leXsolar-NewEnergy Ready-to-go

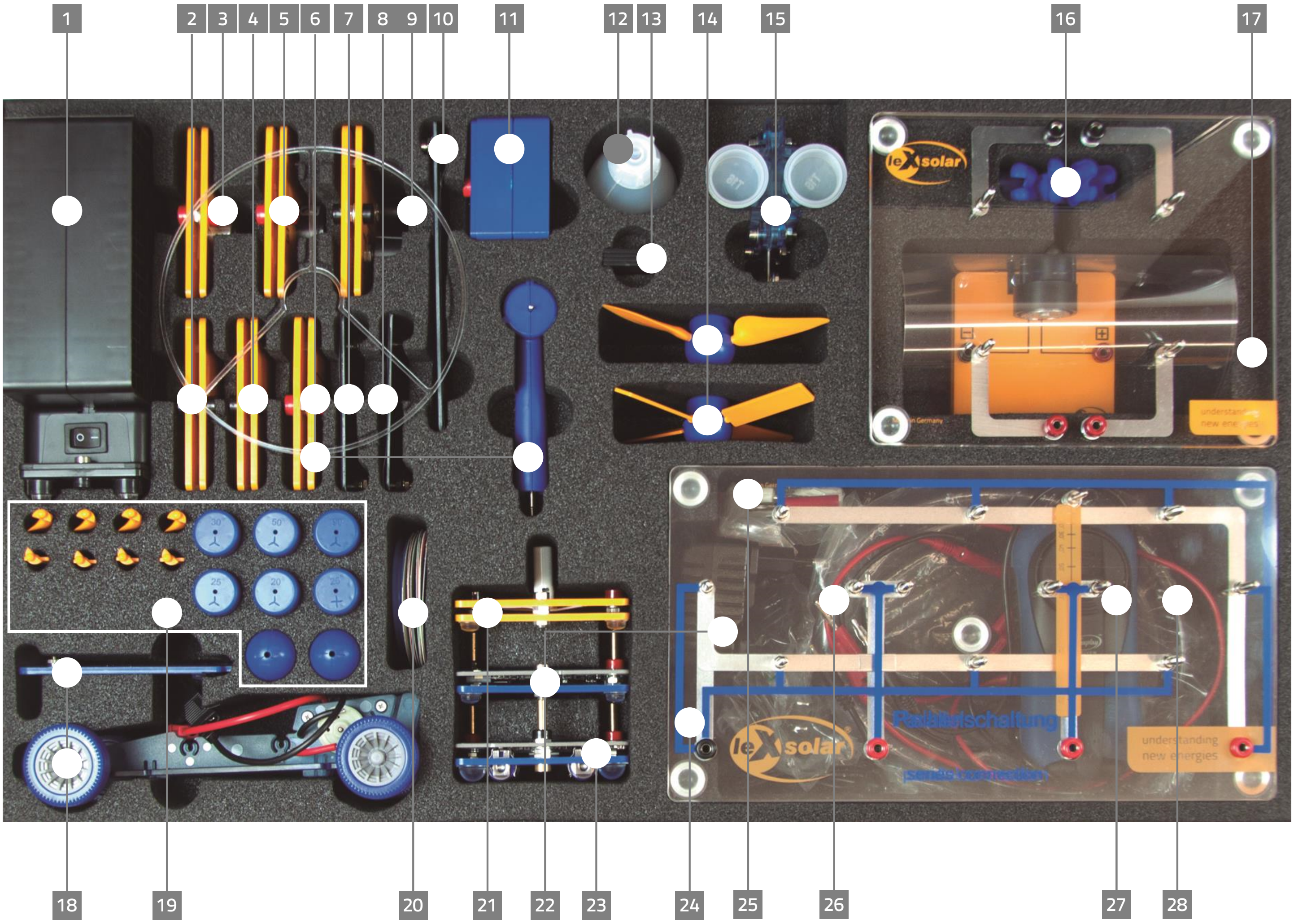
Instructions manual

Layout diagram leXsolar-NewEnergy Ready-to-go

Item-No.2003

Bestückungsplan leXsolar-NewEnergy Ready-to-go

Art.-Nr.2003



1	1400-19 leXsolar-Wind machine 1400-19 leXsolar-Winderzeuger
2	1400-08 LED-module 2mA, red 1400-08 LED-Modul 2mA, rot
3	1100-27 Motor module without gear 1100-27 Motormodul ohne Getriebe
4	1100-26 Light bulb module 1100-26 Glühlampenmodul
5	1100-25 Buzzer module 1100-25 Hupenmodul
6	1400-22 Wind turbine module 1400-22 Windturbinenmodul
7	1100-02 Solar module 0.5 V, 840 mA 1100-02 Solarmodul 0.5 V, 840 mA
8	1100-07 Solar module 1.5 V, 280 mA 1100-07 Solarmodul 1.5 V, 280 mA
9	1100-23 Potentiometer module 1100-23 Potentiometermodul
10	1100-31 Solar module 2.5 V, 420 mA 1100-31 Solarmodul 2.5 V, 420 mA
11	1100-20 Lighting module 1100-20 Beleuchtungsmodul
12	1800-15 Distilled water (100 ml) 1800-15 Destilliertes Wasser (100 ml)
13	1100-29 Solar cell cover set 1100-29 Satz mit Abdeckung f. Solarzelle
14	1400-21 Wind rotor set (assemblied) 1400-21 Windrotoren (montierter Satz)
15	L2-06-067 Reversible Fuel cell L2-06-067 Reversible Brennstoffzelle
16	1900-01 Water wheel module 1900-01 Wasserradmodul
17	1602-01 leXsolar-Base unit small 1602-01 leXsolar-Grundeinheit Small
18	1801-02 Electric model car 1801-02 Elektro-Modellfahrzeug
19	1400-12 leXsolar-Wind rotor set 1400-12 leXsolar-Windrotoren
20	1100-28 Color discs - Set 1 1100-28 Farbscheiben - Set 1
21	1600-02 Capacitor module 5.0F/5.4V 1600-02 Kondensatormodul 5.0F/5.4V
22	9100-05 PowerModule 9100-05 PowerModul
23	9100-03 AV-Module 9100-03 AV-Modul
24	1100-19 leXsolar-Base unit Large 1100-19 leXsolar-Grundeinheit groß
25	2xL2-06-033 Short-circuit plug 2xL2-06-033 Kurzschlussstecker
26	L2-06-012/013 Test lead 25 cm black/red L2-06-012/013 Messleitung 25 cm schw./rot L2-06-014/015 Test lead 50 cm black (2x)/red L2-06-014/015 Messleitung 50 cm schw. (2x)/rot
27	1602-02 Hand generator 1602-02 Handgeneratormodul
28	L2-02-051 Silicone tube 12 mm L2-02-051 Silikonschlauch innen 12mm

Version number
Versionsnummer

III-01.24_L3-03-259_22.05.2019

CE RoHS2

leXsolar – NewEnergy Ready-to-go
Student`s manual

Experiments – Primary level

Experiments – Secondary level

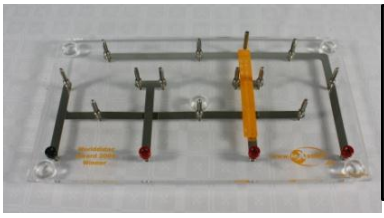
Description of the experimental components
leXsolar-NewEnergy Ready-to-go

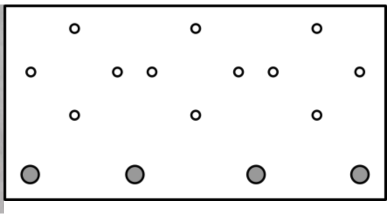
In the following schedule every component of the leXsolar- NewEnergy Ready-to-go case is listed. For every component there is the name with article number, a picture, the pictogram for the circuit diagram and operating instructions. With the aid of the article number it is possible to reorder a specific component.

Base unit Small 1602-01

The base unit is a breadboard where 2 components can be plugged in. The current flows along the wires on the bottom side. To connect the components on the base unit with other components, there are 4 terminals on two opposite sides. The terminals can also be connected by short-circuit-plugs.

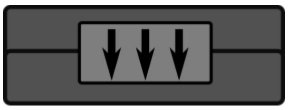
Base unit 1100-19





The base unit is a breadboard where up to 3 components can be plugged in a series and parallel connection. The current flows along the wires on the bottom side. To connect the components on the base unit with other components, there are 4 terminals at the lower end.
The printed circuit diagram show the connections in a series and parallel connection. To change between series and parallel connection, the modules have to be turned by 90°.

Wind machine 1400-19



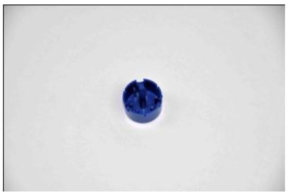
The wind machine is used to control the wind conditions during an experiment with the wind turbine. For those experiments the wind machine has to be connected to the PowerModule (voltage source). For this the negative (positive) pole of the PowerModule has to be connected to the black (red) connection. Towards the connections there is also a seperate on/off-switch. The wind direction is marked with arrows on the upside. The use of the wind machine is only permitted with the PowerModule or a stabilized voltage source. Furthermore, the wind machine has to be protected from intense hits. Otherwise, the rotor blade within the device could break. Misuse leads to termination of warranty.

Specifications:

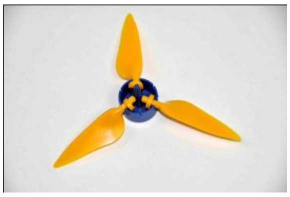
- Maximum voltage: 12V DC (stabilized)
- Wind speed: 0 – 7m/s

Wind rotors 1400-12

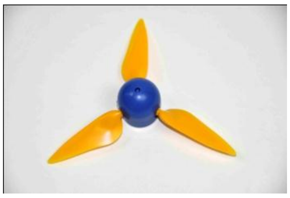
With the available components, rotors with 2, 3 or 4 blades and with a flat or an optimized profile can be created. There is a hub for 4 blades with a pitch angle of 25° and hubs for 3 blades with pitch angles of 20°, 25°, 30°, 50° and 90°.



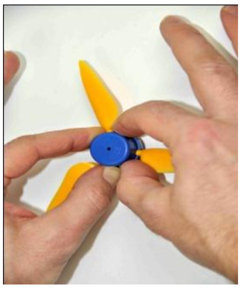
First, a hub with the desired rotor blade pitch and the number of blades should be selected. (The hubs are labeled on the back.) The Two-blade rotor and the Four-blade rotor can both be constructed with the Four-blade hub.



After that, the rotor blades are installed. During the insertion of the blades, make sure that they are installed with the rounded side up.

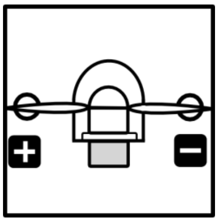


After installation of the rotor blades, the hub-cap will be mounted and lightly pressed against the hub.



To replace the blades, a small nose is located at head of the hub. If the nose is pressed lightly on a hard surface, the hub-cap can be removed easily.

Wind turbine module 1400-22

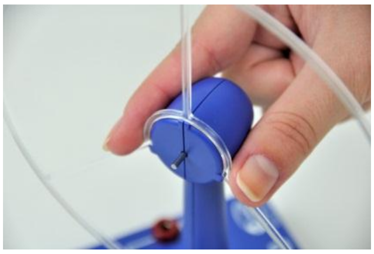


At first the blue wind turbine has to be plugged into the module. The rotor has to be racked at the generator shaft to get a model of a wind turbine. The rotor must not touch the casing to avoid friction, which would considerably impede its rotation. The generator produces a direct current, with its polarity marked on the module. Additionally an angle scale is printed on the module, so it is possible to adjust a certain wind angle.

It is not allowed to touch the rotor during movement due to risk of injury. The rotor may only be touched, when it does not turn!

<u>Handling of the fingerguard of the wind turbine 1400-22</u>

As you can see in the picture, the wind turbine has three small retainer to fix the fingerguard.

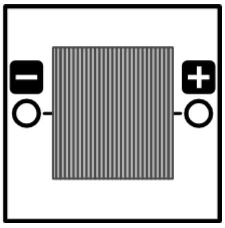


The fingerguard will be attached at the top of the wind turbine and pressed firmly at the lower retainers.

Afterwards, the wind rotor will be fixed at the wind turbine.

Advice: The fingerguard protects the finger against touching the rotor at the side. Do not touch the rotor from the front side because of injury risk!

Solar cell 1100-02 0,5V 840 mA

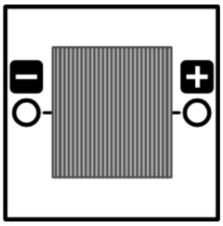
 

The specifications about open circuit voltage and short circuit current can be found on the back surface.

Specifications:

Material: polycristalline silicon
Open circuit voltage: 0,5V
Short circuit current: 840mA
Maximum power: 0,4Wp

Solar module 1100-07 1,5V 280 mA

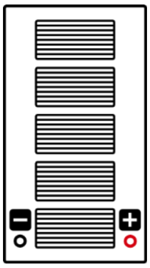
 

This solar module is a serial connection of three solar cells. The specifications about open circuit voltage and short circuit current can be found on the back surface.

Specifications:

Material: polycristalline silicon
Open circuit voltage: 1,5V
Short circuit current: 280mA
Maximum power: 0,13Wp

Solar module, large 1100-31 2,5V 420 mA



This solar module is a serial connection of five solar cells.

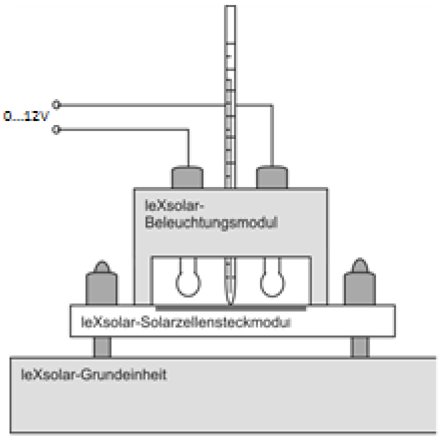
Specifications:

Material: polycristalline silicon
Open circuit voltage: 2,5V
Short circuit current: 420mA
Maximum power: 1Wp

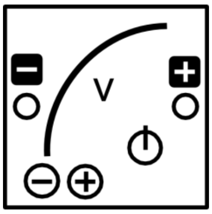
Solar cell cover set 1100-29

Lighting module (1100-20)

The lighting module is operated with the PowerModule. There are 4 light bulbs inside the lighting module. They can or cannot contribute to the lighting by screw or unscrew. It is not recommandable to change the illuminance by changing the voltage since the spectrum of the light will change, which leads to measuring errors. The lighting module has to be setted on the solar cell (see figure). Take care that the lighting should lie only as long as necessarry on the solar cell because of the heat built-up of the solar cell due to heat radiation. Between both connections there is a hole for the laboratory thermometer to measure the temperatur of the solar cell.



PowerModule 9100-05

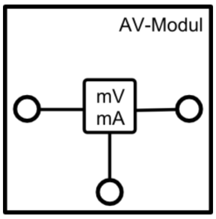


The PowerModule is a compact and intuitively usable voltage source. First, the attached power adapter has to be connected to a power outlet and to the top right input jack. The voltage can be chosen with the „+“- and „-“ -buttons and will be displayed by LEDs. When the desired voltage is chosen, the voltage will be applied by using the yellow on/off- button. In case of a short circuit or currents greater than 2 A the PowerModule will switch off immediately.

Specifications:

- Output voltage: 0-12 V
- Output power: max. 24 W
- Adjustable in 0.5 V steps
- Overcurrent detection >2 A and automatic shutoff
- Input voltage: 110-230 V, 50-60 Hz (with enclosed power adapter)

AV-Module 9100-03



The AV-Module is a combined voltage and current meter. It holds 3 buttons, whose features are described in the display respectively. By pushing a random button the module will switch on. In the disabled state the display shows the leXsolar emblem. When the display does not show anything or the word „Bat“ is shown, it is necessary to change the batteries in the back (2 x AA batteries 1.2 to 1.5V; Take care of the polarity marked on the bottom of the battery case! Do not touch the button while inserting the batteries).
With the top right button the measuring mode can be switched between voltage mode, current mode or combined voltage-current mode. Both measurement mode and required cable connection will be indicated by the circuit symbols on the display. Take care that in voltage mode no current is applied to the right jack. In the combined mode the voltage can be measured with the right jack as well as with the left one. The influence of the internal resistance of the current measurement is compensated internally. The measured values are signed. When the positive pole is connected to a red jack and the negative pole is connected to the black jack, the value of the voltage will be positive. When current is applied from the left to the right, the current value will be positive, as well. The other way around, the algebraic sign changes.

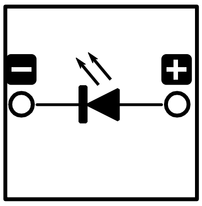
After 30 min without pushing a button or after 10 min of measuring a constant value, the module will switch off automatically. It can measure voltages up to 12 V and currents up to 2 A. In case of exceeding one of the values, the module interrupts the current flow and shows “overcurrent“ or “overvoltage”. This error message can be confirmed by touching a button. The module will resumes measuring, when the values attain acceptable values.

Specifications:

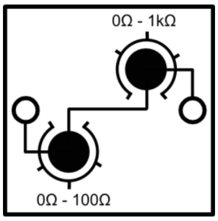
Voltage metering:
- range: 0...12 V
- accuracy: 1 mV
- automatic shutoff in case of overvoltage >12 V

Current metering:
- range: 0...2 A
- accuracy: 0,1 mA (0...199 mA) and 1mA (200 mA...1 A)
- automatic shutoff in case of overcurrent >2 A
- internal resistance <0,5 Ohm (0...200 mA); <0,2 Ohm (200 mA...2 A)

LED-Module 1400-08

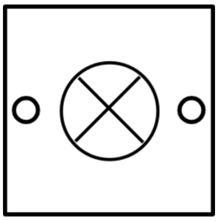


Potentiometer module 1100-61



The potentiometer module holds a 0-10-Ω-potentiometer and a 0-100-Ω-potentiometer. Both are serially conneted, so that the potentiometer can attain resistances between 0 Ω bis 110 Ω. The measuring error amounts to 0.5 Ω for the small resistor and 5 Ω at other one.

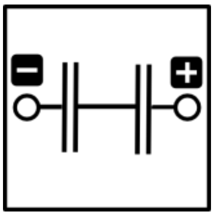
Light bulb module 1100-26



Specifications:

Light bulb P_{typ} = 200 mW (at 3.5 V)
Fuses work up to maximum voltage of 6 V

Capacitor module 1600-02

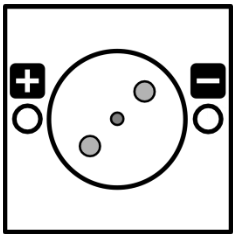


The capacitor module consists of 2 series-connected capacitors. The maximum voltage of the capacitor amounts to 5.4 V. Charging voltages for the capacitor should not exceed 5 V. It is possible to short-circuit the capacitor to discharge, because there are fuses to avoid damages. For quick charging, it is also possible to connect the capacitor directly to a power supply. The voltage source should be switched on at a voltage of 0.5 V and can be increased by 0.5 V every 10 s. The capacitor should be charged with the final voltage for 30 s.

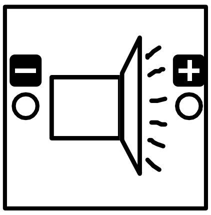
Specifications:

Capacitance: 5 F
Maximum voltage: 5,4 V

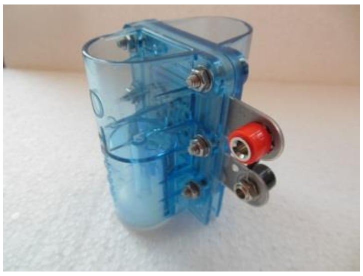
Motor module (1100-27) with color discs set 1 (1100-28)

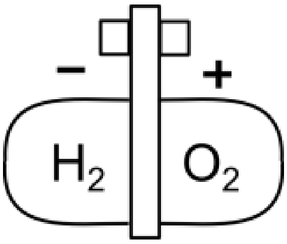


Buzzer module 1100-25

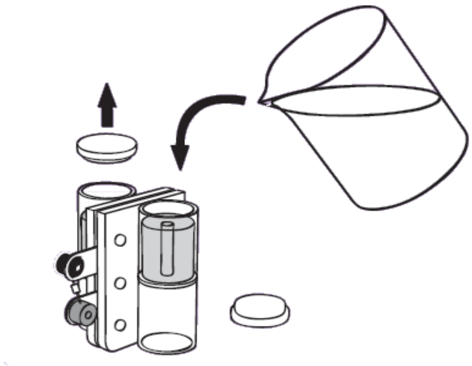


Reversible fuel cell L2-06-067 with distilled water 1800-15





The reversible fuel cell consists of an electrolyzer and a fuel cell. To fill the reversible fuel cell you should proceed in the following way:



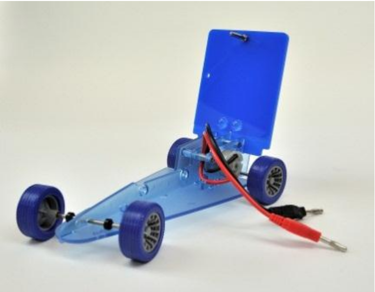
1. Fill the rev. fuel cell with distilled water as shown in the alongside figure.
2. Fill both storage cylinders up to the top of the tubules, which are inside the cylinders.
3. Knock the rev. fuel cell slightly on the table.
4. Continue filling in water until it flows through the tubules.
5. Close the storage cylinders with the plugs and turn over the rev. fuel cell. (the plugs must be on the bottom)

To charge the reversible fuel cell the applied voltage should not exceed 1.5 V. Otherwise the resulting current could exceed 1 A, which would damage the fuel cell.

Water wheel module 1900-01

The water wheel module works with a Pelton Turbine. It has a transparent splash accident protection. Plug the silicone hose Ø 12mm into water tap and direct the water stream onto the Pelton turbine.
If the wheel is not working the water pressure might be too low and you should try to increase the water stream even more, or extend distance between the Turbine and the water tap.

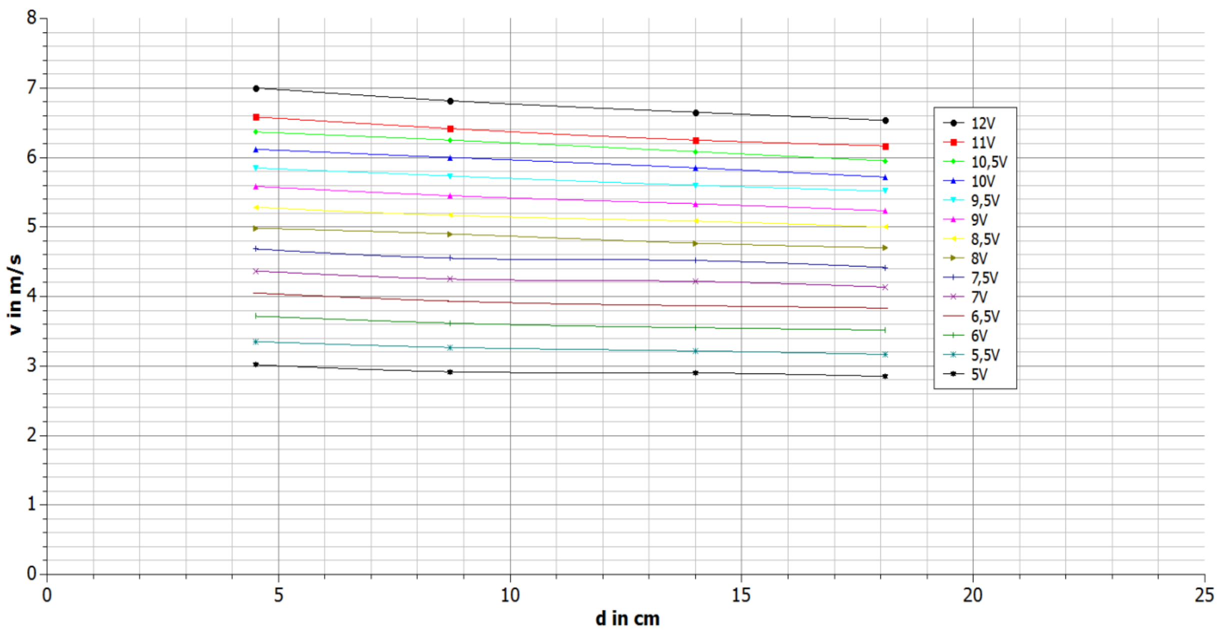
Electric model car with battery adapter 1801-02



The electric model car can be used with the reversible fuel cell or the capacitor module. The fuel cell can be plugged directly in the car. The capacitor can be plugged with the adapter in the car. The car will move when both cables are connected with the voltage source. There will be a short circuit when the wires are held during the short circuit.

Hand generator 1602-02

Wind speed at constant voltage at the wind machine depending on the distance

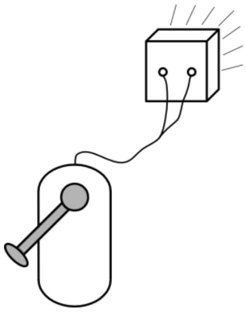


1. From muscular strength to current...to light

Task

Generate current by turning the crank of the hand generator and make the lighting module shine.

Setup



Required devices

- Hand generator
- Lighting module

How to do

Plug both plugs of the hand generator in the lighting module.

Crank the hand generator strongly. What do you see?

Try to turn the crank now very slowly. What do you observe?

Allow your classmate to touch one of the light bulbs carefully for some time while you are cranking rapidly. What can he sense?

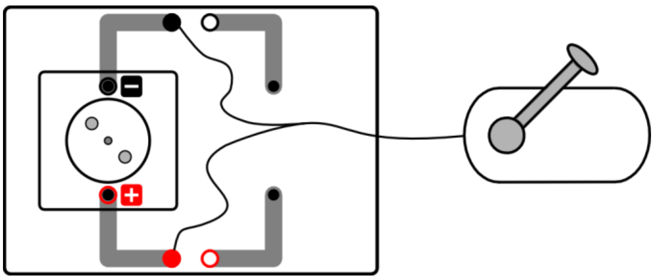
Which energy conversions did you observe in this experiment?

2. From muscular strength to current...to motion

Task

Generate current by turning the crank of the hand generator and drive a motor

Setup

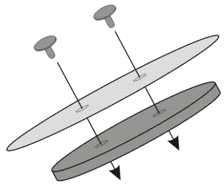


Required devices

- Base Unit
- Hand generator
- Lighting module

How to do

Assemble the experiment as seen in the picture above. Take care to get the correct polarity (red cable into the red socket, black cable into the black socket).



Lift the blue disk carefully from the motor module and loosen the small clips. Fix the red and blue cardboard disk onto the blue rotation disk and put it back on the motor.

Crank the hand generator rapidly! What do you observe?

Try to turn the crank now very slowly. What do you observe this time?

Interchange the cables of the hand generator – that means red cable to black socket and vice versa. Crank slowly. What happens?

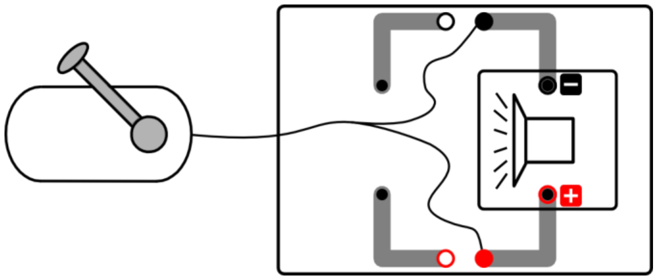
Which energy conversions took part in this experiment?

3. From muscular strength to current…to Noise

Task

Generate current by turning the crank of the hand generator to stimulate the buzzer to make a noise.

Setup



Required devices

- Base Unit
- Hand generator
- Buzzer module

How to do

Assemble the experiment as seen in the picture above. Take care to get the correct polarity (red cable into the red socket, black cable into the black socket).

Crank the hand generator rapidly! What do you observe?

Try to turn the crank now very slowly. What do you observe this time?

Interchange the cables of the hand generator – that means red cable to black socket and vice versa. Crank slowly. What happens? Can you explain your observation?

Which energy conversions took part in this experiment?

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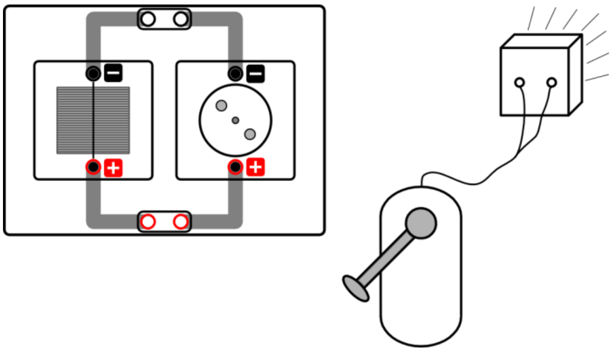
4. The solar cell drives a motor

Task

Assemble the solar cell and the motor so that the motor rotates when light shines on the solar cell.

Setup



Required devices

- Base Unit
- Solar *cell,* 0.5V
- Motor module
- Short-circuit plugs

If there is no sunshine you will also need:

- Hand generator
- Lighting module

How to do

Expose the solar cell to sunlight. If the sun is not shining, then point the lighting module toward the cell and turn the crank rapidly or expose the solar cell to the light from a lamp.

What do you observe?

Move the main board slowly away from the light or ask a classmate to lift the lighting module slowly.
What do you observe?

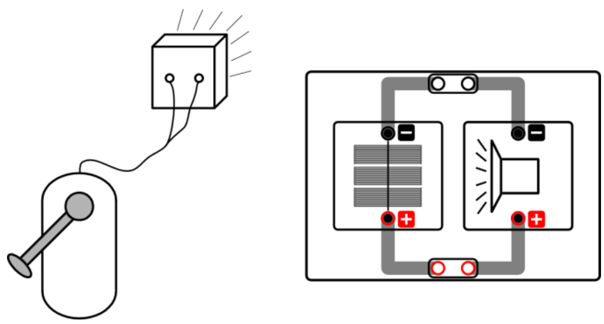
Explain your observation!

5. The solar module powers a buzzer

Task

Assemble the solar module and the buzzer so that the buzzer makes a noise when light shines on the solar module.

Setup



Required devices

– Base Unit
– Solar *module,* 1.5V
– Buzzer module
– Short-circuit plugs

If there is no sunshine you will also need:

– Hand generator
– Lighting module

How to do

Expose the solar cell to sunlight. If the sun is not shining, then point the lighting module toward the cell and turn the crank rapidly or expose the solar cell to the light from a lamp.

What do you observe?

Move the main board slowly away from the light or ask a classmate to lift the lighting module slowly.
What do you observe?

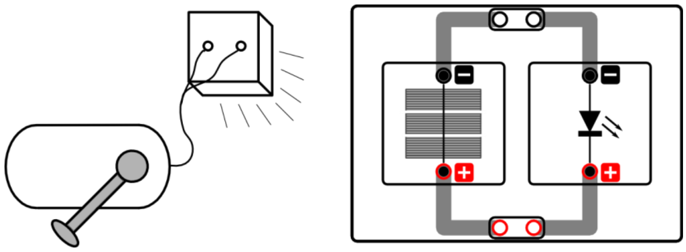
Explain your observation!

6. The solar module powers a LED

Task

Assemble the solar module and the LED so that the LED lights when sunlight shines on the solar module.

Setup



Required devices

- Base Unit
- Solar *module,* 1.5V
- LED module
- Short-circuit plugs

If there is no sunshine you will also need:

- Hand generator
- Lighting module

How to do

Expose the solar cell to sunlight. If the sun is not shining, then point the lighting module toward the cell and turn the crank rapidly or expose the solar cell to the light from a lamp.

What do you observe?

Move the main board slowly away from the light or ask a classmate to lift the lighting module slowly.
What do you observe?

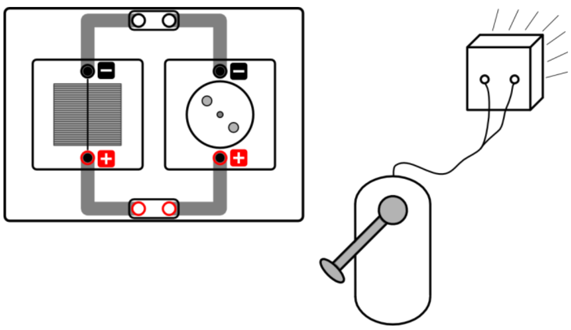
Explain your observation!

7. The larger the solar cell, the ...?

Task

Find out how the motor works with a smaller or larger solar cell.

Setup



Required devices

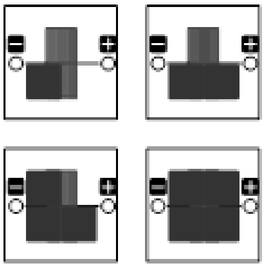
– Base Unit
– Solar *cell,* 0.5V
– Motor module with color disk
– Short-circuit plugs
– Cover plates

If there is no sunshine you will also need:
- Hand generator
- Lighting module

How to do

Expose the solar cell to sunlight. If the sun is not shining, then point the lighting module toward the cell and turn the crank rapidly or expose the solar cell to the light from a lamp.

You can change the active surface area of the solar cell by shading parts of it. Repeat the same experiment using no cover plate, one cover plate, two cover plates, three or four cover plates. Stop the motor each time between experiments and note in which situation the motor is rotating the fastest, the second fastest and so on.



Solar cell scaled down through covering:	*Ranking of rotation speed (1 fastest … 5 slowest):*
• Solar cell without cover	
• One quarter of the solar cell covered	
• Half of the solar cell covered	
• Three quarter of the solar cell covered	
• Solar cell completely covered	

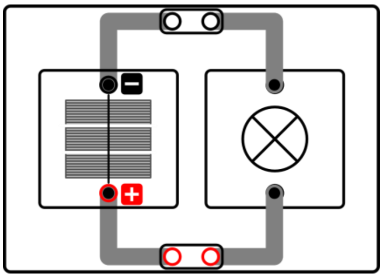
The larger the area of the solar cell, the ______________the color disk rotates!

8. The solar module powers a LED

Task

From which direction does light need to reach the solar cell to make it work the best?

Setup



Required devices

- Base Unit
- Solar *module,* 1.5V
- Light bulb module
- Short-circuit plugs

This experiment has to be carried out in direct sunlight!

How to do

Hold the main board into the sunlight. The solar cell should be perpendicular to the direction of the incoming light. (You can determine that, for example, when the Short-circuit plugs do not throw any shadows.)

Tilt the main board slowly away from the direction of the light and observe the brightness of the lamp.

What do you observe?

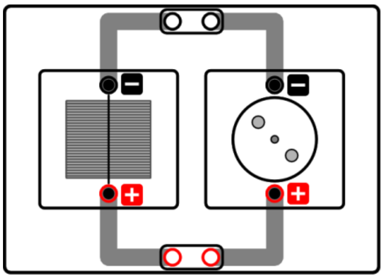
What does your observation mean for the performance of the solar cells on roofs during the day?

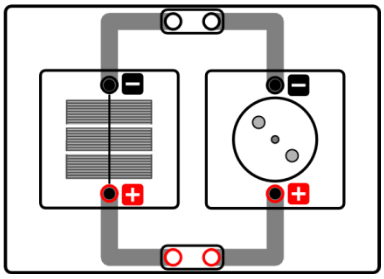
9. From the solar cell to the solar module

Task

Compare a solar cell to a solar module (three solar cells connected).

Setup





Required devices

- Base Unit
- Solar *cell,* 0.5V
- Solar *module,* 1.5V
- Light bulb module
- Motor module
- Buzzer module
- LED module
- Short-circuit plugs

This experiment should be carried out in direct sunlight!

How to do

In this experiment all four consumer modules (motor, light bulb, buzzer, LED) are powered once by a solar cell and once by a solar module.

First set up the experiment with the motor module and characterize the behavior of the module when it is connected to the solar cell, respectively to the solar module. Repeat the experiment for the other consumers (light bulb, buzzer, LED).

	with solar cell	**with solar module**
Motor	___________________	___________________
Buzzer	___________________	___________________
Light bulb	___________________	___________________
LED	___________________	___________________

Some consumers need a minimum voltage to work. What can you conclude from your observations about the difference between solar cell and solar module

____

____

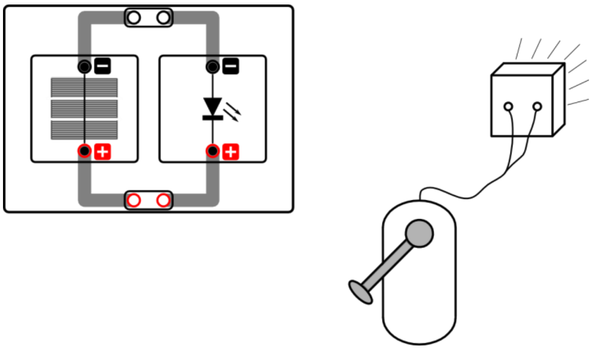
____

10. Shading of solar modules

Task

What happens if parts of the solar module are shaded?

Setup



Required devices

- Base Unit
- Solar *module,* 1.5V
- LED module
- Short-circuit plugs
- Dark strip of paper/cardboard

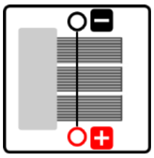
If there is no sunshine you will also need:

- Hand generator
- Lighting module

How to do

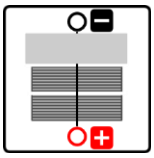
Hold the solar module in the sunlight! If the sun is not shining, then point the lighting module toward the solar module and turn the crank rapidly or expose the solar module to the light of a lamp. What do you observe?

Cover the solar module with two cover plates, as in the picture (right) and illuminate the solar module:



What changes do you observe?

Now cover the solar module with two cover plates like in this picture and illuminate the solar module:



What changes do you observe?

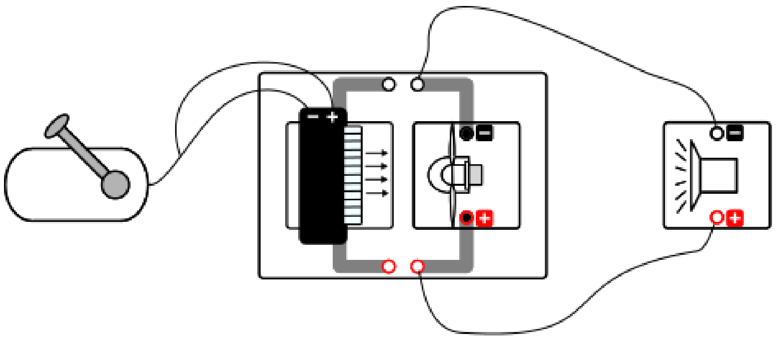
What differences do you observe depending on how you shade the solar module? Can you explain this behavior?

11. The wind turbine powers a buzzer

Task

Assemble the wind turbine and the buzzer so that the buzzer makes a noise when the wind starts to blow.

Setup



Required devices

- Base Unit
- Wind machine
- Wind turbine with optimized profile
- Buzzer module
- Hand generator
- Cables

Warning Risk of injury: Do not touch the rotating rotor!

How to do

Turn the crank rapidly! What happens with the wind turbine module?

What happens with the buzzer?

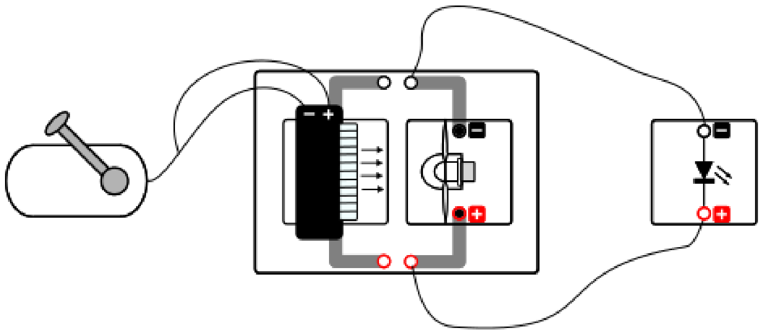
Explain your observation!

12. The wind turbine powers a LED

Task

Assemble the wind turbine and the LED so that the LED lights when the wind starts to blow.

Setup



Required devices

- Base Unit
- Wind machine
- Wind turbine with optimized profile
- LED module
- Hand generator
- Cables

Warning Risk of injury: Do not touch the rotating rotor!

How to do

Turn the crank rapidly! What happens with the wind turbine module?

___

___

___

What happens with the LED?

___

___

___

Explain your observation!

___

___

___

___

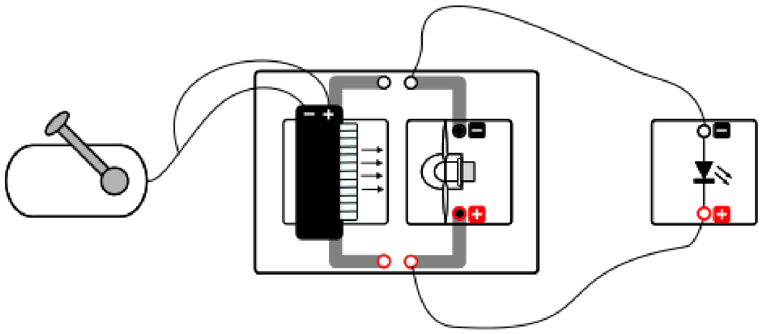
___

13. Influence of the wind direction

Task

Examine the influence of the wind direction on the power of the wind turbine.

Setup



Required devices

- Base Unit
- Wind machine
- Wind turbine with optimized profile
- LED module
- Hand generator
- Cables

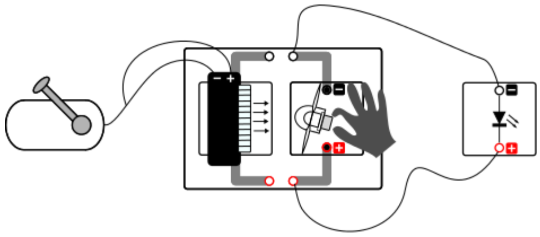
Warning Risk of injury: Do not touch the rotating rotor!

How to do

This experiment should be done in twos. One student turns the crank rapidly during the whole experiment.

Wait, till the LED shines brightly. Now touch the foot of the wind turbine, carefully! Hold your hand flat to avoid injury and obstruction of the air flow.

Turn the wind turbine slowly to the right, as you can see in the picture below. What happens?



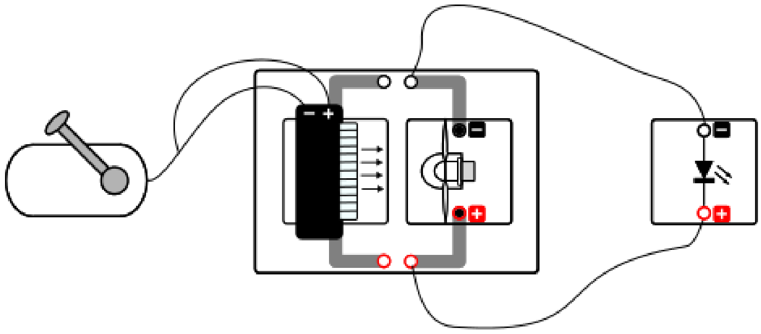
Now change the places and your partner turns the wind turbine to the left. What happens?

14. Influence of the rotor blade shape

Task

Examine the influence of the rotor blade shape on the power of the wind turbine.

Setup



Required devices

- Base Unit
- Wind machine
- Wind turbine with optimized profile and flat profile
- LED module
- Hand generator
- Cables

Warning Risk of injury: Do not touch the rotating rotor!

How to do

First, set up the experiment with the optimized profile.

Turn the crank rapidly! What happens with the wind turbine module?

What happens with the LED?

Now change the rotor to the flat profile and repeat the experiment. What can you observe at the wind turbine and at the LED?

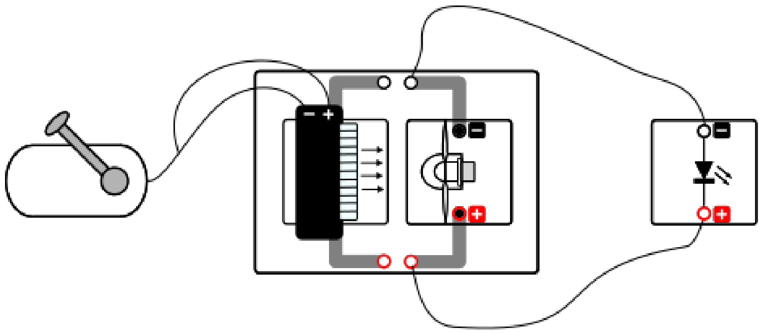
Compare both rotor blade shapes!

15. Influence of the wind speed

Task

Examine the influence of the wind speed on the power of the wind turbine.

Setup



Required devices

- Base Unit
- Wind machine
- Wind turbine with optimized profile
- LED module
- Hand generator
- Cables

Warning Risk of injury: Do not touch the rotating rotor!

How to do

This experiment should be done in twos. One student turns the crank during the whole experiment. In this experiment the crank should be turned with different speeds. Start with the highest speed and observe the LED. Hold your hand behind the wind turbine to feel the wind speed. Now decrease the speed of the crank and observe the LED respectively the wind speed. Now try to fill the table

Speed of the crank	**Wind speed** (1 … high to 4 … low)	**Brightness of the LED** (1 … high to 4 … low)
very fast	______	______
fast	______	______
middle	______	______
slowly	______	______

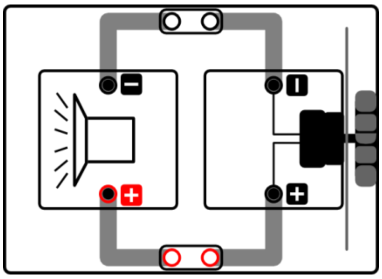
Now change your roles and check your results.

16. The water wheel powers a buzzer

Task

Assemble water wheel module and the buzzer so that the buzzer makes a noise when water is falling on the water wheel.

Setup



Required devices

- Base Unit
- Water wheel module
- Buzzer module
- Tube
- Short-circuit plugs

Additionally needed:
- Two large bowls / boxes
- Water
- Table / chair / higher position

How to do

Set up the circuit like in the picture. Place one bowl of water on the table, the other one is placed on the floor or chair so that you can collect the water with which you will drive the waterwheel.
Now insert the hose with one end in the water and suck the water until the water level in the tube is deeper than the water in the bowl. (Put your finger on the tube so that the water level does not drop again).
Alternatively, you can also put the tube completely into the bowl. Make sure that no air bubbles arise. Now hold your finger on one end of the tube and hold it down to the water wheel. Make sure that the other end of the tube remains in the water.
Hold the base unit with the water wheel over the lower bowl. Now take your finger from the opening of the tube so that the water jet hits the waterwheel.

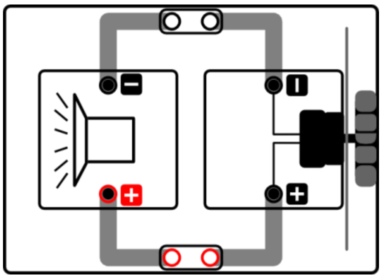
Note your observations!

17. Influence of the water falling height

Task

Examine the influence of the water falling height on the power of a water wheel.

Setup



Required devices

- Base Unit
- Water wheel module
- Buzzer module
- Tube
- Short-circuit plugs

Additionally needed:
- Two large bowls / boxes
- Water
- Table / chair / higher position

How to do

Set up the circuit like in the picture. Place one bowl of water on the table, the other one is placed on the floor or chair so that you can collect the water with which you will drive the waterwheel. Repeat the experiment “The water wheel powers a buzzer”.
Now vary the falling height of the water. What do you observe?

____

____

____

____

Explain your observations.

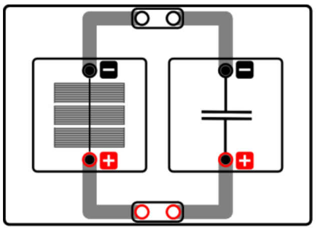
The farther the water falls, the ____________ it gets. If the water drops with greater _____________ on the water wheel, the ____________ is greater and the water wheel turns ____________. This leads to higher ___________. The more current flows, the ____________ is the buzzer.

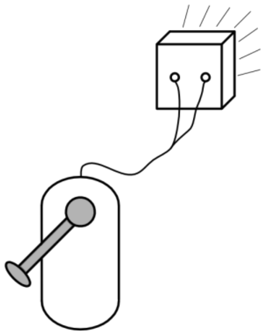
18. Storage of solar energy

Task

Store the energy of a solar module.

Setup





Required devices

- Base Unit
- Solar *module*, 1.5V
- Buzzer module
- Capacitor module
- Short-circuit plugs

If there is no sunshine you will also need:

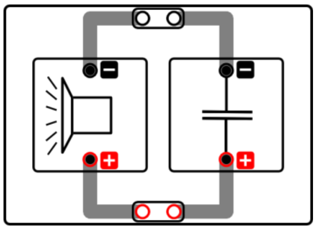
- Hand generator

How to do

Expose the solar module to sunlight. If there is no sunshine, then point the lighting module toward the solar module and turn the crank rapidly or expose the solar module to the light from a lamp – *for minimum one minute!*

Now plug off the solar module from the main board while it is illuminated. If you use the crank, let another student help you.

Now plug the buzzer module on the base plate and connect it to the capacitor module as you can see in the right picture.



What do you observe?

____

____

____

Which property has the capacitor?

____

____

____

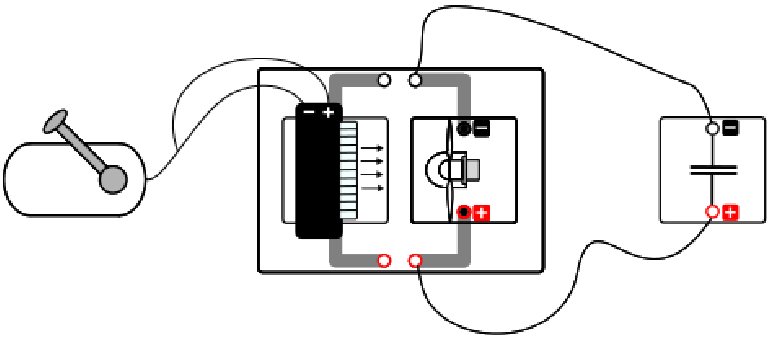
____

19. Storage of wind energy

Task

Store the energy of a wind turbine.

Setup



Required devices

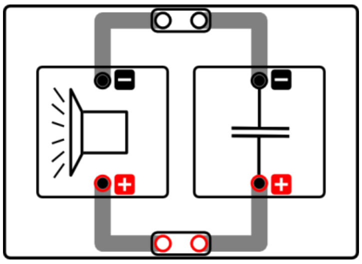
- Base Unit
- Wind machine
- Wind turbine with optimized profile
- Buzzer module
- Capacitor module
- Hand generator
- Cables

Warning Risk of injury: Do not touch the rotating rotor!

How to do

Turn the crank rapidly – *for minimum one minute!* While you crank another student should plug off the capacitor module from the main board.

Now plug the buzzer module on the base plate and connect it to the capacitor module as you can see in the right picture.



What do you observe?

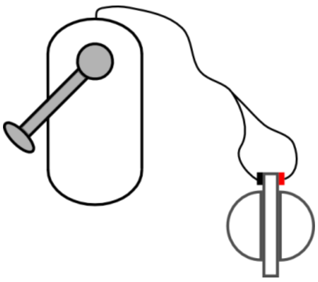
Which property has the capacitor?

20. What is an Electrolyzer?

Task

Find out what an electrolyzer does! What happens to water when being electrolyzed?

Setup



Required devices

- Reversible fuell cell
- Hand generator
- Distilled water

How to do

Set up the experiment as you can see in the picture. Pay attention to the polarity of the plugs (connect the red cable to the red socket and the black one to the black socket).

Fill the reversible fuel cell with distilled water. You can find details regarding the handling of the fuel cell on page 13.

Turn the crank of the hand generator slowly. Have a look on the tanks on both sides of the reversible fuel cell.

What do you observe?

____

____

The reversible fuel cell now acts as an electrolyzer of water. What does an electrolyzer do?

____

____

Turn the crank now more rapidly until you see that the H_2 gas tank is full and small bubbles come out of the water.

What is the overall energy balance of this experiment, that means what did you put in, what happened and what came out?

Input: ____________________

Conversion to: ____________________

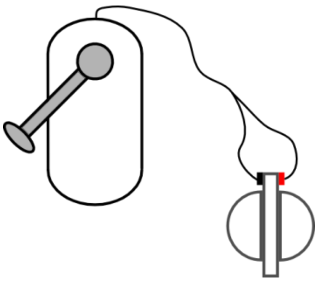
Output: ____________________

21. How can water be split?

Task

What happens in detail when the electrolyzer splits the water? Which amount of gas is coming out?

Setup



Required devices

- Reversible fuell cell
- Hand generator
- Distilled water

How to do

Set up the experiment as you can see in the picture. Pay attention to the polarity of the plugs (connect the red cable to the red socket and the black one to the black socket).

Fill the reversible fuel cell with distilled water. You can find details regarding the handling of the fuel cell on page 13.

Turn the crank of the hand generator rapidly. What happens in the gas tanks? Is the gas volume larger in the H_2 tank or in the O_2 tank?

____

____

As the amount of gas in the gas tanks grows, the water that was initially there has to go elsewhere. That's why the level of water in the upper tank is rising.
Read out the levels of gas while cranking strongly for 90 seconds:

	H_2 tank	O_2 tank
30 seconds:	________________________	
60 seconds:	________________________	
90 seconds:	________________________	

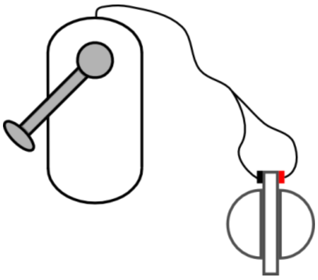
What is the relation between the numbers? ________________________

22. What is a fuel cell?

Task

Find out what a fuel cell does! What does it need and what comes out?

Setup



Required devices

- Reversible fuell cell
- Hand generator
- Distilled water

How to do

Carry out the experiments “What is an Elektrolyzer?” and “How can water be split?”. Then fill in the gaps of the following text.

If you carried out one of the two previous experiments, you know what an electrolyzer is: The electrolyzer __________the liquid water into the two gaseous components____________and _____________. But you have to put in energy in order to make this __________possible. This energy has to be delivered in form of electric energy. The hand generator is able to convert the motion of the crank into_________ energy.

But what about the opposite? Can we put in the gases and get out _________________?

Yes, this is possible! The name of the device that does this can be found in the title: ________________.

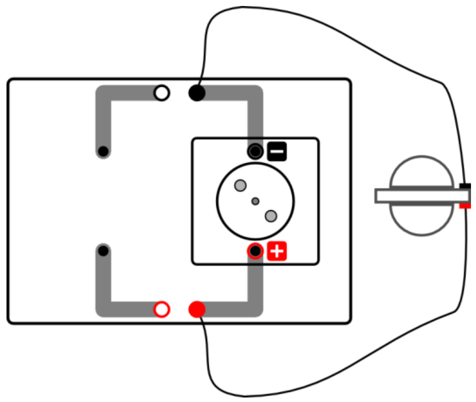
The fuel cell converts the chemical energy of the gases into electric energy. The electric energy can then be used for further applications like motors or buzzer, as you will see in the following experiments.

23. The fuel cell drives the motor

Task

Assemble the fuel cell and the motor module so that the motor rotates.

Setup



Required devices

- Reversible fuell cell
- Hand generator
- Distilled water
- Motor module
- Cables

How to do

Assemble the fuel cell and the motor module as you can see in the above setup. If the gas tanks are not filled with gas, you will have to carry out the experiment “What is an Electrolyzer?” before.

What do you observe, when the motor is connected to the (filled) fuel cell?

What happens with the gas in the gas storage tank?

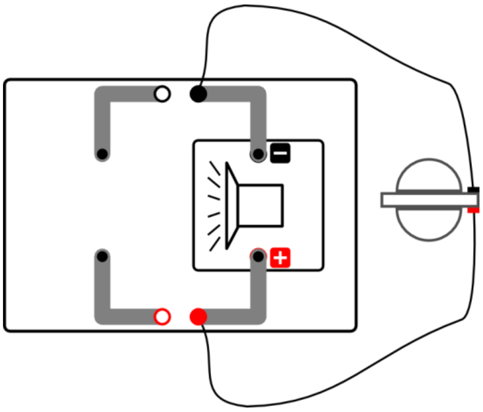
Explain your observation!

24. The fuel cell powers the buzzer

Task

Assemble the fuel cell and the buzzer module so that the buzzer makes a noise.

Setup



Required devices

- Reversible fuell cell
- Hand generator
- Distilled water
- Buzzer module
- Cables

How to do

Assemble the fuel cell and the buzzer module as you can see in the above setup. If the gas tanks are not filled with gas, you will have to carry out the experiment “What is an Electrolyzer?” before.

What do you observe, when the buzzer is connected to the (filled) fuel cell?

____

____

____

What happens with the gas in the gas storage tank?

____

____

____

Explain your observation!

____

____

____

____

____

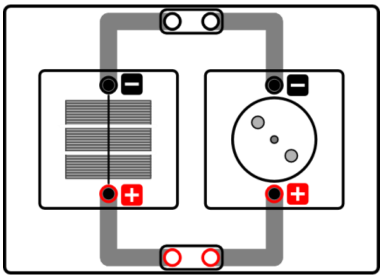
____

25. Energy demand of several consumers

Task

Examine the energy demand of several consumers.

Setup



Required devices

- Base unit
- Solar *modul*e, 1.5V
- Buzzer module
- Motor module
- LED Module
- Light bulb module
- Short-circuit plugs

If there is no sunshine you will also need:

- Hand generator
- Lighting module

How to do

In this experiment the energy demand (respectively power demand) of several consumers is obtained. First, set up the experiment with the motor module. Repeat the experiment with the other consumers (buzzer, light bulb, LED module).
Find the conditions where the consumers just work (minimum conditions). Try with room light, sun light, direct sunlight and so on. What is the ranking of the energy demand of the consumers? (1 meens lowest, 4 meens highest demand)

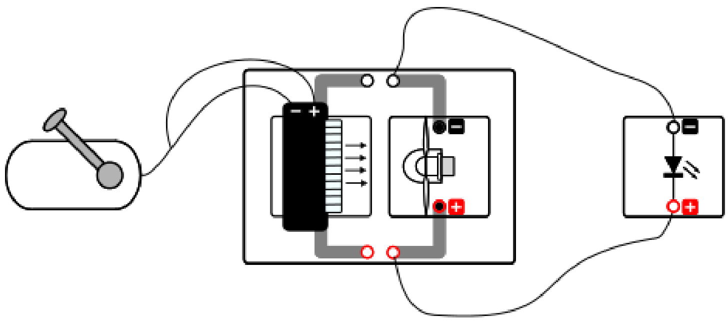
	Minimum conditions (for ex. room light, sun light etc)	Ranking Energy demand
Motor		
Buzzer		
Light bulb		
LED		

26. Comparison of light bulb and LED

Task

Compare the efficiency of a light bulb and a LED.

Setup



Required devices

- Base Unit
- Wind machine
- Wind turbine with optimized profile
- LED module
- Hand generator
- Cables

Warning Risk of injury: Do not touch the rotating rotor!

How to do

Turn the crank rapidly and wait till the LED starts to light. Now decrease the rotational speed of the crank so that the LED is just glowing. Remember how fast you have to turn the crank.

Now use the light bulb instead of the LED. First, do NOT plug in the light bulb! Turn the crank rapidly till the wind turbine is turning very fast. Now let another student connect the light bulb.

Now decrease the rotational speed of the crank so that the light bulb is just glowing. What is your observation?

____

____

____

____

____

____

Which kind of illumination is more economical?

____

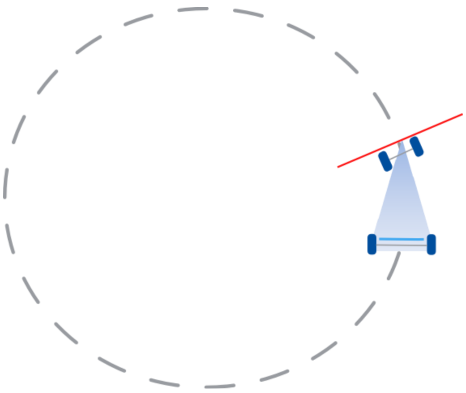
____

27. Storage and output of energy...EMobility

Task

Power the electric car with the capacitor.

Setup



Required devices

- Electric model car with adapter
- Capacitor module
- Hand generator

Advice: Pay attention to the car. It should not hit something, because the axles could get damaged. Hold the car shortly before starting it, because it could tip otherwise.

How to do

Charge the capacitor with the hand generator for about one minute (first slowly, then faster).
Plug then the capacitor onto the adapter plate and attach the plate to the electric model car. Tilt the front axle of the car to the left, so that the car drives a circular path.
Now connect the capacitor with the cables and let the car drive.

Note your observations.

____

____

How can you explain that behavior?

____

____

____

Which energy conversions you have observed in this experiment?

____

____

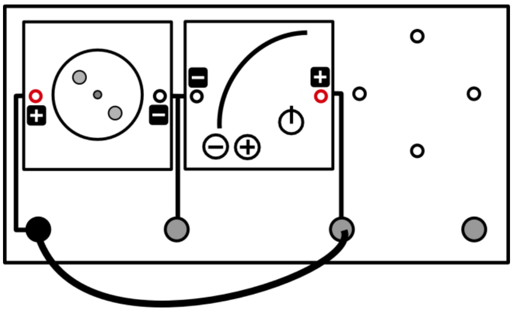
____

1. Forms of energy and consumers

Task

Examine the properties of several consumers in dependence of the applied voltage.

Setup



Required devices

- Base unit
- PowerModule
- Motor module with color disc
- LED module
- Buzzer module
- cable

Execution

1. Set up the circuit with the motor module first and adjust the PowerModule to 1V. Pay attention to the polarity of the plugs. Note your observations.
2. Increase the voltage in steps of 1V (see table)
3. Repeat the experiment with the light bulb, the LED and the buzzer. Note all your observations in the table. Observe not only on what you see and hear, but also touch and LED light bulb, when they run for some time!

Evaluation

Voltage	Buzzer	Motor	LED	Light bulb
1 V				
2 V				
4 V				
6 V				

Fill the gaps:

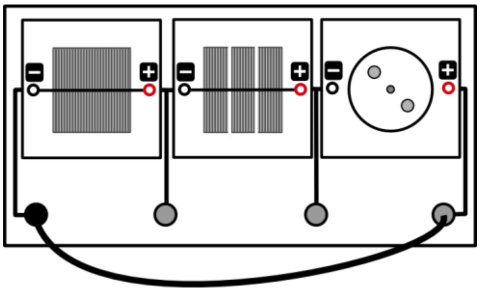
__________________ and __________________are consumers. They convert electrical energy supplied by the Powermodule into other forms of energy. Buzzer and motor convert the electrical energy into __________________ (energy of movement) . (Sounds that we perceive are also movements - vibration of the air). LED and light bulb convert the electrical energy into __________________, the light bulb additionally to __________________. So consumers do not "consume" the electrical energy, but convert it into other __________________________________.

2.1. Basic structure: rotation discs

Task

The following experiments all require the same basic set up: a series connection made up of the solar cell, the solar module and the motor.

Setup

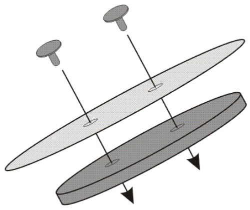


Required devices

- Base unit
- Solar *cell*, 0.5V
- Solar *module*, 1.5V
- Motor module with color disc
- cable

Execution

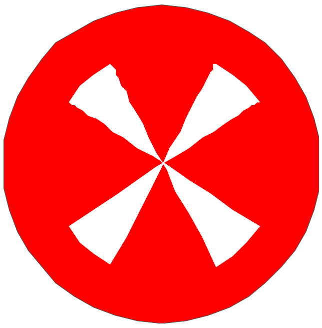
1. Set up a series connection with the solar cell, the solar module and the motor.
2. Now clip the rotation disk onto the motor. Only one other cardboard disk will be added to the rotation disk during the following experiments. The cardboard disk is secured by two colored plastic clips.



Advice: If necessary you can use a plug to take the clips off the rotation disk. Carefully press the plug against the clip from underneath.

2.2 Color qualities

Cardboard disk



Execution

1. Rotate the disk!
2. Place your hand above it so that there is a shadow over one half! Your results will help you understand the color system better.

Evaluation

Color: Which color does the disk have? ____________

Brightness: On the shaded side the color seems...

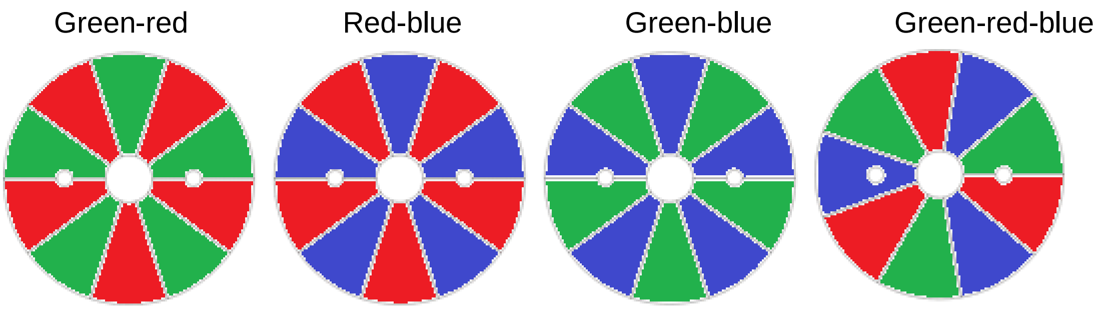
- ☐ brighter than on the illuminated side
- ☐ as bright as on the illuminated side
- ☐ darker than on the illuminated side

Hue: The color in the middle of the disk seems...

- ☐ paler than at the edge
- ☐ the same as at the edge
- ☐ stronger than at the edge

2.3 Mixing colors

Cardboard disks

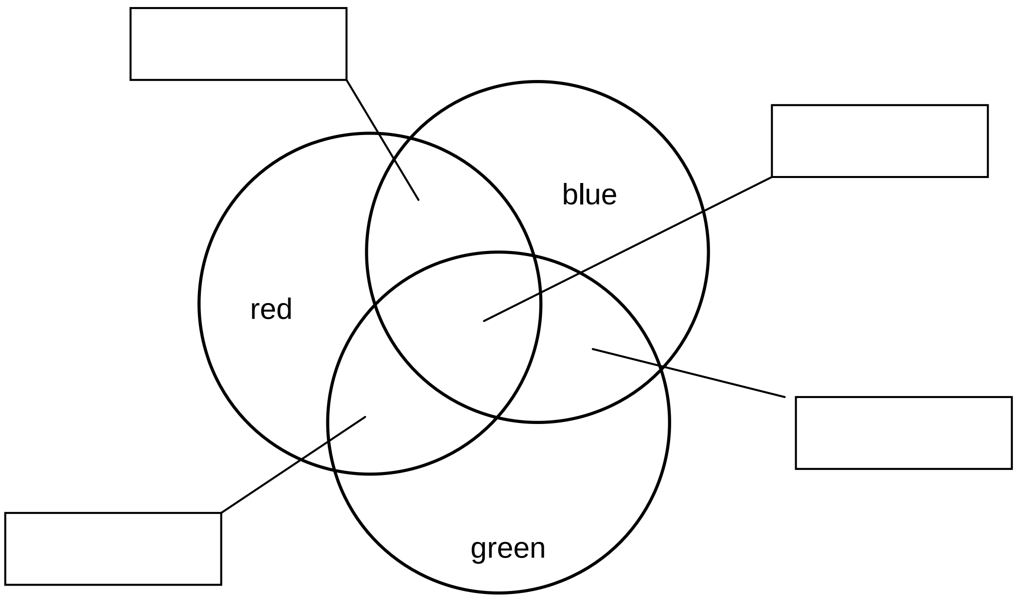


Execution

The segments of the disks have different colors when the disk is not in motion.

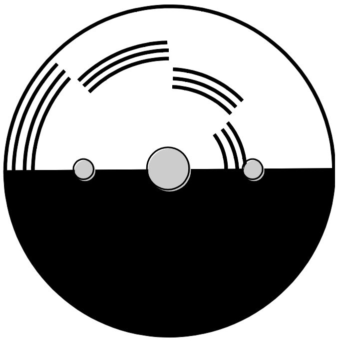
1. Let the disks rotate quickly to make the colors mix!
2. Now color the different segments in the picture below! Start with the pure colors red, green and blue. Then, with the help of your observations, color the four blending segments. Label the marked areas!

Evaluation



2.4 Color-deception with the Benham-disk

Cardboard disk



Execution

1. Rotate the disk anticlockwise at medium speed! What can be observed? If you can't see anything special because the disk rotates too fast, shade the solar cells a little!
2. Change the poling of the motor by plugging it the other way round! What do you observe now?

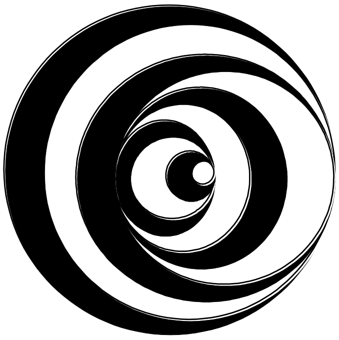
Evaluation

1. What do you observe when the disk is rotating anticlockwise? Which color sequence do you observe from inside to outside?

2. What do you observe when the disk is rotating clockwise? Which color sequence do you observe from inside to outside?

2.5 Relief-disk

Cardboard disk



Execution

Let the disk rotate slowly and note your observations!

Evaluation

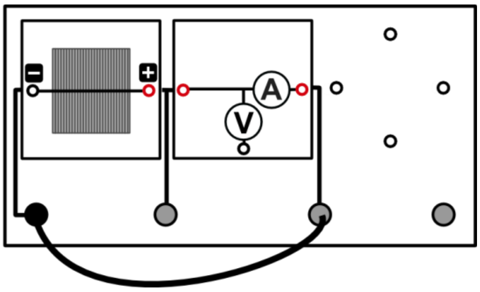
What do you observe when the disk is rotating slowly? If you can’t see anything special because the disk rotates too fast, shade the solar cells a little!

3. Dependence of power of a solar cell on its area

Task

Measure the voltage and the current and determine the power of a solar cell for different active areas! What relation is there between the area and these three measured values?

Setup



Required devices

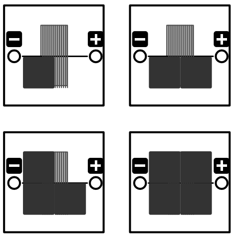
- Base unit
- solar *cell*, 0.5V
- AV-Module
- Covers for solar cells
- cable

Information

In this experiment only short-circuit currents and open-circuit voltages are measured. These cannot be measured simultaneously. Therefore, use the AV-Module only in voltage-mode, respectively in current-mode!

The power will be calculated with the short circuit current and open circuit voltage in this experiment. This power is a fictive power and is not the maximum power of the solar cell. However, this fictive power is used, because it is sophisticated to ascertain the maximum power without facilities. In this context, the comparison of the fictive powers leads to the same result than the comparison with the maximum power.

Execution



1. Set up the circuit according to the diagram!
2. Measure first the open-circuit voltage $V_{oc.}$ Use the AV-Module in voltage-mode and do not plug in the cable yet.
3. Now measure the short-circuit current I_{SC}. Plug in the cable as shown in the setup and use the AV-Module in current-mode.
4. Repeat this measurement with 1/4, half, 3/4 and completely of the solar cell covered!
5. Record the measured data in a table!

Evaluation

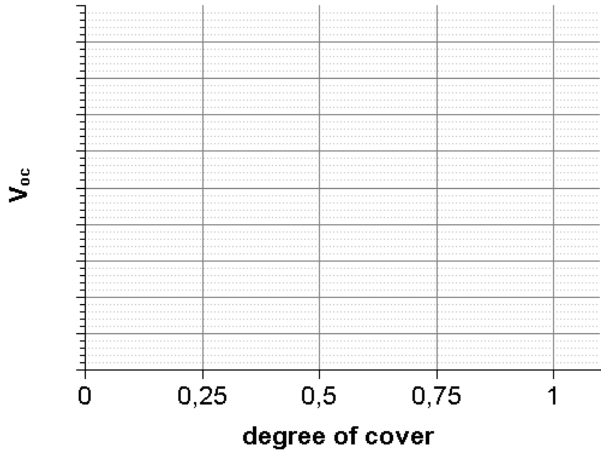
1. Calculate the respective powers *P* of the solar cell according to the measurement and note your values in the table.
2. Plot the results in a diagram (x-axes: degree of coverage (0, 1/4, 1/2, 1); y-axes: *P*, *I* and *V*)!
3. Which relation can be found between the voltage (current, power) and the area of the solar cell?
4. How can that be explained?

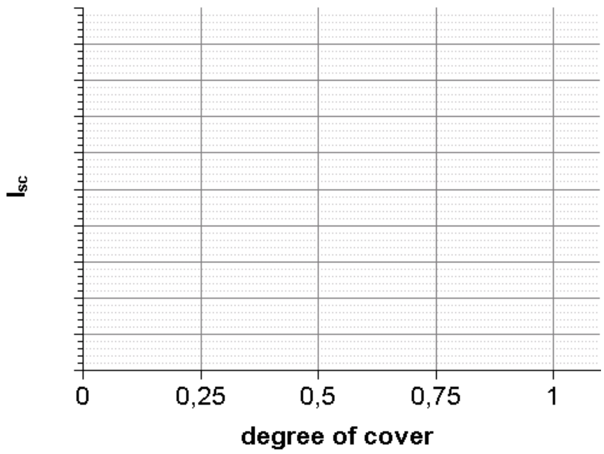
3. Dependence of power of a solar cell on its area

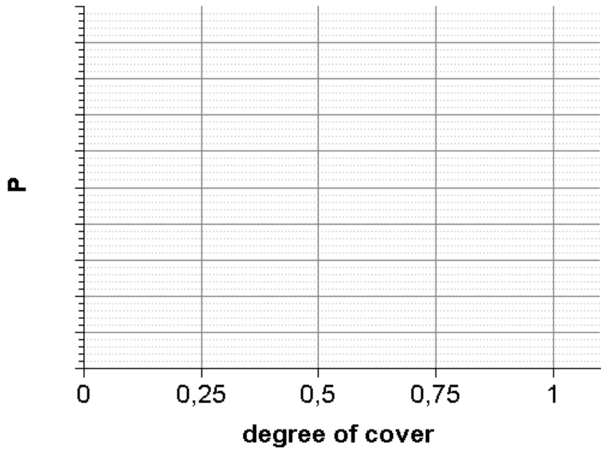
Measurements

	solar cell covered to				
	0 (not covered)	1/4	1/2	3/4	1 (completely covered)
V_{oc} (mV)					
I_{sc} (mA)					
$P = V \cdot I$ (mW)					

Diagrams







Evaluation

3. Relation between…

… voltage and area: ______________________________

… current and area: ______________________________

… power and area: ______________________________

3. Dependence of power of a solar cell on its area

Evaluation

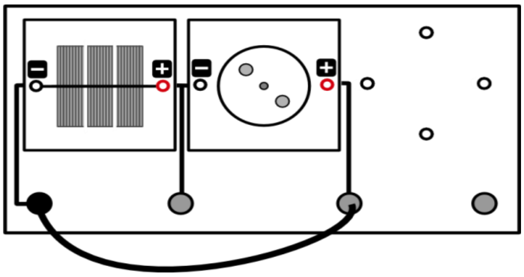
4.

4.1 Dependence of solar cell power on angle of incidence of light (qualitative)

Task

Examine the behavior of the motor depending on the angle of incidence.

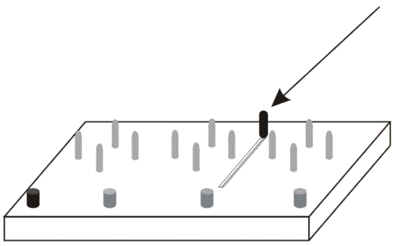
Setup



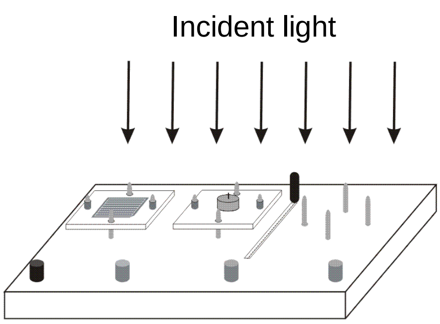
Required devices

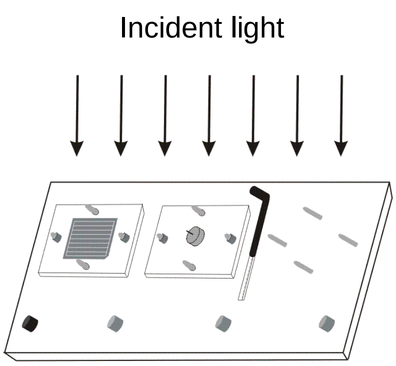
- base unit
- Solar *module*, 1.5V
- Motor module
- Cable

Execution



1. In this experiment the shadow bar is used. It can be found in the upper right hand side of the base unit (see right picture). With this help it is possible to measure the angle by which the base unit is tilted in relation to the light source. In order to do so, the base unit has to be turned in a way so that the shadow of the bar runs along the angle scale. The angle by which the base unit is tilted can then be read through the end of the shadow. First of all, get to know the function of the shadow bar!
2. Set up a series connection out of the solar module and the motor. Now hold the face of the base unit towards the light source. The shadow bar shouldn't be showing a shadow now - the light is reaches the solar cell at a right angle (left picture). Now tilt the base unit so that it doesn't directly face the light source anymore. Now there should be a shadow from the bar (right picture). (Note: The wires closing the circuit and the disk on the motor have not been drawn in favor of clearness!)





4.1 Dependence of solar cell power on angle of incidents of light (qualitative)

Evaluation

1. Note your observations during tilting the base unit. Frame dependence between angle of incidence and the spin speed of the motor.

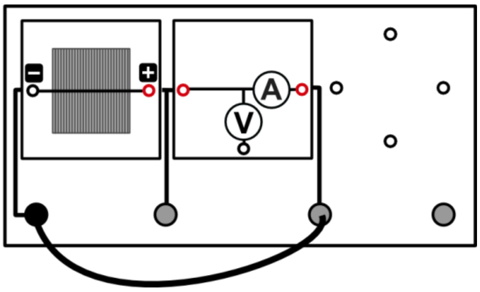
2. Draw conclusions about the solar cell power and the usage of real photovoltaic stations.

4.2 Dependence of solar cell power on angle of incidence of light (quantitative)

Task

Measure the short circuit current and open circuit voltage of the solar cell depending on the angle of incidence.

Setup



Required devices

- base unit
- Solar *cell*, 0.5V
- AV-Module
- Cable

Information

In this experiment only short-circuit currents and open-circuit voltages are measured. These cannot be measured simultaneously. Therefore, use the AV-Module only in voltage-mode, respectively in current-mode!

The power will be calculated with the short circuit current and open circuit voltage in this experiment. This power is a fictive power and is not the maximum power of the solar cell. However, this fictive power is used, because it is sophisticated to ascertain the maximum power without facilities. In this context, the comparison of the fictive powers leads to the same result than the comparison with the maximum power.

Execution

1. Hold the base unit with the solar cell in the direction of the light source (or sun) so that a clearly defined shadow can be seen!
2. Align the base unit so that the angle of incidence α between base unit and incidence light amounts to α = 0°. That means that the shadow bar doesn't shadow.
3. Measure first the open-circuit voltage $V_{oc.}$ Use the AV-Module in voltage-mode and do not plug in the cable yet.
4. Now measure the short-circuit current I_{SC}. Plug in the cable as shown in the setup and use the AV-Module in current-mode.
5. Repeat the experiment for all given angles (see table).Take care that the distance between light source and base unit does not change. Gather the measures values in the table.

Evaluation

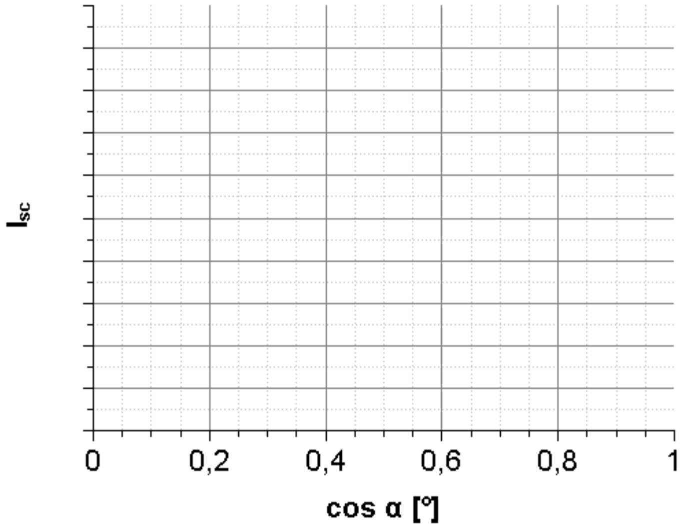
1. Calculate the cosine of the angle of incidence and the fictive power. Record your values in the table.
2. Plot the P- and I_{SC} - cosα - diagram.
3. Describe the dependence of short circuit current and power on the angle of incidence.
4. Explain this dependence geometrically provided that *I ~ A.* This means that the current increases proportionately with the shined area, as seen in experiment 2.

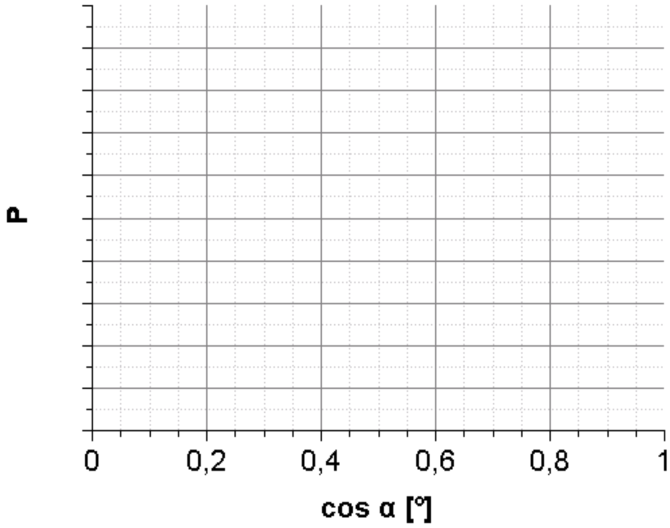
4.2 Dependence of solar cell power on angle in incidence of light (quantitative)

Measurements

α	0°	10°	20°	30°	40°	50°	60°	70°	75°	90°
V_{OC} (V)										
I_{SC} (mA)										
To be calculated values										
cosα										
P=V·I (mW)										

Diagrams





Evaluation

3.

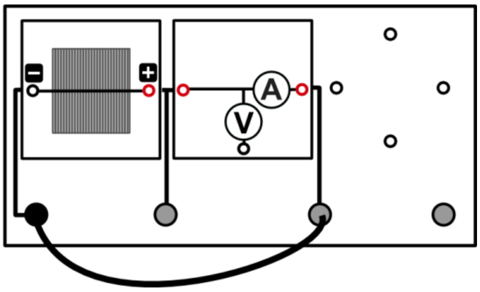
4.

5. Dependence of power of a solar cell on the illumination intensity

Task

Measure the solar cell power during different illuminances!

Setup



Required devices

- base unit
- lightning module
- 1 solar *cell*, 0.5V
- 1 AV-Module
- 1 PowerModule (9V)

Information

The power will be calculated with the short circuit current and open circuit voltage in this experiment. This power is a fictive power and not the maximum power of the solar cell. However, this fictive power is used, because it is sophisticated to ascertain the maximum power without facilities. In this context, the comparison of the fictive powers leads to the same result than the comparison with the maximum power.
Do not change the illuminance by changing the voltage at the lightning module because the lamps will become another spectrum what leads to measuring errors.
The lighting module should not be on the solar cell for too long in order to prevent the solar cell from heating up which leads to measuring errors.

Execution

1. Set up the experiment according to the circuit diagram.
2. Apply with the PowerModule a voltage of 9V at the lightning module and let shine one lamp (you can remove the other lamps by unscrew them from the lightning module). Put it on the solar cell.
3. Measure first the open-circuit voltage $V_{oc.}$ Use the AV-Module in voltage-mode and do not plug in the cable yet.
4. Now measure the short-circuit current I_{SC}. Plug in the cable as shown in the setup and use the AV-Module in current-mode.
5. Repeat the measurement with 2, 3 and 4 lamps in the lightning module. Note the measured values in the table.

Evaluation

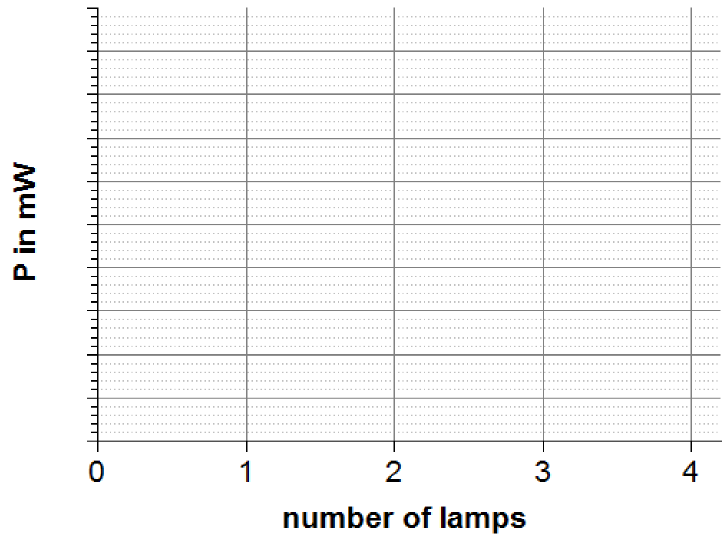
1. Calculate the solar cell power for every number of lamps and note your values in the table.
2. Plot the *n*-*P*-diagram (*n*...number of lamps)!
3. Name the relation between the solar cell power and the illuminance.

5. Dependence of power of a solar cell on the illumination intensity

Measurements

	lighting with				
	0 Lamp	1 Lamp	2 Lamps	3 Lamps	4 Lamps
V_{OC} (V)					
I_{SC} (mA)					
$P=V \cdot I$ (mW)					

Diagrams



Evaluation

3.

The higher the illuminance the _______________ the power is.

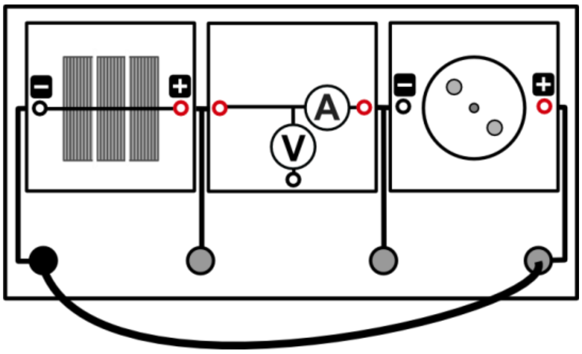
The relation between illuminance and power is _______________.

6.1 Dependence of solar cell power on load

Task

Measure the solar cell power depending on the consumer.

Setup



Required devices

- Base unit
- Lightning module
- Solar *module*, 1.5V
- AV-Module
- Buzzer module
- Motor module
- 1 PowerModule (9V)

Execution

1. Set up the experiment according to the circuit diagram. Apply with the PowerModule a voltage of 9V at the lightning module and put it on the solar module.
2. Measure the voltage V and current I at the solar module. Use the AV-Module in voltage-current-mode.
3. Repeat the measurement with the buzzer module. Note your measured values in the table.

Evaluation

1. Calculate the power of the solar cell and the resistance of each consumer. Note your values in the table.
2. Compare the solar cell power depending on the different consumers. Draw conclusions between resistance and power.

Measurements

	Motor module	Buzzer module
V (V)		
I (mA)		
P=V·I (mW)		
R=V/I (Ω)		

Evaluation

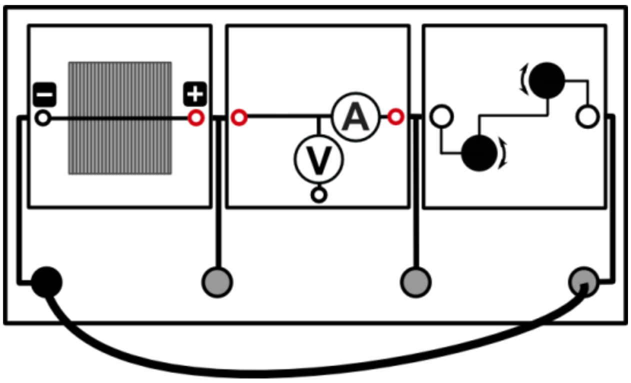
2.

6.2 The I-V-characteristics and filling factor of a solar cell

Task

Measure the I-V-characteristics of the solar cell.

Setup



Required devices

- Base unit
- solar *cell*, 0.5V
- AV-Module
- Potentiometer module
- Lightning module
- PowerModule (5V)

Execution

1. Set up the experiment according to the circuit diagram. Connect the lightning module with the PowerModule (5 V) and lay it on the solar cell. All four lamps inside the lightning module should shine. Set the highest resistance at the potentiometer.
2. Make out sensible voltage values and measure the corresponding current. For this purpose, decrease the resistance of the potentiometer. Use the AV-Module in voltage-current-mode.
3. Measure the open-circuit voltage and short-circuit current without potentiometer, as well. In this measurement use the AV-Module in voltage-mode, respectively current-mode
4. Not your measured values in the table.

Evaluation

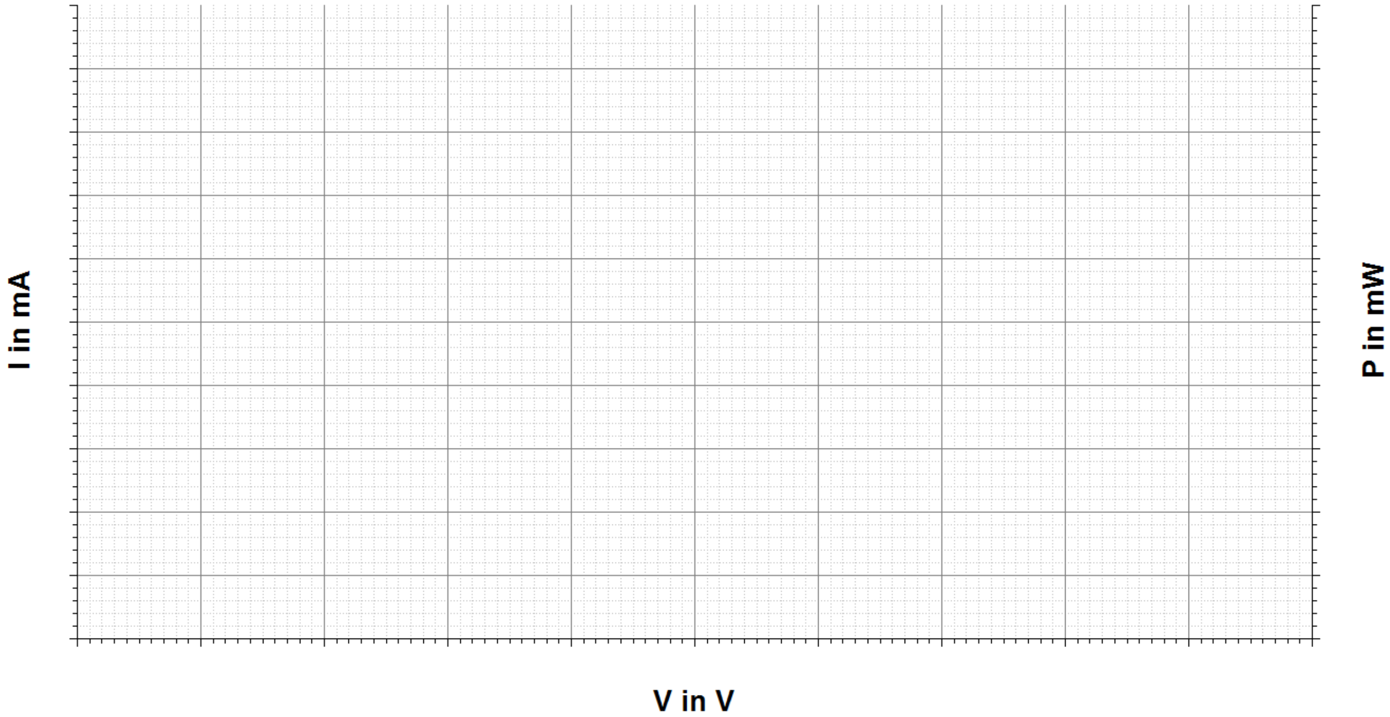
1. Draw the I-V-curve of the solar cell.
2. Calculate the respective power of the solar cell for each data point and plot the V-P-characteristic curve in the same diagram.
3. Describe the curves.
4. Draw the I-V-characteristic of a 10 Ω- and a 100 Ω-resistance into your diagram. Explain the meaning of the intersection points between the characteristic curves of the solar module and the resistances.
5. Draw conclusions about the solar cell power depending on the resistance.
6. The filling factor FF displays the relation between the power at the MPP and the power that is calculated by multiplying the open-circuit voltage with the short-circuit current ($FF = P_{MPP}/V_{oc} \cdot I_{sc}$). Calculate the filling factor.
7. Calculate approximately the efficiency of the solar cell, when it operates at the maximum power point. (Advice: The short circuit current amounts 840 mA at an illuminance of 1000 $\frac{W}{m^2}$ 840 mA. Both quantities are proportionate.)

6.2 The I-V-characteristics and filling factor of a solar cell

Measurements

V (V)										
I (mA)										
P=*V*·*I* (mW)										

Diagrams



Evaluation

3.

6.2 The I-V-characteristics and filling factor of a solar cell

Evaluation

3.

4.

5.

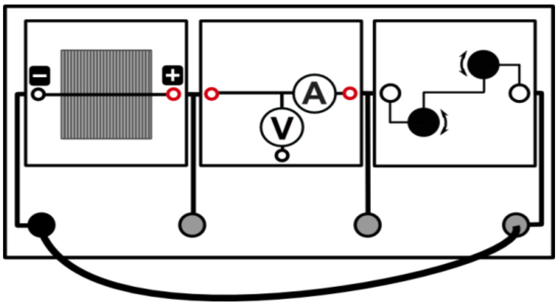
6.

6.3 Dependence of I-V-characteristics of a solar cell on illuminance

Task

Measure the I-V-characteristics of a solar cell depending on illuminance.

Setup



Required devices

- Base unit
- solar *cell*, 0.5V
- AV-Module
- Potentiometer module
- Lightning module
- PowerModule (5V)

Execution

1. Set up the experiment according to the circuit diagram. Connect the lightning module with the PowerModule (5 V) and lay it on the solar cell. At first, one lamp should shine.
2. Set the maximum resistance at the potentiometer.
3. Make out sensible voltage values and measure the corresponding current. For this purpose, decrease the resistance of the potentiometer. Use the AV-Module in voltage-current-mode.
4. Measure the open-circuit voltage and short-circuit current without potentiometer, as well. In this measurement use the AV-Module in voltage-mode, respectively current-mode
5. Repeat the measurement with 2, 3 and 4 Lamps.

Measurements

With one lamp:

V (V)										
I (mA)										
P=V·I (mW)										

With two lamps:*V* *(V)*										
I (mA)										
P=V·I (mW)										

With three lamps:

V (V)										
I (mA)										
P=V·I (mW)										

6.3 Dependence of I-V-characteristics of a solar cell on illuminance

Measurements

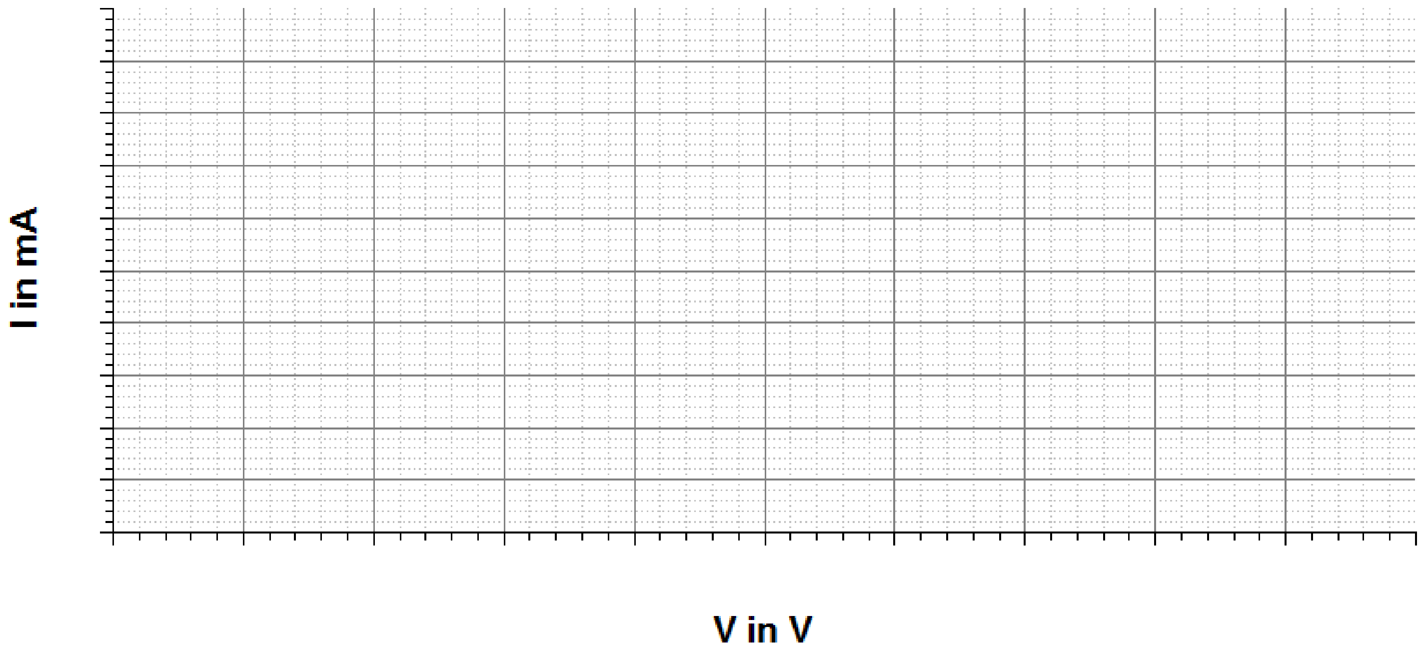
With four lamps:

V (V)										
I (mA)										
$P=V\cdot I$ (mW)										

Evaluation

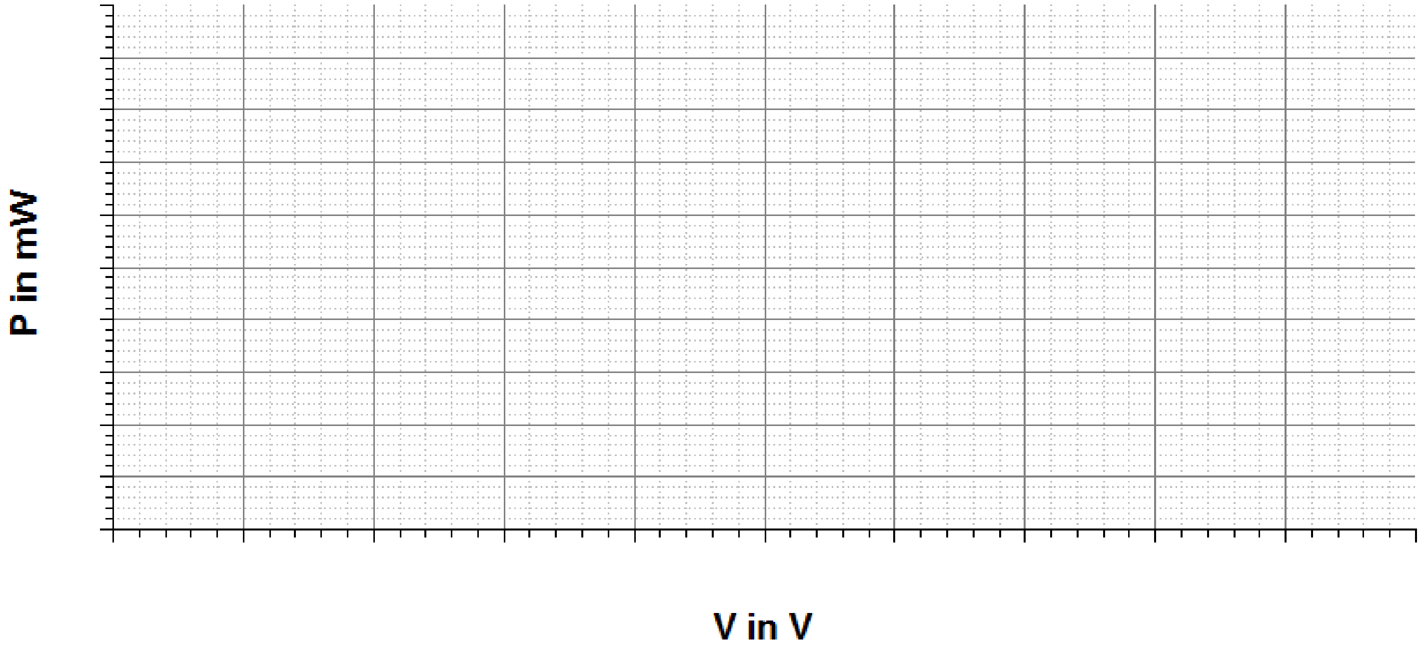
1. Calculate the power for each measurement and note your values in the table.
2. Plot the measured values into the V-*I*- and *V*-*P*-diagram of a solar cell depending on illuminance.
3. Compare the different I-V-curves and explain the differences.
4. Compare the point of maximum power.

Diagrams



6.3 Dependence of I-V-characteristics of a solar cell on illuminance

Diagrams



Evaluation

2.

3.

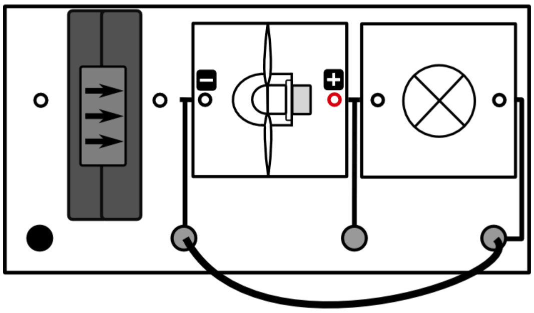
7.1 Influence of changing wind speeds (qualitative)

Task

Examine the brightness of a light bulb, which is powered by a wind turbine.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine with PowerModule (variable)
- Wind turbine module (with three rotor blades, 25°, optimized profile)
- Light bulb module
- Cable

Information

In this experiment you can examine how electricity generated by the wind turbine changes when the wind speed changes. The variation of wind speed is done by changing the voltage at the wind machine.

Execution

1. Set the experiment up according to the experiment set-up.
2. Change the voltage at the wind machine with the PowerModule. Start with 12V.
3. Observe how the brightness of the light-emitting diode changes and enter your observations in the table. Color in the corresponding number of fields.

Evaluation

Voltage V at PowerModule (V)	The light bulb lights…		
	bright	dimly	not
4			
6			
8			
10			
12			

Now complete the sentences:

With a higher voltage at the wind machine, the wind speed ______________.

The ______________the wind speed, the brighter the light bulb.

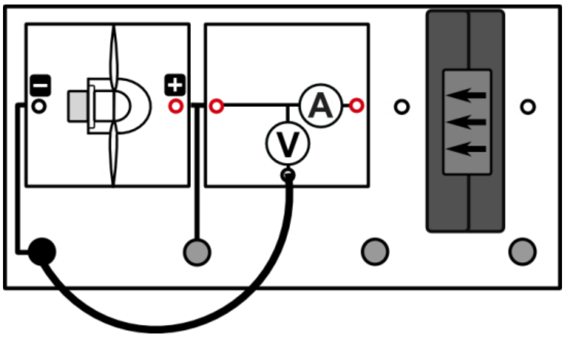
7.2 Influence of wind speed on the wind turbine (quantitative)

Task

Examine the voltage at the turbine when the wind speed at the wind turbine is changed.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine with PowerModule (variable)
- Wind turbine module (with three rotor blades, 25°, optimized profile)
- AV-Module
- Cable

Execution

1. Set the experiment up according to the experiment set-up.
2. Change the wind speed by variation of the voltage of the PowerModule V_{Pow}. Note your observations.
3. Now measure the voltage V_{gen} at the turbine at different wind speeds and enter your values in the table. Use the AV-Module in voltage mode.
4. You can determine the values for the speed with a wind force transducer or read it off the respective chart (see page 14).

Observation

____

____

____

____

____

Measurements

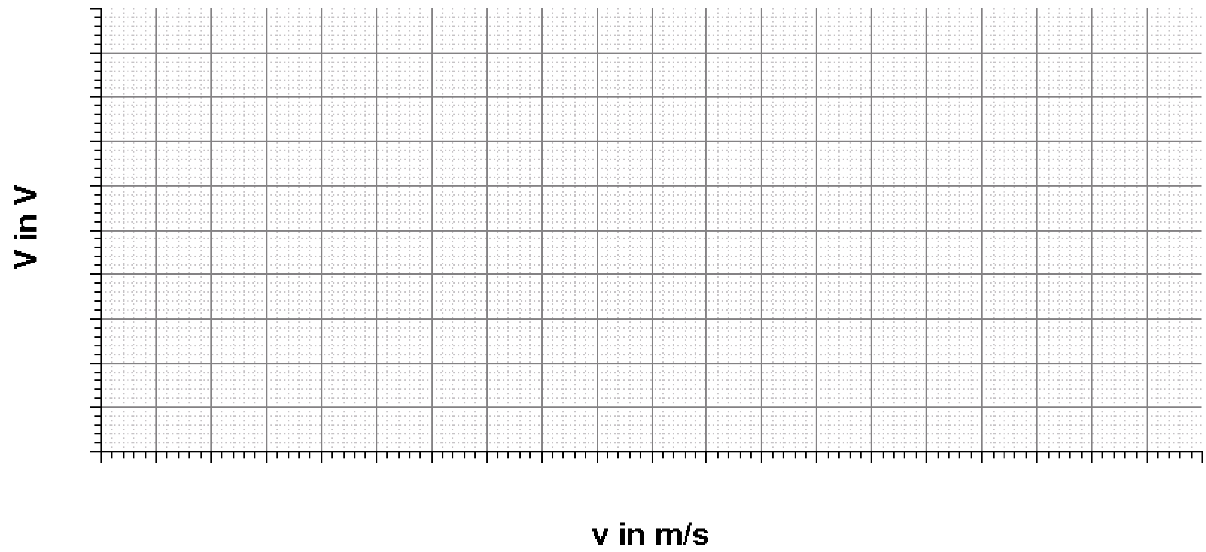
V_{Pow} in V					
v in m/s					
V_{gen} in V					

7.2 Influence of wind speed on the wind turbine (quantitative)

Evaluation

1. Enter your measurements in the specified charts.
2. Describe the correlation between the wind speed and the voltage at the wind turbine?

Diagrams



Evaluation

2.

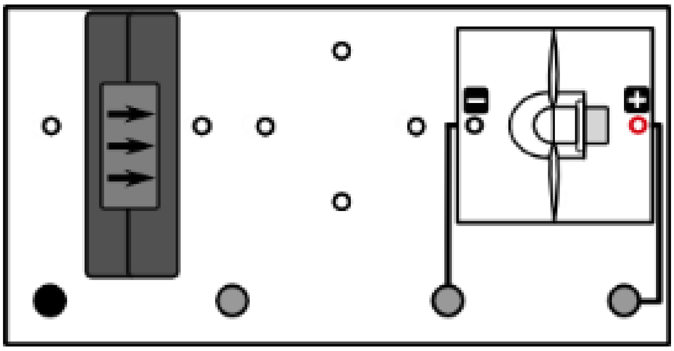
8. Start-up wind speed at a wind turbine

Task

Examine how high the wind speed must be for the wind turbine to be able to start.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine with PowerModule
- Wind turbine module (with three rotor blades, 25°, optimized profile)

Information

A wind turbine only starts to turn when there is sufficiently high wind speed. This is called start-up wind speed. With this experiment you can examine how high the start-up speed is in this model of a wind turbine.

Execution

1. Set the experiment up according to the experiment set-up.
2. Set different voltages V with the PowerModule and observe the wind turbine. Note the lowest voltage, at which the wind turbine starts to rotate and the highest, at which it does not start.
3. Determine the wind speed interval the wind speed has to be inside and note it. (Take the value of the relevant chart (see page **Fehler! Textmarke nicht definiert.**) or follow step 4 if you have a wind force transducer.)
4. Switch off the wind machine, remove the wind turbine and restart the wind machine with one of the noted wind speeds. Now measure the wind speed with the wind force transducer where the wind turbine was located before. Repeat the measurement with the other noted voltage value.

Measurements

Highest voltage of the PowerModule at which the wind turbine does not start: ________________

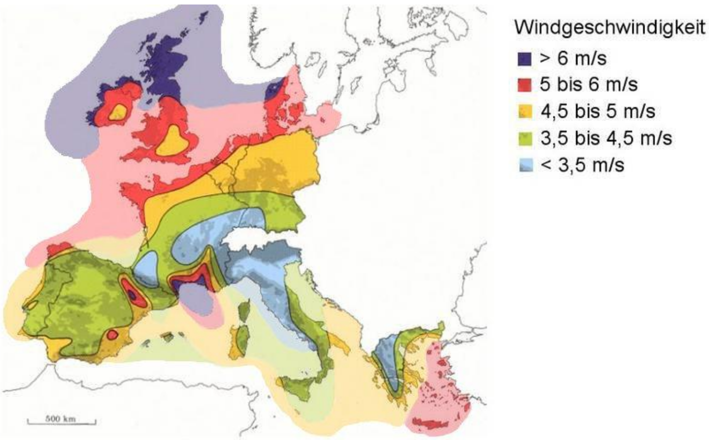
Lowest voltage of the PowerModule at which the wind turbine starts: ________________

The start-up speed is located in the interval: [________________]

8. Start-up wind speed at a wind turbine

Evaluation

1. What conclusions can you draw from these insights for the operation of wind turbines?
2. Find out more about the start-up speeds of real wind turbines and compare it with your measured values. Can you explain the differences?
3. Average wind speeds in Europe are depicted on the map.



http://www.wind-energie.de/de/technik/entstehung/windpotential (16.11.2010)

Based on this illustration, explain with reasons in which areas wind turbines can be used efficiently. Where is the use of wind energy less profitable?

Solutions to the exercises

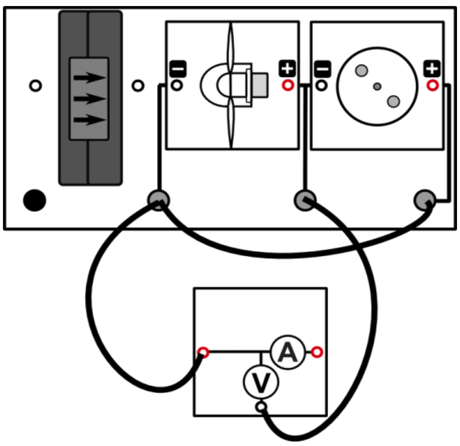
9. Changing the turbine voltage by connecting several consumers

Task

Examine how the generated voltage changes when the turbine is connected to different types of consumers (horn, light bulb and motor).

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (12V)
- Wind turbine module (with three rotor blades, 25°, optimized profile)
- AV-Module
- Buzzer module
- LED module
- Motor module
- Light bulb module
- Cables

Execution

1. Build up the experimental setup initially without a buzzer, motor, LED or lamp module.
2. Set the voltage at 12 V on the PowerModule and start the wind machine.
3. Measure the voltage at the turbine when no module is connected (V_{oc}). Use the AV-Module in voltage-mode.
4. Now plug the buzzer, motor, LED and light bulb one after the other into the socket provided, write down your observations. Measure the respective voltage that is generated at the turbine.

Observation

____

____

____

Measurements

V_{oc} = ______ V_{motor} = ______

V_{horn} = ______ $V_{light\ bulb}$ = ______

V_{LED} = ______

9. Changing the turbine voltage by connecting several consumers

Evaluation

1. Which component was responsible for the biggest change in the voltage at the turbine and which had the least effect?
2. Explain the behavior of the voltages that you observed.
3. What conclusion can you draw from it for the resistances of the individual devices? Compare it with each other (> , < , =).

1.

2.

3.

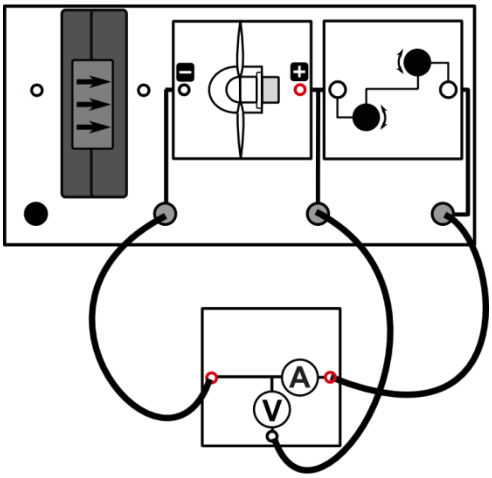
10. Characteristic curves of a wind turbine

Task

Record the current-voltage characteristics of the wind rotor. Also determine the load resistance at which the maximum output is achieved.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (12 V)
- Wind turbine module (with three rotor blades, 25°, optimized profile)
- Potentiometer module
- AV-Module
- Cables

Information

Before beginning the measurement, the potentiometer module must be adjusted to its highest possible resistance value.

Execution

1. Set the experiment up according to the experiment set-up.
2. Set different resistance values with the potentiometer module and measure the respective current. Reduce the voltage in steps of 0.2 V and enter your measurements in the table. Use the AV-Module in voltage-current-mode.
3. Measure also the voltage at the turbine when no potentiometer is connected (V_{oc}). Use the AV-Module in voltage-mode. After that measure the short-circuit current of the wind turbine. Use the AV-Module in current-mode then.

Measurements

V in V												
I in mA												
R in Ω												
P in mW												

10. Characteristic curves of a wind turbine

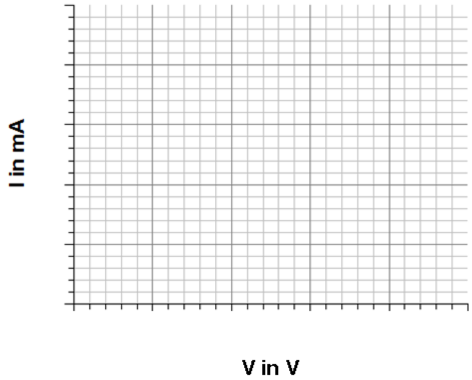
Measurements

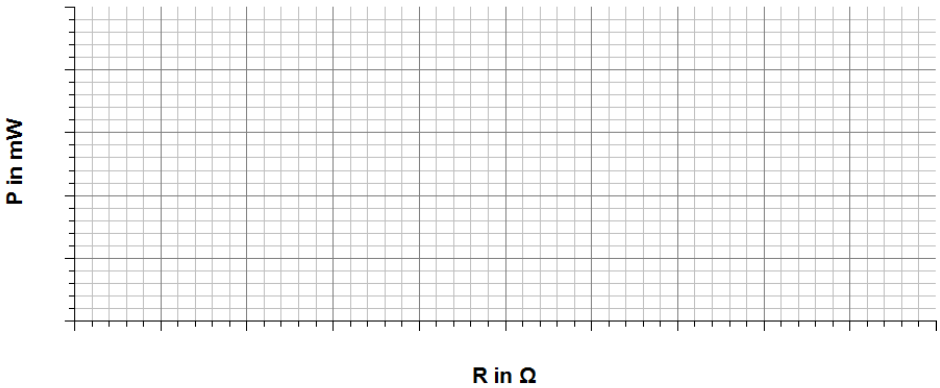
V in V												
I in mA												
R in Ω												
P in mW												

Evaluation

1. Calculate the Power P and the resistance R for every measuring point and note your values in the table.
2. Enter your values in the respective charts.
3. From the charts, determine the voltage value at which the output of the wind turbine is the greatest. How big is the load resistance at which the maximum output at the turbine is achieved?
4. What consequence follows from these results for the operation of real wind turbines?
5. The maximum output of a wind turbine depends therefore on the load resistance at the turbine. Name possible effects or physical variables that could also have an effect on the output of a wind turbine.

Diagrams





Evaluation

3. V_{max} = _________ R_{max} = _________

4.

____

____

5.

____

____

____

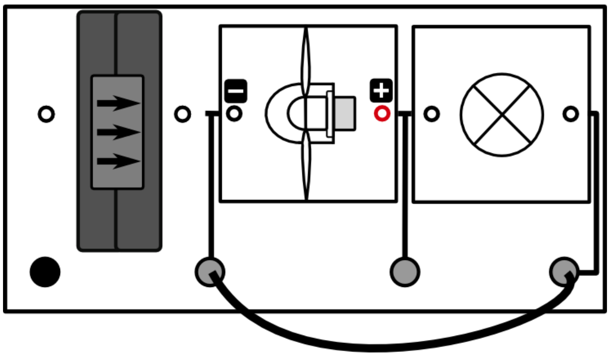
11.1 Influence of the number of rotor blades (qualitative)

Task

Examine the brightness of a light-emitting diode, which is powered by a wind turbine with two, three or four rotor blades.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (7.5 V)
- Wind turbine module (with two, three and four rotor blades, 25°, optimized profile)
- Light bulb module
- Cable

Execution

1. Set the experiment up according to the experiment set-up.
2. Put the 2-blade rotor on the wind turbine and turn the wind machine on (PowerModule voltage 7.5 V) Observe the light bulb.
3. Now change the rotor blades and place the three and four-blade rotors one after the other on the wind turbine and observe the light bulb (You can find details regarding the change of the rotor blades on page 6).
4. Write down your observations and make a cross in the respective fields of the table.

Observation

The light bulb lights up...

	bright	faintly	no light
2 blades			
3 blades			
4 blades			

11.1 Influence of the number of rotor blades (qualitative)

Evaluation

1. How does the brightness of the light bulb change when it is powered by different rotors? Describe your results.
2. In Europe mainly three-blade rotors are used in wind turbines. Try to find a possible explanation.

1.

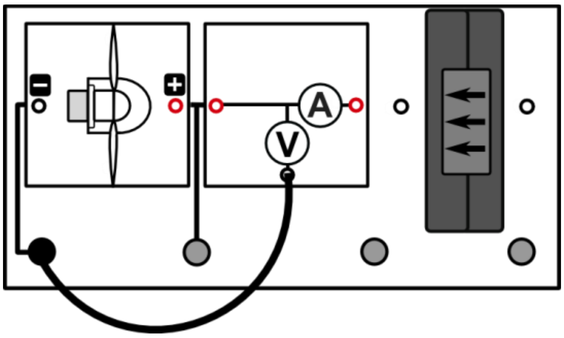
2.

11.2 Influence of the number of rotor blades (quantitative)

Task

Examine the voltage at the wind turbine at different numbers of rotor blades.

Setup



Required devices

- Base unit
- Wind generator module with power supply (9 V)
- Wind turbine module (with two, three and four rotor blades, 25°, optimized profile)
- AV-Module
- Cables

Information

The individual rotors need different amounts of time until they produce a consistent peripheral speed and so a consistent voltage. The voltage should only be recorded when the reading no longer changes.

Execution

1. Set the experiment up according to the experiment set-up.
2. Place the two-blade rotor on the wind turbine. Measure the voltage in dependence of the wind speed by varying the voltage V_{Pow} at the PowerModule and enter all your values in the provided fields. Use the AV-Module in voltage mode.
3. You can determine the values for the speed with a wind force transducer or read it off the respective chart (see page 14).
4. Repeat your measurement with the three and four-blade rotor.

Measurements

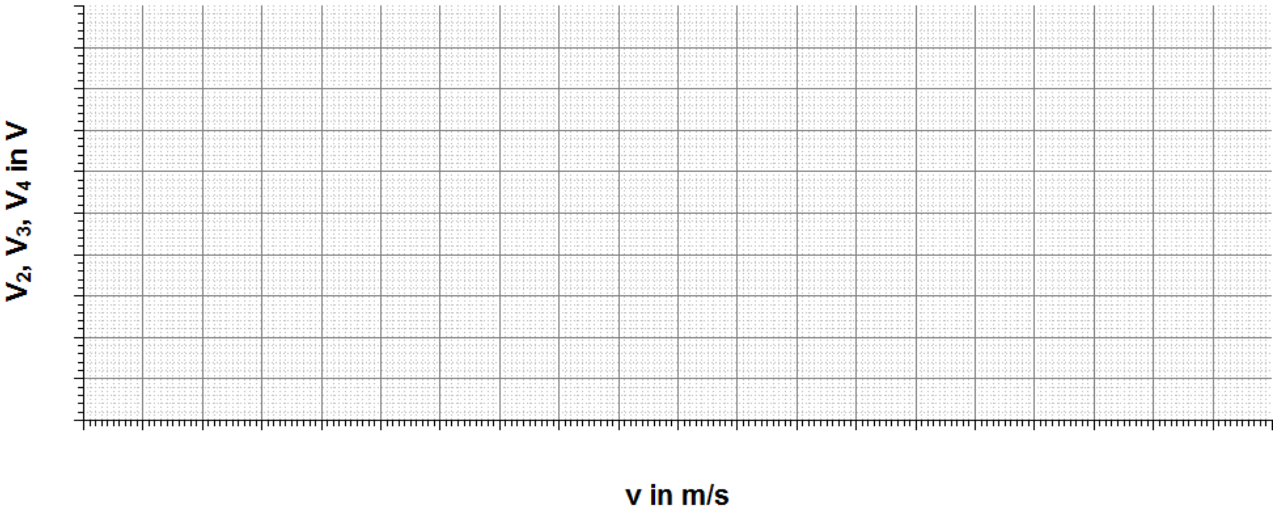
V_{Pow} in V	v in m/s	V_2 in V	V_3 in V	V_4 in V

11.2 Influence of the number of rotor blades (quantitative)

Evaluation

1. Enter your measurements in the respective charts.
2. With which number of rotor blades the biggest voltage can be generated, which generates the lowest? What do you assume is the correlation between the number of rotor blades and the generated voltage?
3. The voltage generated at the wind turbine also changes at different wind speeds. Based on your results, explain why the use of three-blade and not four-blade rotors for power generation is preferred.

Diagrams



Evaluation

2.

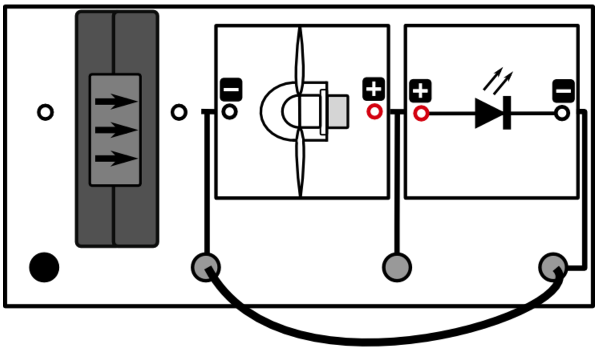
3.

12.1 Influence of the wind direction (qualitative)

Task

Examine how the brightness of the LED changes when the wind direction to the wind turbine changes.

Setup



Required devices

- Base unit
- Wind generator module with power supply (12V)
- Wind turbine module (three rotor blades, 25°, optimized profile)
- AV-Module
- Cables

Execution

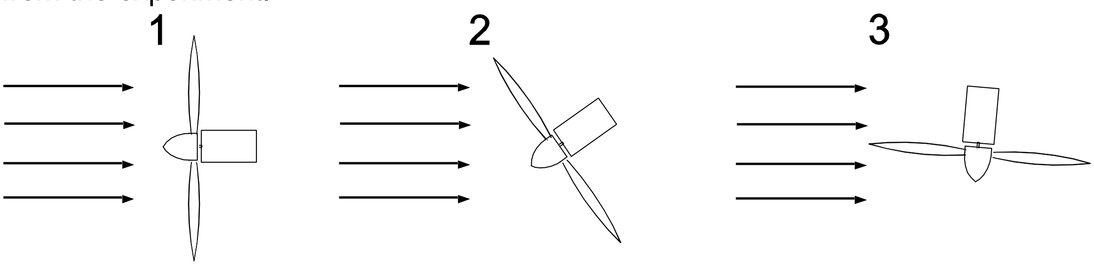
1. Set the experiment up according to the experiment set-up.
2. Turn on the wind generator with a selected voltage of 6 V.
3. Turn the wind generator carefully to the right and left and observe the LED. Write down your observations. Turn not more than 45 °, thus the rotor blades do not hit against the wind generators.

CAUTION! When rotating the base, do not reach into the rotor blades – **risk of injury!** – While rotating, the wind generator should be turned off.

Observation

Evaluation

Wind turbines are depicted in the figures. The arrows identify the direction of the air flow (wind direction). Which plant can generate the highest output, which the lowest? Give reasons based on your observations from the experiment.



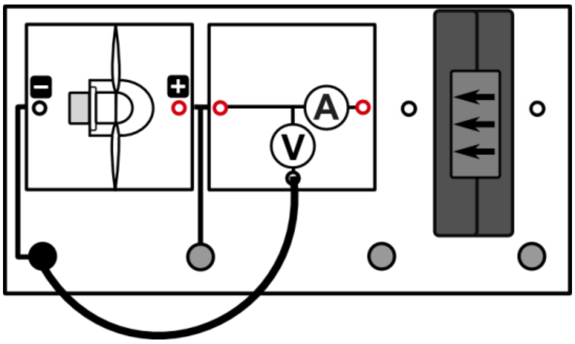
12.2 Influence of the wind direction (quantitative)

Task

Examine the voltage supplied by the wind turbine when the direction of air flow to the rotor changes.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (12 V)
- Wind turbine module (three rotor blades, 25°, optimized profile)
- AV-Module
- Cables

Information

When setting the angle of rotation, it must be ensured that your line of vision is always perpendicular to the angular scale.

CAUTION! When rotating the base, do not reach into the rotor blades – **risk of injury!** – While rotating, the wind machine should be turned off.

Execution

1. Set the experiment up according to the experiment set-up.
2. At the start, adjust the angle of rotation to 0°.
3. Switch on the PowerModule (12V) and measure the respective voltage at the turbine. Use the AV-Module in voltage-mode. Enter your measurement in the table and switch the PowerModule off.
4. Now gently rotate the wind turbine by 10°. Repeat the measurements with the respective angle adjustments (see table) and enter all measurements in the table.

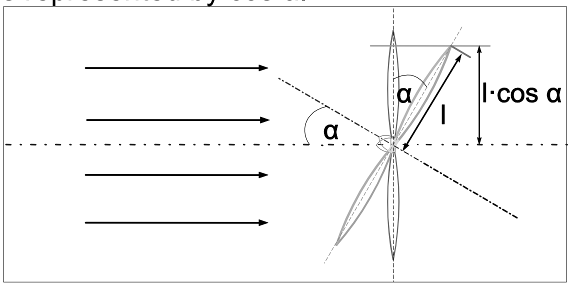
Measurements

α in °	0	10	20	30	40	50	60	70	80	90
cos α										
V in V										

12.2 Influence of the wind direction (quantitative)

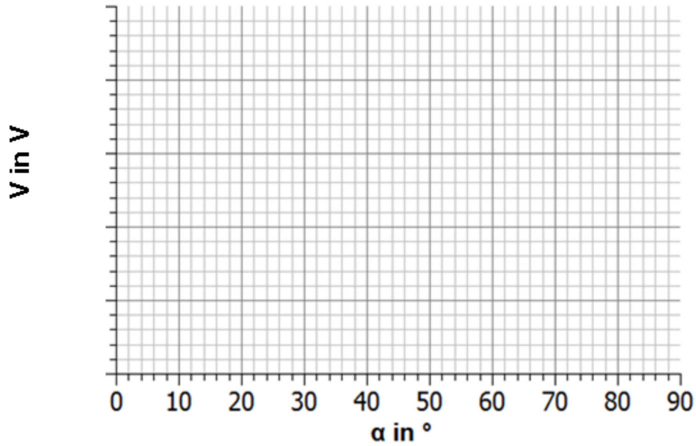
Evaluation

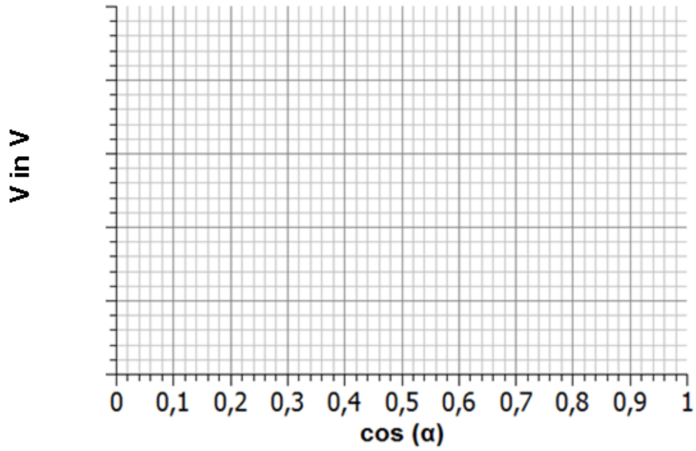
1. Enter your measurements in the respective charts.
2. The size of cos α is a measure for the work surface area of the wind on the wind rotor (as shown in the figure). Describe the dependence of the voltage on the angle of rotation and the work surface area of the wind at the wind rotor which is represented by cos α.



3. The direction from which the flowing air hits a wind turbine is important for the voltage generated. Describe a way of changing a system to always be capable of generating the maximum voltage.

Diagrams





Evaluation

2.

3.

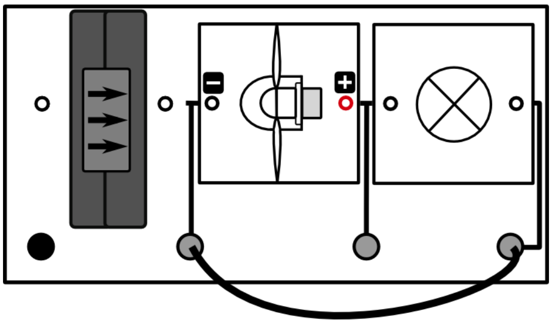
13.1 Influence of the rotor blade pitch (qualitative)

Task

Examine the influence of the rotor blade pitch on the brightness of an illuminated light bulb.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (9 V)
- Wind turbine module (three rotor blades, all angles, optimized profile)
- Light bulb module
- Cable

Execution

1. Set the experiment up according to the experiment set-up.
2. Put the 3-blade rotor with a rotor blade pitch of 20° on the wind turbine and turn the wind machine on (PowerModule voltage: 9V).
3. Observe the brightness of the light bulb and enter your observations in the table. Color in the corresponding number of fields.
4. Now change the rotor blade pitch and place the different rotors (20°, 25°, 30°, 50°, 90°) one after the other on the wind turbine and observe each time the light bulb.

Supplement: Repeat the measurement with the flat rotor blades.

Evaluation

Blade pitch	20°	25°	30°	50°	90°	Example
The LED lights up…						bright weak not at all

Now complete the sentences.

With large rotor blade pitch, the light bulb lights up ___________. The light bulb lights up most at an angle of ___________.

Supplement: With the flat profile you can observe, ____.

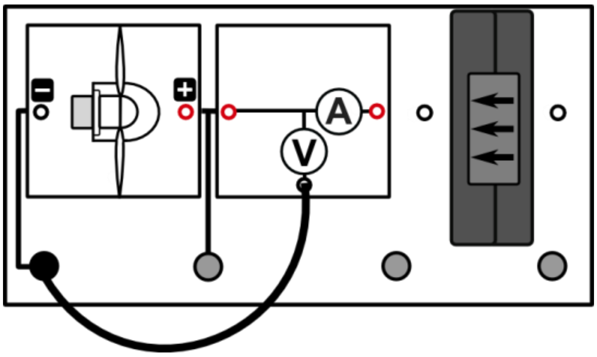
13.2 Influence of the rotor blade pitch (quantitative)

Task

Examine the influence of the rotor blade pitch on the voltage at the wind turbine.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (12 V)
- Wind turbine module (three rotor blades, all angles, optimized profile)
- AV-Module
- Cables

Execution

1. Set the experiment up according to the experiment set-up. Put the 3-blade rotor with a rotor blade pitch of 20° on the wind turbine and turn the wind machine on (PowerModule voltage: 12V).
2. Measure the voltage at the turbine and enter your value in the table. Use the AV-Module in voltage mode.
3. Now change the rotor blade pitch and place the different rotors (20°, 25°, 30°, 50°, 90°) one after the other on the wind turbine and measure the voltage at the turbine.
4. Repeat the measurement with the flat rotor blades.

Measurements

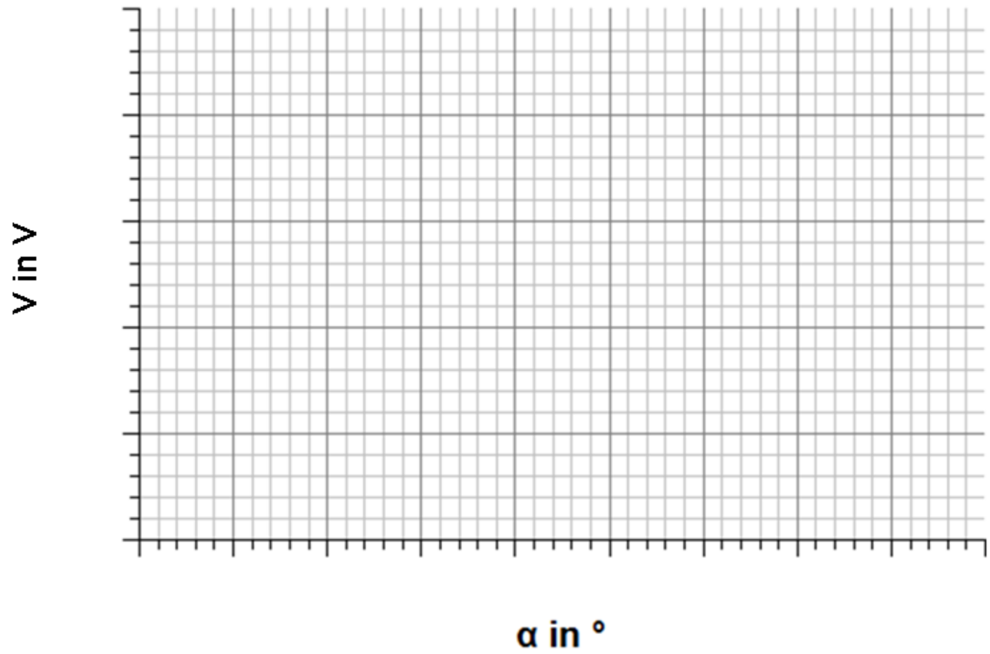
α / °	20	25	30	50	90
$V_{optimized}$ in V					
V_{flat} in V					

13.2 Influence of the rotor blade pitch (quantitative)

Evaluation

1. Enter your measured values in the diagram. If you are using also the flat profiles, mark the associated curve with a different color.
2. Describe the correlation between voltage and pitch of the rotor blades.
3. What course do you expect for angles smaller than 20 °?

1.



2.

3.

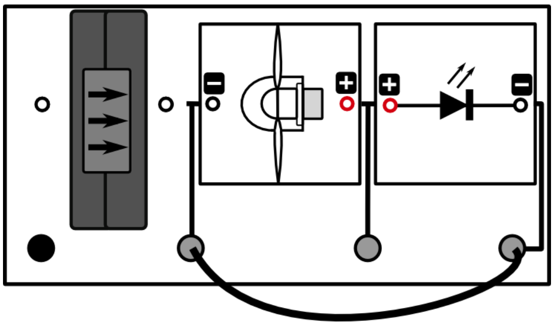
14.1 Influence of the blade shape (qualitative)

Task

Examine the brightness of a light-emitting diode, which is powered by a wind turbine with different shaped rotor blades.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (12 V)
- Wind turbine module (three rotor blades, 25°, optimized and flat profile)
- LED module
- Cable

Execution

1. Set the experiment up according to the experiment set-up.
2. Put the 3-blade rotor with the optimized profile on the wind turbine and turn the wind machine on (PowerModule voltage 12 V).
3. Observe the brightness of the LED.
4. Repeat the measurement with the rotor blade with flat profile and observe the change of brightness.

Evaluation

1. Which blade shape illuminates the LED stronger?
2. Examine the shape of the two rotor blades closer. What are the differences?
3. Do you know any examples where the flat profile is used?

1.

2.

3.

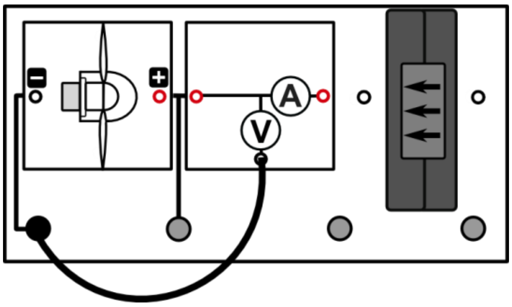
14.2 Influence of the rotor blade shape (quantitative)

Task

Examine the voltage generated at the wind turbine for different shapes of rotor blades.

Caution injury risk: Do not touch the moving rotor!

Setup



Required devices

- Base unit
- Wind machine module with PowerModule (9 V)
- Wind turbine module (three rotor blades, 25°, optimized and flat profile)
- AV-Module
- Cable

Execution

1. Set the experiment up according to the experiment set-up.
2. Place the three-blade rotor with the optimized profile on the wind turbine and turn the wind generator on. (PowerModule voltage 9V).
3. Measure the voltage V_{opt} generated at the wind turbine. Use the AV-Module in voltage-mode.
4. Repeat the measurement with the three-blade rotor with flat profile.

Measurements

V_{opt} = ________

V_{flat} = ________

Evaluation

1. Which blade shape generates a higher voltage?
2. What is the influence of the blade shape on the output of a wind turbine?

1.

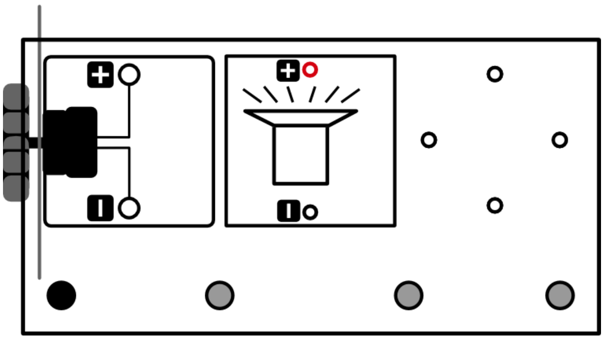
2.

15.1 Water as an energy source (qualitative)

Task

Use a water wheel as a source of energy to power a buzzer.

Setup



Required devices

– Base Unit
– Water wheel module
– Buzzer module
– Tube

Additionally needed:
- Two large bowls / boxes
- Water
- Table / chair / higher position

Execution

1. Set up the circuit like in the picture. Pay attention to the polarity of the modules.
2. Place one bowl of water on the table, the other one is placed on the floor or chair so that you can collect the water with which you will drive the waterwheel.
3. Now insert the hose with one end in the water and suck the water until the water level in the tube is deeper than the water in the bowl. (Put your finger on the tube so that the water level does not drop again). Alternatively, you can also put the tube completely into the bowl. Make sure that no air bubbles arise.
4. Now hold your finger on one end of the tube and hold it down to the water wheel. Make sure that the other end of the tube remains in the water.
5. Hold the base unit with the water wheel over the lower bowl. Now take your finger from the opening of the tube so that the water jet hits the waterwheel and note your observations.

Observations

____

____

Evaluation

1. What energy conversion takes place?

____

____

____

____

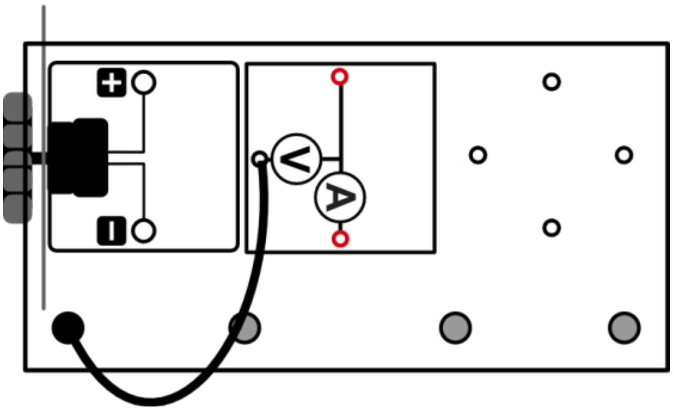
____

15.2 Water as an energy source (quantitative)

Task

Determine the open-circuit voltage of the water wheel module

Setup



Required devices

– Base Unit
– Water wheel module
– AV-Module
– Cable
– Tube

Additionally needed:
- Two large bowls / boxes
- Water
- Table / chair / higher position

Execution

1. Set up the circuit like in the picture. Pay attention to the polarity of the modules.
2. Place one bowl of water on the table, the other one is placed on the floor or chair so that you can collect the water with which you will drive the waterwheel. Measure the distance h between both bowls.
3. Now insert the hose with one end in the water and suck the water until the water level in the tube is deeper than the water in the bowl. (Put your finger on the tube so that the water level does not drop again). Alternatively, you can also put the tube completely into the bowl. Make sure that no air bubbles arise.
4. Now hold your finger on one end of the tube and hold it down to the water wheel. Make sure that the other end of the tube remains in the water.
5. Hold the base unit with the water wheel over the lower bowl. Now take your finger from the opening of the tube so that the water jet hits the waterwheel.
6. Measure the voltage V at the water wheel module. Use the AV-Module in voltage mode.

Measurements

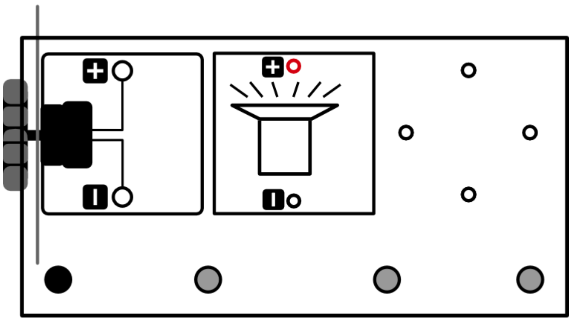
V= ___________at a height of________

16.1 Influence of the water falling height (qualitative)

Task

Examine how the water falling height influences the volume of the buzzer.

Setup



Required devices

- Base Unit
- Water wheel module
- Buzzer module
- Tube

Additionally needed:
- Two large bowls / boxes
- Water
- Table / chair / higher position

Execution

1. Set up the circuit like in the picture. Pay attention to the polarity of the modules.
2. Place one bowl of water on the table, the other one is placed on the floor or chair so that you can collect the water with which you will drive the waterwheel.
3. Now insert the hose with one end in the water and suck the water until the water level in the tube is deeper than the water in the bowl. (Put your finger on the tube so that the water level does not drop again). Alternatively, you can also put the tube completely into the bowl. Make sure that no air bubbles arise.
4. Now hold your finger on one end of the tube and hold it down to the water wheel. Make sure that the other end of the tube remains in the water.
5. Hold the base unit with the water wheel over the lower bowl. Now take your finger from the opening of the tube so that the water jet hits the waterwheel and note your observations.
6. Repeat the experiment for different falling heights (for example chair-floor, table-chair, table-floor…)

Observations

Evaluation

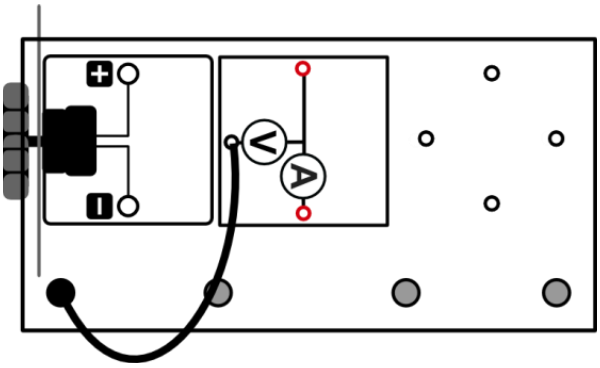
1. What could be the reason for the behavior of the buzzer.

16.2 Influence of the water falling height (quantitative)

Task

Examine how the water falling height influences the voltage of the water wheel module.

Setup



Required devices

- Base Unit
- Water wheel module
- AV-Module
- Cable
- Tube

Additionally needed:
- Two large bowls / boxes
- Water
- Table / chair / higher position

Execution

1. Set up the circuit like in the picture. Pay attention to the polarity of the modules.
2. Place one bowl of water on the table, the other one is placed on the floor or chair so that you can collect the water with which you will drive the waterwheel. Measure the distance h between both bowls.
3. Now insert the hose with one end in the water and suck the water until the water level in the tube is deeper than the water in the bowl. (Put your finger on the tube so that the water level does not drop again). Alternatively, you can also put the tube completely into the bowl. Make sure that no air bubbles arise.
4. Now hold your finger on one end of the tube and hold it down to the water wheel. Make sure that the other end of the tube remains in the water.
5. Hold the base unit with the water wheel over the lower bowl. Now take your finger from the opening of the tube so that the water jet hits the waterwheel.
6. Measure the voltage V at the water wheel module. Use the AV-Module in voltage mode.
7. Repeat the experiment for different falling heights (for example chair-floor, table-chair, table-floor…). Measure each the falling height h and the voltage of the water wheel V. note your values in the table.

Measurements

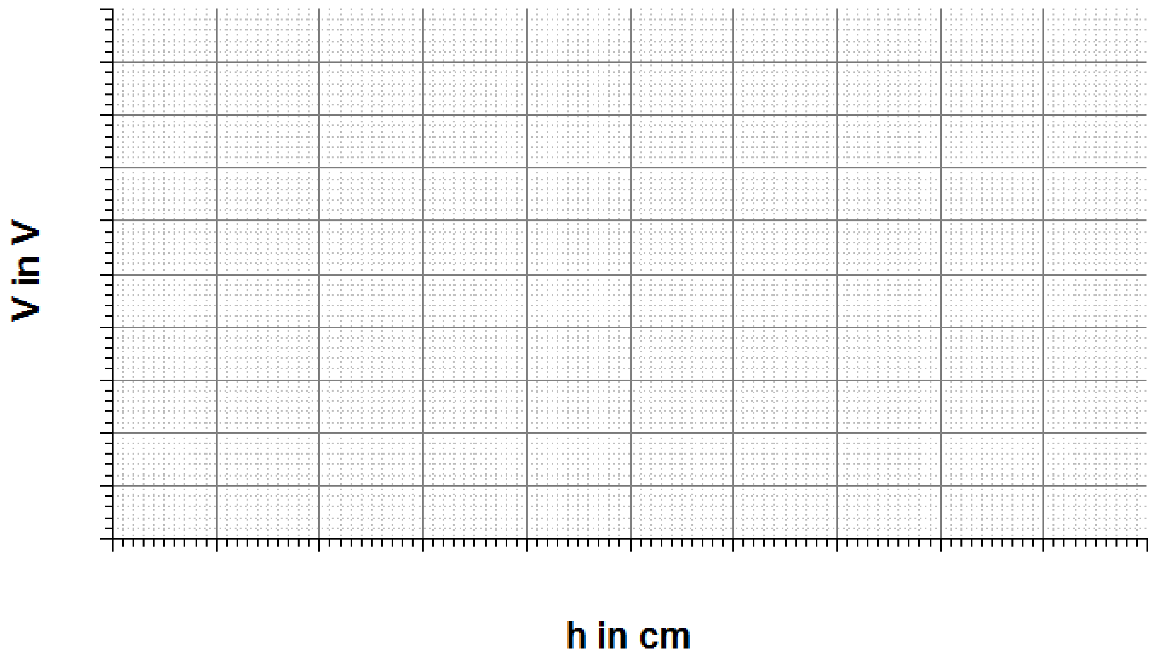
h in cm					
V in V					

Evaluation

1. Enter your values in the respective chart.
2. Expain your measurement results.

16.2 Influence of the water falling height (quantitative)

Diagrams



Evaluation

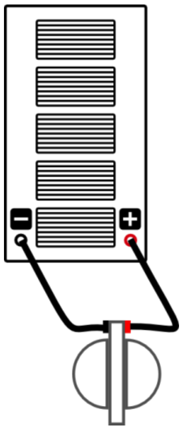
2.

17. What does an electrolyzer?

Task

Find out what an electrolyzer does.

Setup



Required devices

- Large solar module
- Reversible fuel cell
- Cables
- Distilled water

Execution

The included fuel cell is a so-called reversible fuel cell which can work both as an electrolyzer and a fuel cell.

1. Fill the reversible fuel cell with distillated water. You find handling instructions on page 13.
2. Set up the experiment according to the picture above. Pay attention to the polarity of the connections.
3. Now illuminate the solar module with direct sunlight or a lamp and observe the tube at the upper socket on the "O_2" side of the fuel cell. Note your observations.
4. Now, shade the solar module with your hand. Note your observations.

Observations

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____

____

Evaluation

1. What can you say about the gases in both containers?
2. What does a reversible fuel cell do when it is used as an electrolyzer? Which energy conversion takes place?
3. Explain your observations made in step 3 and 4.

Evaluation

4. In the reversible fuel cell, driven as an electrolyzer, water (chemical symbol: H_2O) is broken down into the two gases hydrogen (H_2) and oxygen (O_2). Knowing that, can you explain your observations? Try to set up a reaction equation.
5. How could you test if the gas in the container labeled "H_2" is indeed hydrogen?

1.

2.

3.

4.

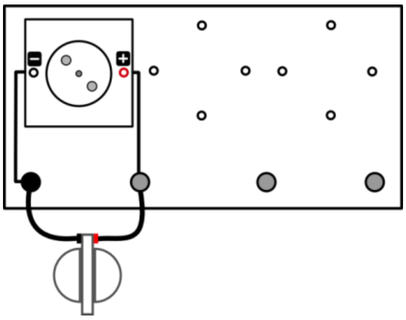
5.

18. What does a fuel cell?

Task

Find out what a fuel cell does.

Setup



Required device

- Base unit
- Reversible fuel cell
- Cables
- Motor module and /or light bulb

Execution

1. If you just did the experiment "What does an electrolyzer do?", the gas storage containers are already filled with hydrogen and oxygen. If not, fill the gas storage containers as described there. The "H2" container should be filled at least to the 10 ml mark.
2. Now, place the motor or lamp module as load on the socket of the base unit and close the circuit with cables as shown in the diagram. Note your observations.

Observation

____

____

____

Evaluation

1. What does a fuel cell do? Which energy conversion takes place?
2. In experiment "What does an electrolyzer do?" you already thought about which reaction takes place in the electrolyzer (water is broken down into hydrogen gas and oxygen gas). Where do the gases "vanish" to when you attach a load (motor or lamp) to the fuel cell?

____

1.

____

____

____

2.

____

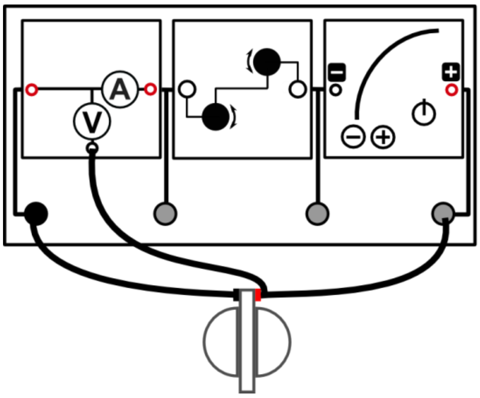
____

19. Characteristic curve of the electrolyzer

Task

Use the electrolyzer to produce hydrogen and record the corresponding I-V-curve.

Setup



Required devices

- Base unit
- Reversible fuel cell
- Potentiometer module
- AV-Module
- PowerModule
- Cables

Execution

1. Fill the reversible hydrogen fuel cell with distillated water. You find handling instructions on page 13.
2. Set up the experiment according to the circuit. Pay attention to the polarity of the connections. Adjust the voltage of the PowerModule to 2V. **This value must not be exceeded!**
3. Adjust the potentiometer to the maximum resistance of 110Ω and measure the voltage V and current I at the reversible fuel cell. Use the AV-module in current-voltage-mode. Note your values in the table.
4. Decrease the resistance at the potentiometer module in several steps and measure each the voltage V and current I. Note your values in the table.

Advice: The current circuit should be open at the beginning (for example by removing a cable) to avoid the start of the experiment without recording data.

Measurements

V in V								
I in mA								

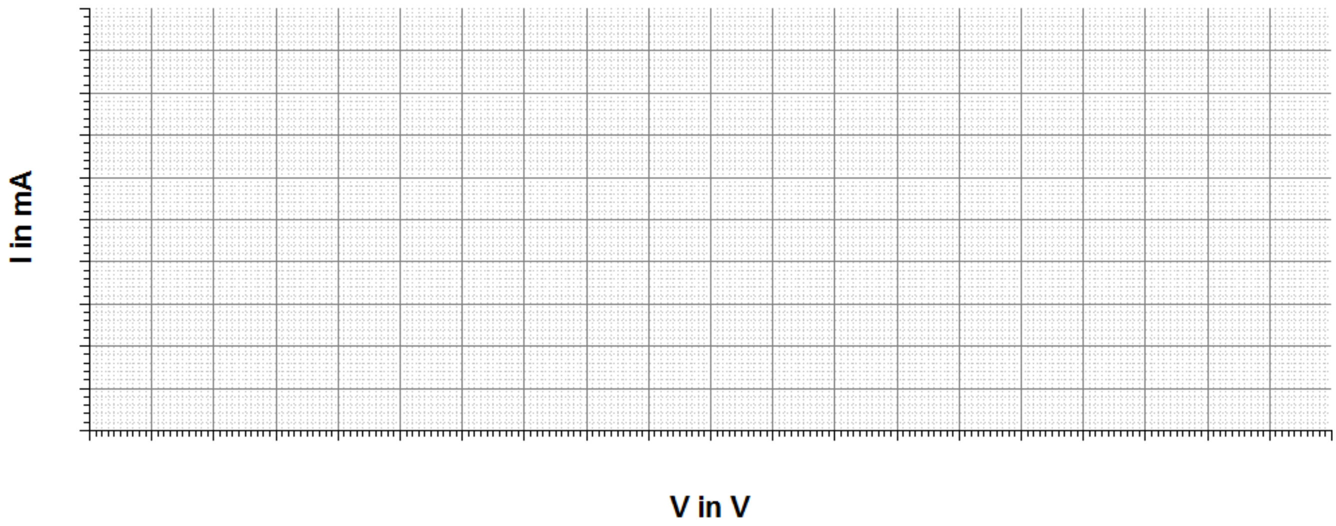
V in V								
I in mA								

19. Characteristic curve of the electrolyzer

Evaluation

1. Enter your values in the diagram.
2. Describe and interpret the characteristic curve of the electrolyzer.

Diagrams



Evaluation

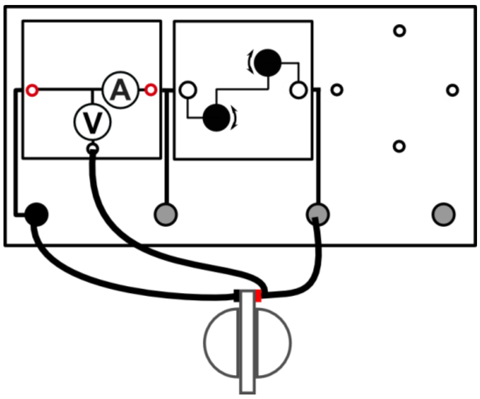
2.

20. Characteristic curve of the fuel cell

Task

Record the I-V-curve of a PEM fuel cell.

Setup



Required devices

- Base unit
- Reversible fuel cell
- Potentiometer module
- AV-Module
- Cables

Preparation

First, you have to produce appr.10ml of hydrogen. For handling instructions see page 13.Directly after H_2 production the hydrogen fuel cell will behave like a capacitor. For this reason you should decrease its voltage down to approximately 0.9 V before measurement by letting a current of roughly 500 mA flow for 20 seconds.

Execution

1. Set up the experiment according to the circuit diagram. Do not plug in the potentiometer yet.
2. Measure the open-circuit voltage of the fuel cell and note your value in the table.
3. Plug in the potentiometer and adjust it to the maximum resistance of 110Ω. Measure the voltage V and current I at the reversible fuel cell. Use the AV-module in current-voltage-mode. Note your values in the table.
4. Decrease the resistance at the potentiometer module in several steps and measure each the voltage V and current I. Note your values in the table.

Evaluation

1. Enter your values in the diagram.
2. Describe the course of the I-V-characteristic.
3. Which area of the curve should be used for the operation of a consumer? Justify your answer.
4. Explain the decrease of voltage at higher currents.

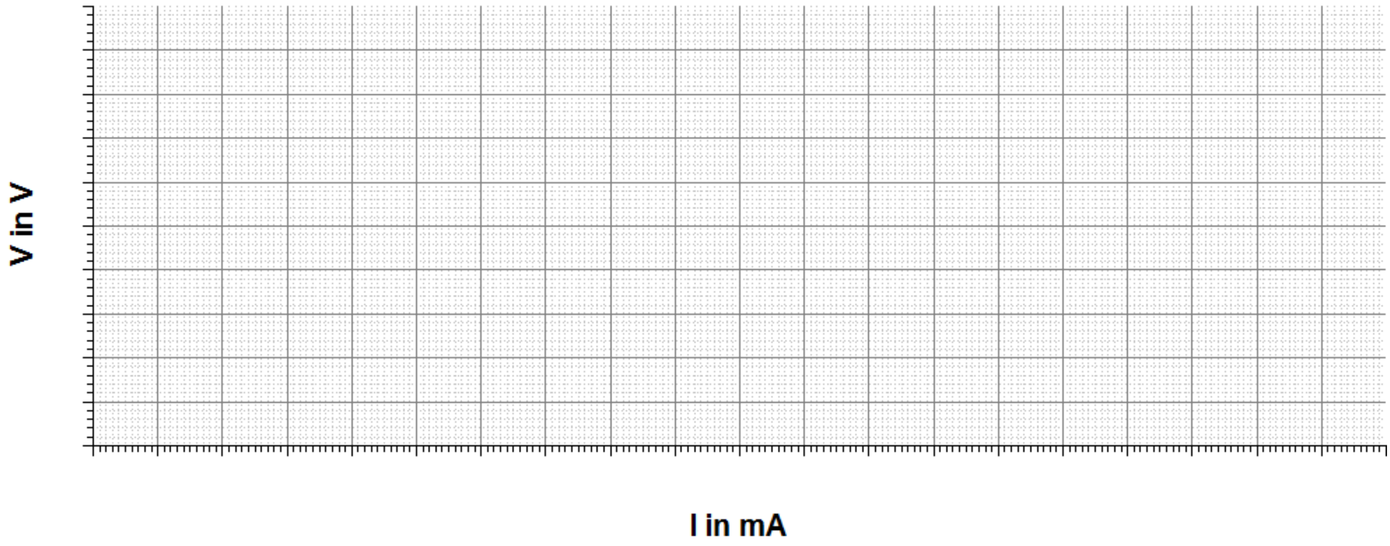
20. Characteristic curve of the fuel cell

Measurements

V in V														
I in mA														

V in V														
I in mA														

Diagrams



Evaluation

2.

Evaluation

3.

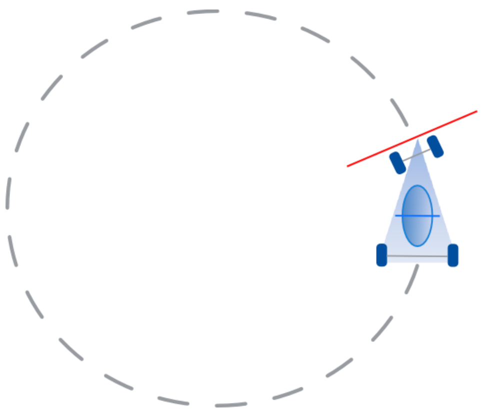
4.

21. Operation of the electric car with the reversible fuel cell

Task

Observe the driving behavior of the car with the fuel cell and conclude the characteristics from it.

Setup



Required devices

- Electric car with module plate
- Reversible fuel cell
- 1 Stop watch

Preparation

For the experiment you need enough space (min. 2x2m). Tilt the front axle of the car to the left, so that the car drives a circular path. Mark the starting and the finishing line of the car on the circular path with adhesive tape or something like that. Produce 12ml of H_2 with the fuel cell (For handling instructions see page 13).

Execution

1. Measure the open circuit voltage V_{OC} of the fuel cell after the production of 12ml H_2 and record your data in the table.
2. Plug the fuel cell module onto the car and first connect only **one** cable.
3. Position the car at the starting line and connect the second cable shortly before putting down the car.
4. Measure the time that the car needs for 4 rounds and repeat the measurement several times without stopping the car. Record your data in the table.
5. Let the car drive for 5 minutes and note your observations.
6. Calculate the difference to the previous round to determine the time for 4 rounds.

Advice: Pay attention to the car. It should not hit something, because the axles could get damaged. Hold the car shortly before starting it, because it could tip otherwise.

21. Operation of the electric car with the reversible fuel cell

Evaluation

1. Compare the operation of the electric car with the fuel cell to the operation with conventional accumulators or the capacitor.
2. Inform yourself about the application of fuel cells in the automotive industry. Which forms of storage of hydrogen are in use?

Measurements

	4 rounds	8 rounds	12 rounds	16 rounds	20 rounds	Observation after 5min (resp.when the car stops)
Fuel cell: V_0 =						
time in s						
time for 4 rounds						

Evaluation

1.

2.

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