Tasks
Model 1 – Manual generator / Muscle power

Construction task

Build model 1 according to the instructions. Observe the following points while building:

- The gear drive should move easily. The spur gears may not get stuck on the axle bearings, so as to prevent any unnecessary frictional loss. The axes may not shift in either a radial or axial direction.
- The red cable of the solar motor generator is connected to the input jack on the LED marked with a + (plus pole).
- The LED is only designed to show how the solar motor can be used to generate electricity. It may be operated with a maximum of 2 V direct current. Higher voltages will immediately destroy it.

The solar motor generator is the heart of this model. It is driven with the help of a gear drive.

Each gear converts the movement of a drive into the movement of one or more drives. The manual generator has two parallel axes. One is the input (crank) and the other is the output.

The Z40 gear of the input axle interlocks with a Z10 gear on the drive axle. The Z40 gear of the output axle, in turn, interlocks with a Z10 gear on the motor shaft of the generator.

The fischertechnik solar motor (0.5-2V) is a DC machine and can both convert the rotational energy produced into electrical current (generator function) as well as be operated with direct current itself (motor function).

In our model, the rotational energy generated by activating the hand crank is converted into electrical energy by the generator. As you can easily see, the small Z10 gear on the generator must turn extremely quickly to make the LED light up. The manual generator, therefore, is designed as a two-stage transmission gear.

Topic task

1. How often does the small Z10 gear turn on the generator when you turn the hand crank one time? Calculate the gear ratio for this two-stage gear. Note: In general, the gear ratio of a multi-stage gear is the product of the gear ratios for the individual stages.
2. Turn the hand crank counter-clockwise as well. Why can't the LED light up with this direction of rotation?

3. What forms of energy conversion do you use with the manual generator model?
4. What other forces can the power of your muscles replace and use a generator to generate power?
5. What term is used to graphically describe the relation between the two variables of current and voltage of electrical components?

Experimental task

1. Complete measurements to determine from what voltage U in V and current I in mA the green LED lights up. What conclusions can you already draw from your measured values?
2. Optional: Repeat the experiment with different colour LEDs.

Model 1 – Manual generator / Muscle power

Joerg Torkler

Topic

Renewable energy introductory model Flow of energy and energy conversion.

Learning objective

- Forms of energy and energy converters. From kinetic energy (muscle power) to electrical energy. Use of gear technology.
- The practical application of a multi-stage gearbox and calculating the speed ratio.
- Technical use of a generator.
- Forward voltage. A property of semiconductor diodes.

Time required

45 minutes.

Solution sheet model 1 – Manual generator / Muscle power

Topic task

1. The Z40 on the drive axis interlocks with the Z10. The Z10 is permanently connected to a Z40 via an axle.
   The Z40 of the drive axle then interlocks with another Z10 on the generator shaft. When the Z40 completes a rotation, the first Z10 and therefore also the Z40 complete four rotations. Therefore, the second Z10 makes 4 x 4 = 16 full rotations. The gear ratio for the two-stage transmission gear is therefore 1:16.

   Formula

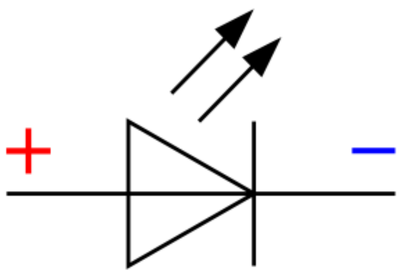
   Gear stage: i1= $\frac{zAbtrieb}{zAntrieb} = \frac{10}{40} =$ 10:40 = 1:4

   Gear stage: i2= $\frac{zAbtrieb}{zAntrieb} = \frac{10}{40} =$ 10:40 = 1:4

   The gear ratio for the overall gear itot is then calculated by multiplying the individual gear ratios for the respective gear stages.

   itot = (1 * 1):(4*4) = 1:16

2. To make an LED light up, you must switch it in the forward biased direction. The electrical current can only flow through an LED in one direction. When voltage is applied, electrons or holes are created in the barrier layer of the p-n transition. There is a recombination of electrons and holes. The energy released is output from the diode in the form of light.

   LED wiring symbol

   When you choose the technical current direction (charge flows from plus to minus), then you say that current flows from the anode (+) to the cathode (-).

3. Turning the hand crank causes the generator to convert kinetic energy into electrical energy (current). The second energy converter is our LED, which converts the electrical energy into radiant energy and heat.

4. Wind power or hydropower

5. **Characteristic curve.** The current voltage characteristic curve is characteristic for the respective component, and is therefore considered an important parameter. The relation between the measured values is shown as

a line in a flat coordinate system. The LED is a semiconductor element (semiconductor diode), and its characteristic curve is **non-linear**.

Experimental task

1. Try to show with LEDs that an LED always needs a minimum voltage to output a minimum amount of light. This minimum voltage (forward voltage, threshold voltage) is around 80% from ULED. The maximum permitted current of an LED initially has no influence on this. The reason for this is in how the semiconductor crystal works. Current cannot flow at a very low voltage (e.g. U = 1.5 V for batteries). Only when the current is higher are sufficient free electrons released from the inner crystal lattice of the semiconductor material, so that current can flow in the LED.

   Source: Thomas Habig: LEDs mit Vorwiderstand. ft:pedia 2/2011, p. 17.

2. Optional: In this experiment, we notice that diodes have colour-specific forward voltages. Therefore, the characteristic curves of green, yellow or red LEDs differ.

Tasks
Model 2 – Water turbine / hydropower

Construction task

Build model 2 according to the instructions. Observe the following points while building:

- The shaft of the waterwheel should move smoothly so that the belt (O-ring) on the transmission wheel can transmit the rotational movement to the drive wheel of the solar motor.
- The red cable of the solar motor generator is connected to the input jack on the LED marked with a + (plus pole).
- The LED is only designed to show how the solar motor can be used to generate electricity. It may be operated with a maximum of 2 V direct current. Higher voltages will immediately destroy it.
- Also ensure that the motor does not come into contact with water.
- Use the additional extension cable with the light for measurements with the multimeter, and note the distance to the water source.

A water turbine is a turbine that allows us to make use of hydropower. In a hydropower plant, the kinetic energy of the flowing water is converted into mechanical energy using the water turbine.

As the turbine shaft rotates, it drives a generator that converts the rotational energy into electrical current.

In our model, the waterwheel transmits its rotational energy to the transmission wheel. The rotational movement of the transmission wheel is then transmitted to the drive wheel of the solar motor via a round belt (O-ring) This type of drive is called a belt drive.

The solar motor here acts as a generator and converts the rotational energy into electrical energy, causing the LED to light up.

Topic task

1. Electricity from hydropower. Hold the water wheel under a tap and let it spin fast enough to light up the LED. Note the direction of rotation. What factors directly impact the speed of the generator shaft in your experiment, and does this increase the performance of the water turbine in generating power?
2. Hydropower is the only renewable energy source that can also be stored. How can hydropower be stored?

3. What is the advantage of water storage power plants over other types of hydropower plants?
4. What regions offer the best conditions for using hydropower?
5. Even if regional conditions are good, there may be arguments against actually constructing a hydropower plant. What are they?

Experimental task

1. Prove your experiments for topic task 1. Measure the voltage at different heights of the stream of water to the waterwheel, and enter your measurement results on the sheet. What observations can you make, and why?
2. What happens to the LED during the experiment?

Model 2 – Water turbine / hydropower

Joerg Torkler

Topic

We will be investigating hydropower using a model and learning about alternative types of energy generation in the context of renewable energy.

Learning objective

- Forms of renewable energy and energy converters. From kinetic energy (hydropower) via mechanical energy (generator) to electrical energy.
- Types of power plants and storing hydropower
- Ecological aspects of using hydropower
- Performance and effectiveness of water turbines
- The practical use of a belt drive as a way to transfer movement or force between gear components that are far apart from one another.

Time required

45 minutes.

Solution sheet model 2 – Water turbine / hydropower

Topic task

1. The greater the height the water falls from, the greater the force of the water that can be used to generate energy. The relationship between the quantity of water (volume flow rate) and optimal alignment of the stream of water on the shovels of the water turbine also increase the rotational speed of the generator shaft in our model. The power it delivers should not be confused with the individual effectiveness of a turbine, which describes the efficiency of the turbine itself. The type of turbine and age of the turbine play a role here, among other factors. To achieve optimal performance, the design of the turbine must be adapted to the different fall heights and water flow quantities.
2. In water storage power plants, the energy of the water is stored when the water in a river is dammed up to create a reservoir. As needed, the water in the reservoir is fed through the hydropower plant to produce electricity. Electrical energy is stored in the form of the potential energy of surface water.

   In pump storage power plants, the water is pumped to a greater height in the reservoir using energy (excess electricity). The water is used as the storage medium.
3. Water storage power plants are controllable, meaning they can be used exactly when electricity is needed.
4. A) Mountainous regions with large amounts of precipitation and significant slope differences are good locations for hydropower plants.
   B) Large rivers with height differences (run-of-river power plants). Because the water flows continuously, electricity is generated 24 hours a day. However, in contrast to pump storage power plants, no water (no potential energy) can be stored.
   C) Bays and river deltas in oceans and seas where tidal power plants can use the potential energy and kinetic energy of the water as it ebbs and flows to generate electricity.
5. Building hydropower plants can have major impacts on the landscape, people, and animals. Huge reservoirs must be created for storage power plants; in some circumstances, this may even require people to move from their homes. There may be native animal or plant species in the affected region whose habitat could be significantly impacted by the construction of a hydropower plant.

Experimental task

1. Voltage increases the higher the water jet is positioned above the turbine. You learned the reason for this in topic task 1. As the fall height of the water increases, the water pressure on the turbine increases, and thereby the rotational speed. This causes the output voltage on the generator to increase.

2. The LED becomes brighter, the more voltage is generated by the generator, and current can flow through the LED.

Tasks
Model 3/4/5 – Wind turbine / Wind energy

Construction task Model 3

Build model 3 according to the instructions. Observe the following points while building:

- The shaft of the windmill should move smoothly so that the belt (O-ring) on the transmission wheel can transmit the rotational movement to the drive wheel of the solar motor.
- The black cable of the solar motor generator is connected to the input jack on the LED marked with a + (plus pole).
- The LED is only designed to show how the solar motor can be used to generate electricity. It may be operated with a maximum of 2 V direct current. Higher voltages will immediately destroy it.

In a wind power plant, the kinetic energy of the air (wind power) is converted into electrical energy.

The blades of modern wind turbines are called rotor blades, and are held together by a rotor hub. The rotor hub and rotor blades make up the rotor. The rotor is at the start of the functional chain of a wind power plant. It is attached to a shaft, and the rotation of the shaft is used to drive a generator that converts the rotational energy into electrical current.
We differentiate wind power plants based on their rotational axes. We differentiate between horizontal and vertical rotational axes.
In our model with a horizontal axis, the rotor actuated by the wind transmits its rotational energy to the transmission wheel. The rotational movement of the transmission wheel is then transmitted to the drive wheel of the solar motor via a round belt (O-ring) This type of drive is called a belt drive. This type of drive is not used in modern wind power plants (see model 5 – Wind turbine).

The design principle is similar to a typical windmill or sawmill. Actually, after electricity was discovered and the generator was invented, the first attempts to generate electricity with wind power were based on the concept of a windmill. Instead of converting the kinetic energy of the wind into mechanical energy, a generator was used to generate electrical energy. As fluid mechanics were developed over time, the structures and blade shapes also became more specialised. Modern windmills are much larger, and have a rotor diameter of approx. 90 to 126 meters.

The solar motor here acts as a generator and converts the rotational energy into electrical energy, causing the LED to light up.

Topic task

1. A wind turbine only starts to turn when there is a high enough wind speed. This is called the start-up wind speed. In contrast to models 4 and 5, model 3 is designed for strong wind. Hold a tabletop fan or powerful hair dryer in front of the rotor, first holding it far away. Then reduce the distance until the rotor blades begin to turn. Note the distance so that you can compare it to model 4 later. Alternatively, you can also keep the distance the same. In this case, note the setting at which the blades begin to turn. What other factors in addition to wind speed can influence the effectiveness of our windmill (with even rotor blades)? A little tip: Experimental tasks 1 and 2 will help you answer the question.
2. To assess the economic efficiency of a wind turbine, you must calculate its performance. How is the performance of a wind turbine calculated?
3. How many households can a 3 megawatt wind turbine supply that reached full load hours in 2000? A 4-person household uses an average of 3,500 kilowatt hours per year.
4. The energy a wind turbine can generate depends on the wind strength. What could help us decide to set up a wind turbine?
5. There are advantages and disadvantages to wind power as well. Which ones can you name?

Experimental task 1

1. During the experiment for model 1, the manual generator, you already discovered that an LED requires a minimum level of voltage to light up. Our windmill would have to turn very fast to generate this voltage. However, our windmill continues to generate energy even at a slower rotational speed. Measure the voltage on the generator at different distances from the fan, and note the results so that you can compare them later on with model 4. What conclusions can you already draw?
2. Shorten the rotor blades by removing the green plates, then compare the measured voltage values with those from the previous experiment. Do these results confirm your hypothesis from topic task 1?

Construction task Model 4

Build model 4 according to the instructions. Observe the following points while building:

- The shaft of the windmill should move smoothly so that the belt (O-ring) on the transmission wheel can transmit the rotational movement to the drive wheel of the solar motor.
- The black cable (with green flat plug) of the solar motor generator is connected to the input jack on the LED marked with a + (plus pole).
- The LED is only designed to show how the solar motor can be used to generate electricity. It may be operated with a maximum of 2 V direct current. Higher voltages will immediately destroy it.

There are two basic types of wind turbines. Those with a horizontal rotational axis (model 3) and those with a vertical rotational axis.

The oldest, most well-known wind power plants in the world are the vertical wind power plants that have been built since 1700 B.C. The major difference is that they are independent from the direction of the wind.
Over the centuries, inventors and engineers have worked to continuously improve the effectiveness of windmills. While the initial models were still built with flat blades, ongoing scientific discoveries on fluid mechanics (the understanding of the movements of fluid and gaseous media) resulted in new rotor designs (Savonius rotor, Darrieus rotor).

Experimental task 2

1. Our model also allows you to experiment with basic flow behaviour phenomena. Hold a hair dryer or fan in front of the rotor blades - first directly in front, then offset to the side. What conclusions can you draw from your observations, and why is this the case?
2. Now compare your results on start-up speed from model 3 with this model, and measure the voltage at different distances. What can you determine?

Construction task Model 5

Build model 5 according to the instructions. Observe the following points while building:

- The red cable of the solar motor generator is connected to the input jack on the LED marked with a + (plus pole).
- The LED is only designed to show how the solar motor can be used to generate electricity. It may be operated with a maximum of 2 V direct current. Higher voltages will immediately destroy it.

This model is closest to the design of a modern wind turbine. The aerodynamic properties of the rotor directly determine how much wind energy can be converted into mechanical work.

Experimental task 3

1. Now compare your results on start-up speed from model 3 and 4 with this model 5, and measure the voltage at different distances from your wind source. What can you determine?

Model 3/4/5 – Wind turbine / Wind power

Joerg Torkler

Topic

We will be investigating wind power with 3 different models and learning about alternative types of energy generation in the context of renewable energy.

Learning objective

- Forms of renewable energy and energy converters. From kinetic energy (wind power) via mechanical energy (generator) to electrical energy.
- Effectiveness and technical challenges when building wind power systems with different designs.
- Calculating potential of wind power.
- Using measuring equipment.
- Advantages and disadvantages of wind energy

Time required

45 minutes.

Solution sheet Model 3/4/5 – Wind turbines

Topic task

1. In addition to wind speed, the efficiency of a wind turbine depends on a) the work angle (the angle by which the rotor blades are turned in relation to the rotational axis). In our model with flat blade surfaces, a work angle of approx. 30 degrees will be most favourable.
b) in our model (flat blade surfaces) from the area of the rotor blades
c) the amount of bearing friction. Rotors, gears or generators can never be 100 percent efficient, because heat loss occurs due to bearing friction or friction between air molecules.
The power it delivers should not be confused with the individual effectiveness of a wind power generator, which describes the efficiency itself. The rotor type and design of the rotor blades play an important role here, among other factors. To achieve optimal performance, the design of the rotor blades must be adapted to the different wind conditions.
2. The power of a wind turbine is dependent on the wind and wind speed, air density and efficiency of the system. First the power of the wind is calculated, and then it is multiplied by the efficiency of the system.
3. To calculate the maximum possible current generation for a year, you must multiply the power of a wind turbine by the number of hours per year. Result: The wind turbine outputs 6 gigawatt hours. This is 6,000 megawatt hours, or 6,000,000 kilowatt hours. This could supply approx. 1714 households for one year.
4. Wind atlas. The wind atlas is an important instrument for planners, project managers and approval authorities to identify suitable locations for wind energy. When determining how suitable locations are for wind turbines, the windiness of the area also plays a role.
5. a) Advantages:
- There are no emissions of harmful gases such as carbon dioxide, nitrogen oxide and sulphur dioxide as with conventional power generation.
- Expensive imported raw materials (coal, oil) are eliminated
- The actual space used is minimal in comparison to other power generation plants
b) Disadvantages
- Wind cannot be stored. It must be converted immediately into electricity.
- The wind does not always blow at the expected strength.
- Animals, particularly birds, can be hit by wind turbines.

Experimental task 1

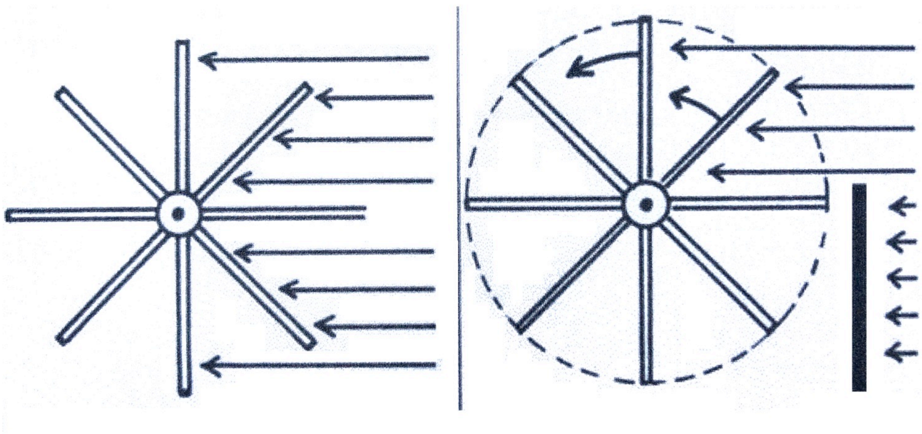
1. The wind does not always have to be blowing at top speed to evaluate the economic efficiency of a wind turbine. Wind turbines are designed and used so as to work with different wind speeds and directions. They are assigned to

wind classes. A wind turbine which turns continuously can deliver more electricity per year in some circumstances than a system which is designed for very strong winds, but must be switched off frequently to avoid storm damage. The wind speed at which a wind turbine automatically shuts off is called the shut-off speed.

2. Yes, the surface area of the rotor blades does influence the effectiveness of the wind turbine.

Experimental task 2

1. The wind hitting the rotor from the side makes it turn faster. Moving air exercises the same force on all bodies it hits. Rotational movement can only occur if the thrusts on two opposing blades or shovels are unequal.



2. Model 4 starts to turn earlier. It requires less wind force to generate energy. This is why vertical wind turbines are used at lower wind speeds and close to the ground.

Experimental task 3

1. The effectiveness of a wind turbine depends primarily on the optimal aerodynamic design of the rotor blades. The rotor is at the start of the functional chain of a wind power plant.

Tasks
Model 6 – Functional model / Solar energy

Construction task Model 6

Build model 6 according to the instructions. Observe the following points:

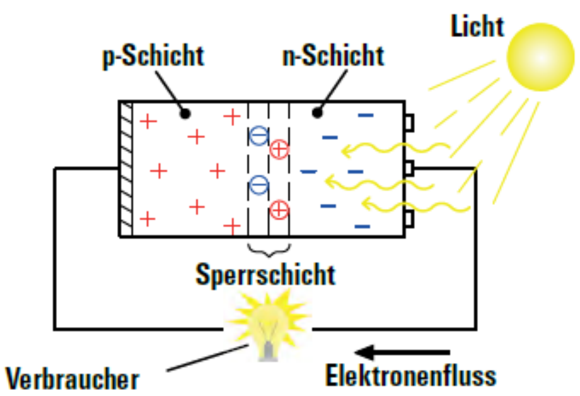
- Use a sufficiently strong artificial light source for your experiments (such as an incandescent bulb or halogen spotlight over 60 watts).
- Always keep a minimum distance away from the light source (depending on the light intensity, at least 30 cm), since the solar modules can become very hot.

Basic solar cell

A solar cell or photovoltaic cell is an electrical component that converts the radiant energy in the light directly into electric energy (direct current). Because we are using sunlight here, this is by definition a renewable energy source. The physical basis of the conversion is the photovoltaic effect.

Most solar cells are made of the semiconductor silicon. The silicon blocks are cut into slices approx. 0.5 millimetres thick. The slices are then contaminated with different foreign atoms, meaning they are purposefully contaminated to cause an imbalance in the silicon structure. This creates two layers, the positive p-layer and the negative n-layer.

To put it simply, the flow of electricity in the solar cell is created when electrons from the negative n-layer move to the positive p-layer after having been excited by the incident light, via the connected device (such as a solar motor, LED). The more light (or energy) hits the cell, the more the electrons move.



p-Schicht	p-layer
n-Schicht	n-layer
Licht	Light

Sperrschicht	Barrier layer
Verbraucher	Device
Elektronenfluss	Flow of electrons

Each solar module consists of two solar cells, connected in parallel. Each cell delivers a voltage of 1 V and a maximum current of 440 mA.

The solar motor has a rated voltage of 2 V, but begins turning at 0.3 V (start-up voltage) (idling, meaning that the shaft of the motor does not have to drive a model).

Topic task

1. Solar technology allows us to use the sun's energy in many different ways. What types of use are there?
2. What type of use did you build the functional model for? What specialist term is used to describe this use?

In general, we can differentiate between direct and indirect sunlight. Direct sunlight strikes the solar module directly, and is the strongest. Indirect or diffuse sunlight is when clouds cover the sun, or if the light is reflected.

The angle of incidence between the sunlight and solar module can also change, depending on the time of day and the season.

Experimental task 1

1. When converting power generation to photovoltaics, researchers ask themselves how they can achieve the best possible efficiency.

   Test structure:

   - Use just one solar module for this experiment
   - Direct a light source towards the solar module
   - Do not change the distance between the light source and solar module
   - The button is closed
   - A geo-triangle can help you determine the angle

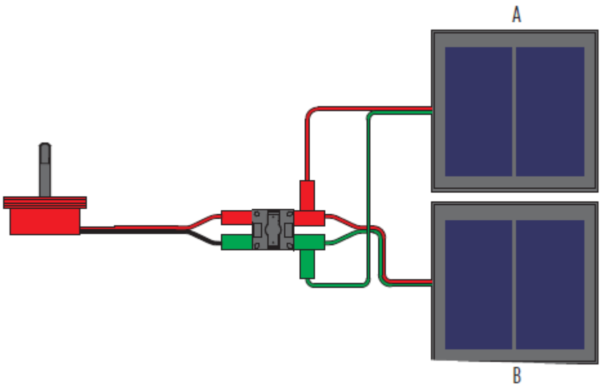
   Use the adjusting lever to change the angle of the solar module to the light source, and measure the voltage (V) to find out the angle of incidence for the light at which the solar module delivers the most energy.
2. Use the adjusting lever to change the angle of the solar module to the light source, and find out from which voltage the motor under load turns the indicator, and how much current is flowing when it does.

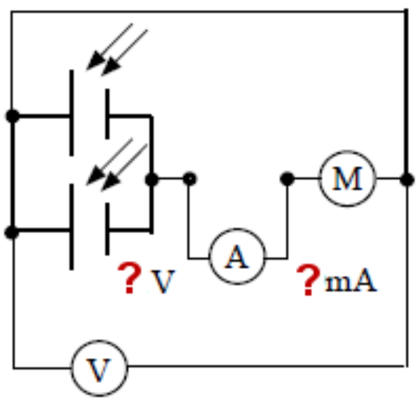
You will find that the motor cannot produce very much force if it is operated with only one solar module.

Additional solar modules can be connected in different ways. The overall effect of doing so will depend on whether they are connected in parallel or in series.

Experimental task 2

1. Now, connect the second solar module in parallel with the first module. The button is not shown on the image.





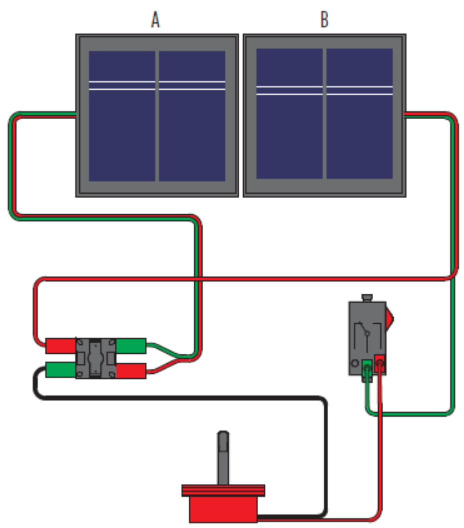
Measureme
nt setup

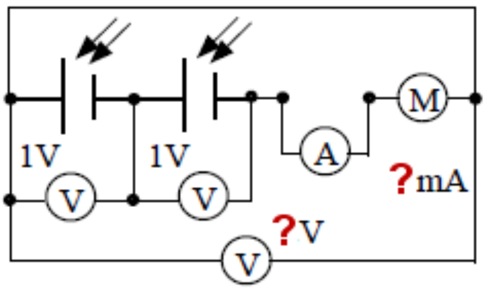
What happens to the voltage (V) and amperage (A) when both modules are connected in parallel?

2. Reduce the distance to the light source first with one module and then with two modules connected in parallel. Find out which motor variant (under load) can make the indicator move first.
3. In your observation, does the change affect the speed or torque of the motor?

Experimental task 3

1. Now, connect the second solar module in series with the first module.





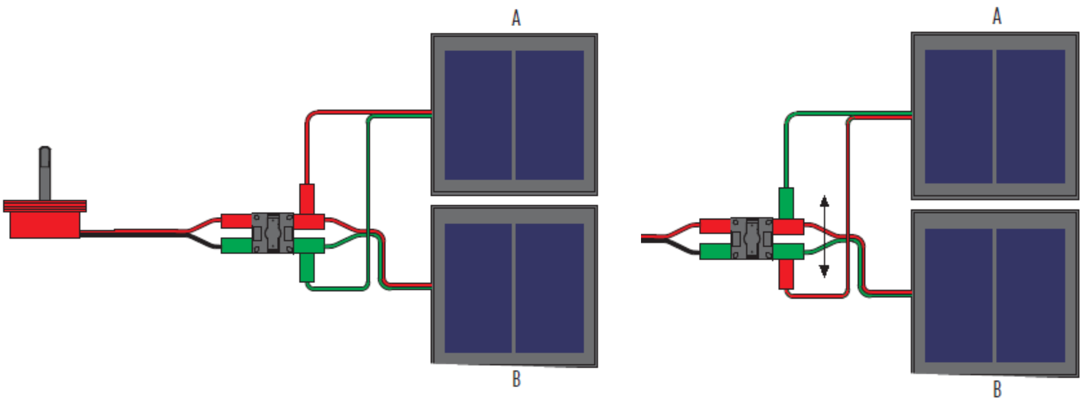
Measureme
nt setup

What happens to the voltage (V) and amperage (A) when both modules are connected in series?

2. Compare the rotational speed of the indicator between parallel and series connection with the same distance from the light source. What can you conclude from this?
3. Cover one solar module with a piece of paper or with your hand while the run indicator is turning. Do so both with the modules connected in parallel and with them connected in series. What can you observe while *shadowing the modules*?
4. Under what lighting circumstances is a parallel connection better than a series connection for your fischertechnik models?

Experimental task 4

1. Now you are an expert in wiring solar modules. There is a third option for connecting the modules to one another. This is called antiparallel wiring. To do so, change the wiring used in parallel connection by exchanging the red and green plugs on the second solar module.



What effect does antiparallel wiring have when you shadow the individual modules?

2. What is the electrical component that triggers the same effect called?

Solar vehicle construction task

To test out the different types of wiring, you can build the solar vehicle model for the following experiments.

Experimental task 5

What type of wiring did you choose, and why?

Storage of electrical energy - Goldcap

Unfortunately, our solar vehicle stops working as soon as they are away from the light source or in a shadow.

However, we can use an energy storage device to convert our solar car to an electric vehicle and operate it independently of the sun's energy.

The **Goldcap** contained in the building set is one such energy storage option. It consists of two pieces of activated carbon that are separated from one another by only a thin layer of insulation. The Goldcap stands out for its extremely high capacity. The capacitor you are using has a capacity of 10 F (Farad).

You can use the Goldcap like a small battery. The advantage it has over a battery is that you can charge the Goldcap very quickly; it cannot be overloaded, and does not undergo deep discharge.

Note:

The Goldcap may never be connected to a voltage greater than 2.3 V; otherwise, it may explode! Never connect the Goldcap to a normal 9 V fischertechnik power supply.

When mounting the plug on the Goldcap, you must ensure the plug's polarity is correct (connect the red plug to the plus terminal).

Goldcap solar filling station construction task

Before we can use the Goldcap, it needs to be charged up. To do so, we will use the Goldcap filling station model from the building instructions.

- Note that the red plug on the Goldcap (+) must be connected to the red plug on the solar module.
- Ensure the light source is the correct distance from the solar module, so that the solar module does not become overheated or damaged.
-

Experimental task 6

1. Measure the voltage on the Goldcap while charging. What is the maximum amount the Goldcap can be charged using the solar module?
2. What happens if the solar module is covered by a shadow during the charging process?
3. What trick can you use to check the charge level of the Goldcap even without a measurement device?
4. What would be an alternative way to charge the Goldcap, besides solar power?

Electric vehicle construction task

After charging, connect the Goldcap to the vehicle motor instead of the solar cells. See the Electric vehicle building instructions.

Experimental task 7

1. How can you optimise your electric vehicle so it will drive farther?

Optional:

- Use the Goldcap with other fischertechnik models.
- You can test out different experimental setups with model 6.
    a. Solar module → Goldcap → Motor
    b. Solar module → Fuel cell → Voltage converter → Motor

Model 6 – Functional model / Solar energy

Joerg Torkler

Topic

We will be investigating solar energy using a functional photovoltaic model, and learning about alternative types of energy generation in the context of renewable energy.

Learning objective

- Forms of renewable energy and energy converters. From radiant energy (solar energy) to electrical energy.
- Function, effectiveness and technical challenges when designing solar systems.
- Electrical circuits: Parallel, series and antiparallel connection
- Using measuring equipment.
- Storing solar energy

Time required

90 minutes.

Solution sheet model 6 – Solar energy

Topic task

1. a) Solar collectors generate warmth and heat
   b) Solar thermal power stations generate electrical power by converting heat into water vapour
   c) Solar cookers or solar ovens heat food
   d) Solar cells generate direct current
2. Photovoltaics: Solar cells generate direct current.

Experimental task 1

1. The optimal angle of incidence is 90 degrees to the light source.
2. From approx. 0.3 V and 200 mA (please check)

Experimental task 2

1. Parallel connection: The voltage (V) remains the same. The amount of electricity (A) increases.
2. The motor makes the indicator turn earlier with the modules connected in parallel, although the existing voltage (V) is unchanged. The motor can be loaded more.
3. The torque of the motor increases. The torque is current-dependent. The speed is voltage-dependent. Torque is required to start up and accelerate.

Experimental task 3

1. Series connection: The voltages (V) of the two solar modules change. The amount of electricity (A) remains the same.
2. The rotational speed of the indicator is faster with series connection, since the speed of the motor is voltage-dependent.
3. The run indicator stops with series connection, in contrast to parallel connection.
4. In very poor lighting circumstances. A parallel connection of the solar module still delivers current with the same voltage, even if the solar module is partially shadowed.

Experimental task 4

1. The rotational direction of the motor changes.
2. Pole reversing switch

Experimental task 5

A series connection is best suited for the solar vehicle because the motor is under a very heavy load, and therefore requires a high start-up voltage.

Experimental task 6

1. 2 Modules •1V=2V.
2. The connected solar modules discharge the Goldcap
3. If you connect the green LED from the building set in parallel. When it begins to light up, the Goldcap has a charge level of at least 1.7V. The LED acts as a charge control indicator.
4. For example from wind power with the wind turbine model.

Experimental task 7

You can optimise the electric car by re-installing the solar module and connecting the Goldcap in parallel to the solar module. Note that the red plug on the Goldcap (+) must be connected to the red plug on the solar module.

Tasks
Model 7 – Fuel cell charging station / chemical energy

Fuel cells are used to convert the chemical energy in a fuel (such as hydrogen) into electrical current. A fuel cell, therefore, is not used to store energy, but rather to convert it.

The fischertechnik fuel cell is what is called a *reversible* fuel cell.

- It can use the energy carriers of hydrogen and oxygen to deliver electrical energy (energy converter).
- However, it can also be operated as an electrolyzer, so that electrical energy is converted into storable chemical energy (water electrolysis).

Excess power generated from renewable energies (in particular wind power and photovoltaics) can therefore be stored chemically on an intermediate basis in the form of hydrogen.

The effectiveness of reversible (hydrogen) fuel cells is between 30 to 40 % when generating direct electrical energy. The rest is released heat energy. In the 1960s, NASA technicians recognised the advantages of this technology for space flights, and installed 3 fuel cells in the Apollo capsules with a total power of just seven kilowatts.

Fuel cell cars do fill up on hydrogen, but drive with the help of an electric motor, meaning that they are electric cars. The technology is still being developed.

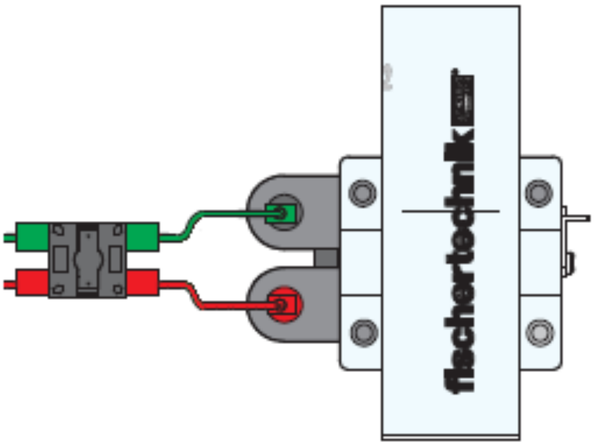
Construction task Model 7

First, read the operating manual for the fuel cell and familiarise yourself with how fuel cells function. Then build model 7 (fuel cell charging station and fuel cell vehicle) according to the instructions.

Fill the fuel cell with distilled water, and connect the fuel cell to the charging station.

Observe the following points:

- Lightly knock the fuel cell against the table so that the water can better flow around the membrane and the collecting metal plate, before inserting the fuel cell into the car.
- Ensure the connection points with the charging station have the correct polarity.
- Check whether the ON/OFF switch on the fuel cell vehicle is open before connecting the fuel cell to the voltage converter.



Once the solar module or solar cells are illuminated with sufficient solar energy or a suitable light source, the generation of hydrogen and oxygen will begin. The gases will be stored in their respective storage cylinders. The water will be pressed into the overflow chambers above.

The fuel cell is fully “charged” once all water has been pressed out of the hydrogen storage cylinder into the overflow chamber above. This process will take around 15 – 60 minutes, depending on the light intensity.

You can disconnect the fuel cell from the solar modules at any time. This will stop the production of hydrogen and oxygen.

Topic task

1. Observe the amount of gas in the two storage cylinders when generating hydrogen and oxygen. What do you observe?
2. What chemical formula can you use to describe the two functions of a reversible fuel cell?
3. How is this regulated reaction, which produces water, electricity and heat, called in contrast to an oxyhydrogen reaction?

Experimental task

1. Now, connect the voltage converter of the fuel cell car to the fuel cell. The fuel cell has a significantly greater drop in voltage as current increases, in contrast to batteries. In applications with different load requirements, therefore, a voltage converter is required in most cases. This allows the voltage level of the feed into the circuit to be controlled. Allow the car to drive straight ahead and measure the time until half the tank is empty. Use the second half of the tank for the car to drive around a curve. Here as well, measure the time until the

tank is empty. What is the energy consumption of the fuel cell like when the car is driving straight ahead, in contrast to when it is driving around a curve?

2. When cars drive around curves, the outer wheel travels farther than the inner wheel. The outer wheel therefore turns more quickly. To allow for the two wheels to travel at different speeds, just one of the wheels is driven; the other is mounted on the shaft so that it can rotate freely. How does the car drive differently if the drive wheel is on the inside or outside?
3. What technical invention can be used to drive both wheels at different speeds?

Optional:

1. Test the operation of the fuel cell with other fischertechnik models.
2. Try to operate the fuel cell in parallel with the solar modules.
3. You can test out other experimental setups: Solar module → Goldcap (parallel connection) →Fuel cell → Motor.

Model 7 – Fuel cell charging station / chemical energy

Joerg Torkler

Topic

Converting chemical energy into electrical energy. When the hydrogen required for the combustion reaction is generated using electricity from renewable sources, the fuel cell can be considered renewable energy.

Learning objective

- Forms of renewable energy and energy converters. From chemical energy to electrical energy.
- Water electrolysis. Function and effectiveness of a hydrogen fuel cell.
- The electrochemical reaction of *cold combustion*.
- Storage of electricity from renewable energy sources (solar / wind energy)

Time required

45 minutes.

Solution sheet model 7 – Fuel cell charging station / chemical energy

Topic task

1. Twice as much hydrogen is produced as oxygen.
2. a) Energy conversion: Decomposition of water caused by electrical current into hydrogen and oxygen. $2\ H_2O \rightarrow 2\ H_2 + O_2$
   Anode (+): $4\ (H^+) + 4\ (e^-) + O_2 \leftarrow 2\ H_2O$
   Cathode (-): $2\ H_2 \leftarrow 4\ (e^-) + (H^+)$
   b) Water electrolysis: Hydrogen reacts with oxygen to form water, which is continually removed from the fuel cell. The chemical equation corresponds to the oxohydrogen reaction, but the reaction occurs in a regulated fashion instead of an explosive one. $2\ H_2 + O_2 \rightarrow H_2O$.
   Anode (+): $4\ (H^+) + 4\ (e^-) + O_2 \rightarrow 2\ H_2O$
   Cathode (-): $2\ H_2 \rightarrow + 4\ (e^-) + 4\ (H^+)$
3. *Cold combustion.* This reaction is restrained in the fuel cell, occurring in a controlled manner and at room temperature. In this case, hydrogen does not react directly with the oxygen in the air, but instead transmits its electrons to the platinum anode, which works as a catalyst.

Experimental task

1. When the vehicle is driving around a tight curve, the motor requires more energy than when the vehicle is driving straight ahead. Therefore, more hydrogen is consumed when the vehicle is driving in circles.
2. The speed and duration of driving time change, depending on whether the driven wheel is on the inside or outside
3. Differential gear. This is also called a differential, since it compensates for the different distances travelled by the interior and exterior wheels on an axis around a curve, as well as the differences between the front and rear axles in all wheel drive. It was patented in 1827 by Frenchman Onésiphore Pecqueur (1792–1852).