leXsolar-SmartGrid Ready-to-go

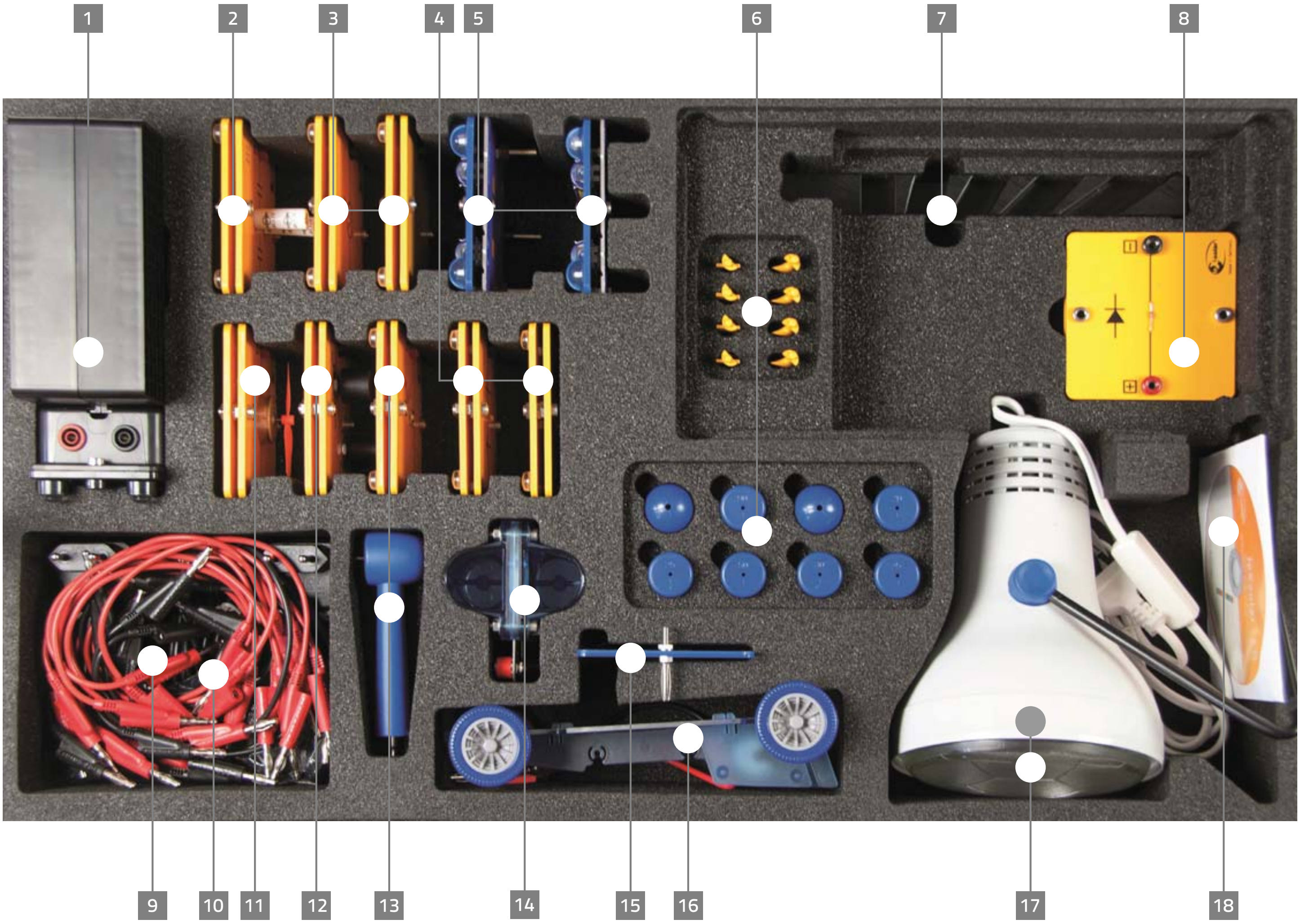
Teacher's Manual

Layout diagram leXsolar-SmartGrid Ready-to-go

Item-No.1605

Bestückungsplan leXsolar-SmartGrid Ready-to-go

Art.-Nr.1605



1	1400-19 leXsolar-Wind machine 1400-19 leXsolar-Winderzeuger
2	1600-02 Capacitor module 5.0F/5.4V 1600-02 Kondensatormodul 5.0F/5.4V
3	2x1100-26 Light bulb module 2x1100-26 Glühlampenmodul
4	2x1600-01 Power grid module 2x1600-01 Stromnetzmodul
5	2x9100-04 SmartMeter 2x9100-04 SmartMeter
6	1400-12 leXsolar-Wind rotor set (8 blades, 6 hubs, 2 caps) 1400-12 leXsolar-Windrotoren (8 Flügel, 6 Naben, 2 Kappen)
7	1118-17 Base for solar panel 1118-17 Standfuß Solarmodul
8	1100-21 Diode module 1100-21 Diodenmodul
9	3xL2-06-014 Test leads black 50 cm 3xL2-06-015 Test leads red 50 cm 3xL2-06-014 Messleitung schw. 50 cm 3xL2-06-015 Messleitung rot 50 cm
10	4xL2-06-012 Test leads black 25 cm 7xL2-06-013 Test leads red 25 cm 4xL2-06-012 Messleitung schw. 25 cm 7xL2-06-013 Messleitung rot 25 cm
11	1100-27 Motor module 1100-27 Motor module L2-02-017 Yellow propeller L2-02-017 Luftschraube (Propeller) gelb
12	1100-61 Potentiometer module 110 Ohm 1100-61 Potentiometermodul 110 Ohm
13	1400-22 Wind turbine module 1400-22 Windturbinenmodul
14	L2-06-067 Reversible Fuel cell Pro L2-06-067 Reversible Brennstoffzelle Pro
15	Battery adapter for 16 Akku-Adapter für 16
16	1801-02 Electric model car with 15 1801-02 Elektro-Modellfahrzeug mit 15
17	L2-04-116 Illuminant 120W with L2-04-080 Lamp housing L2-04-116 Leuchtmittel 120W mit L2-04-080 Lampengehäuse
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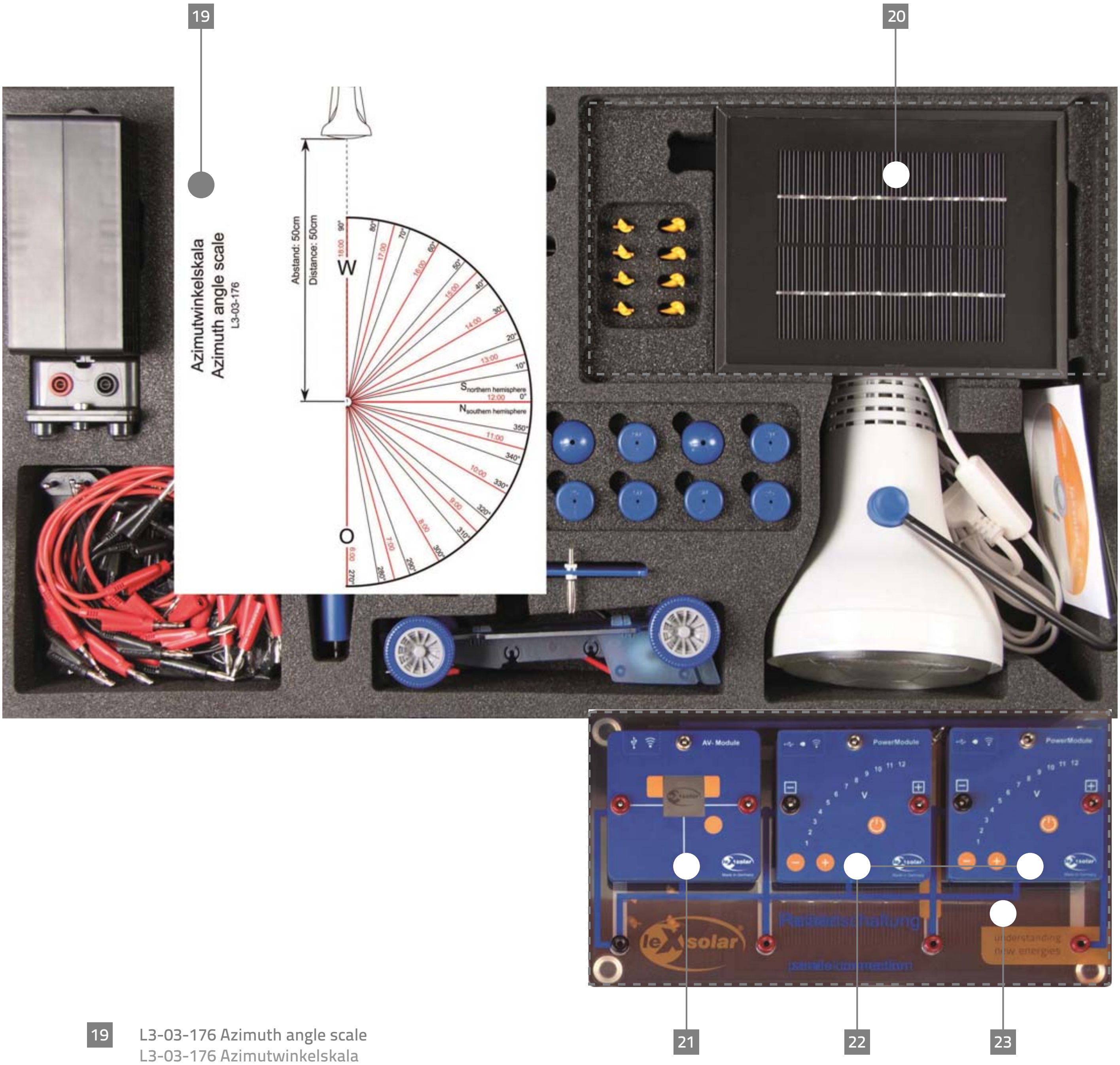
Version number
Versionsnummer

III-01.24_L3-03-169_05.01.2016

CE RoHS2

Layout diagram leXsolar-SmartGrid Ready-to-go
Item-No.1605

Bestückungsplan leXsolar-SmartGrid Ready-to-go
Art.-Nr.1605



19	L3-03-176 Azimuth angle scale L3-03-176 Azimutwinkelskala
20	1100-53 Solar panel 5.22 V, 380 mA 1100-53 Solarmodul 5.22 V, 380 mA
21	9100-03 AV-Module 9100-03 AV-Modul
22	2x9100-05 PowerModule 2x9100-05 PowerModul
23	1100-19 leXsolar-Base unit 1100-19 leXsolar-Grundeinheit groß

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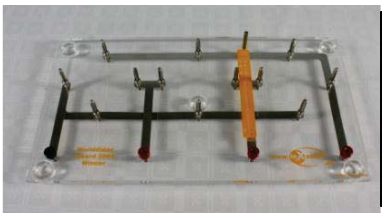
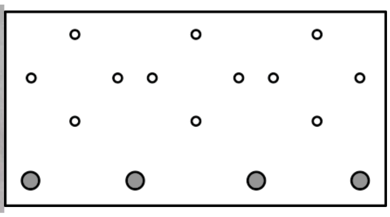
Chapter 1: Description of the experimental components of leXsolar-SmartGrid Ready-to-go

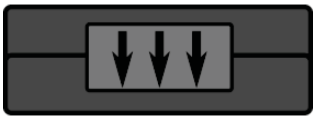
In the following schedule every component of the leXsolar-SmartGrid Ready-to-go is listed. For every component there is the name with article number, a picture, the pictogram for the circuit diagram and operating instructions. With the aid of the article number it is possible to reorder a specific component.

Base unit 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 diagrams 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

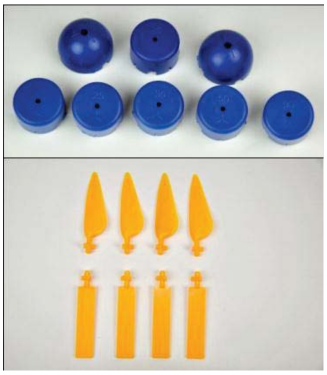



The wind machine is used to control the wind conditions during an experiment with the wind turbine. For those experiments the wind machine has to be connected to the PowerModule (voltage source). For this the negative (positive) pole of the PowerModule has to be connected to the black (red) connection. 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.

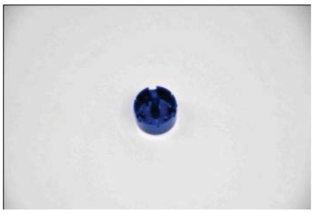
Specifications:

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

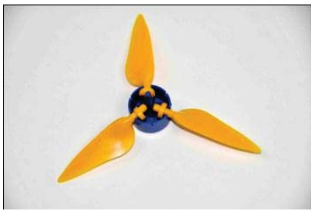
Wind rotor set 1400-12



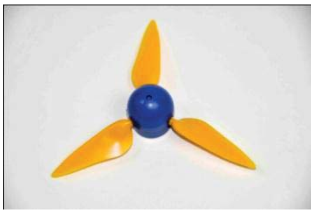
With the available components, rotors with 2, 3 or 4 blades and with a flat or an optimized profile can be created. There is a hub for 4 blades with a pitch angle of 25° and hubs for 3 blades with pitch angles of 20°, 25°, 30°, 50° and 90°. To assemble you should proceed in the following way:



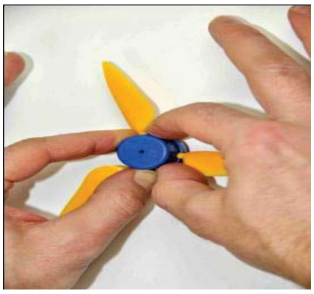
First, a hub with the desired rotor blade pitch and the number of blades should be selected. (The hubs are labelled on the back.) The Two-blade rotor and the Four-blade rotor can both be constructed with the Four-blade hub.



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

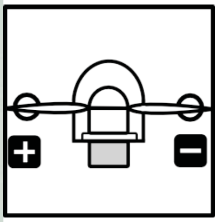


After installation of the rotor blades, the hub-cap will be mounted and lightly pressed against the hub.



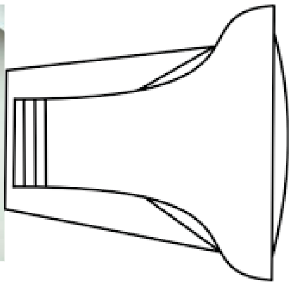
To replace the blades, a small nose is located on the head of the hub. If the nose is pressed lightly on a hard surface, the hub-cap can be removed easily.

Wind turbine module 1400-22

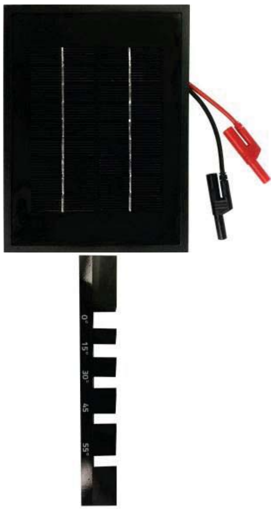


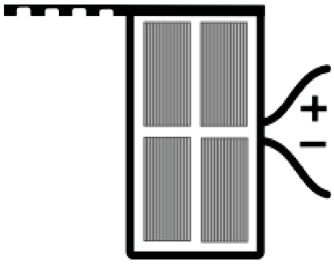
At first the blue wind turbine has to be plugged into the module. The rotor has to be racked at the generator shaft to get a model of a wind turbine. The rotor must not touch the casing to avoid friction, which would considerably impede its rotation. The generator produces a direct current, with its 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!

Lamp housing (L2-04-080) with illuminant 120W (L2-04-116)



Solar module 5.22V, 380mA (1100-04) with base (1118-17)



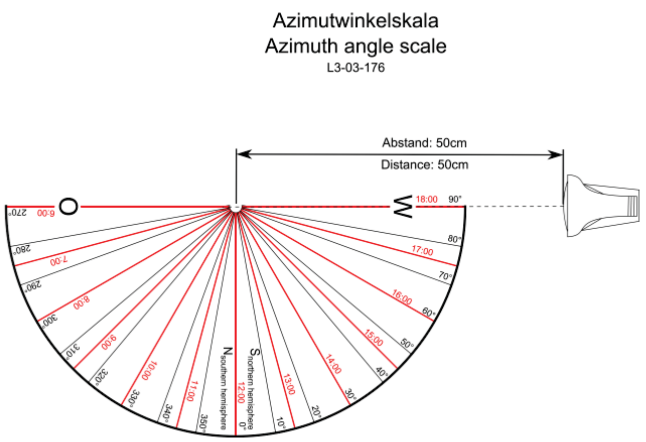


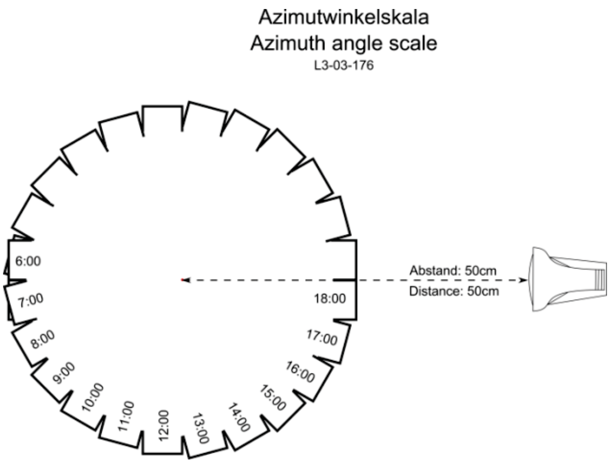
During every experiment there has to be a minimum distance of 50 cm between the solar module and the lamp. The solar module warms up due to the illumination and can be damaged irreparably, when the distance is lower. The lamp must only be switched on during experiments and must not be directed at another person. Due to heat build-up during operation, a cooling time has to be observed before touching and repackaging the lamp. During an experiment there should be no objects or persons in or near the light path. Otherwise there will be reflections, which could falsify the measured values.

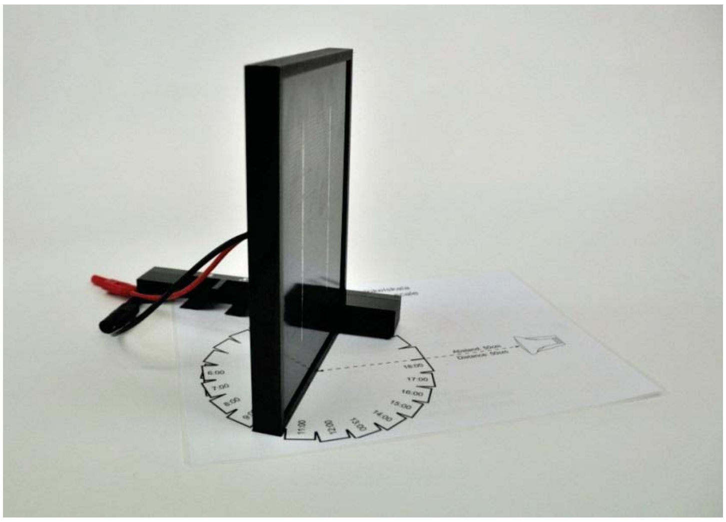
<u>Specifications:</u>
Lamp: 120 W PAR-Lamp

Solar module:
- 4,5 V open circuit voltage
- 840 mA short circuit current
- 3,75 Wp peak power

Azimuth angle scale L3-03-176

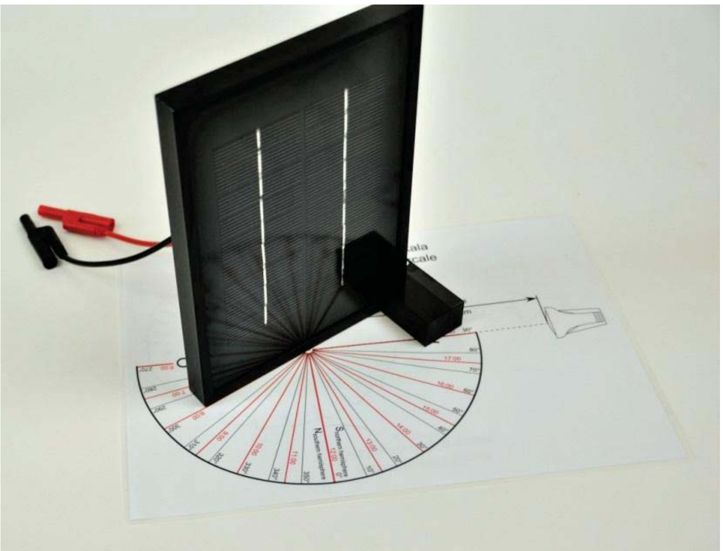






Solar module in 10 o'clock position

With the azimuth angle scale it is possible to set up the azimuth angle between the solar module and the lamp. On one page there are rectangles arranged in a circle and labelled with corresponding times of day. If the solar module is placed in a certain rectangle, the azimuth angle is set up for the chosen time of day. For example, in the alongside figure the solar module is arranged in the 10 o'clock position.

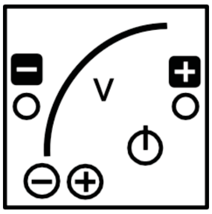


Solar module in 8 o'clock position

The second page can be used for a more exact configuration of a specific azimuth angle. The angle is set up, when the leading edge of the solar module is located at the corresponding line.
In the alongside figure the solar module is arranged in an azimuth angle of 300°. On both scales the position of the lamp is marked. The distance between the lamp and the center of the solar module has to amount to at least 50 cm.
The center of the solar module has to be located at the center of the angle scale.

Advice: The azimuth angle scale does not name the deviation angle of the solar module concerning the south, but name the azimuth angle of the sun in the astronomic meaning! In the experiment is assumed that the solar module is aligned to south (optimal direction). Therefore the used azimuth angle is not the term used in solar engineering, where 0° describe an aligned solar module to the south (-90° to the east, +90° to the west).

PowerModule 9100-05

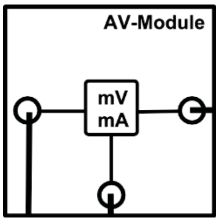


The PowerModule is a compact and intuitively usable voltage source. First, the attached power adapter has to be connected to a power outlet and to the top right input jack. The voltage can be chosen with the „+“- and „-“ -buttons and will be displayed by LEDs. When the desired voltage is chosen, the 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.
In the Smart Grid experiments the PowerModule is on the one hand used as voltage source for the wind machine or the electrolyzer or on the other hand as a simulation of a power plant or a transformer station.

<u>Specifications:</u>

- 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.

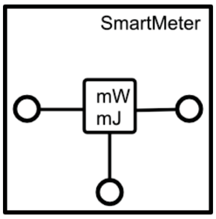
After 30 min without pushing a button or after 10 min of measuring a constant value, the module will switch off automatically. It can measure voltages up to 12 V and currents up to 2 A. In case of exceeding one of the values, the module interrupts the current flow and shows “overcurrent“ or “overvoltage”. 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)

SmartMeter 9100-04

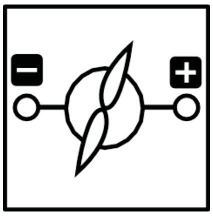


The SmartMeter is a power and energy meter with a switch function. In the SmartGrid experiments it acts as an electric meter.
The SmartMeter measures the voltage and the current at the positions as denoted on the imprint. With the measured values, power and energy are calculated and displayed. The energy meter can be reset by pushing the button on the right.
The current flow can be interrupted with the switch button at any time. For all measurements the usual polarity definitions are valid (red jack positive pole, black jack negative pole). Therefore it is possible to measure negative power values, which will reduce the energy value.
Information about the maximum voltage and current, error messages and advice concerning the battery are identical with the AV-Module and can be found in the description of the AV-Module.

Specifications:

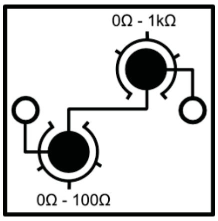
Voltage and current metering correspond to the AV-Module
Power metering 0-24 W
Maximum energy count: 0-200 mWh

Motor module (1100-27) with yellow propeller (L2-02-017)



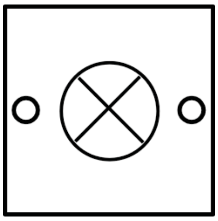
The motor module acts as a consumer in SmartGrid experiments.

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

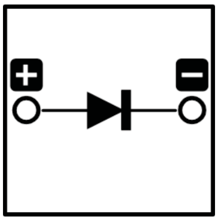


The light bulb module acts as a consumer in SmartGrid experiments.

<u>Specifications:</u>

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

Diode module 1100-21

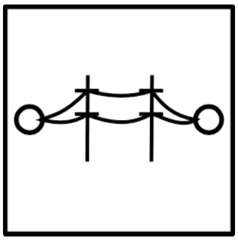


The diode module is used to avoid a return current to the wind turbine in SmartGrid experiments with many voltages sources. Without the diode the turbine could act as a motor.

Specifications:

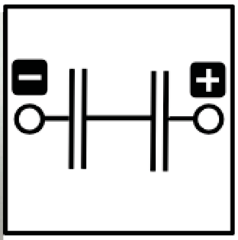
Schottky diode
$U_{forward}$ = 0.33 V
Maximum current: 200 mA (500 mA Peak <1 s)

Grid module 1600-01



The grid module is used as a simulation of a power line and consists of a positive temperature coefficient (PTC) fuse. The PTC-fuse is a resistor, which attains a resistance of 3-5 Ω, up to a current of 190mA. In the process it reaches temperatures of up to 50°C. In the experiments it illustrates the power drain due to thermal energy. Up to the stated current the relation between temperature and resistance is, as with metals, approximately linear.
If the current is higher than 190mA, it cannot be used as a simulation because the resistance increases enormously and the current gets lower. This is not the behavior of a real power line. The measuring of the temperature is just possible by using a temperature sensor, because the released thermal energy is too low for thermometers.

Capacitor module 1600-02

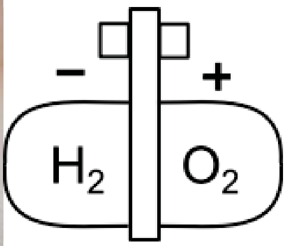


The capacitor module consists of 2 series-connected capacitors. The maximum voltage of the capacitor amounts to 5.4 V. Charging voltages for the capacitor should not exceed 5 V. It is possible to short-circuit the capacitor to discharge, because there are fuses to avoid damages. For quick charging, it 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.

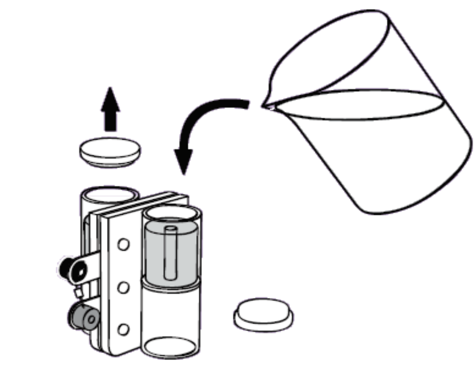
<u>Specifications:</u>

Capacitance: 5 F
Maximum voltage: 5,4 V

Reversible fuel cell L2-06-067



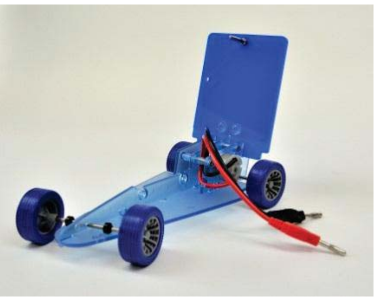
The reversible fuel cell consists of an electrolyzer and a fuel cell. To fill the reversible fuel cell you should proceed in the following way:



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.

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.

You can find the required components for each experiment in the following charts. These charts should help you to decide which experiments could be performed at the same time respectively which components you should reorder to perform certain experiments.

The kind and number of experiment can be read in the first row. The correlation between number and name of the experiment can be found in the chart below.

The available devices are presented in the first column. The number tells you the amount of this device in the case. If the number is missing, the component is just once available.

A cross means that the component is needed for the experiment. Is there a number instead of a cross, the number tells you the required amount for the experiment.

	PV-basic experiments			Wind-basic experiments			Estore-basic experiments						
Components	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	3.4	3.5	3.6	3.7
Base unit				X	X	X	X	X	X	X	X	X	
Wind machine				X	X	X							
Wind rotor + blades				X	X	X							
Wind turbine				X	X	X							
Lamp	X	X	X										
Solar module	X	X	X										
Azimuth angle scale													
PowerModule (2)				1	1	1	1	1			1	1	1
AV-Module	X	X	X	X	X	X	X	X	X	X	X	X	
SmartMeter (2)										1		1	
Motor module													
Potentiometer module	X	X	X	X	X	X	X	X	X	X	X	X	
Light bulb module (2)													
Diode module													
Grid module (2)													
Capacitor module											X	X	X
Reversible fuel cell							X	X	X	X			X
Electric model car													X

1.1	The I-V-characteristic of a solar module	3.1	The I-V-characteristic of an electrolyzer
1.2	The I-V-characteristic of a solar module depending on the illuminance	3.2	Behavior of the voltage and the current during charging of an electrolyzer
1.3	The I-V-characteristic of a solar module depending on the temperature	3.3	The I-V-characteristic of a fuel cell
2.1	The dependence of the power on the pitch angle and the blade design	3.4	Behavior of the voltage and the current during discharging a fuel cell
2.2	The dependence of the power on the number of blades	3.5	The t-V- and t-I-characteristic of a capacitor during charging
2.3	The dependence of the power on the wind direction	3.6	The t-V- and t-I-characteristic of a capacitor during discharging
		3.7	The I-V-characteristic of a LiFePo-battery during discharging

	Smart Grid experiments													
Components	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	4.11	4.12	4.13	4.14
Base unit		X	X	X	X		X	X	X	X	X	X	X	X
Wind machine		X											X	X
Wind rotor + blades		X											X	X
Wind turbine		X											X	X
Lamp	X			X	X		X	X	X	X	X	X		X
Solar module	X			X	X		X	X	X	X	X	X		X
Azimuth angle scale	X			X	X		X							
PowerModule (2)		1	1			1	1	1	1	1	1	1	1	2
AV-Module	X	X		X	X	X	X	X	X	X	X	X	X	X
SmartMeter (2)			1	1	1		2	1	1	1		1		1
Motor module			X	X	X									X
Potentiometer module	X	X						X	X		X	X	X	
Light bulb module (2)			2	2	2	2	2	2	2	2	2	2		2
Diode module														X
Grid module (2)						2	2	2	2	2	2	2	1	2
Capacitor module					X									X
Reversible fuel cell											X			
Electric model car														

4.1	The power fluctuations of a photovoltaic station	4.8	The behavior of the voltage in a line grid with photovoltaic station depending on the consumption
4.2	The power fluctuations of a wind turbine	4.9	The behavior of the voltage in a line grid with photovoltaic station depending on the distance to the transformer
4.3	Energy supply of a building by a power plant	4.10	The behavior of the voltage in a line grid with photovoltaic station and an intelligent transformer station
4.4	Energy supply of a building by a power plant and a photovoltaic station	4.11	The behavior of the voltage in a line grid with photovoltaic station and an energy storage (fuel cell / E-Mobility)
4.5	Energy supply of a building by a power plant, a photovoltaic station and an energy storage	4.12	The behavior of the voltage in a line grid with photovoltaic station and load management
4.6	The behavior of the voltage in a conventional line grid	4.13	Power line monitoring
4.7	The behavior of the voltage in a line grid with photovoltaic station	4.14	Scenario experiment: Smart Grid

Chapter 2: Sample solutions of the experiments

Primary notes

The details for every experiment are separated into preparation, implementation and follow-up procedure.
The advice for preparation contains information about the educational objectives of the experiment, necessary prior knowledge, previous experiments and detailed advice about the procedure and evaluation. This information assists in

- the classification of the experiment in a sequence of lessons,
- the classification of the experiment as of a lesson,
- the preparation of the experiment concerning necessary knowledge of the students,
- an effective implementation of the experiment to get the best measurement results,
- the avoidance, recognition and correction of errors during the procedure,
- the decision, whether the experiment can be conducted by the teacher or the students
- the preparation of follow-up topics about smart grid

The implementation is separated into the subchapters: task, primary notes, setup and equipment, procedure and measured values. The instructions are conceptualized a way, that an immediate usage by students without given measured values is possible. This means, that the students are able to do the experiment on their own, make an appropriate evaluation and understand the physical processes, given they possesses of the required knowledge.

The evaluation consists of

- exercises in comprehending the measured values
- exercises in elucidating the physical processes of the experiment and the real situation
- exercises in suggesting tasks for the following lessons

Every task consists of sample solutions and is considered a suggestion for your own lesson. With the given foreknowledge the students should be able to solve every task on their own. Nevertheless, it could be necessary for students to solve some tasks in groups or that intermediate tasks are given. Furthermore, there are (German) references so that students are enabled to solve the task by investigations of their own.

The experiments are subdivided in preliminary experiments and smart grid experiments. The preliminary experiments should impart technical knowledge about the main components, which is necessary for the smart grid experiments. Moreover the preliminary experiments are important to become acquainted with the handling of the leXsolar components.
Some of the smart grid experiments are quite complex and will require 3 to 4 students to do the experiment. The complex setups consist of many different components, so that there are many potential sources of error. Therefore it is important that the setups and the procedures are implemented conscientiously. This limits the liberty of experimenting, but it is necessary to get sensible and comparable results.

The protocols without sample solutions can be found in the separate instruction manual or on the leXsolar-CD as pdf- or word-file (docx). With the purchase of the product you acquire the right to a free usage of the protocols for the purposes of education. This includes variation of text passages or figures within the word-file (providing the source is acknowledged).

1.1 – 1.3 Basic experiments on photovoltaic

Educational objectives

Experiment 1.1: The I-V-caracteristic of a solar module

- The students measure, plot and describe the I-V curve and the V-P curve of a solar module.
- The students interpret the intersection between the I-V-characteristic of a solar module and a resistor as operating point.
- The students realize by reference to the I-V curve, that voltage, current and power of a solar module depend on the connected resistor.
- The students calculate the resistance of the MPP at room temperature. Hereby, the students know approximately where the operation point is located for certain resistances

Experiment 1.2: The I-V characteristic of a solar module depending on illuminance.

- The students measure and plot the I-V- and V-P-characteristic curves of a solar module.
- The students compare voltage, current and power output to the results of experiment 1.1 using the same resistance and ascertain a decrease of every value.

Experiment 1.3: The I-V-characteristic of a solar module depending on temperature

- The students measure and plot the I-V- and V-P-characteristic curves of a solar module.
- The students compare voltage, current and power output of the solar module to the measurement results of experiment 1.1 using the same resistance. They observe, that the maximum power decreased, however the power does not decrease for every resistance.

Foreknowledge

- The students know, that a solar cell converts light energy into electric energy.
- The students know, that power is the product of voltage and current.
- The students can plot the I-V-characteristic curve of an ohmic resistance.

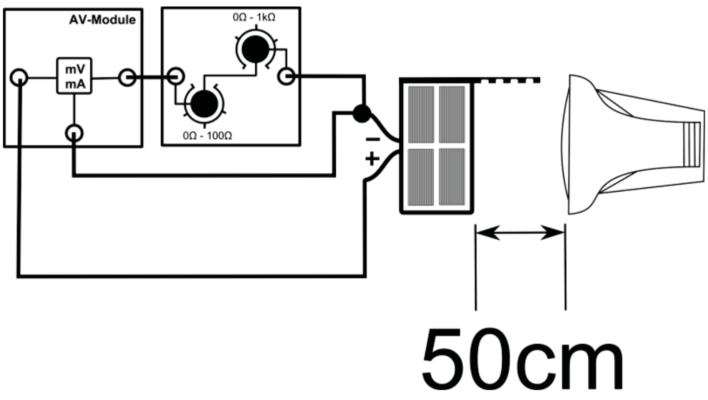
Experimental and reworking advices

- All 3 experiments should be made with the same setup. A reconstruction of the same setup is very time-consuming, because small variations of the angle of incidence will cause major variations of the I-V-characteristic. Hereby, the students could conclude falsely by comparing different curves. It is recommended to do the experiments successively.
- It may be advisable to point to the analogy of the characteristic curves of a solar cell and a diode because of the p-n-junction within both devices.
- The students should know that real photovoltaic stations use an MPP-tracker (Maximum Power Point) to realease always the maximum power.
- The internal resistance of the solar module at the MPP amounts dependent on the temperature between 30Ω und 40Ω. The connected consumers have a smaller resistance in the smart grid experiments. That means the operation point is always to the left of the MPP.
- Natural sunlight is an additional source of inaccuracies of measurement. The sample values have been measured in a darkened room.
- Additional theoretical facts and fundamental experiments on photovoltaics can be found in the teacher's manual photovoltaic on the leXsolar-CD.

Task

Measure the I-V-characteristic of the solar module.

Setup



Equipment

- Lamp
- Solar module
- AV-Module
- Potentiometer module
- cables

Procedure

1. Set up the experiment according to the circuit diagram. Set the maximum resistance on the potentiometer. Arrange the solar module vertically in front of the lamp in a distance of 50 cm so that it will be illuminated entirely. The lamp should be aligned horizontally.
2. Ensure that every component is connected in series and that the voltage of the solar module is measured in a parallel connection.
3. Switch on the lamp and decrease the resistance of the potentiometer. Always measure voltage and current to a given resistance. You will measure useful values, if you note the values after a variation of 20 mA of current or a variation of 0.5 V of voltage. Do not try to set certain values of current or voltage because the accuracy of the potentiometer will not be sufficient. Measure the open circuit voltage and the short circuit current as well.
4. Calculate the power of the module for each measuring point.

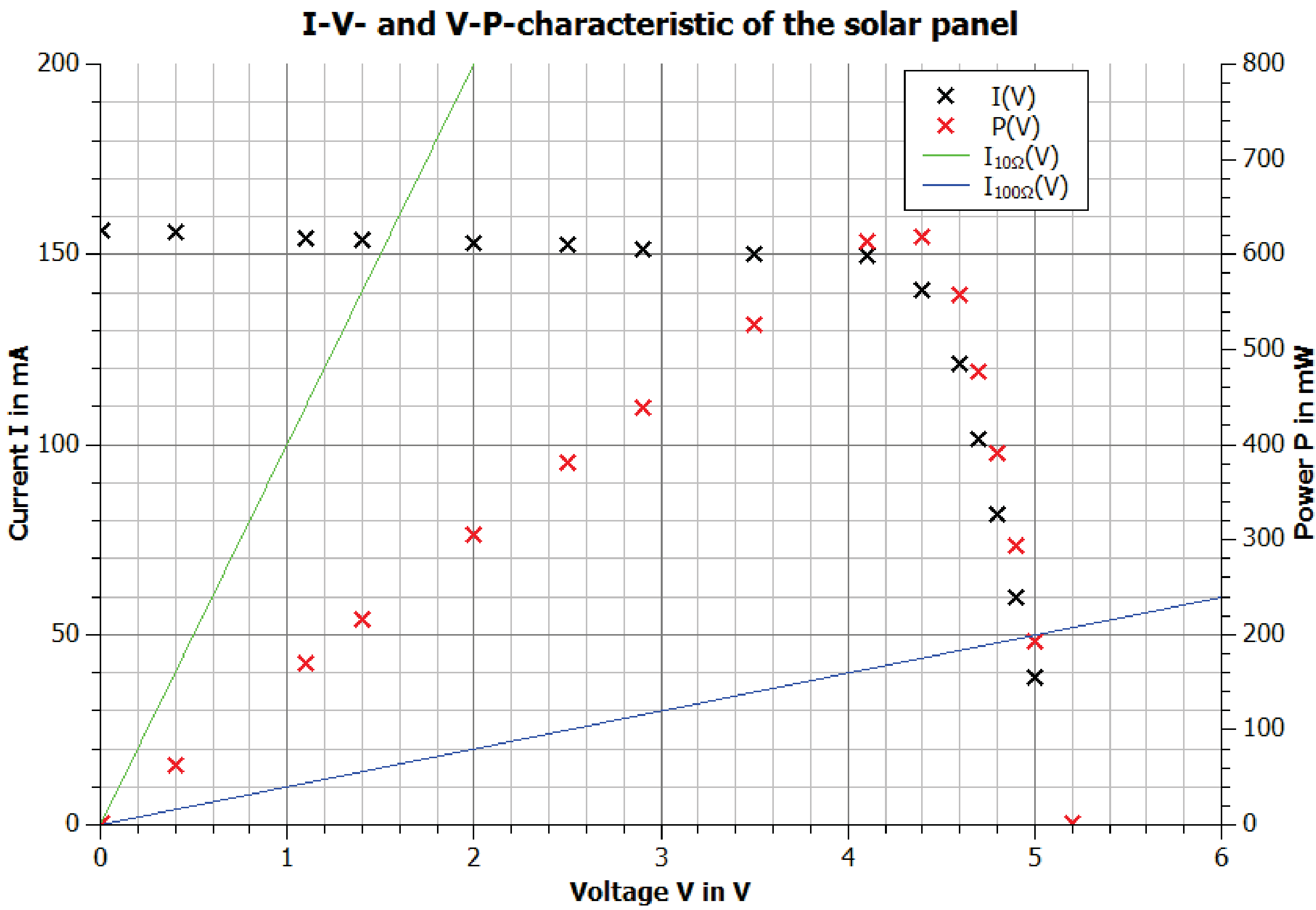
Measured values

V in V	5,2	5	4,9	4,8	4,7	4,6	4,4	4,1	
I in mA	0	44,8	59,9	81,5	101,5	121,2	140,7	149,7	
P in mW	0	224	293,5	391,2	477,1	557,5	619,1	613,8	

V in V	3,5	2,9	2,5	2	1,4	1,1	0,4	0	
I in mA	150,1	151,4	152,6	152,9	153,8	154,1	155,7	156.3	
P in mW	525,4	439,1	381,5	305,8	215,3	169,5	62,3	0	

Evaluation

1. Plot your measuring points in the I-V- and V-P-diagram and draw the according curves.



2. Describe the behavior of the curves.

   The current between 0 V and 4 V is approximately constant at 150 mA. Up to 4 V the current decreases fast, so that it is zero at 5.2 V.
   The power is depending of the voltage. The highest power is achieved at a voltage of 4.4 V and amounts to 610 mW. The lowest power is reached at 0 V and 5.2 V and amounts to 0 mW. In the interval [0 V; 4.4 V] the power rises linearly and in the interval [4.4 V; 5.2 V] it decreases rapidly.

3. 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.

   At the intersection points you can read out the voltage and the current of the solar module depending on the resistance.

4. Evaluate the voltage and energy output of the solar module depending on the connection of a certain consumer.

   Depending on the resistance of the consumer, there will be a different voltage and power. Therefore, the solar module is neither a voltage source, which provides the same voltage for every consumer, nor a power source, which releases the same power to every consumer.

5. Calculate the resistance, which generates the highest power of the solar module.

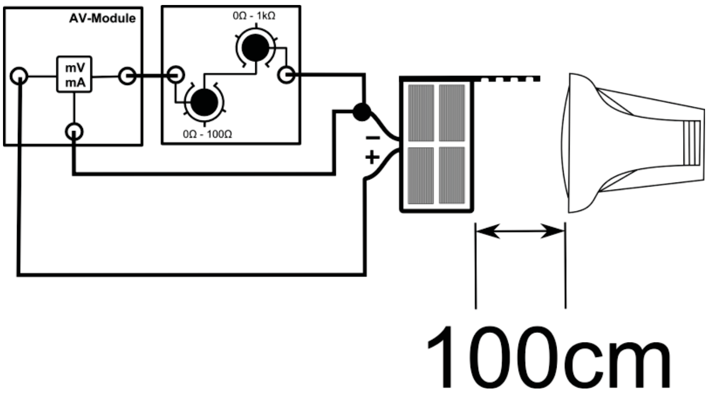
   The Maximum Power Point (MPP) is achieved at a voltage of 4.4 V and a current of 140.7 mA. Therefore the resistance has to amount to: $R_{MPP} = \frac{V}{I} = \frac{4.4\,V}{0,14\,A} \approx 31\,\Omega$

1.2 The I-V-characteristic of a solar module depending on the illuminance

Task

Measure the I-V-characteristic of the solar module with a lower illuminance as in experiment 1.1.

Setup



Equipment

- Lamp
- Solar module
- AV-Module
- Potentiometer module
- cables

Procedure

1. Set up the experiment according to the circuit diagram. Set the maximum resistance on the potentiometer. Arrange the solar module vertically in front of the lamp in a distance of 100 cm so that it will be illuminated entirely. The lamp should be aligned horizontally.
2. Ensure that every component is connected in series and that the voltage of the solar module is measured in a parallel connection.
3. Switch on the lamp and decrease the resistance of the potentiometer. Always measure voltage and current to a given resistance. You will measure useful values, if you note the values after a variation of 20 mA of current or a variation of 0.5 V of voltage. Do not try to set certain values of current or voltage because the accuracy of the potentiometer will not be sufficient. Measure the open circuit voltage and the short circuit current as well.
4. Calculate the power of the module for each measuring point.

Measured values

V in V	5	4.7	4.5	4	3.5	3		
I in mA	0	41	60	77	82	82		
P in mW	0	192.7	270	308	287	246		

V in V	2.5	2	1.5	1	0.3	0		
I in mA	81	82.3	83.3	83	83.5	84		
P in mW	202.5	164.6	125	83	25.1	0		

Evaluation

1. Plot your measuring points in the I-V-diagram and the V-P-diagram. Add the measuring points of experiment 1.1.