

1. Eco Power – Energy from Renewable Energy Sources

We all need great quantities of energy every day. Let's take a look at normal everyday activities for this:

Our radio alarm clock wakes us up in the morning. Of course, it gets electricity from a socket outlet. We get up, switch on the electric lights, shower with warm water, which is heated by the central heating system using oil or gas. Then we dry our hair with an electric hair-dryer. The central heating system has already heated our apartment or home, so that we are not cold during breakfast. The water for the tea is boiled on the electric or gas stove. The butter is stored in the refrigerator at night and consequently is really hard. Of course, we switch on the radio or television during breakfast, so that we can find out the latest news and weather.

Then we go to school by bus or car, which requires fuel. We could continue for a long time to describe what we need energy for. The list would become infinitely long. To put it simply, we need an extremely large amount of energy.

And where does this energy come from? A majority of it is produced from the fossil fuels oil, gas and coal. A large part of our needs are covered by nuclear power. But these kinds of energy production have decisive disadvantages:

- The fossil fuel supplies are limited on the earth.
- Pollutants are created during the burning of oil and coal, which pollute our environment. CO₂ is also produced, which is responsible for the continual warming of the earth's atmosphere (greenhouse effect).
- Nuclear energy entails the danger of radioactivity being released following an accident, despite the high safety standards. Additionally, radioactive waste is created, which emits radioactivity for many thousands of years.

These are sufficient reasons for looking for alternatives, which are compatible with our environment and are available in unlimited supplies if possible. These alternative energy forms do in fact exist. We call them regenerative or renewable energy supplies. We deal with energy production from water, wind and the sun in our Eco Power Kit. Using numerous models, we see how you can generate and store electricity from them and then finally drive fischertechnik models using them too. Have fun!

2. The Term Energy

We talk about energy all the time, but what does it mean and how can we measure it?

By energy we mean the capability of a body to perform work. The measurement unit with which we measure energy and work is called joule (J).

Different energy forms exist, for example:

- Kinetic energy, the energy that is released when a body moves.
- Potential energy, the energy that a body has when it is at specific height.
- Electric energy in the form of electric power and current.

Electric energy or work is also expressed kilowatt hours (kWh).
Kilo=1000, Watt=power, hours=time during which power is produced.

Example:

An incandescent bulb has a power of 100 watt. It lights for 10 hours. The energy required for this is:

$$100 \text{ W} \cdot 10 \text{ h} = 1000 \text{ Wh} = 1 \text{ kWh}$$

To make it clear how much energy a kWh contains, let's perform the following experiment:

A bicycle generator has a power of 3 watt. When the generator is switched on, the kinetic energy of the wheel is converted into electric energy.

Task 1:

How much energy is converted during one hour of riding?

Solution:

$$\text{Energy} = 3 \text{ W} \cdot 1 \text{ h} = 3 \text{ Wh} = 0.003 \text{ kWh}$$

Task 2:

How long do you have to ride a bicycle to convert 1 kWh (1000 Wh)?

Solution:

We can derive the following from the formula energy = power•time:

$$\text{Time in hours} = \text{energy/power} = 1000 \text{ Wh}/3 \text{ W} = 333.33 \text{ h}$$

333.33 h correspond to 13.88 days. This means that we would have to pedal continuously for almost 14 days to convert the energy of 1 kWh, which our incandescent bulb from the previous example needs to light 10 hours.

If we now consider that a family of four has an average energy requirement of approx. 4,000 kWh per year, then we realize quickly that we will not get very far searching for environmentally compatible energy sources with a bicycle. Then we had better devote our attention to other energy sources.

3. Energy from Water

3. 1. The Kinetic Energy of Water

Man has been using the kinetic energy of water to drive machines directly for hundreds of years.

Task 1:

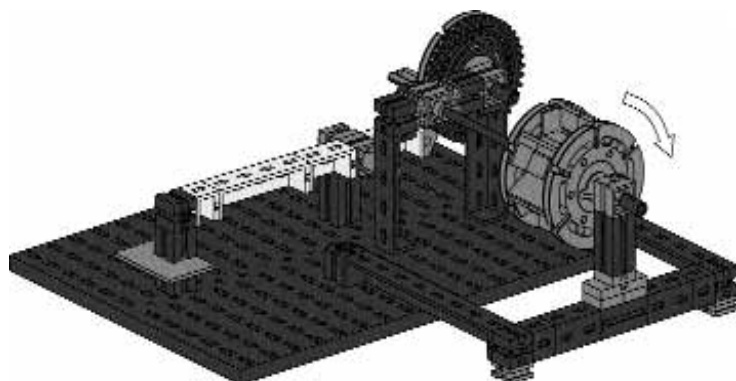
What machines can you think of that are driven directly by water power?

Solution:

- Watermills
- Sawmills
- Hammer-mills

The drive principle is the same for all these machines. The water is routed onto a waterwheel, the wheel turns and the movement is transferred directly to the respective machine.

To make the drive principle clear, now build the model of a hammer-mill (see the assembly instructions on page 4).



You can hold the waterwheel under a water faucet. Note the direction of rotation of the wheel given in the assembly instructions.

Iron, which was first made red hot, was forged with such hammer-mills in previous times.

Task 2:

What are the disadvantages of this form of using water power?

Solution:

- The energy can only be used where water flows (at rivers or streams). It cannot be transported to other places.
- The energy cannot be stored. It must be used immediately when it is available.
- The energy is only available for a limited purpose (driving a few machines).

Task 3:

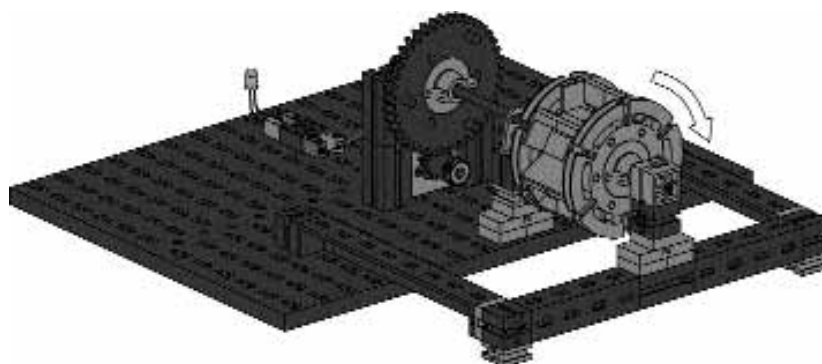
How is water power used today?

Answer:

We generate electric current using water power, which is available for any number of uses.

3.2 Electric Power from Water Power

To see how this functions, now build the model of a hydraulic turbine (see the assembly instructions on page 7).



The solar micromotor is used as a generator for this. If you rotate the shaft of the motor, voltage is generated using a magnetic field in the motor, which can be tapped at the motor connections. If we connect the green LED, electric current flows and the LED lights. Because the motor shaft has to rotate very quickly, the movement of the waterwheel or the turbine wheel is converted in the relation 1:4. Hold the waterwheel under a water faucet again and let the wheel rotate so quickly that the LED lights. Note the direction of rotation again.

Caution!

- This experiment is very well suited to flooding a kitchen or bathroom. That might be a lot of fun, but it could have unpleasant results, because your parents would probably react in a strange way in such cases. When the jet of water hits the blades of the hydraulic turbine on the sides, the amount of splashed water is kept within limits and the wheel rotates ideally at the same time.
- The motor is arranged in such a way that it does not become wet when you handle the model carefully. A few splashes of water will not affect it. But you should not hold it directly under the water faucet or dip it into water.
- The LED is only for showing how electric current can be generated using the solar micromotor. It is not suitable for lighting conventional fischertechnik models. It may be operated with a maximum of 2 volts. It burns out immediately if the voltage is higher. It may not be connected to a 9 V fischertechnik current supply in any case.

Task 1:

What are the advantages of this kind of generating electric current compared to those using fossil fuels such as oil or coal?

Solution:

No polluting fumes are created in this kind of generating electric current.

Task 2:

What interventions into the environment must be taken to make it possible to use water power (hydroelectric power)?

Solution:

Dams have to be built at lakes or rivers to ensure that there is always sufficient water for producing electricity. The height of drop always has to be high enough to give the water the required potential energy to drive the turbines.

Task 3:

In which regions is this kind of electric current preferred and why?

Solution:

- In mountainous regions, because whole valleys can be dammed in part with giant dams. The water can plummet hundreds of meters, and consequently an enormous amount of potential energy is available for driving turbines.
- On rivers with natural differences of altitude, where the water can also be dammed.
- At the North Sea, where tidal power stations use high and low tides for generating electricity from water.

4. Wind Energy

Wind power is another way of generating electricity from regenerative energy. It is continuously windy in many regions. The kinetic energy of the air can be used in turn and converted into electric power.

We want to demonstrate this kind of energy production using the model of the wind power plant (see the assembly instructions on page 10).

We will also use the motor as a generator for producing electricity and the LED to display that it really functions.

**Note:**

It is important that the blue rotor is mounted on the correct side on the red take-up, so that it produces optimum efficiency. There is a small fish on one side of the rotor blade. This symbol must point in the direction of the motor.

If you now hold a hair-dryer or table fan in front of the rotor, it starts to turn, gets faster and faster and the LED starts to light.

We will need this model later when we deal with the topic of Storing Energy. But you can dismantle it now, because you can reassemble it quickly.

Task:

The fact that this kind of energy production is compatible with our environment – similar to water power – is obvious, because no exhaust pollutants are produced. But what disadvantages does wind power have compared to water power or conventional energy production from oil or coal?

Solution:

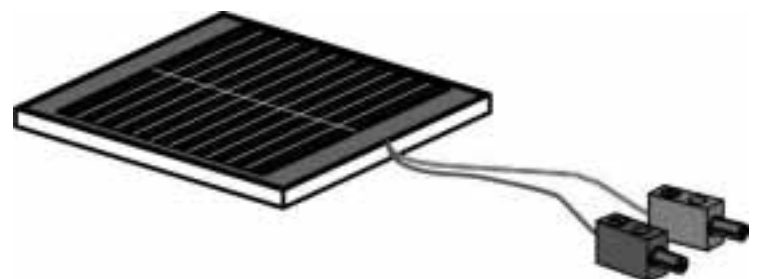
- Electric current can only be produced when there is wind. Wind cannot be dammed like water in a reservoir and used when needed.
- Some critics maintain that wind power plants are blots on the landscape, because they of course are always in open areas where they can be seen from a large distance.
- They kill many birds.

5. Solar Energy

If we burned all fossil fuel supplies (wood, coal, oil and gas) of the earth for producing energy, it would only produce an energy quantity that the sun radiates to the earth in three days. Our task is to use this tremendous and at the same time inexhaustible energy supply to produce electric energy (using solar cells).

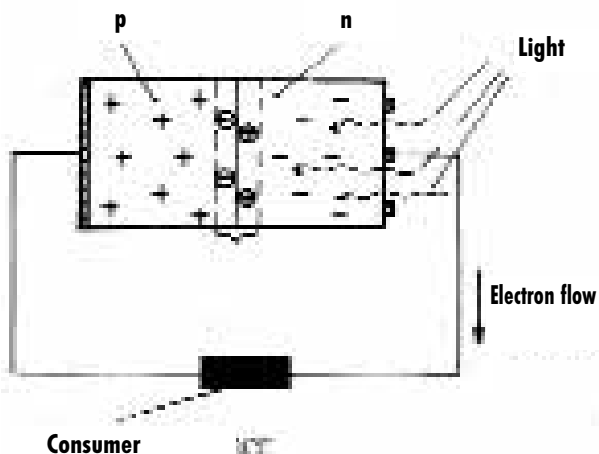
5.1 The Solar Cell

But what is a solar cell exactly and how can we convert sunlight into electric energy using it? Solar cells are made of silicon. The silicon blocks are cut into disks approximately 0.5 millimeter thick. These disks are then doped with various impurity additions, i.e., specifically contaminated,



which creates an unbalance in the silicon structure. This creates two different layers: the positive p-layer and the negative n-layer.

Put simply, the electric current flow is created by the movement of electrons from the n-layer, activated by the light hitting them, via the connected consumer (e.g., motor) to the p-layer.

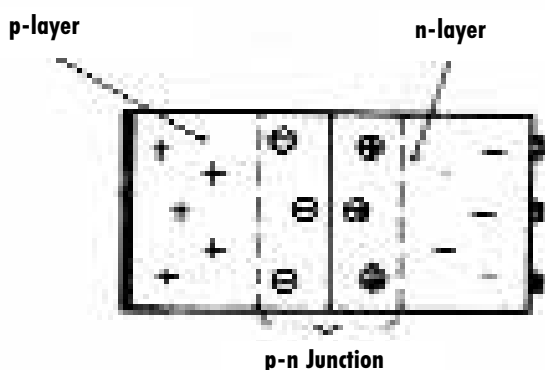


For all interested physicists, a somewhat more detailed explanation follows about how electric power is produced in a solar cell.

A surplus of electrons is created on the n-layer, because the added impurities have more electrons than the silicon, i.e., free electrons "buzz" around on this side. These electrons can move specific distances if they have sufficient energy.

To the contrary, electrons are lacking on the positive side p-layer, because the added impurities on this side have fewer free electrons than silicon. So-called "holes" are created. These holes can take-up electrons if there are any nearby. Then the free electrons from the n-layer migrate to the p-layer and fill the holes.

Since the electrons have too little energy and cannot move a random distance to the holes, only those holes in a specific area in the middle are filled. This area is called the p-n junction.



The more light (i.e., energy) that hits the cell, the "more movable" the electrons become; in other words, they can migrate farther. When we connect a solar cell to a consumer (motor, lamp or similar device), they move preferentially in this direction (this can be imagined as a suction effect). Because we can imagine a current flow as a cycle, electrons move repeatedly to the n-layer and migrate again to the p-layer. This flow of electrons results in the current flowing, i.e., the motor rotates.

Now test this behavior by connecting one single solar cell to the solar motor from our kit and try out how much light is needed to get the motor running.



The solar cell provides 0.6 V and a maximum current of approx. 930 mA. The motor has a rated voltage of 2 V, but it already starts to rotate starting from 0.3 V (idling, i.e., without necessity of model driving the motor shaft). Consequently, it can be run with one single solar cell.

Experiment 1:

Find out which brightness is required for the motor to rotate. You can use a lamp with an incandescent bulb (fluorescent bulbs are not suitable) for this. Maybe there is enough daylight in your room for the motor to move without an additional light source.

Experiment 2:

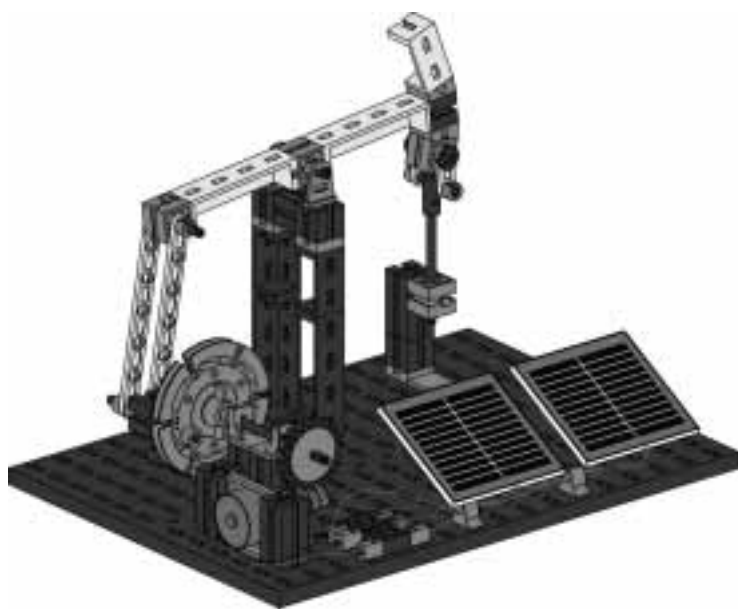
If you have a current and voltage measurement device, you can measure from which voltage the motor starts to rotate and how much current flows.

You will see that the motor cannot develop very much power when it is driven with only one solar cell. When we now want to drive a fischertechnik model, various options exist for getting more power from the motor.

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5.2 Series Connection of Solar Cells

Build the oil pump model for this (see the assembly instructions on page 12).



Using such an oil pump, for example, you can pump oil from deep below the earth in desert regions where the sun shines continuously. To drive this model, the motor needs a rather high starting voltage for it to rotate at all. Consequently, two solar cells are connected in a series, as described in the assembly instructions. As a result, the voltages of the two solar cells are added together.

Task 1:

What is the maximum voltage supplied to the motor?

Solution:

$$2 \cdot 0.6 \text{ V} = 1.2 \text{ V}$$

Task 2:

What is the maximum current available?

Solution:

The current, which flows through the two solar cells, remains constant in the series connection. It is a maximum of 930 mA.

Task 3:

What voltage does the motor need to start moving for this model?

How much current does it use then?

(Of course, you can only answer this question if you have a measuring device. For example, the measured values also depend on how friction free the pump was assembled and from which position it must start to run.)

Solution:

Voltage: Approx. 0.5 V

Current: Approx. 20 mA

5.3 Parallel Connection of Solar Cells

Build the rotating swing model for this (see the assembly instructions on page 16). Make certain when assembling the model that all axles and cogwheels can move easily.



The motor should not rotate too quickly in this model, because otherwise the "seats" of the rotating swing can then turn over. But this model should already move with the least amount of light possible. Consequently, the two solar cells are connected in parallel.

In parallel connection, the voltage remains the same as with one cell. On the other hand, this "double cell" can produce more current than one single cell with the same brightness thanks to the larger solar cell surface, which is available.

Experiment 1:

Find out which brightness is required for the rotating swing to move.

Experiment 2:

Try to drive the model with one single solar cell and find out which brightness is required for this.

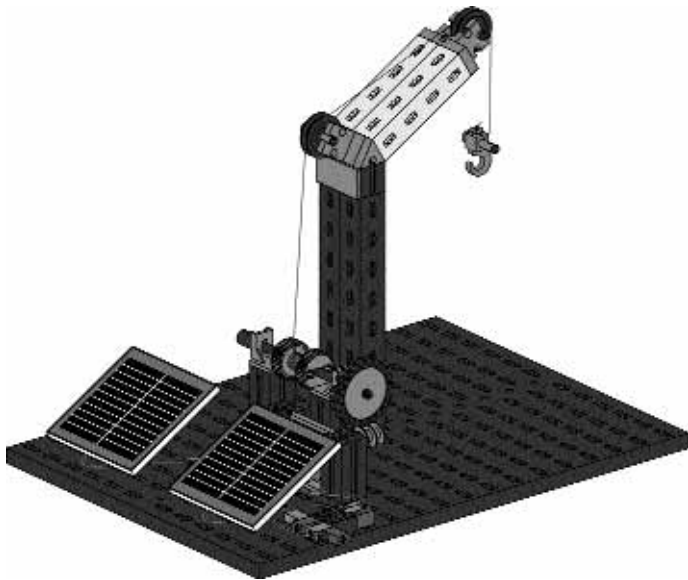
Experiment 3:

Connect the two solar cells in a series (like for the oil pump; see the assembly instructions on page 13 for the connection diagram). You can judge yourself whether the passengers would get motion sickness with this.

5.4 Bridge Circuit Connection of Solar Cells

What could this be? Very simple: two solar cells are connected parallel in such a way that the plus pole of one solar cell is connected with the minus pole of the other solar cell. The following models will show what you can do with this.

Crane model (see the assembly instructions on page 20).

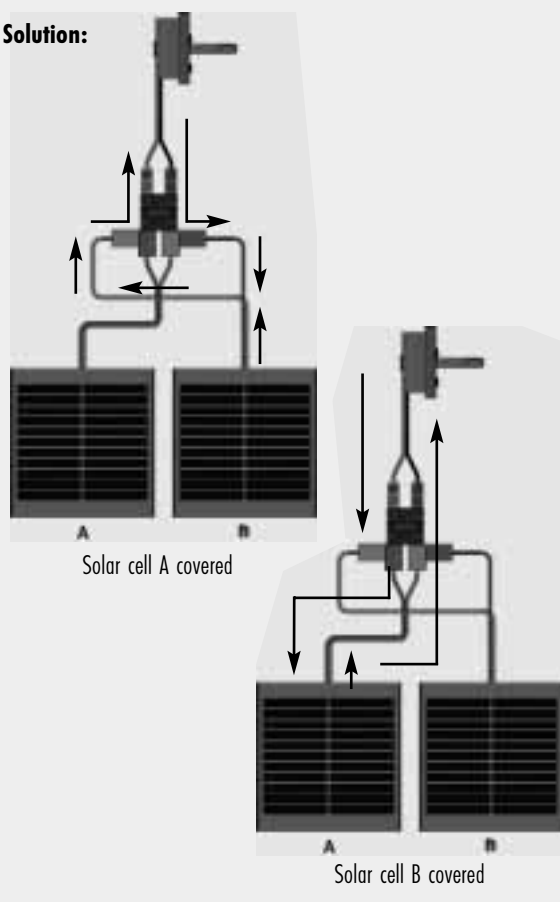


A load should be lifted using solar energy with this model. The trick with antiparallel connection is that the motor does not move as long as both solar cells are lit equally bright. If you cover one solar cell, the motor moves in one direction; if you cover the second cell, it moves in the other direction. In this way, you can replace a pole-reversing switch with two solar cells.

Task 1:

Draw a sketch to illustrate how the reversal of the motor rotation direction (or the current direction of the motor) happens when you cover one solar cell.

Solution:



Task 2:

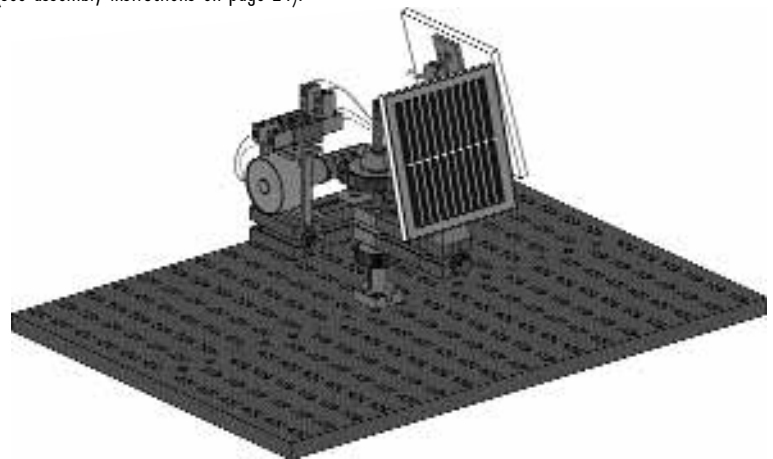
How can we make it possible for the crane to lift a heavier load?

Solution:

- Through series connection of the two solar cells (but then the motor can only rotate in one direction)
- By increasing the gear reduction, e.g., by using a cogwheel with 40 teeth instead of one with 20 teeth. You must reconstruct the crane for this.

Solar Cell Tracker System

Another use of the antiparallel connection is the solar cell tracking system (see assembly instructions on page 24).



This simple device makes it possible for the solar cells to "move along with" the sun and orient themselves like a compass to the sun. The "tip" where the two solar cells meet always points in the direction of the sun. Pay attention during assembly to the correct connection of the cable, because otherwise the model might move away from the sun instead of to it.

Task 1:

How does this simple principle of solar cell tracking function?

Solution:

If the tip points in the direction of the sun, both cells light simultaneously and the motor does not move. If the sun moves, one of the two cells receives more light. The motor starts to rotate and does this until both cells receive the same amount of light again.

Task 2:

What do we use such a device for?

Solution:

Mostly for solar cells. To ensure that they always receive the optimum amount of light from the sun, they are set to track the sun. In reality, this is often computer-controlled and programmed with very expensive software. But, as you can see it can be done very easily.

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6. Storing Electric Energy

Next we want to find out why it is necessary to store energy, which comes from regenerative energy carriers.

Build the solar energy-powered vehicle model for this (see the assembly instructions on page 27). It is driven by two solar cells.



Task 1:

How are the cells connected to each other and why?

Solution:

The cells are connected in a series, because the motor is heavily loaded and consequently requires a high initial voltage.

Experiment:

Find out which light source is required to drive a solar energy-powered vehicle and what would be its maximum speed. (it's best to do this outdoors).

You have certainly already noticed in your experiment that this drive mode has a decisive disadvantage. The vehicle stops as soon as it is away from the light source or is in the shade. Of course, this makes it rather difficult to make a lot of progress.

We would be a lot more independent if we could supply the vehicle via an energy store, which is charged with regenerative energy and with which the car can be run independent of wind and weather for a certain time.

6.1 Goldcap Energy Storage



Such an energy storage unit is the Goldcap contained in the assembly kit. A Goldcap has nothing to do with gold or a gold alloy. The term is the trade name of this capacitor.

It is composed of two active carbon pieces, which are separated by only a thin insulation layer. The Goldcap is distinguished by its extremely high capacity. The capacitor we use has a capacity of 10 F (farad). Customary capacitors have capacities in the order of magnitude of a few μ farad (= 0.000001 F).

You can use the Goldcap like a small battery. The advantage compared to a battery is that the Goldcap can be recharged very quickly. It cannot be overcharged with a solar cell nor can it be drained.

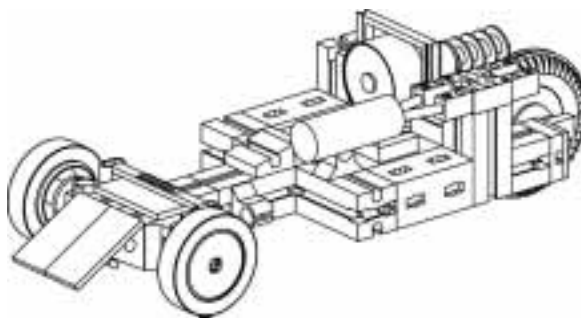
But caution!!

The Goldcap may not be connected to a voltage exceeding 2.3 V, because otherwise there is danger of explosion. Consequently, never connect the Goldcap to a customary 9 V fischertechnik power supply.

When you connect the terminal to the Goldcap, pay attention to the correct polarity of the terminals (connect the green terminal to the minus). We recommend that you cut the connection wires of the Goldcap to the same length.

6.2 Charging the Goldcap with Solar Energy

Charge the Goldcap by connecting it to two solar cells connected in a series. The red terminal of the Goldcap (+) is connected to the red terminal of the first solar cell, and the green terminal of the Goldcap (-) is connected to the green terminal of the second solar cell. Charge the Goldcap for approx. 10 minutes, for example, under an incandescent bulb with 100 W at a distance of 40 cm (if you put it closer, the solar cell will get too hot) or in sunlight. After it has been charged, connect the vehicle motor instead of the solar cells to the Goldcap.



Task 1:

Why does the car go so slowly and stop again relatively quickly?

Solution:

You can only charge the Goldcap with a voltage of 1.2 V using the two solar cells. As a result, it is only charged to half its capacity and can only run the car for a short time. Of course, that's not so great. You will see that there is a better solution.



Task 2:

How many solar cells would be required to charge the Goldcap completely?

Solution:

4 cells • 0.6 V = 2.4 V. The storage could be charged completely with this.

Note:

If the Goldcap is charged using solar cells, it is discharged via the connected solar cells as soon as it gets dark. Consequently, the Goldcap should only remain connected with solar cells as long as light is hitting them.

Experiment 2:

Try out how long the car can run with one full tank. What speed can it reach?

These things are above all influenced by whether the car runs on a smooth surface or a carpet and how fully the Goldcap is charged.

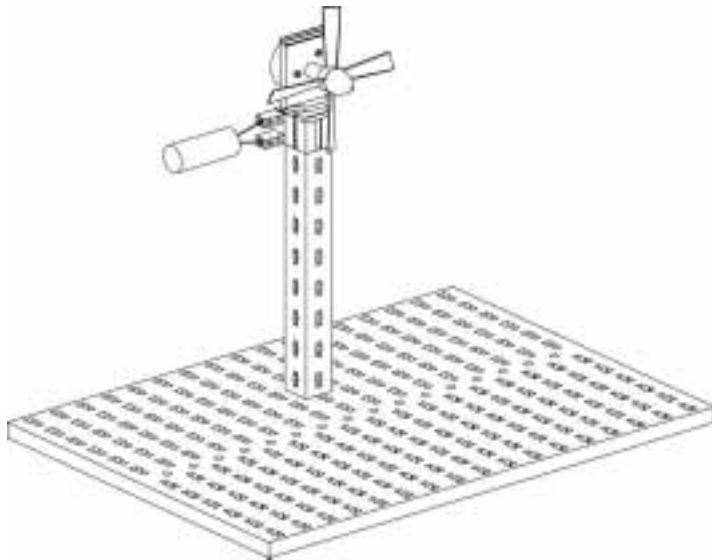


Because you can generate a higher voltage with the wind power plant than with two solar cells, the vehicle runs faster and longer than when charged using the solar cells.

Whether the energy storage is charged using wind or solar energy makes no difference. The experiments with the Goldcap should above all demonstrate one possibility for driving a vehicle using regenerative energy without being directly dependent on the sun's rays.

6.3 Charging the Goldcap with Wind Energy

Now we want to charge the energy storage with wind energy. Build the wind power plant again for this (see the assembly instructions on page 10). But do not connect the LED to it, but instead the Goldcap. You need to take only the motor out of the solar energy-powered vehicle. The other parts for the wind power plant are contained in the assembly kit. Connect the



plus pole of the motor (red) to the plus pole of the Goldcap (red). Then get the propeller rotating with a fan or hair-dryer. The motor now functions as a generator again and charges the Goldcap. At the beginning, the propeller cannot be moved very easily, but the fuller the storage, the easier it rotates. When the hair-dryer is taken away, the energy from the Goldcap starts the motor again. But be careful, because the storage is emptied again when this happens. The Goldcap should be charged for approx. 20 minutes.

Experiment 1:

You can measure the voltage in the Goldcap parallel to charging (if you have a measurement device). You can read the extent to which the Goldcap is charged. The faster the propeller rotates, the greater the voltage that can be generated and the more the Goldcap can be charged (to a max. 2.3 V).

7. What's Next?

You have learned various possibilities using the Eco Power assembly kit for generating electricity using regenerative energy sources. Solar energy technology is excellently suited for driving fischertechnik models. If the models are larger and heavier than those displayed in the assembly kit, you will certainly need a few additional solar cells, which then must be connected in a series. You can get them from the fischertechnik individual part service at any time. This will make it possible to expand and enlarge the solar energy system, which started in this assembly kit with simple models.



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