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Experimentation instructions manual for the solar module SUSE CM4MBV

10 experiments on 13 pages

Lab wires can be connected to the 3 sockets for measurements and experiments.

Red Socket:	**Positive pole of the solar cell**
Yellow Socket:	**Positive pole of the electric motor**
Black Socket:	**Shared negative pole**

If the connective plug is inserted, the positive poles of the solar cell and the electric motor are connected electrically, with enough light intensity the solar motor is rotating.

If the connective plug is removed, the electric motor and the solar cell are seperated and can be used for different experiments.

At the top of the connective plug there is a test socket, so that measurements are possible with inserted connective plug.

This instructions manual contains 10 experiments. Either all experiments are conducted in this order or single experiments are selected.

Needed additional devices: Overhead projector or halogene spot light as light source, if the experiments are not conducted outside, lab cables and a multimeter. For experiment 10 a storage module SUSE 4.11 is also needed.

The solar cell used in the solar module SUSEmod2 has specified data, with these the light intensity of the irradiating light can be measured in W/m² and the solar module can be calibrated to exactly 1000 W/m².

The Experiments

Experiments 1- 7: The Solar cell as an energy converter from radiation energy to electrical energy and from electrical energy in mechanical energy.

1. The open-circuit voltage U_{oc} of the solar cell

Remove connective plug!

The value should be in the range between 0.55 and 0.61 V, 0.5 – 0.55 V for a cloudy sky, independent from the area! With equal irradiance all solar cells should show approximately the same voltage, the standard test value being 0.6 V. Small differences are due to differences in quality. **The open-circuit voltage depends only on the *light's intensity* and the *material of the solar cell*. Our solar cell' s material is silicon Si.**

> Use a multimeter in the measurement range of **20 V DC** and connect the voltmeter to both poles (red-black) of the illuminated solar cell with lab cables.

U_{oc} = the electrical voltage U of the unloaded solar cell
oc = open circuit **measured in bright sunlight or on the overhead projector**

The measurements:

Location of the measurement	Outside in the sunshine directed to the sun or overhead projector	Outside with sunshine in the shadows	Outside with cloudy sky	In illuminated room on the desk
Open-circuit voltage U in V				
Open-circuit voltage U in V a)Solar cell 50% covered with black cardboard or aluminium foil b) Solar cell covered entirely with plastic pockets		No measurements		
Open-circuit voltage U in V With solar motor **Connective plug inserted**				

What do you notice in the measurements for the open-circuit voltage? Express it here:
For a high-class explanation you can also use the solar cell data on the previous page!

2. The short-circuit current I_{SC} of the solar cell

In contrast to other power sources (battery, power supply) solar cells may be short-circuited, the short-circuit current actually is a very important quantity for solar cells.

For the measurement of the current use a multimeter with a measurement range of 10A DC, that is connected to + and – of the solar cell.
Only for measurements inside use the measurement range of 200 mA or 20 mA !

The value of the short-circuit current is ***directly proportional to the cell area and to the light's intensity***/ irradiance. Standard test value: This solar cell with a cell area of 28.6 cm² should have a current of 0.9 A at a light's intensity of 1000 W/m².

The measurements: Remove connective plug!

Location of the measurement	Outside in the sunshine directed to the sun or overhead projector	Outside with sunshine in the shadows	Outside with cloudy sky	In illuminated room
Short-circuit current **I_{sc} in A** **I_{sc} in mA** (convert)				
Short-circuit current **I_{sc} in A** a)Solar cell 50% covered with black cardboard or aluminium foil b) Solar cell covered entirely with plastic pockets		No measurements		
Connective plug inserted in A				

What do you notice in the current measurements for the short-circuit current? Note your observations/explanations here:

3. The electrical power of the solar cell P_E in W (Watt)

There are no new measurements needed here. Calculation from both of the previously identified values U_{oc} and I_{sc}

simplified approach, P is open-circuit voltage x short-circuit current x 0.8, so P should be about 0.54 W in the ideal case with 1000 W/m² irradiation, if the cell has an area of 28.5 cm² (The factor 0.8 is explained by the characteristics and the MPP of the solar cell).

The measurements:

Location of the measurement	Outside in the sunshine directed to the sun	Outside with sunshine in the shadows	Outside with cloudy sky	In illuminated room
Short-circuit current I_{sc} in A Transfer values				
Voltage U_{oc} in V Transfer values				
Power P $U_{oc} \times I_{sc} \times 0{,}8$ **in W**				
Power P $U_{oc} \times I_{sc} \times 0{,}8$ **in mW**				

4. The quality of the solar cell

That is the current density j in mA/cm²

The current density j indicates how much short-circuit current a 1 cm² big piece of the solar cell produces, the more the better! **Therefor the irradiation must be 1000 W/m²** (international standard value), because with lower irradiation <1000 W/m² the current density j is certainly also lower! So we take the value of the bright sunshine or on the overhead projector.

There are no new measurements needed here. Calculation with both the previously identified values U_{oc} und I_{sc}

That's how we calculate the curret density j:

$$j = \frac{\text{Short-circuit current in mA}}{\text{Cell area in cm}^2} = \ldots\ldots\ldots\ldots \text{ mA/cm}^2$$ **at 1000W/m² irradiation!**

Our solar cell is a square with the side length of 5.2 cm it' s area A is.................cm²

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

The quality of the solar cell is...

Very good – good – medium - bad

Very good: > 34 mA/cm² Good : 28-33 mA/cm² Medium: 24....28 mA/cm²
Bad: < 24 mA/cm²

With an irradiation of 1000W/m² !! Theoretical maximum value: 44 mA/cm²

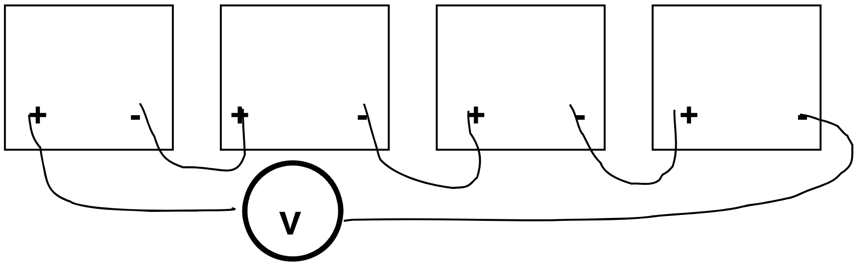
5. Series connection of solar cells

The modules can be connected in series discretionary and reach higher voltages!

Multiple modules in series connection:

Place the modules in the sunlight or (with the upside down!) on a overhead projector and connect the modules in series (as shown in the graph below). 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!

Module 1 Module 2 Module 3 Module 4 Series connection of



Individual module:	U_{oc} in V	I_{sc} in A
Module 1:...........	....	....
Module 2:...........	....	....
Module 3:...........	....	....
Module 4:...........	....	....

Complement the table downwards, if you connect more than 4 modules in series

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

$U_{overall}$=.............................V

I_{SC} =...............................A

What stands out? Describe and explain!

Explanation in terms of series connection:

Establish a series connection consisting of 6 solar modules and connect it to A) a Solar Radio SUSE 4.36 and B) an LED module SUSE 4.15, test the function of the radio/the LED module a) outside b) on the overhead projector, c) in front of a halogen spot light, d) in an illuminated room. Write down your results here:

6. Determination of the efficiency factor of a solar cell

Example: Overhead projector or sunlight with the irradiation of 1000 W/m²

1. Convertion of the light power 1000 W/m² or 0.1W/cm² to the real area of the solar cell: **The cell has an area of 27.04 cm², at 1000 W/m² it receives a light power of 27.04 cm² x 0.1 W/cm² = P = 2.704 W.**

2. The electrical power from exercise 3 was **P_E = 0.432 W** for the measured cell

3. Efficiency factor= electrical power: light power x 100 = Efficiency factor in %

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

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

Efficiency factors of solar cells:

Monocrystalline cells: 15- 21 %

Polycrystalline cells: 12 – 20 %

Experimental exercise:

Determine the efficiency factor of the solar cell of the module with an irradiation with a halogen spot light 120-150 W, distance about 30 cm. The light's intensity (irradiance) of the light is <1000 W/m² and is determined with the equation from experiment 7.

Method:

1. Measurement of the open circuit voltage U_{oc} ad the short-circuit current I_{sc} :

   U_{oc} = ...V I_{sc} = ...A

2. Using the equation P = U_{oc} x I_{sc} x 0.8 the electrical power P of the solar cell is determined:

   P_E = ...*....................*0,8 = ...W (I)

   U_{oc} I_{sc}

3. Using the equation from exp. 7 the irradiance of the light in W/m² is determinded:

   $$S_x = \frac{I_{mes}\text{ (in A)} * 1000}{0{,}9\text{ A}}$$

   S_x = ...W/m²

   Here I_{mes} is the short-circuit current measured in bei 1.)

   S_x is the irradiance of the light in W/m²

   S_x is the light power per 1 m², given that the area of the solar cell is just 27.04 cm² we have to calculate the amout for our solar cell by dividing the value by 10 000 (because 1 m² has 10 000 cm²) and then multipling with 27.04, that is the real light power P_L onto the solar cell:

   P_L = ... * $\frac{27{,}04}{10\ 000}$ .... =................................W (II)

   S_x

We obtain the efficiency factor by dividing the electrical power P_E by the light power and multipling the value with 100 to obtain a percentaged value:

$$\text{Efficiency factor } \eta = \text{----------} * 100 = \frac{P_E}{P_L} * 100 = \ldots\ldots\ldots\ldots\ldots\%$$

If the measurements/calculations are done correctly the efficiency factor should be near 16 %.

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

The brightness (intensity) of the light is called irradiance S and is measured in W/m² (Watt per m²).
With the calibrated solar cell used here the **light intensity in W/m²** in front of a halogen spot light or on an overhead projector or outside can be determined exactly.

1000 W/m² is the intensity of the light radiation of the sun beneath a cloudless sky in the summer and it is an international standard value for solar cells.

Short-circuit current I_{scc} of the solar cell at an irradiance of 1000 W/m²

I_{SCC} = ...0.9...................A = ...900...............mA

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

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

$$\frac{I_{scc} \text{ in A}}{1000 \text{ W/m}^2} = \frac{I_{mes} \text{ in A}}{S_x \text{ in W/m}^2} \quad \text{or reorganized to } S_x: \quad S_x = \frac{I_{mes} \text{ (in A)} * 1000}{0.9 \text{ A}}$$

Where:	I_{scc}	in A	the calibrated short-circuit current at 1000 W/m² **= 0.9 A**
	I_{mess}	in A	the measured short-circuit current at the irradiance S_x
	S_x	in W/m²	the irradiance of light radiation

Measurements outdoors and in front of light sources:

Light radiation	**Short-circuit current I_{sc} in A**	**Irradiance S_x in W/m²**
Bright sunshine measured directly facing the sun		
Bright sunshine measured in the shadows		
Cloudy sky		

Very dull weather		
On the plate of an overhead projector		
10 cm **above the plate** of an overhead projector		
40 cm ahead of a halogen lamp 35 W (Spot light SUSE 5.16)		
40 cm ahead of halogen spot light 150 W		
Inside of a room facing a window		

What do you notice? Explain here:

Experiments 8-10: Energy conversions from electrical energy to mechanical energy and vice versa. Storage of electrical energy (Exp. 10).

8. Experiments with the solar motor I

You need 4 solar modules SUSE CM4MBV for these experiments!

Experiment 8.1:

Keep the connective plug inserted in one device (device 1) and remove the connective plug from the 3 other devices. You also need 3 red and 3 black lab cables.

Go outside with the devices or experiment inside on an overhead projector or in front of a halogen spot light. **Irradiate the device No. 1 with light** and additionally **connect a 2nd motor** to it (black socket of device 2 on black socket of device 1, yellow socket of device 2 on the socket in the connective plug in device 1)!

What do you notice? Write it down here:

Now add a third motor by connecting it to the second motor with lab cables, yellow socket gets connected with yellow socket, black socket with black socket.

What do you notice? Write it down here:

Now add a fourth motor by connecting it to motor 3 with lab cables.

What do you notice? Write it down here:

xperiment 8.2

You need 4 devices SUSE CM4MBV here as well, remove the conective plug for all 4 devices!

Establish a series connection with 2 solar modules and connect the positive pole of one solar cell and the negative pole of the second solar cell to the solar motor of the third module:

What do you notice? Write it down here:

Now establish a series connection with 4 solar modules and connect the positive pole of the first solar cell and the negative pole of the 4th solar cell to a solar motor.

What do you notice? Write it down here, explain the observations of these experiments:

9. Experiments with the solar motor II

The little electric motor can also be used as a generator. Then it produces electric energy through rotation. If we blow into the blue propeller it rotates the motor thereby producing electrical energy. We can conduct two experiments with that:

Experiment 9.1

Remove the connective plug and connect a voltmeter with the measurement range of 20 V DC to the contacts of the solar motor (yellow and black socket).
Not strongly blow into the blue propeller and meter the produced voltage U, conduct the experiment 3 times and blow harder every time:

Experiment No.	Achieved voltage U in V
1 blew weakly	

2 blew strongly	
3 blew very strongly	

Experiment 9.2

Connect 2 solar motors with two lab cables to each other, yellow socket with yellow socket and black socket with black socket.
Now blow strongly into the propeller of the first motor and observe the second motor.
Now blow strongly into the propeller of the second motor and observe the first motor.

What do you observe in the Experiments 9.1 and 9.2, which energy conversions take place here? Explain here:

10. Experiments with the solar motor and a storage module

The storage module SUSE 4.11 or 4.12 can store electrical energy that is produced by the solar cell or by the generator (motor used as generator).

10.1 Storage of the electrical energy of a solar cell

Remove the connective plug!

With two lab cables connect the positive and the negative pole of the solar cell (red-black socket pair) with the right polarity (red to red, black to black) to the solar storage unit SUSE 4.11 or 4.12 and charge the storage unit by irradiating the solar cell with light, either with natural sunlight or with irradiaton by a halogen lamp. The charging time should represent about 5 minutes.
Now remove the lab cable from the positive pole (red) of the solar cell and connect it to the positive pole of the motor (yellow socket).

What do you observe? Explain and discuss here:

10.2 Consolidation of 10.1

Conduct the experiment in exactly the same way, but connect a voltmeter in the measurement range of 20 V DC to the socket pair of the solar storage unit SUSE 4.11. With a stop watch determine the voltage U in the very moment of the connection between the storage unit and the solar motor and write down the values into the table:

Time in min	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
U in V																

Was do you observe? Evaluate the table, explain here:

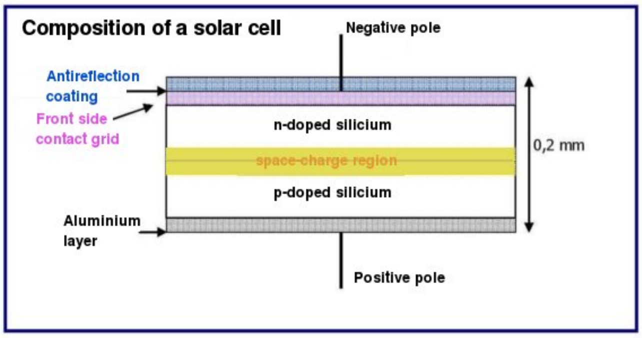
10.3 Charging the storage unit with the solar motor

Connect the black and yellow socket pair of the solar motor to the solar storage unit. Because of the inversion of the poles in the generator mode of the motor the yellow pole of the solar motor must be connected to the black negative pole of the storage unit, the black pole of the solar motor to the red positive pole of the storage unit.
Now blog strongly into the propeller for about one minute and observe the effect afterwards:

What do you observe? Explain and evaluate here:

You also may connect a voltmeter like in 10.2 and measure the voltage and observe the development.

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

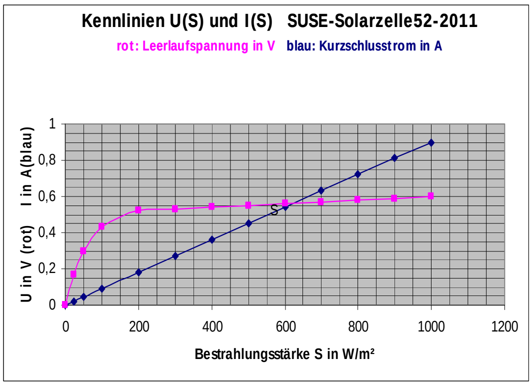
A solar cell provides a **typical voltage of 0.5 – 0.6 V** in open-curcuit mode (= voltage without a connected consumer load).The exact value of the **open-circuit voltage** depends on the material of the semiconductor, the doping, the temperature, and the irradiance S, but **not on the area**.
The open-circuit 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 **15-20%**, viz. only 15-20% of the incoming light is transformed into energy, depending on the solar cell type.



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.