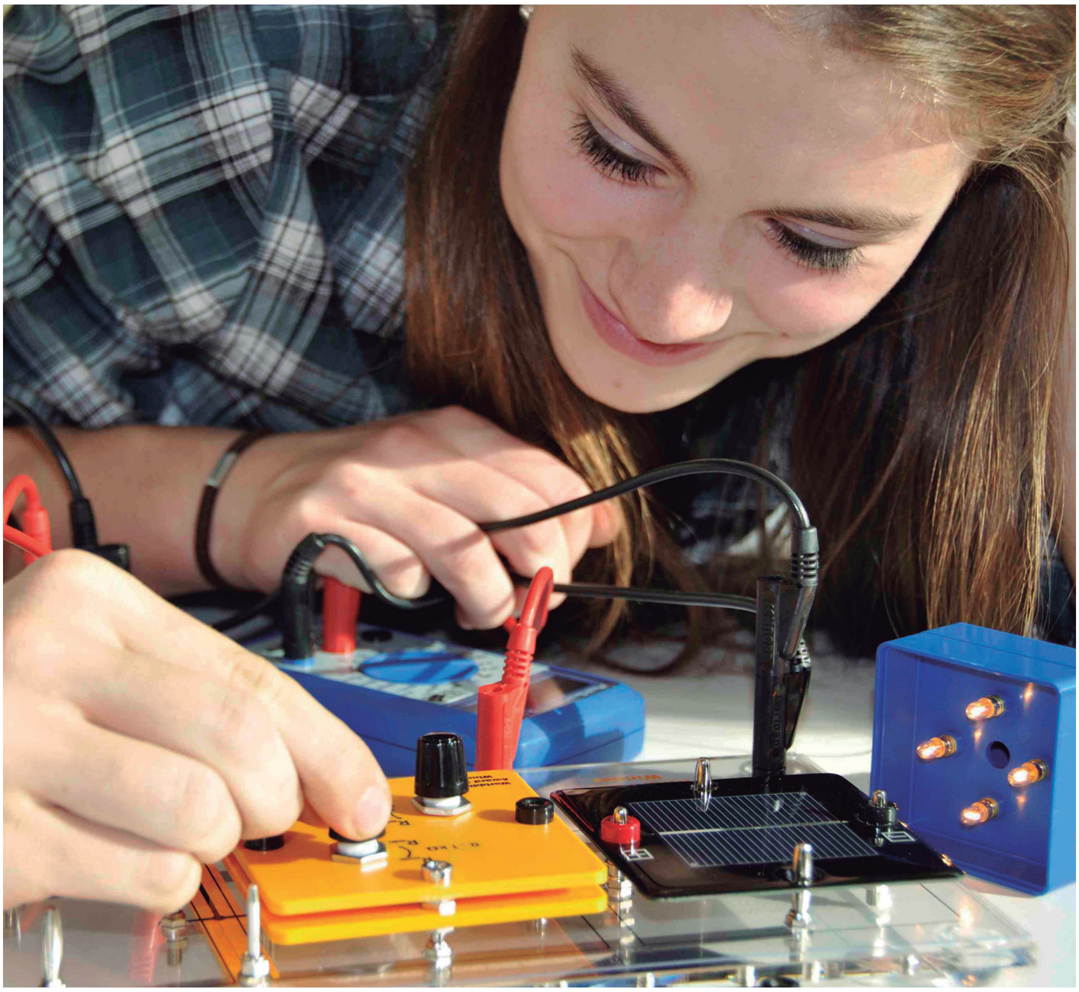
leXsolar-PV Large



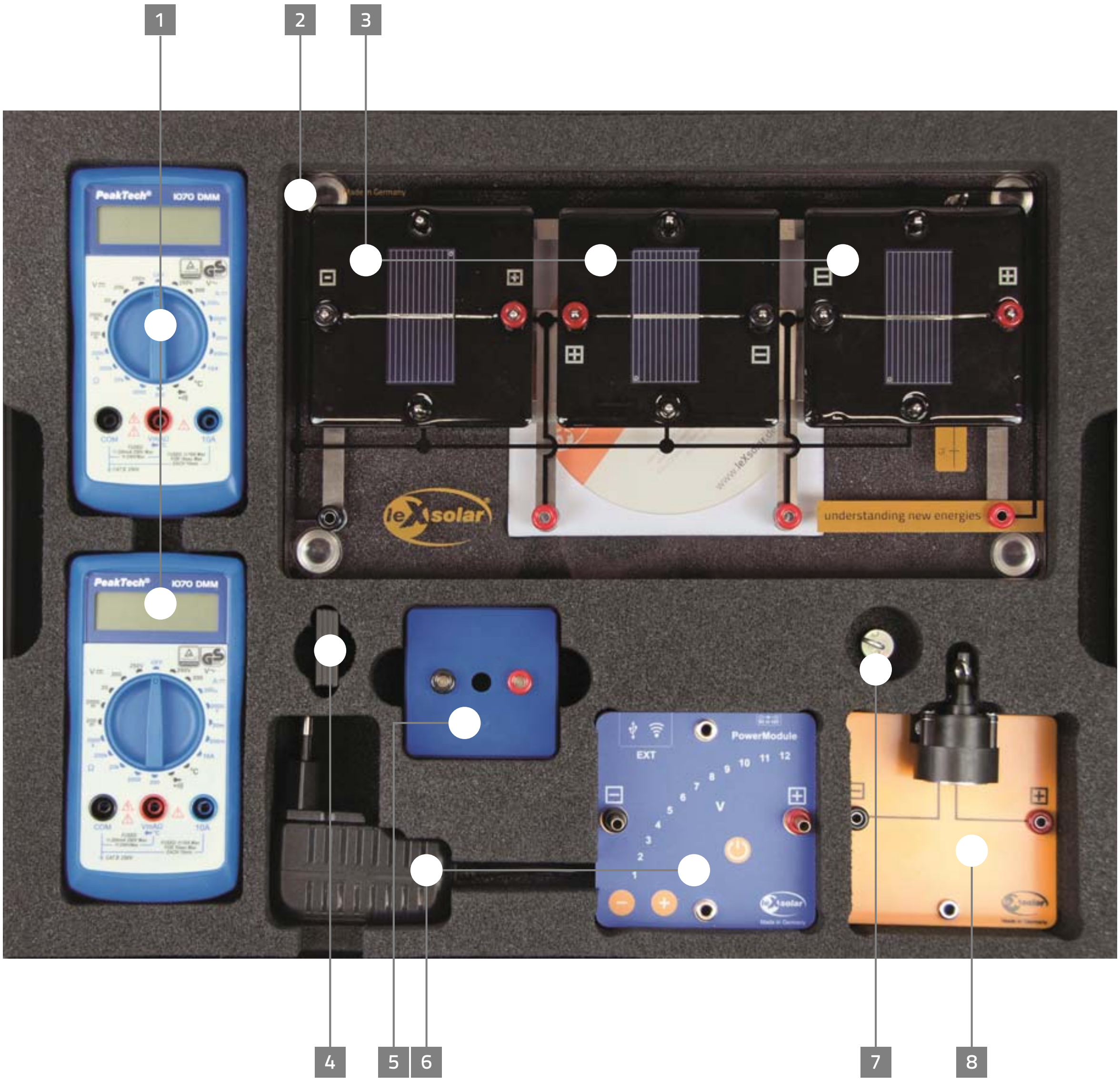
Teacher's Manual

Layout diagram leXsolar-PV Ready-to-go

Item-No.1105

Bestückungsplan leXsolar-PV Ready-to-go

Art.-Nr.1105



1	2xL2-06-011 Digital multimeter 2xL2-06-011 Digitalmultimeter
2	1100-19 leXsolar-Base unit 1100-19 leXsolar Grundeinheit groß
3	3x1100-01 Solar module 0.5 V, 420 mA 3x1100-01 Solarmodul 0.5 V, 420 mA
4	1100-29 Solar cell cover set 1100-29 Satz Abdeckung f. Solarzelle
5	1100-20 Lighting module 1100-20 Beleuchtungsmodul
6	9105-05 PowerModul with power supply 9105-05 PowerModul mit Stromversorgungsgerät
7	L2-05-024 Hook weight 20g L2-05-024 Hakengewicht 20g
8	1100-24 Gear motor module 1100-24 Getriebemotormodul

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Versionsnummer

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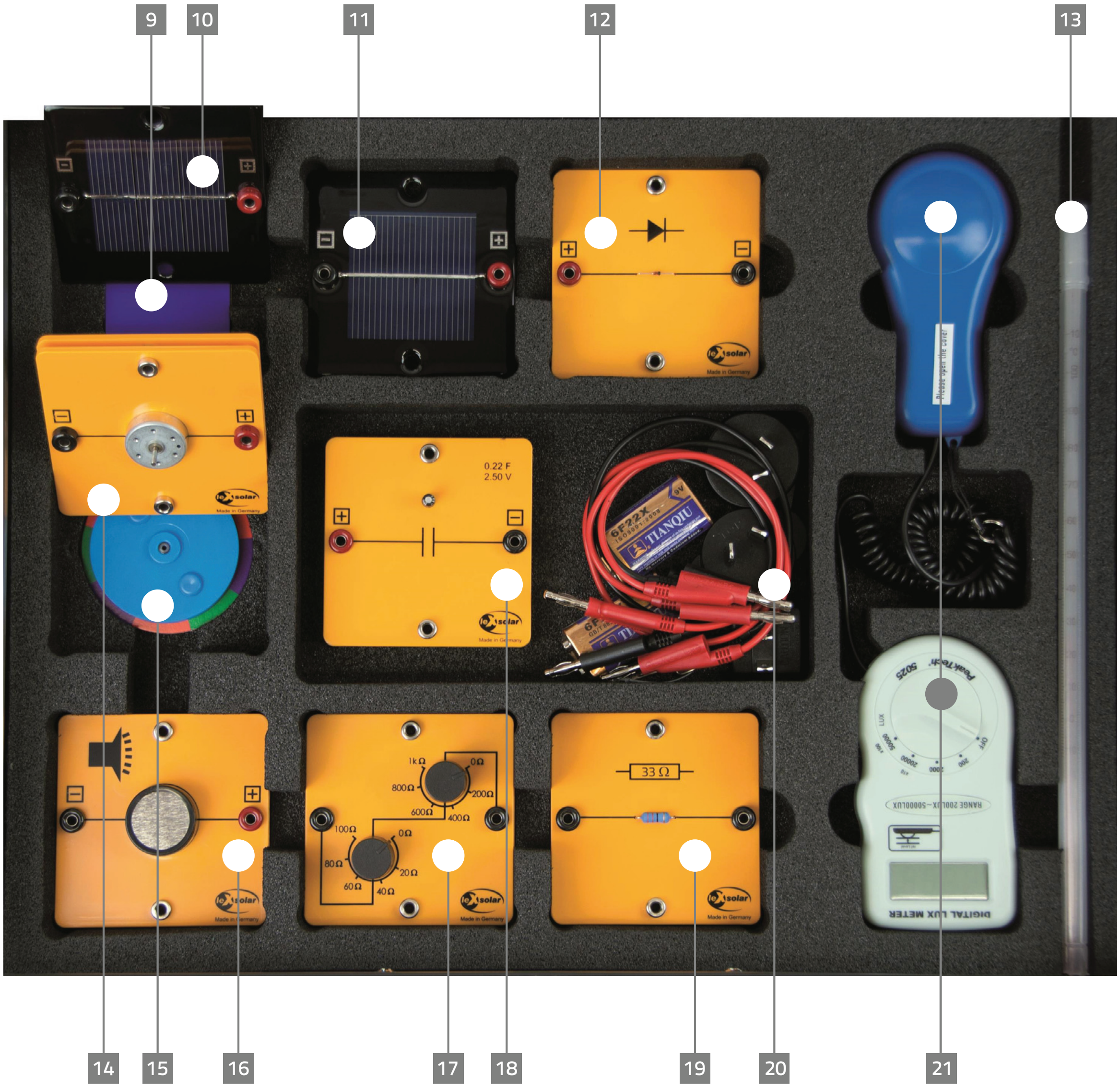

9	1100-30 Color filters 1100-30 Satz Farbfilter
10	1100-02 Solar module 1.5 V, 280 mA 1100-02 Solarmodul 1.5 V, 280 mA
11	1100-07 Solar module 0.5 V, 840 mA 1100-07 Solarmodul 0.5 V, 840 mA
12	1100-21 Diode module 1100-21 Diodenmodul
13	L2-06-016 Laboratory thermometer L2-06-016 Laborthermometer
14	1100-27 Motor module 1100-27 Motormodul
15	1100-28 Color discs with mount-Set I 1100-28 Farbscheiben-Set I
16	1100-25 Buzzer module 1100-25 Hupenmodul
17	1100-23 Potentiometer module 1100-23 Potentiometermodul
18	1400-07 Capacitor module 220 mF, 2.5 V 1400-07 Kondensatormodul 220 mF, 2.5 V
19	1100-22 Resistor module 1100-22 Widerstandsmodul
20	L2-06-012 Test lead 25 cm, black L2-06-012 Messleitung 25 cm, schwarz L2-06-013 Test lead 25 cm, red L2-06-013 Messleitung 25 cm, rot 2xL2-06-014 Test lead 50 cm, black 2xL2-06-014 Messleitung 50 cm, schwarz 2xL2-06-015 Test lead 50 cm, red 2xL2-06-015 Messleitung 50 cm, rot
21	L2-06-034 Luxmeter L2-06-034 Luxmeter

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Contents

2 Introduction

2.1 What is photovoltaics?

Photovoltaics (PV) is the *direct* conversion of light into electrical energy using solar cells (also called photovoltaic cells). By using sunlight it is a renewable energy source, by definition.
The emphasis is on *direct*, here, because all other renewable energies need at least one detour to generate electric power. This detour is a turbine with a generator in the case of heat energy as energy source (solar thermal, geothermic and biomass energy). In the case of kinetic energy as energy source (wind, hydro and tidal energy) at least a generator is necessary. Photovoltaics however does not need any of these appliances with moving parts. Hence it is low-maintenance and long-living. Due to this exceptional position there are high expectations of the future role of photovoltaics.

2.2 Photovoltaics in the spectrum of renewables

In principle only three of earth's energy sources can be considered as unlimited on the human time-scale. Those three establish a basis for all renewable energies. Though the denotation as renewable or regenerative energies is in fact wrong from the physical point of view, it is used widely.

Figure 2.1 shows the three energy sources (solar power, geothermic energy and rotational energy of the earth) and the forms of renewable energies which are supplied by them, respectively. The relation between the different forms of absorption, reflexion and utilization of solar energy is depicted in
Figure 2.2. It is quite obvious that the energy conversion used by humanity is negligible compared to the total solar irradiation reaching earth. Hence, photovoltaics offers a nearly inexhaustible potential for human power supplies.

2.3 Costs

Nowadays the biggest problem of photovoltaics is the relatively high costs. A kilowatt hour (kWh) electricity generated by a photovoltaic power plant today (2008) costs 0.20 … 0.50€ depending on the plant's location. Believable studies anticipate a price of about 0.10€ in 2030. The main reason for this cost reduction is the so called economy of scales. The higher the quantity of produced goods the cheaper it becomes because of the development of production processes.

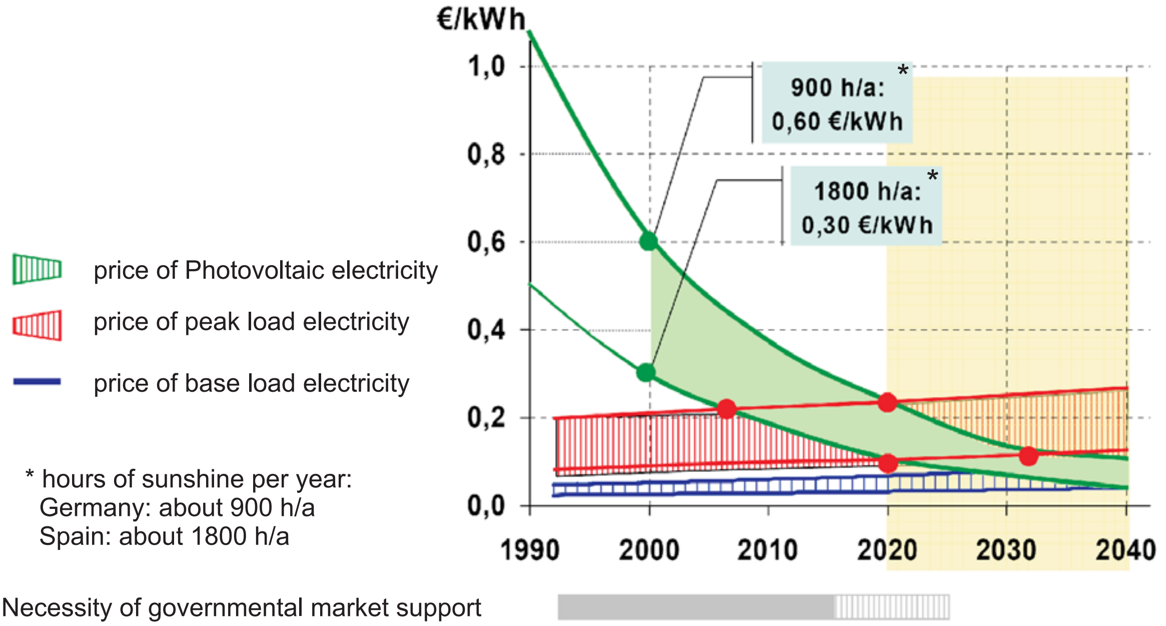

Figure 2.3: Estimated cost trend of electricity generated from photovoltaics compared to electricity from non-renewable energy sources. Source: SCHOTT-Solar

Figure 2.3 shows the costs for electricity generated from photovoltaics at two locations with different solar illumination. In order to compare different locations one defines the so-called peak-load-hours. This value corresponds to the time by which the sun would have to illuminate a defined area with maximum power (1000W/cm²) in order to transmit the same total energy as reaches the surface of the location during a whole year.
In Germany this value is between 900h and 1200h. However, for Spain it is 1800h and for the so-called sunbelt, the deserts of the northern hemisphere, it reaches 2000h. Consequently in sunny regions it is possible to generate more than twice the power per year than Germany using the same photovoltaic power plant. The expenses for power generated by photovoltaics are therefore only half as much as in Germany. This fact is reflected by Figure 2.3, as well.
The costs of electricity from PV power plants in Spain will, according to the forecast of Fig 2.3, reach the costs of conventional base load electricity before 2030. In Germany this is expected not before 2040. However, the price of conventional peak load electricity will be reached much earlier which would make governmental market support unnecessary.

2.4 Efficiency

Often also the power conversion efficiency (PCE) of solar cells is called a problem. At the moment it is typically 14 … 17%. As described below (Chapters 4 and 5) the efficiency of solar cells is limited by physical reasons. Hence there will be no solar cell on the market with efficiencies of more than 25% in 2030.
But the quantity of solar irradiation theoretically allows the complete coverage of mankind's power requirement by photovoltaic technology also with nowadays efficiencies. Solar irradiation exceeds the requirement by a factor of at least 10.000. Because economic efficiency is a

result of costs *and* power conversion efficiency, PCE it not a big problem of photovoltaic technology at all.

2.5 Applications

Photovoltaics can either be used for feed-in public network or supplying isolated applications or buildings far away from public network. When using photovoltaics for feed-in an inverter is necessary besides the solar module to change from direct current (DC) to alternating current (AC) used by the network. Currently photovoltaics' contribution to the overall electric power requirement is very low. In Germany it is 1.6% (2006). This percentage is generated by large-scale photovoltaic power plants with wattages of some Megawatt (MW) one the one hand and by small solar plants on top of private roofs with wattages of 1 … 10 kW on the other hand. At the moment photovoltaics is only competitive due to government aid in terms of the Renewable Energy Sources Acts. These laws were enacted in many European countries in the last years starting in Germany in 2000.
Nevertheless photovoltaics is competitive for supplying isolated applications already today. For isolated applications or buildings whose connection to public network would be to expensive, photovoltaics in combination with suitable storage solutions like accumulators and other energy sources like wind power can assure power supply.
Well-known and widely-used isolated solutions with solar cells are calculators or wrist-watches.

2.6 Questions

Which device is necessary to convert wind power into electric power?
Which devices are necessary to convert heat energy (e.g. solar thermal energy) into electric power?
What is the big advantage of photovoltaics concerning electricity generation compared to all other renewables?
Which application for solar cells do you know?

6 Experiments leXsolar-PV Medium

General information

The following experiments are devided into the parts electricity and optics. Their sequence and numbering in the student's booklet ant this teacher's booklet are identical. Most of the basic experiments intentionally dispense with measuring devices (like, e.g., multimeters) and focus on a qualitative understanding of the observations. That proves to be a good way to introduce the principles of scientific working to younger students. That is also why no or only elementary knowledge of the respective topics is required.
Based on those simple experiments some of the results are analysed quantitatively in continuative experiments. They address older students since now the use of measuring devices and some basic knowledge about the underlying physical processes are needed.
Primarily it is the goal to make the students familiar with the elementary circuits (series and parallel connection) and some important devices. Of course a basic understanding of the photovoltaics technology is to be gained, as well. On the other hand the performance of solar cells under different illumination conditions is to be examined. Furthermore it is possible to explain optical illusions and coloured mixtures with the help of coloured discs.

Preparation: What is photovoltaics?

In order to motivate the class for the topic photovoltaics it is useful to discuss the term in a discussion. Certainly the students have seen solar cells before and have heared about them from their parents or the news. Now we want to collect this knowledge.

1. What are the advantages and disadvantages of solar energy?

Advantages	Disadvantages
no emission of exhaust gases	expensive production
no noise disturbance	comparatively low efficiency (→ needs very large areas)
long lifetimes	dependent on illumination intensity (low yield in winter and no operation during the night)
production from common chem. elements	toxic substances are used for manufracturing in low quantities
regenerative (preserves natural resources)	
low maintenance and operating costs	

2. Where is it possible to use solar plants?
   Solar plants are used as so called off-grid systems in remote areas in order to allow self-supply with electrical power in satellites, pocket calculators, watches, solar cars etc.

6.1 Series and parallel connection of solar cells

6.1.1 Series and parallel connection of solar cells (phenomenological) (M1.1)

Experiment

The leXsolar horn module is connected with one, two or three solar cells either in series or in a parallel connection. Depending on the number of solar cells in the circuit and on the wiring noises of different volume are to be expected. During the whole experiment the illumination intensity should not change.

Evaluation

Even at ideal illumination at least two serial connected solar cells are needed to produce a sound. The more serial connected solar cells drive the horn, the louder and faster the sound. In contrast the horn is silent using a parallel connection – no matter how many solar cells are used. In a parallel connection the total voltage corresponds to the voltage of a single solar cell which is not sufficient to drive the horn.

Explanation

The horn needs a minimum voltage of 0.8V to work. However, even under an ideal illumination a silicon solar cell generates only about 0.6V. Since in a series connection the voltages add, there are at least two solar cells needed to reach the threshold voltage. In a parallel connection the voltage is constant, i.e. independent on the number of solar cells in the circuit. The threshold voltage cannot be reached and the horn is not activated. The illumination during the experiment is only secondary because the leXsolar horn module nees currents as low as 1mA to work properly.

6.1.2 Series and parallel connection of solar cells (quantitative) (M1.2)

This experiment is identical to experiment L1 of the Large Experiments. Execution and Evaluation are described in chapter 7.1.

6.2 Dependence of the power of the solar cell on its area (M2)

This experiment is identical to experiment L2 of the Large Experiments. Execution and Evaluation are described in chapter 7.2.

6.3 Dependence of the power on the angle of incidence of the light (M3)

This experiment is identical to experiment L3 of the Large Experiments. Execution and Evaluation are described in chapter 7.3.

6.4 Dependence of the open-circuit voltage on the temperature

This experiment is identical to experiment L9 of the Large Experiments. Execution and Evaluation are described in chapter 7.9.

6.5 Dependence of the power of the solar cell on the illumination intensity (M5)

This experiment is identical to experiment L4 of the Large Experiments. Execution and Evaluation are described in chapter 7.4

6.6 Shading of solar cells (M6)

6.6.1 Shading of solar cells in a series connection (phenomenological) (M6.1)

Experiment

First a series connection of a horn and two solar cells is to be set up. The reaction of the horn is to be written down. This first circuit 1 acts as a reference for further comparative measurements with the horn in circuit 2. Here three solar cells are connected in series and act as power supply. One of them is, however, covered with the blue covers.

Evaluation

As already observed in experiment 2 the horn will make a noticable sound when connected with 2 solar cells. If adding a third solar cell and shading it, the students will not expect a change, at first, since the illuminated solar cell area does not change. But this assumption is wrong, because the shaded solar cell acts as a resistance. The horn will not be audible anymore.

Explanation

A shaded solar cell does not bridge the circuit, but acts as an infinitly high resistance. There is now or only a evanescently low current flow through the horn module which is not sufficient to generate a sound. This is caused by the so called *diode character* of the solar cell which can be explained microscopically with the structure of the doped semiconducting layers. Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.** gives a quantitative explanation of this behaviour.

Application

The solar cells in big solar modules are usually connected in series. Shading (e.g. due to the fall of leaves in autumn) imposes the danger of a partial breakdown of the system. This danger is eliminated by bridging each cell or a string of cells with a semiconductor diode – a so called bypass diode. The current generated in the uncovered cells is now not blocked by the shaded cells but rather takes the way with the lowest resistance over the bypass diode.

6.6.2 Shading of solar cells in a series connection (quantitative, bypass diode) (M6.2)

This experiment is identical to experiment L10.1 of the Large Experiments. Execution and Evaluation are described in chapter 7.10.1

6.6.3 Shading of parallel-connected solar cells (M6.3)

This experiment is identical to experiment L10.2 of the Large Experiments. Execution and Evaluation are described in chapter 7.10.2.

6.7 Diode character of solar cells (M7)

6.7.1 Diode character of solar cells 1: I-V characteristics under dark conditions (M7.1)

This experiment is identical to experiment L7.1 of the Large Experiments. Execution and Evaluation are described in chapter 7.7.1.

6.7.2 Diode character of solar cells 2: Reverse and forward biasing in the dark and under illumination (M7.2)

This experiment is identical to experiment L7.2 of the Large Experiments. Execution and Evaluation are described in chapter 7.7.2

6.8 I-V characteristics (M8)

6.8.1 I-V characteristics and filling factor of the solar cell (M8.1)

This experiment is identical to experiment L8.1 of the Large Experiments. Execution and Evaluation are described in chapter 7.8.1

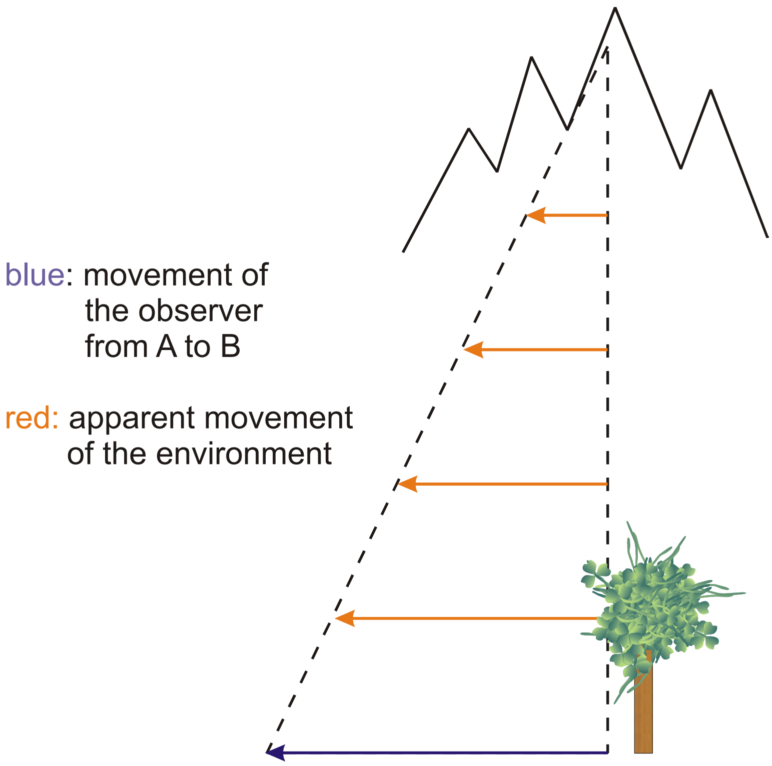

Figure 6.8: Objects which are far away move more slowly than objects which are close by.

6.12 Centrifugal force (M12)

Experiment

This experiment is rather assigned to mechanics than to optics, but is usually very popular amongst the students. In addition to the constituent parts available from leXsolar experiment some further materials are needed which should be prepared prior to the experiment.
We suggest using a wooden ball as weight, but it is also possible to use, e.g., a clew of aluminum foil. At first the preparation of the experiment requires some handicrafts for the students. The toothpick has to be prepared as follows: Remove the ends at both sides using scissors. Now a groove is carved into one of the ends in order to facilitate the fastening of the string. The other end has to be plugged into the middle of the rotating disk. In order to make this possible the disk must only stick slightly on the motor, so that both, the axle of the motor and the toothpick fit into the hole.
A series connection between the motor and two small solar cells should be sufficient to turn the "carrousel". When starting the motor it is favourable to uphold the string in order to avoid the wraping of the string around the toothpick at slow rotational speeds.

Evaluation

This experiment imparts a descriptive picture of the inertia to the students. After initiating the rotation the wooden ball turns just like the gondola of a chairoplane: the faster the motor rotates, the higher rises the ball. When breaking the circuit the rotation of the motor slows down untill it finally stops. The height of the ball decreases in the same degree. However, when suddenly stopping the disk at its full speed, the ball keeps turning and wraps around the toothpick.

Explanation

The so called centrifugal force is responisble for the raising of the wooden ball in the first place. The faster the motor turns, the higher is the centrifugal force. After the circuit is broken the speed of the motor decreases, and the height of the ball decreases on this account, as well. When suddenly stopping the disk, the ball keeps turnig due to its inertia.

7 Experiments leXsolar-PV Large

General information

The following experiments are hierarchized according to their level of difficulty. The order is not conform to the complexity of the execution, but the explanation of the observed effects. Sequence and numbering in student's and teacher's booklet are identical. It can not be avoided that some of the additional experiments belonging to easy experiments refer to experiments which are explained later on. However, when working through the whole chapter those interrelations will become clear.

The graphs given in the comments on the experiments were all measured with leXsolar experiment. Due to different room illuminations it is possible to have quantitative differences to your own results. So the given diagrams are only meant as qualitative clue. The explanations and evaluations of the experiments will, ouf course, give detailed answers to all questions asked for in the student's booklet. However reading only the instruction to the experiments is not a prerequisite for understanding this chapter.

In most experiments the dependence of the power of the solar cell on a certain physical quantity is to be analysed. Hereby it is usually sufficient to measure only the short circuit current I_{sc} instead of the power P. Since the open circuit voltage of the solar cell is constant over a wide range of illumination intensites, this simplification is tolerable. However, it is necessary to explain this fact to the students very carefully prior to the experiment. For some other experiments the power has to be explicitly calculated from $P = V_{oc} \cdot I_{sc}$. This power represents a maximum which can not be reached in reality. In order to achieve the comparability of different measurements the use of this theoretical quantity is justified.

7.1 Series and parallel connection of solar cells (L1)

Notice: This experiment is identical to experiment 1.3 (M) of the Experiments Medium.

Experiment

This experiment eludicates the quantitative behaviour of amperage and voltage at series or parallel connection. Therefore several solar cells are to be plugged on the main board either in series or parallel connection. In each case voltage and current are to be measured subsequently.

Evaluation and explanation

A series or parallel connection of solar cells commensurates mainly with a series or parallel connection of power supply units (e.g. batteries) and has therefore the same result. In case of a series connection the voltages of the single cells are added whereas the amperage in the whole circuit does not change; in case of a parallel connection the single amperages are added and the voltage remains constant:

	series connection	parallel connection
voltage	$V_{tot}=V_1+V_2+\ldots$	$V_{tot}=V_1=V_2=\ldots$
amperage	$I_{tot}=I_1+I_2+\ldots$	$I_{tot}=I_1+I_2+\ldots$

The total amperage at non-uniform illumination of the solar cells equals the amperage of the weakest solar cell. Such variations can be due to qualitative differences between nominally equal solar cells.

Application: connection of solar cells to solar modules

The present-day technology allows only for the production of solar cells with a limited area. In today’s mass production crystalline silicon solar cells are usually manufactured with an area of 12x12cm². The voltage of such a cell is limited to 0.6 V (see chapter 5). These low voltages are hardly useful for technical applications. Therefore several solar cells are connected together to units, so-called modules. In most cases commercially available modules feature nominal voltage in the range of 12…48 V.

7.2 Dependence of the power of the solar cell on its area (L2)

Notice: This experiment is identical to experiment 5 (M) of the Experiments Medium.

Experiment

The student measures the short-circuit current of the large solar cell against the active area. For this purpose a quarter, half and three quarter of the cell surface are covered with the blue plastic cover plates one after another.
As already mentioned the amperage follows the same behaviour as the power; therefore a voltage measurement is not necessary.

Evaluation

The measurements reveal proportionality between power and solar cell surface (Figure 7.1). A voltage measurement with a high-resistive measuring device would result in the conclusion that this proportion remains almost constant for all three different areas, because it shows a logarithmic dependence on the total power irradiated.

15%. According to the measurement the efficiency of the motor-transmission arrangement is about 10%. Therefore the calculation of the overall efficiency according to

$$\eta_{ges} = \eta_1 \cdot \eta_2 \cdot \ldots \eta_n$$

results in 0,03%.

7.6 Internal resistance of the solar cell

7.6.1 Dependence of the internal resistance of the solar cell on the illumination intensity (L6.1)

Experiment

In this experiment the solar cell works as power source with an internal resistance. In order to analyze this property a solar cell (having a defined open circuit voltage V_{oc} as well as an internal resistance R_i) and a constant load resistance (over which terminal voltage $V_{terminal}$ is dropping) are connected in series. Since there is also a voltage drop at the internal resistance $V_{Ri} = I \cdot R_i$, the two above mentioned voltages deviate from each other.

Now terminal voltage, open circuit voltage and the respective current are to be measured depending on the illumination intensity which can be changed as already described in experiment 7.4. It is recommended to measure the open circuit voltage first and then to close the circuit in order to do the remaining measurements.

The voltage applied at the illumination module should not exceed 6V because at very high illumination intensities the internal resistance is negligibly low and therefore terminal voltage and open circuit voltage do not differ considerably much.

Evaluation

It is possible to draw the following equivalent circuit:

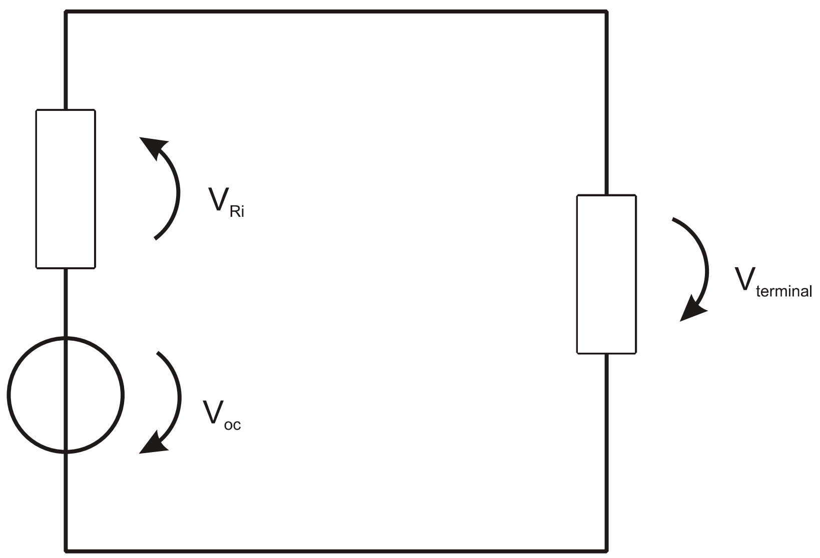

Figure 7.10: Equivalent circuit for a solar cell with internal resistance.

According to the mesh rule the terminal voltage is calculated by $V_{terminal} = V_{oc} - IR_i$. The internal resistance can be derived easily by rearranging the equation and can than be plotted against the respective amount of lamps n. This results in a non-linear correlation. At first the internal resistance drops quickly and asymptotically approaches zero at higher illimuniation intensities (see Figure 7.11).

The relation between illuminantion intensity and internal resistance was already examined in experiment 7.4.2. Because the voltage is approximately constant for varying illumination intensity, it is the variable internal resistance which forces the current to follow a saturation curve. As soon as the internal resistance of the solar cell is sufficiently low, the total resistance can be considered constant (equal to the external load resistance). At this stage the current hardly changes.

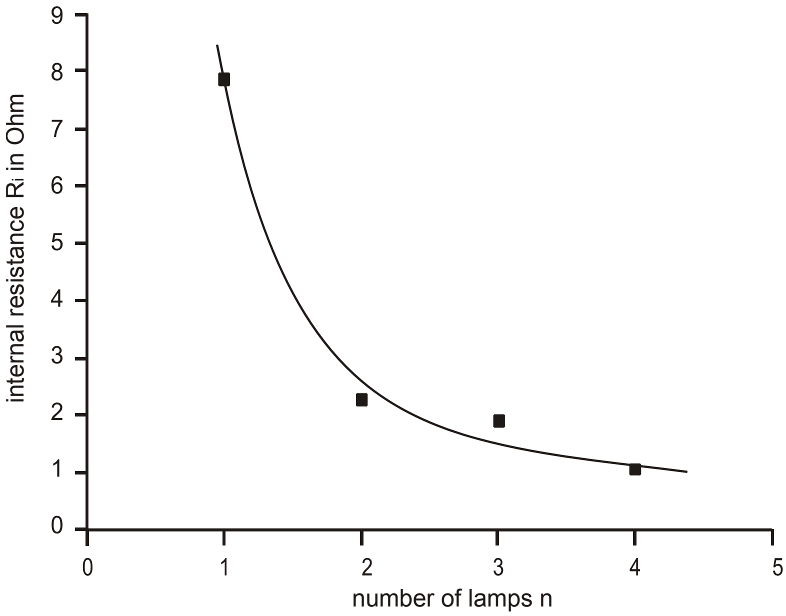

Figure 7.11: Dependence of the internal resistance of a solar cell on the illumination intensity.

7.6.2 Dependence of the internal resistance of the solar cell on distance to the light source (L6.2)

Experiment

Basically this experiment is very similar to experiment 7.6.1. But now the light intensity impinging on the solar cell is modified by changing the distance of the light source to the solar cell. Therefore, the room where the experiment is taking place should be darkened in order to achieve best results. It is recommended to install the leXsolar main board holding the solar cell vertically on the table. That way the distance to the light source can be modified by simply moving the leXsolar illumination module (which is operating as light source with 10V) on the tabletop. The distance can be measured with a long ruler mounted on the table which can also be used as calibre for the movement of the lamp.

Evaluation

The results are qualitatively consistant with the results from experiment 7.6.1. The only difference is the type of variation of the illumination intensity. It was changed linearly by unscrewing the lamps. However in this case the light intensity is decreases quadratically with increasing distance of the lamp to the solar cell (see Figure 7.12).

Evaluation

At solar cells connected in parallel the effect observed in experiment 7.10.1 does not appear, since the darkened cell acts as a resistor which is connected to the other cells in parallel. The total power decreases only by the part of the shaded cell, i.e. one third or two thirds, respectively.

7.11 The solar cell as a measuring device for the transmission (L11)

Experiment

This experiment simulates the use of solar cells in optical measuring devices. The cell acts as measuring device for the transmittance of foils. Before this experment can be done, the meaning of the term transmission should be discussed in class.
Because the short circuit current of the solar cell is in proportion to the illumination intensity, this experiment is comparatively easy. The students only cover the cell successively with the foils from the supplied set of grey foil and compare the measured short circuit current with the short circuit current of the uncovered cell. These measurements can be used to calculate the percentage of transmitted light very easily. The experiment can also be performed with additional material, for example with window glass or transparent synthetic material. However it is important that these materials are preferably achromatic. If the monochromaticity is too high the preferably passed frequency can adulterate the measurement due to the spectral response of the solar cell (experiment 12).

7.12 Dependence of the power of the solar cell on the frequency of the incident light (L12)

Experiment

In this experiment the student can reveal the relation between the frequency of the incident light and the solar cell power with simple means. The implementation only requires differently coloured glasses, e.g. as supplied with the leXsolar box, and a large solar cell. The student places the differently coloured glasses on the cell and determines the solar cell power constant illumination intensity. It is important that the glasses have approximately the same transmittance as is the case for the colour filters supplied with the leXsolar box.

Evaluation

The solar cell power at red light is higher than at blue light.

Erklärung

Looking at the absorption spectrum of silicon it might be assumed that the higher the energy of the incident radiation the higher the extractable power. But the experiment has disproven this assumption. The low-energy red light caused a higher solar cell power than the shortwave and therefore high-energy blue light.
First of all the spectral response depends on the band gap E_G of the semiconductor, in this case silicon. However, also other effects like doping, the antireflection coating and many others play an important role. As a whole these effects are responsible for the absorption of red light being higher than the absorption of blue light. Consequently it is obvious that there is no general response curve for a certain material, rather there has to be a specific measurement for every single solar cell. Therefore Figure 7.26 only shows how the curve looks like in principle.

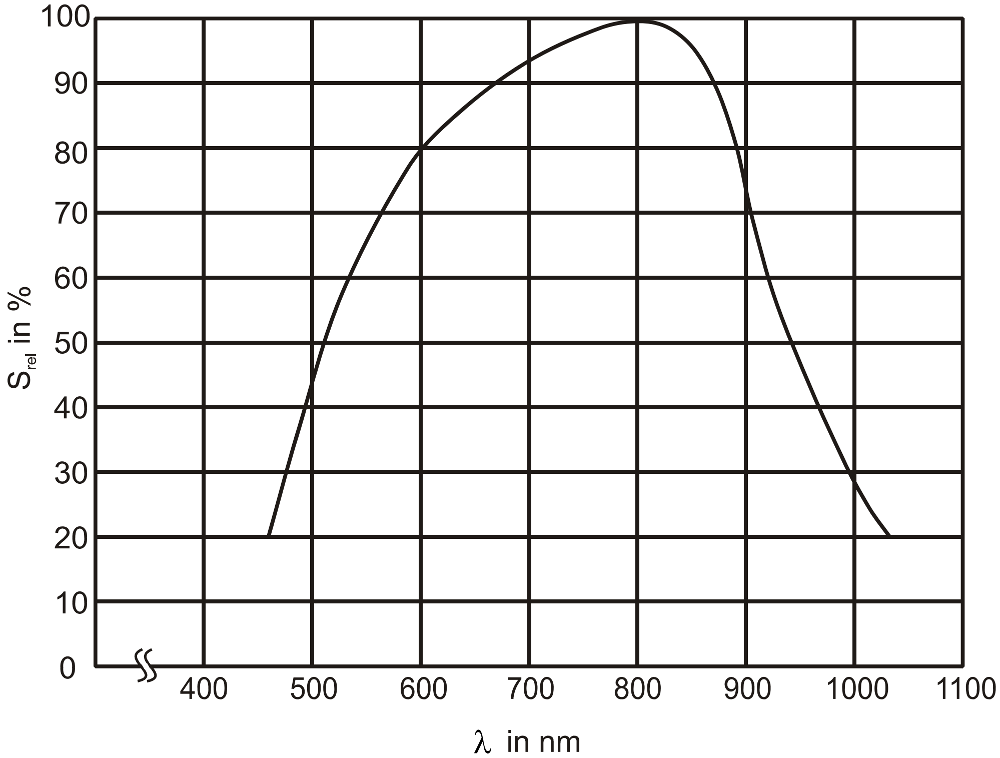

Figure 7.26: Dependence of the power of a solar cell on the wavelength of the incident light.

But back to the answer of the discrepancy explained in the beginning. Why does the graph on the left side again tend towards zero? Compared to the right side the photons in this area should have sufficient energy to generate electron-hole pairs.

Chapter 5 introduced the depth of penetration of photons into the material as $L_G = 1/\alpha$. That means the bigger the absorption constant α, the closer is the light absorption to the surface of the material, and therefore the smaller the depth of penetration. But the surface of a semiconductor is a place with a high recombination rate due to the existance of certain defects in the crystal lattice. So, if many photons are being absorbed close to the surface the generated charge carriers almost immediately recombine at those surface defects. Therefore the output of charge carriers again tends toward zero.

Application

In order to manufacture solar cells with a high efficiency, it is necessary to use semiconductor materials whose sensitivity maximum is adjusted to the spectrum of the sun. The substance which would achieve the highest efficiency at sunlight ought to have a band gap between 1.3 and 1.5 eV. Silicon has a band gap of 1.1 eV which is only a good average value compared to other substances used in photovoltaics. However, large deposits in the earth's crust as well as the easy and sophisticated processing speak for the use of silicon.

With expansion “Measuring without Measuring Devices”:

1. Introduction

The expansion „Measuring without Measuring Devices“ of the experimenting system leXsolar-PV is designed for use in the lower grades of secondary school. The modules in this expansion allow for experiments in the field of optic and electricity studies in Physics lessons. The red thread of the experiments is the solar cell. Students become familiar with the concept of a solar cell as a power source as well as various physical effects of optic and electricity.
In order to do the experiment, no or little knowledge is needed in the various fields. Measuring devices such as multimetres are not needed. The three new plugging modules, the horn, the lamp and the motor, are used as measuring devices. Measuring is done by differentiating between light or dark, loud or faint. The results are thus of a qualitative nature, however the students will learn how to tackle physical problems systematically.

2. List of Parts

1 leXsolar-lamp module (1.5 V, 15 mA)
1 leXsolar-horn module (min. 0.8 V, 1 mA)
1 leXsolar-motor module (min. 0.45 V, 12 mA)
1 rotation disk for the motor module with naps for attaching
1 set of rotation disks

The leXsolar-lamp module only requires a voltage of 0.5 V to light. A lens at the upper end of the leXsolar lamp that concentrates the light makes it perfectly visible. However the lamp will not shine brightly but merely glow in every case. The students should therefore concentrate and perhaps hold the lamp closer to their eye and shade the lamp against incoming light from other sources.

The leXsolar horn module consists of a Piezo-horn. It requires a minimum voltage of 0.8 V, however a very low amperage of 1 mA will suffice.

The leXsolar-motor module for „Measuring without Measuring Devices“ has a solar motor that will work with very low voltages and amperages. In contrast to the motor module in the standard system, this module does not have a gear unit and can therefore reach many r.p.m.

3. The Experiments

The use of „Measuring without Measuring Devices“ is the same as that of the basic system leXsolar-PV. The very straightforward changing from a series to a parallel connection is an advantage here as well. As no multimetres have to be connected, measuring wires can simply be used to close the circuit.
The student’s instructions are arranged in a way that require no pre-knowledge in order to execute the experiments. It is however important to deal with the introductory experiments at full length to ensure that the students are in common with leXsolar-PV as well as some basics such as series and parallel connections.

As the solar cell is the power supply during all experiments, a certain degree of illumination is required to be able to execute the experiments proposed in the student's booklet. For instance, normal room lighting will not be sufficient on cloudy days. Ideally experiments should be executed outside during sunshine or indoors next to large windows during sunshine. Alternatively it is possible to install a small desk-light on each place. This should illuminate the complete leXsolar-main board evenly. Before the experiments are executed the illumination should be checked. That can be done by using circuit 1 from experiment 1. If the lamp glows the illumination is sufficient.

The order of the student's experiments was parted into electricity studies and optic.
The aims of the experiments of electricity studies are:
-understanding the way in which the plugging system works
-getting to know the solar cellas a power source
-comparing important effects of the circuit types series and parallel connection
-getting to know different electric users

The aims of the experiments of optics are:
-illustration of the solar cell's dependence on light
-getting to know the different types of radiation
-visual understanding of colour systems
-understanding of various optical delusions

The experiments will help students understand scientifically systematic working and interest them to findout more about this topic.

The following pages contain the results of the experiments in the student's booklet and the answers for the gap texts. The order is therefore the same as in the student's booklet.

Part 1 Electricity studies

7.13 Working with the leXsolar-plugging module (L13)

Circuits 1 and 2 are simply variations of the same series connection. Therefore the lamp glows in both cases. In circuit 3 the circuit is not closed, therefore the lamp doesn't glow. Circuit 4 equals the first two.
Circuit 5 is a parallel connection of three solar cells, the lamp glows. The circuit is not closedin circuit 6, therefore the lamp doesn't glow. The student should find this out for himself using the circuit diagram of the main board. This circuit is extremely important to ensure thorough understanding of the way the leXsolar-main board works.

7.14 Comparison of series and parallel connected solar cells (L14)

In a series connection of the solar cells the voltages of the single cells are added whereas the amperage remains the same. In a parallel connection of the solar cells the voltages of the single cells are remain the same whereas the amperages are added.

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