How can light be converted to electrical energy?

Task
To examine the behaviour of a solar cell on being illuminated.

Equipment

Plug-in board	06033.00	1
Wire building block	39120.00	2
Universal holder	39115.02	2
Lamp holder E10	17049.00	1
Filament lamp, 6V/0.5 A, E10, 1 pc.	35673.03	(1)
Potentiometer, 250 Ω	39103.21	1
Solar cell, 0.5 V, 0.3 A	06752.11	1
Connecting cable, 25 cm, red	07313.01	2
Connecting cable, 25 cm, blue	07313.04	2
Connecting cable, 50 cm, red	07314.01	1
Connecting cable, 50 cm, blue	07314.04	1
Multi-range meter	07028.01	2
Power supply, 0...12 V-,6 V~, 12 V~	13505.93	1

Set-Up and Procedure

— Connect up the circuit as shown in Fig. 1; clamp one side of the solar cell in the universal holder and allow the other side to lie on a wire building block; connect the potentiometer as an adjustable resistor; place the filament lamp first in position 1.
— Select the 1 V- and 30 mA- measurement ranges.
— Connect the filament lamp to the sockets for 6 V~ and switch on the power supply.
— First set the potentiometer to 0, i.e. put the maximum load on the solar cell; measure the voltage U and current strength I and enter the measured values in Table 1.
— Change the potentiometer setting stepwise, so that the voltage is increased up from 0.20 V in steps of 0.05 V, and from 0.40 V up in steps of 0.01 V; measure the current strength at each step and note the values for U and I in Table 1.
— Remove a wire building block and measure the voltage at I = 0 A; enter the values for U and I in Table 1.
— Replace the wire building block and set the potentiometer to 0.
— Place the filament lamp in position 2 and repeat all the previous measurements under the resulting changed conditions; enter the measured values in Table 2.
— Switch off the power supply.

Measurement Results

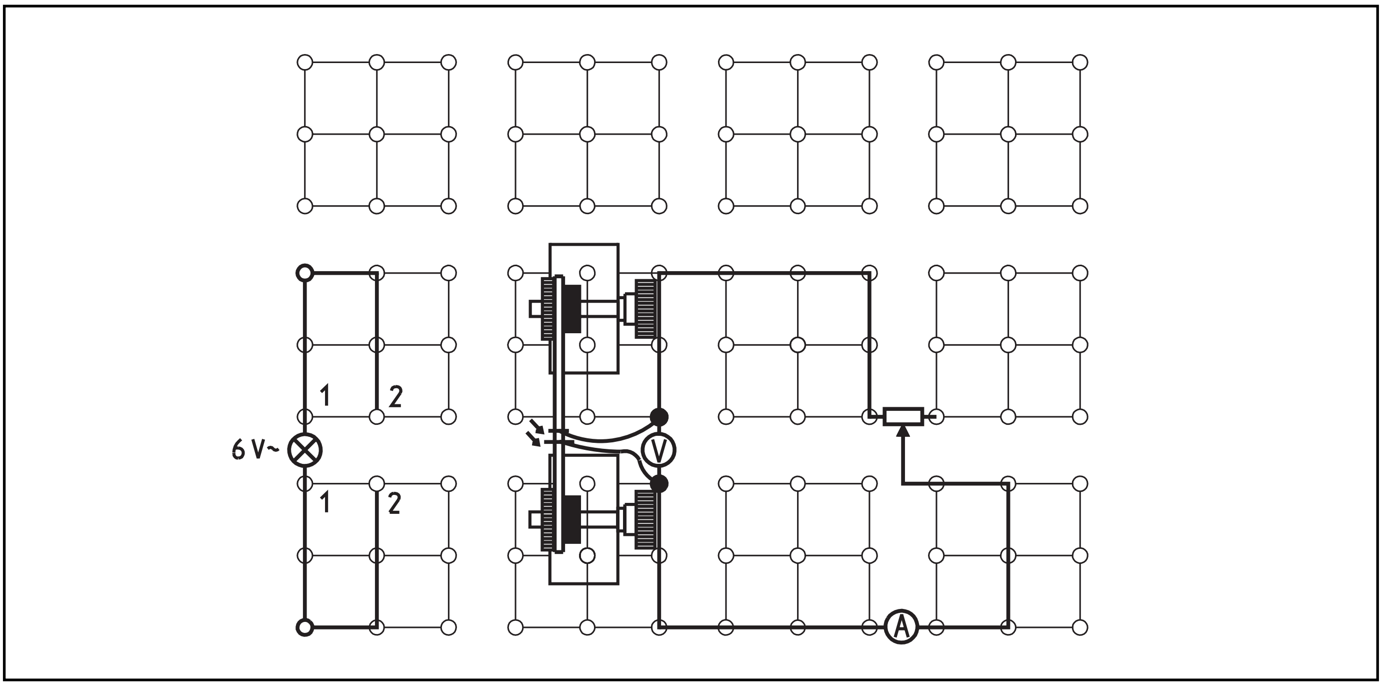
Table 1: 1st series of measurements

U /V	I /mA	P /mW	R /Ω

Table 2: 2nd series of measurements

U /V	I /mA	P /mW	R /Ω

Fig. 1



Evaluation

1. Plot graphs of the voltage U and current strength I in Fig. 2 for each of the series of measurements to illustrate the connection between them
2. Calculate the electrical power $P = U \cdot I$ of the solar cell for all pairs of values for U and I in Tables 1 and 2, and enter the results in the third columns.
3. Also calculate the load resistance R for all pairs of values for U and I and enter the results in the fourth columns.
4. For each series of measurements, plot a graph in Fig. 3 of the electrical power P of the solar cell as a function of the load resistance R.
5. The voltage which is measured with no load on the solar cell (at I = 0 A), is called the nominal voltage U_0. How large is U_0 in each case?

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6. The current measured when the solar cell is short circuited (theoretically at U = 0 V)) is called the short-circuit current I_S.
   a) Why is the voltage at the solar cell larger than 0 V when the potentiometer is set to 0?

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   b) Determine the short-circuit current I_S from the two measurement curves (Fig. 2) by extrapolation.

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7. How do the the short-circuit current I_S and the nominal voltage U_0 change when the illuminating intensity changes?

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8. From the course of the curves in Fig. 3 it can be seen that the electrical power P of the solar cell has a maximum in each of the cases examined.
   a) Which connection clearly exists between the maximum attainable power of the solar cell and the illuminating intensity?

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   b) How large are the two maximum values for the power which were obtained in this experiment?

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Fig. 2

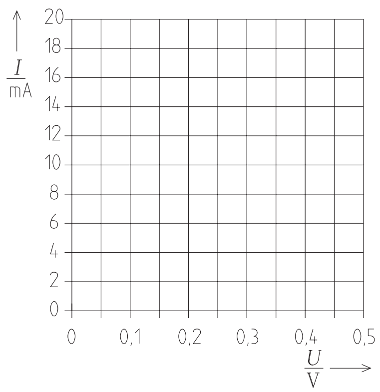
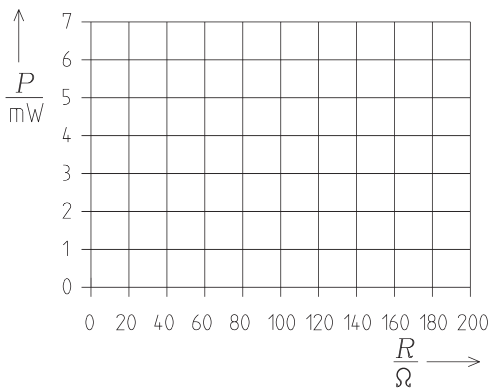


Fig. 3



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Solar cells play a substantial role in the development of alternative, non-fossil energy sources. They transform light energy directly into electrical energy and are, therefore, the most favourable solution for special areas of application.
The students should become familiar with the basic principle of converting light energy into electrical energy by investigating the electrical characteristics of solar cells. Furthermore, the solar cell will serve as an example to clearly illustrate the characteristics and behaviour of an active two-terminal network and its load behaviour. Particularly important here is the consideration of the maximum useful power, alongside the understanding of the characteristic quantities nominal voltage and short-circuit current.

Notes on Set-Up and Procedure

A 250 Ω potentiometer serves as load resistor. When connecting the potentiometer (see Fig. 1), ensure that the left part of it, which is represented by the value shown by the potentiometer adjusting knob, is included in the circuit.
The internal resistance of the ammeter cannot be neglected. The measurement range should therefore not be smaller than 30 mA. When the potentiometer is set to 0, the voltage measured is not 0. V. When the measurement range is reduced to 3 mA, the voltage increases further. The short-circuit current can be determined by extrapolating the measurement curve, however.
The illuminating intensity is changed by varying the position of the filament lamp. In each series of measurements, the position of the lamp must remain unchanged throughout the complete procedure!

Table 1: 1st series of measurements

U /V	I /mA	P /mW	R /Ω
0.11	9.8	1.1	11
0.20	9.7	1.9	21
0.25	9.5	2.4	26
0.30	9.3	2.8	32
0.35	8.7	3.0	40
0.40	7.3	2.9	55
0.41	6.9	2.8	59
0.42	6.0	2.5	70
0.43	5.3	2.3	81
0.44	4.1	1.8	107
0.45	2.6	1.2	173
0.46	0.0	0.0	–

Table 2: 2nd series of measurements

U /V	I /mA	P /mW	R /Ω
0.20	17.7	3.5	11
0.25	17.5	4.4	14
0.30	17.2	5.2	17
0.35	16.7	5.8	21
0.40	15.0	6.0	27
0.41	14.5	5.9	28
0.42	13.8	5.8	30
0.43	12.8	5.5	34
0.44	11.0	4.8	40
0.45	9.0	4.0	50
0.46	7.4	3.4	62
0.47	4.7	2.2	100
0.48	0.0	0.0	–

Measurement Results

Evaluation

1. Refer to Fig. 2.
2. Refer to the third columns of Tables 1 and 2.
3. Refer to the fourth columns of Tables 1 and 2.
4. Refer to Fig. 3.
5. U_{01} = 0.46 V; U_{02} = 0.48 V.
6. a) The ammeter constitutes an electrical resistance, and a complete short-circuit is therefore not attained.
   b) I_{S1} = 9.8 mA; I_{S2} = 17.8 mA.
7. The short-circuit current I_S increases when the illuminating intensity increases.
   The nominal voltage U_0 is almost independent of the illuminating intensity.
8. a) The greater the illuminating intensity, the greater the maximum attainable power.
   b) P_{max1} = 3.0 mW; P_{max2} = 6.0 mW

Fig. 2

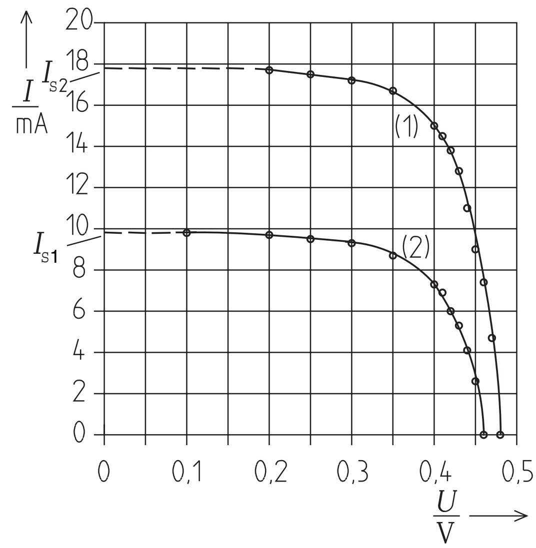
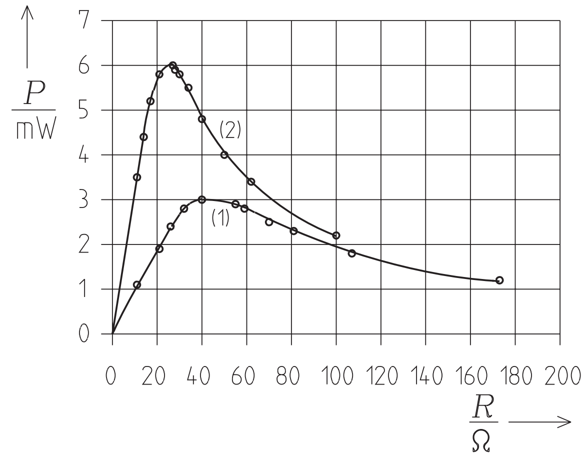


Fig. 3



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Remarks

The nominal voltage of a solar cell is about 0.5 V.; its internal resistance decreases when the intensity of the incident light increases. The internal resistance is not constant at a given illuminating intensity, however, but is dependent on the load. If the internal resistance was constant, the characteristic curve for current-voltage (Fig. 2) would be a line with a negative slope between I_S on the I-axis and U_0 on the U-axis.

Attaining maximum power is called power matching.

A change in the illuminating intensity causes a change in the internal resistance of the solar cell and, consequently, its load behaviour.

In Germany, under favourable conditions, one can reckon that the illuminating sunlight has a power of 1000 W/m^2. The power which solar batteries can provide is dependent on their efficiency (10 ... 15%).

When comparing the different possibilities for producing energy, their disadvantages must also be taken into consideration. For instance, a very large amount of energy is needed to manufacture solar cells. In addition, the washing out of heavy metals from solar batteries is a great environmental problem, and their initial cost is very high.

Solar cells are large surface area diodes, in which light can enter the pn-junction and produce pairs of charge carriers there. The semiconductor substrate is on a metallic support, and a metal lattice on the upper side allows the electrons to flow off. Exposing the solar cell to light produces a voltage of between 0.5 V and 0.6 V in open-circuit operation. When a load resistor is connected, a current flows. The strength of this current depends on the size of the resistance, on the intensity of the incident light and on the surface area of the solar cell. The nominal voltage and short-circuit current, the characteristic quantities of a current source, can be adjusted to meet individual requirements through series and parallel connection of solar cells to solar batteries.