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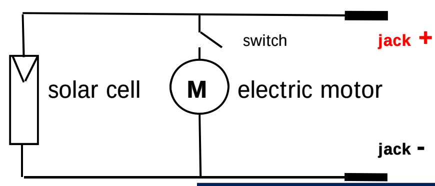
Experimentation manual for experiments with the solar module SUSE CM312/CM315

QR- english | QR - deutsch

Name:................................School:..Date:............

The electric circuit of the solar module



1. The **solar modules SUSE CM312/CM315** are identically constructed **beginner's modules** with different solar cells:
SUSE CM312: 50 x 33 mm, SUSE CM315: 52 x 26 mm, else with the same implementation. Lab wires can be connected to the jacks to connect a multimeter or additional devices, here the solar cell voltage and the short-circuit current can be measured. The solar module is easily assembled and can be applied with multiple experiments to demonstrate photovoltaics (conversion of light radiation to electric energy). With the switch the solar motor can be turned off or on.

SUSE CM 312

SUSE CM 315

The solar modules SUSE CM312/CM315
On the roof-shaped plexiglass base plate the solar cell is placed on one side, on the other side the electric motor with propeller, the switch and the 2 jacks.

Possible light sources for the experiments are:

- direct sunlight (bright sunshine or clouded sky)
- the light on the glass plate of a powerful overhead projector
- the light of a floodlight (halogen spot light 120 W)

Electrical and mechanical data of the solar cell and the solar module:
Solar cell CM312: Dimensions: 50 x 33 mm **Solar cell CM 315:** Dimensions 52 x 26 mm
Solar module: SUSE CM312: Dimensions: 85 x 65 mm with glass plate **SUSE CM315:** Dimensions: 60 x 30 mm laminate
Electric data with S = 1000 W/m² - Open circuit voltage: SUSE CM312 and SUSE CM315: 0.62 V
Short-circuit current: SUSE CM312: 550 mA SUSE CM315: 450 mA

With the self-constructed device SUSE CM312/315 energy conversion processes can be demonstrated in a solar module with solar cell, electric motor, and propeller and researched with measurements.
After the self-construction of the solar module the solar cell is **held into light radiation for a first test (natural sunlight or the light of halogen spot lamps). Here several energy conversion processes run down,** edit the following **„energy boxes“** and fill them with your **own text.**

Didactic note
This experiment book shows all kinds of experiments with the self-built solar module. The responsible teacher choses suited experiments in line with the study group and the time budget!

Energy conversion processes at SUSE CM312 / CM315

Light Energy form

Characteristics of the energy form light

Solar cell Energy converter **from light to current** Energy conversion process in the solar cell

Electric motor Energy converter **from current to rotation** Energy conversion process in the electric motor

Propeller Energy converter **from rotation to airstream** Energy conversion process by the propeller

The experiments with the solar module SUSE CM312 / CM315

2. The electric voltage of the solar cell

The open circuit voltage V_{OC} of the solar cell oc = open circuit

V_{OC} is the electric voltage V of the unstressed solar cell, no device is connected to the solar cell, the motor turned off!

Use a multimeter in the measurement range of 20V DC and connect the voltmeter to the two jacks of the illuminated solar cell with 2 lab wires in the right polarity.

The value of the voltage V_{oc} should be **between 0.59 V and 0.62 V in the sunlight**, **with clouded sky 0.52 V- 0.58 V**, **indoors approx. 0.3 V**, ***independent of the area*!** With the same irradiance all solar cells should have roughly the same voltage, the standard test value being 0.62 V. Small differences are due to quality differences.

The open circuit voltage only depends on the *light intensity*, the *material*, and the *quality* of the solar cell, not the area! With our solar cell the material is silicon Si.

Measurements on the voltage of the solar cell:

Measurement site	Outdoors with bright sunshine adjusted towards the sun or on OH projector	Outdoors with sunshine in the shadows	Outdoors with clouded sky	Inside a lit room
Open circuit voltage V in V Solar-Motor ON				
Open circuit voltage V in V Solar-Motor OFF				

3. The maximum current of a solar cell = short-circuit current

The short-circuit current I_{SC} of the solar cell sc = short circuit

In contrast to other power supplies (battery, power supply unit,...) solar cells may be short-circuited, the short-circuit current actually is a very important value for solar cells. The current flows directly from the solar cells negative pole over the amperemeter to the positive pole here.

Verwende zur Stromstärkemessung ein Multimeter im Messbereich 10A DC, welches mit Laborkabeln an + und – Buchse der Solarzelle angeschlossen wird
Nur für Messungen im Innenraum den Messbereich 200 mA oder 20 mA verwenden!

The ***value of the short-circuit current*** is ***directly proportional to the cell area and the light intensity***/irradiance, as well as dependent on the quality. Standard test value: With a solar cell of the module **SUSE CM312** the short-circuit current is exactly **0.55 A = 550 mA** with a light intensity of 1000 W/m², with **SUSE CM315 0,45A = 450 mA**.

Additional measurements:

Measurement site	Outdoors with bright sunshine adjusted toward the sun or on OH projector	Outdoors with sunshine in the shadows	Outdoors with clouded sky	Inside a lit room
Short-circuit current I_{sc} in A and in mA **Solar motor ON**				
Short-circuit current I_{sc} in A and in mA **Solar motor OFF**				

What do you notice in the voltage and current measurements? Note your observations/explanations here:

4. The electric power of the solar cell P_E in W (Watt)

$P_E = V_{OC} \times I_{SC} \times 0.8 =$.................W The factor 0.8 arises from the I(V) and P(V) characteristic curves of the solar cell and can be determined exactly in an experiment for higher Secondary School levels with the solar module SUSE 5.15.

No new measurements necessary, calculation with the two already determined values V_{oc} and I_{sc}

Simplified approach: Power P is open circuit voltage x short-circuit current x 0.8. The factor 0.8 is explained by the characteristic curve and the MPP of the solar cell and can be determined exactly from the P(V) characteristic curve of the solar cell.

Additional calculations: (Motor turned off), measurement values from exercises on page 3

Measurement site	Outdoors with bright sunshine adjusted towards the sun or on OH projector	Outdoors with sunshine in the shadows	Outdoors with clouded sky	Inside a lit room
Short-circuit current I_{sc} in A Transfer values				
Open circuit voltage V_{oc} in V Transfer values				
Power P $V_{oc} \times I_{sc} \times 0.8$ **in W**				
Power P $V_{oc} \times I_{sc} \times 0.8$ **in mW**				

5. The quality of the solar cell = current density j in mA/cm²

Extremely good: 40 mA/cm²
Very good: 36-39 mA/cm²
Good: 33-35 mA/cm²
Medium: 29- 32 mA/cm²
Bad: < 29 mA/cm²
With an irradiance of 1000 W/m², T = 25°C !!

The **current density j** (in mA/cm²) specifies, how much current a **1 cm² piece of solar cell** produces, **the more, the better**! **For that purpose the irradiance has to be exactly 1000 W/m²** (international standard value = bright sunshine or OH projector), because with a lower irradiance <1000 W/m² the current density j of course is also lower!

$$j = \frac{\text{Short-circuit current in mA}}{\text{Cell area in cm}^2} = \text{............mA/cm}^2 \text{ with irradiance 1000 W/m}^2 \text{ !}$$

The current density of the used cell is..........................mA/cm²

The quality of the solar cell is...
Extremely good - Very good – good – medium- bad

Type of the solar cell in the solar module: Please encircle cell type

monocrystalline solar cell – polycrystalline solar cell

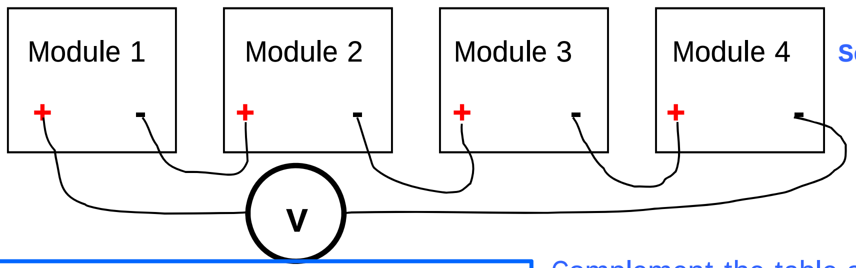
In a few words, explain the different composition of these two cell types (Internet or NILS-ISFH-PV compendium).

6. Series connection of solar cells

Solar cells have a low current, but they can be **connected in series** in any number to reach higher voltages!
In photovoltaic technology there are most often 18...72 solar cells connected in series in the big solar modules.

Several modules SUSE CM312/CM315 in series connection:

Place the modules in the sunlight or (with the upper surface facing down!) on an overhead projector and connect the modules in series (as shown in the drawing).
Of course you can also connect more than 4 modules in series, with 6 solar cells in series connection you can already operate a 3V radio! Try it!



Series connection of 4 modules

Modules in series:	V_{oc} in V	I_{sc} in A
Modul 1+2:.................	....	....
Module 1+2+3:.................	....	....
Module 1+2+3+4:.................	....	....

Complement the table at the bottom, if you connect More than 4 modules in series!

Values for the series connection of ....modules:

V_{ges}=.............................V

I_{sc} =.............................A

Explain the series connection here! Draw a circuit diagram with 4 solar cells, note and explain your observations:

Develop a series connection of <u>6 solar modules</u> and connect the following devices:
A) a solar radio SUSE 4.36
B) an LED module SUSE 4.15 red, green or rainbow

Test the function of the radio / the LED module with the 4 possibilities:
a)outdoors
b)on the OHP
c)30 cm in front of a halogen spot lamp 120 W
d) on a table in a lit room

Note the results here and explain:

Additional experiments see pages 11 + 12:

- **Connection of a cell phone charging device to 14-20 solar cells in series connection**
- **Charging of an energy storage and subsequent driving of the SUSE solar vehicle 1.2 or 4 with solar modules CM312 / CM315 in series connection**

7. Open circuit voltage V_{OC}, short-circuit current I_{SC}, Power P in dependence of the radiated area of the solar cell

Generally the whole area of the solar cell is illuminated by light. In practice it can happen though, that solar cells in solar modules on roofs can be shadowed, e.g. by shadows of chimneys, houses, trees, or by fallen leaves in autumn etc. Then the electric values of the solar cell change. This effect is what we want to investigate in this experiment by partially covering the solar cell with black cardboard or aluminum foil.

Experiment set-up:

We place the solar module SUSE CM312/CM315 on the basic device SUSE 4.0, exactly at the black line, so that the solar cell faces the halogen lamp. This position shall remain unchanged during the experiments, only switch on the lamp for the experiments for the solar cell not to heat up much. At the jacks we connect a multimeter (positive wire red, negative wire black), the motor is turned off.

Experimental procedure:

We measure the open circuit voltage V_{OC} (measurement range 20V DC) and the short-circuit current I_{SC} (measurement range 10A DC), calculate the power P ($P = 0.8*V_{OC}*I_{SC}$) and note the values in the table.

Now we cover the solar cell with black cardboard or aluminum foil exactly one half (up to the silver middle line) and measure again, afterwards we cover ¾ (=75%) of the solar cell and again measure the values.

Covering	Open circuit voltage in V	Short- circuit current in A	Power in W
No covering			
50% covered			
75% covered			

Analysis: What do you notice in the results? Note your observations and explanations here:

8. Determination of the efficiency factor of a solar cell

> The efficiency factor specifies which % of the irradiated light energy is converted to electric energy.

Requirement: Overhead projector or sunlight with an irradiance of 1000 W/m² Or theoretical calculation with the known data of the solar cell

1. **Conversion of the light power 1000 W/m²** or rather 0.1 W/cm² to the **real area** of the solar cell:

   The cell CM315 has an area of 13.52 cm², CM312 has 16.5 cm², it receives from 1000 W/m² on it's real area a <u>light power</u> of:

   ... W

2. **The electric power** (exercise 4) was with the measured cell: **P_E =..........................W**

3. Efficiency factor = Electric power P_E : light power P_L * 100 = Efficiency factor in %

Efficiency factor $= \dfrac{P_E}{P_L} \cdot 100 =$ **............................%**

The efficiency factor of the used solar cell is............................%.

Efficiency factors of solar cells:

Monocrystalline cells: 17- 22 % Polycrystalline cells: 15 – 19 %

The used solar cell was a..cell.
Monocrystalline / polycrystalline

Its measured efficiency factor was:...
very good – good – medium - bad

9. Measurements of the light intensity (irradiance S) in W/m²

With the calibrated solar cell used here the light intensity can be determined exactly, because the short-circuit current is proportional to the light intensity = irradiance S.

1000 W/m² is the intensity of the light radiation of the sun with cloudless sky in the summer and the international standard measurement value for solar cells.

Short-circuit current I_{sc} of the solar cell with an irradiation of 1000 W/m²

SUSE CM312: I_{SC}= 0,55A = 550mA **SUSE CM315: I_{sc}= 0,45A = 450mA**

Measurement of the irradiance S of light (light intensity) in W/m²:

Because the short-circuit current I_{sc} of a solar cell is proportional to the irradiance S, it holds:

$$\frac{I_{sc} \text{ in A}}{1000\ \mathrm{W/m^2}} = \frac{I_{mes} \text{ in A}}{S_x\ \mathrm{W/m^2}}$$

or solved for S_x:

$$\boxed{S_x = \frac{I_{mes} \text{ (in A)} \cdot 1000\ \mathrm{W/m^2}}{0.55\ \mathrm{A} / 0.45\ \mathrm{A} \text{ resp. for CM315}}}$$

It is: I_{sc} in A the calibrated short-circuit current at 1000 W/m² **= 0.55 A / 0.45 A**
I_{mes} in A the measured short-circuit current at the irradiance S_x
S_x in W/m² the irradiance of the light radiation in the experiment

Measurements outdoors and with light sources:

Light radiation	**Short-circuit current I_{sc} in A**	**Irradiance S_x in W/m²**
Bright sunshine, measured directly towards the sun		
Bright sunshine, measured in the shadows		
Clouded sky		
Very gloomy weather		
On the plate of an overhead projector		
10 cm **above the surface** of an overhead projector		
40 cm in front of halogen spot lamp 35 W (Spot light SUSE 5.16)		
40 cm in front of halogen spot lamp 150 W		
Indoors, directed towards the window		
Indoors, directed towards the ceiling		

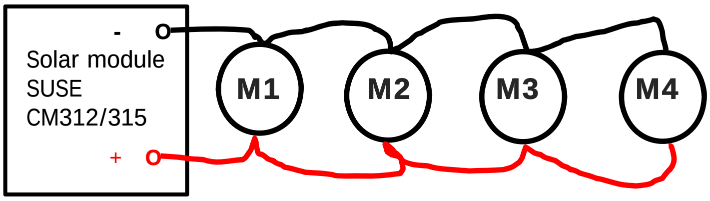
What do you notice? Explain here:

10. Experiments with additional solar motors

For this experiment 4 additional solar motors SUSE 4.16 are necessary.
The power of the solar cell is with sunlight, lightly clouded sky, or with irradiation with halogen light so big, that in addition to the built-in electric motor it can drive extra electric motors. These can be connected to the solar cell in **parallel or series connection**.

10.1. Parallel connection with max. 4 additional motors M1-M4:

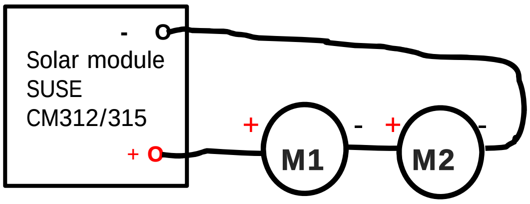
Adjust the solar cell towards the sun or illuminate it with halogen light. Turn the solar motor on. Connect the red jack of the solar module to the red jack of the solar motor and both the black jacks with one lab wire each (red, black respectively). Test the function of both motors! Add another motor by connecting the jack in the red wire to the red jack of the 2nd motor with another red wire and black to black. Test again. Continue the experiment further until 4 additional motors are connected.



Parallel connection of 4 additional motors

10.2 Series connection with max. 4 additional motors M1-M4:

Adjust the solar cell towards the sun or illuminate it with halogen light. Turn the solar motor on. Construct the following circuit:



Test this circuit! If the motors are running, you can complement M3 and M4 in series connection. Test this version also!

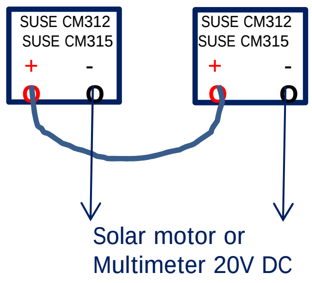
Note your observations and results here, explain the differences of the results between parallel and series connection.

Additional question (sophisticated) using the technical data of the solar cell:
How many motors can you connect in bright sunshine in parallel and series connection, if each motor needs 0.4V/40mA?

11. 7 additional experiments for experiments with SUSE CM312/CM315 to puzzle and quest

11.1 **Wrong series connection of 2 modules CM312/CM315**, tests with solar motor and multimeter
11.2 **4 solar motors SUSE 4.16 with different speeds and rotational direction** on 2 modules CM312/CM315
11.3 Charge your smartphone with current from solar cells
11.4 Connect LEDs to solar modules!
11.5 **Use modules SUSE CM312/CM315** as **solar filling station** for 2 solar electric vehicles SV4 or SV1.2 with race
11.6 **Show your age** (Father, mother, grandma, granddad,...) with 1x SUSE CM312/CM315 and 100 mA-meter analogue or 200mA meter digital.
11.7 **Energy carrier**, carry energy inside to operate an LED in a darkend room with xx modules CM312/315, storage component SUSE 4.12 and LED module SUSE 4.15.

11.1 Wrong series connection of 2 modules CM312/CM315, tests with solar motor and multimeter



2 solar modules SUSE CM312 or CM315 are placed outdoors in the sun or in the classroom ca. 30 cm in front of a halogen spot lamp 120 W (or basic device SUSE 4.0) next to each other, the solar cells pointing towards the lamp. The motors of the two modules are turned on. Both the positive poles are connected, the solar motor or a multimeter in the measurement range 20 V DC it connected to both the negative poles.
Test the outcome of the false series connection and **prepare an explanation**.

Required components: 1x halogen spot lamp 120 W on pedestal or basic device SUSE 4.0 with switchable socket, 2 solar modules SUSE CM312/CM315, 1 solar motor SUSE 4.16, 1 multimeter, 2 lab wires red + black

11.2 Connect 4 solar motors SUSE 4.16 with different speeds and rotational direction to 2 modules SUSE CM312/CM315! The 4 propellers should rotate with different speeds and in different directions! Outdoors experiment in natural daylight or in the lab with halogen spot lamp 120 W.

Required components: 1x halogen spot lamp 120 W on pedestal or basic device SUSE 4.0 with switchable socket, 2 solar modules SUSE CM312/CM315, 4 solar motors SUSE 4.16, 1 multimeter, 10 lab wires, 5x black, 5x red

11.3 Charge your smartphone with solar power!

Smartphones are charged with 5V DC, usually with a USB plug cable.
For this we take the charging module SUSE 4.17, which has 5V DC at a USB jack at the output, at the input we need solar current with a voltage of 8V up to 24V.
Think about how solar modules SUSE CM312/CM315 have to be connected to get 8V. Conduct the experiment! With a multimeter you can measure, if 8V have been reached.
With the USB measurement device you can measure and observe the output voltage of the charging module, the charging current and the energy quantity (in mAh), that is taken up by the smartphone!
You can also use bigger modules (many solar cells in aluminum frame)! Try it!

Required components: Several solar modules SUSE CM312/CM315, 1 multimeter, several lab wires, 1 smartphone charging device SUSE 4.17, solar modules 5W or 10W or 20W from the lab, USB measurement device

11.4 Connect 4 LED modules SUSE 4.15 (red, green, blue, rainbow) to **several solar modules SUSE CM312/CM315** in a way, that they all glow simultaneously!

LEDs need a minimum voltage to glow, this is different for different colors: red ca. 1.6V, green ca. 2V, blue ca. 2.8V, rainbow ca. 3V. Go outdoors with several modules SUSE CM312/CM315 or in front of a halogen lamp in the lab and make the LEDs glow.

Required components: 1x halogen spot lamp 120 W on pedestal or basic device SUSE 4.0 with switchable socket, several solar modules SUSE CM312/CM315, 4 LED modules SUSE 4.15 red+blue+green+rainbow, 1 multimeter, several lab wires

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11.5 2 Solar vehicles SV1.2 or SV4 are charged with **4 solar modules SUSE CM312/CM315** as a solar filling station and drive races.

With the electric energy from solar cells we can charge the 2 electric vehicles SV1.2 or SV4, SV1.2 needs 5.0V max. charging voltage, SV4 2.4V max.

From several solar modules SUSE CM312/CM315 or other modules from the lab, build yourself a solar filling station, charge the vehicles and let them drive! Possibly drive a race with 2 vehicles, that were charged on different solar filling stations!

The experiment can be conducted outdoors or in the lab with halogen light.

Required components: 1x halogen spot lamp 120 W on pedestal or basic device SUSE 4.0 with switchable socket, several solar modules SUSE CM312/CM315, 2 solar vehicles SV1.2 or SV4, 1 multimeter, several lab wires

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11.6 Show your age (father, mother, grandma, granddad...) with 1 solar module SUSE CM312/CM315

The solar module is placed in the classroom in front of a halogen spot lamp 120 W (or basic device SUSE 4.0), the solar cells point towards the lamp. To the red-black jack pair an analogue amperemeter (demonstration device) or a digital amperemeter (measurement range 200 mA) is connected, the solar module is now moved further away, so that the needle shows exactly “100” = age 100 years.

Through smart covering/shadowing of the solar cells by hand the needle amplitude/display can be decreased until the desired age is shown.

Required components: 1x halogen spot lamp 120 W on pedestal or basic device SUSE 4.0 with switchable socket, 1 solar module SUSE CM312/CM315, 1 analogue amperemeter 100 mA (demonstration device) or a digital amperemeter, 2 lab wires

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11.7 Energy carrier: Carry energy inside to operate an LED in a darkened room.

Outdoors, produce electric energy with max. 7 solar modules SUSE CM312/CM315 and fill up a solar storage device SUSE 4.12. Carry the energy in the storage module into the darkened room to operate an LED.

Required components: several solar modules SUSE CM312/CM315 (7 max.), 1 energy storage device SUSE 4.12, 1 LED module SUSE 4.15, multimeter, several lab wires

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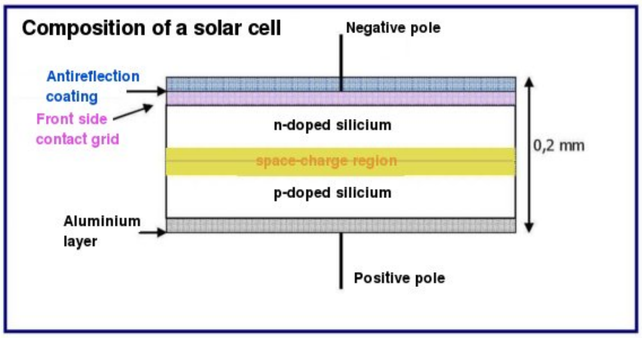
Have fun with the experiments!
Additional experimentation devices are available at NILS-ISFH!
If you have any problems, your NILS-ISFH- tutor or sundidactics- tutor will help you!
Do you have other ideas for experiments? Try them out!

12. Composition and function of a silicon solar cell II from class level 8/9 upwards (ISCED-level 2 and 3)



A solar cell is a large-area silicium semiconductor diode, the **n-doped layer is the surface** of the solar cell, here the light gets in, the blue coloration is due to the **transparent** (!) thin antireflection coating.**The n-doped layer is the negative pole of the solar cell!** The thin silver conductors serve as electrical conductors for the take-up of the current. **The p-doped layer is the lower surface (bottom side) of the solar cell**, normally it is coated razor-thin with aluminium therefor looking grey. Deposited silver conductors serve for the soldering of wires. Here the **positive pole of the solar cell** is located. **The internal photoelectric effect of seperation of charges occurs at the p-n-junction.**

How does a solar cell work? **Level II**

1. Electric voltage U

A solar cell provides a **typical voltage of 0.5 – 0.6 V** in open-curcuit mode (= voltage without a connected consumer load).The exact value of the **open-circuit voltage** depends on the material of the semiconductor, the doping, the temperature, and the irradiance S, but **not on the area**.

The open-circuit voltage does not depend on the area of the solar cell and (over a certain threshold) just slightly on the light's intensity.

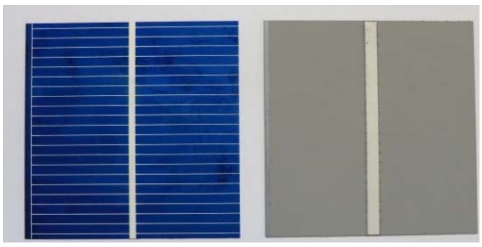
2. Electric current I

The maximum electric current I (= short circuit current) that a solar cell can provide depends on 2 factors:

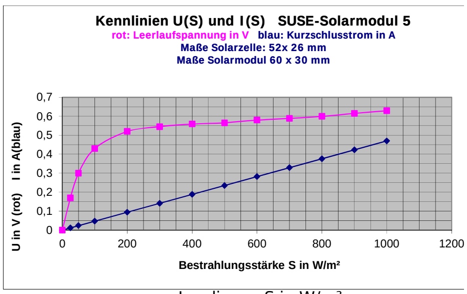
- **Area of the solar cell** : The bigger the area the bigger is I (proportional)!
- **Intensity of the incoming light radiation:** The higher the light's intensity S, the higher is I (proportional)!
- Quality of the solar cell (very good solar cells: I = 30 - 40 mA/cm²!)

The **cause of the current** are the **free electrons generated by incoming light quanta** in the junction layer (p-n-junction) per time unit. Because of the internal electric field they diffuse to the (n-doped) surface of the solar cell and from there they arrive at the (p-doped) lower surface through the external circuit. This process is called **"internal photoelectric effect"**, explained by Einstein 1905.

If current is extracted from the solar cell the voltage U decreases. The exact linkage between voltage and current is shown in the U-I characteristic diagram of a solar cell as explained in the level III file. The **maximum power** is only reached in one certain point, viz. at a certain discrete voltage and current, this point is called **MPP = maximum power point**, important in practice! The **efficiency factor of a solar cell** is about **16-21%**, viz. only 15-20% of the incoming light is transformed into energy, depending on the solar cell type.



The complete technical data of the SUSE solar module are found at www.sundidactics.de



Irradiance S in W/m²

Left-hand side: The U(S)-characterization diagram (red) and the I(S)-characterization diagram (blue) of the SUSE solar cell.. The irradiance S is the light intensity in Watt per m², 0 meaning absolute darkness, 1000 meaning bright sunshine with blue sky in the summer half-year.

Top left: The top side of the SUSE solar cell 52 x 52 mm with a thickness of 0.2 mm. The blue coloration is the (transparent!) antireflection layer, the bright lines (pure silver!) are electrical conductors, the front side contact grid is the negative pole of the solar cell. On the wide line cell connectors or cables can be soldered. Beneath the blue layer the silicium crystals are visible.

Top right: The lower surface of the SUSE solar cell 52 x 52 mm. The grey layer is the metallic back side, pure aluminium, the positive pole of the solar cell. Because aluminium can not be soldered, a silver stripe to solder cell connectors or connection cables is plated.

13. 26 questions on the solar module and the experiments

Easy
Medium
High level

1. What material do solar cells consist of?
2. Which energy conversion takes place in a solar cell?
3. Why are solar cells blue on the front side and gray on the back?
4. What do the many thin lines on the front of the solar cells mean?
5. Where are the electric poles of the solar cell?
6. How big is the electric voltage of a solar cell with an irradiance by sunlight with bright sunshine? ($S = 1000\ W/m^2$)
7. To get a higher voltage, 8 solar cells are connected in series. Draw this connection and state the voltage, if this series connection is illuminated by bright sunshine.
8. How thick is a solar cell (specification in mm and in µm!)?
9. What is meant by "short-circuit current"? Why may a solar cell be short-circuited, but never a rechargeable battery?
10. How can the quality of a solar cell be determined by measurements?
11. How can the light intensity (= irradiance S) be determined with the solar cell of your solar module?
12. With gray, clouded sky you measure a short-circuit current of $I = 50\ mA$ with your solar cell. How big is the light intensity (irradiance) of the daylight?
13. How big is the efficiency factor of a standard solar cell?
14. A big, square 6-inch solar cell (6 inches = 156 mm) has an open circuit voltage of 0.61 V and a short-circuit current of 8.1 A in bright sunshine. Now it is cut by a laser into 9 equal squares with an edge length of 52 mm. How big are the open circuit voltage and the short-circuit current of a small solar cell?
15. A whole school class with 30 students connects their modules in series and places them in the bright sunshine. How big are the voltage and the short-circuit current of the series connection?
16. You want to charge a smartphone with the self-made solar modules. This device needs a charging voltage of 5 V. How do you have to proceed? Draw a circuit diagram and explain!
17. How big are open circuit voltage, short-circuit current and electric power of your solar cell with clouded sky with $S = 500\ W/m^2$?
18. Square solar cells are produced in the dimension of 6 inches. How big is the edge length in mm?
19. 10 solar cells are connected in parallel. What effect does this connection have?
20. Which element is often used for n-type doping, which for p-type doping?
21. A solar cell in a solar module on a roof if covered by a fallen leaf 70%. How does this affect it's voltage/current/power?
22. The solar cell from exercise 21 is connected in series to 35 other solar cells. How does the 70% coverage affect the other cells?
23. On which factors does the value of the short-circuit current of a solar cell depend?
24. On which factors does the open circuit voltage of a solar cell depend?
25. A solar cell (wrapped up in black paper) can also be used as a semiconductor diode: Explain!
26. Explain the two solar cell characteristic curves on p. 13.