrogen technology be developed? Draw and label a sketch.

Answer: A drawing of an elaborate overall concept for integrating hydrogen technology into the energy supply is available on the media portal of the Siemens Stiftung; see the “Energy utilization chains” medium in the media package for the experiment “Experimento | 10+: B6 Renewable energies.”