A5 Properties of solar cells – Voltage, current and power

1 First investigations with the solar cell

1.1 Apparatus and materials

- 4 connecting cables, alligator clip to alligator clip
- 1 halogen lamp, 20 W*
- 1 overhead transparency
- 1 propeller (for large solar motor)
- 1 ruler
- 1 sheet of paper, black, DIN A4
- 1 sheet of tracing paper
- 1 sheet of writing paper
- 1 solar cell, 0.5 V/150 mA
- 1 solar motor, large, iron armature, 0.4 V/25 mA

*You can also conduct the experiment in direct sunlight.

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

1.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.
Halogen light bulbs become very hot. Do not touch them.

1.3 Conducting the experiment

- If the solar cell has not been used yet, remove the protective wrap.
- Attach the connecting cables to the solar cell. Make sure that the alligator clips do not touch each other; otherwise the circuit will short.

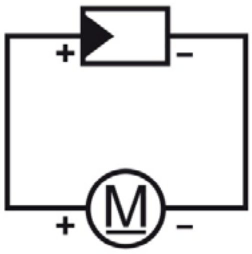

Fig. 1: Circuit diagram.

- Now use the other alligator clips to connect the motor with the attached propeller to the solar cell.
- Place or hold the solar cell in light so that the light strikes it perpendicularly.
- Use the ruler to determine the distance from the light source (for a 20-watt halogen lamp, usually approx. 15 cm) at which the electric motor runs "nice and fast."
- Maintain this precise distance in the next experiments.


Fig. 2: Experiment setup.

- Examine the connection to see how it must be made so that the propeller rotates clockwise.
- Change the lighting conditions by gradually covering the surface of the solar cell with the black paper.
- Investigate how the motor's speed depends on the angle of incidence by rotating the solar cell in the light (without the black paper covering it).
- Hold other transparent or translucent materials in front of the solar cell.
- For each action, check the effect on the motor's speed.

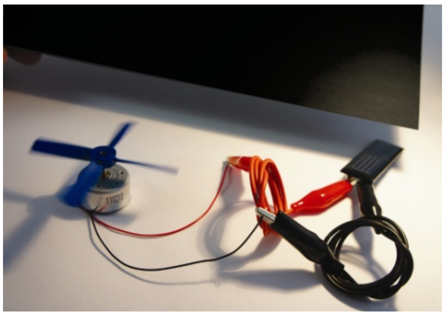

Fig. 3: Shading the solar cell with black paper.

1.4 Observation

Share your observations with a classmate and write them down.

1.5 Analysis

List the factors that influence the power output of a solar cell.

1.6 Questions

How should solar cells be mounted to houses so that they can be used most effectively?

2 Short-circuit current and no-load voltage at different distances from the lamp

This subexperiment works only with a lamp and not with sunlight.

2.1 Apparatus and materials

- 1 digital multimeter
- 1 halogen lamp, 20 W
- 1 measuring cable assembly, banana plug to alligator clip, red and black for each
- 1 ruler
- 1 solar cell, 0.5 V/150 mA

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

2.2 Safety information

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2.3 Conducting the experiment

- Attach the multimeter to the solar cell. Use the 2,000-mV range to measure the voltage, and use the 200-mA range to measure the current. Take measurements with one multimeter and simply switch between voltage and current on the meter.

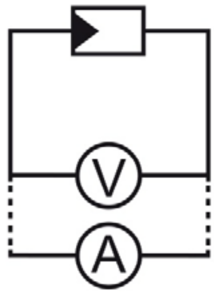

Fig. 4: Circuit diagram. Measurement using one multimeter by switching the measurement range from voltage (V) to current (A).

- Using the ruler, gradually increase the distance between the solar cell and the lamp in 5-cm increments. Start with a distance of 5 cm.
- For each distance, measure the voltage (no-load voltage) on the solar cell and the current (short-circuit current). Note the value that is reached at each given distance.

Fig. 5: Measuring the voltage at different distances.

2.4 Observation

Plot the values you measured on a graph (distance and current, distance and voltage).

2.5 Analysis

a) How does the distance and thus the illuminance affect measured current and voltage?
b) What changes to a greater extent when you change the lighting conditions: the current or the voltage?

2.6 Questions

You can use a solar cell to measure the lighting conditions at a location.
Which variable is better for this purpose, the current or the voltage? Explain your answer.

3 What happens when you connect solar cells in series or in parallel?

3.1 Apparatus and materials

- Cardboard
- 6 connecting cables, alligator clip to alligator clip
- 1 halogen lamp, 20 W*
- 1 pair of scissors
- 1 propeller (for large solar motor)
- 2 rubber bands
- 2 solar cells, 0.5 V/150 mA
- 1 solar motor, large, iron armature, 0.4 V/25 mA

*You can also conduct the experiment in direct sunlight.

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

3.2 Safety information

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3.3 Conducting the experiment

- Cut a strip of cardboard to a size such that two solar cells will fit on it side by side. The solar cells must protrude a bit on each end so that you can mount them to the cardboard using the rubber bands (see Fig. 6). (Purpose: To have the same angle and same brightness for both cells during measurements.)

Fig. 6: Mounting the solar cells on a cardboard strip.

- Connect one of the two solar cells to the solar motor (with the attached propeller). Adjust the distance to the lamp such that the motor just begins to turn. When you move the solar cells, make sure that the alligator clips connected to the solar cells do not touch each other, in order to prevent a short circuit (otherwise the voltage and current will be zero).

- Now connect the other solar cell in parallel (see Fig. 8) Compare the motor's speed.

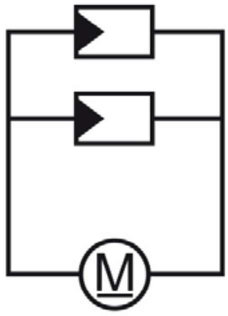

Fig. 7: Circuit diagram for parallel circuit.

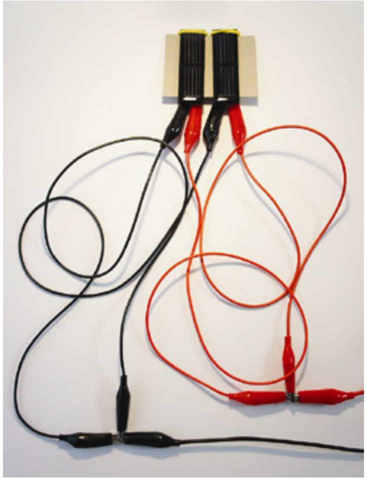

Fig. 8: Wiring for a parallel circuit. Do not connect the second solar cell directly to the first (risk of loose connection and short circuit). Instead, connect it using a cable junction.

- Now connect the solar cells in series (see Fig. 11) and again compare the motor's speed.

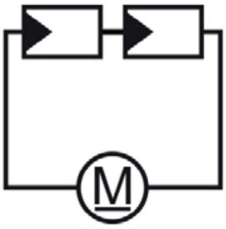

Fig. 9: Circuit diagram for series circuit.

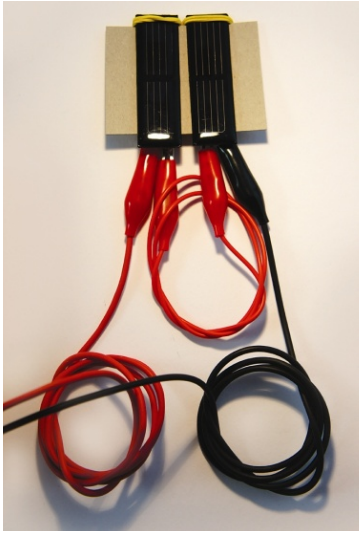

Fig. 10: Wiring for a series circuit.

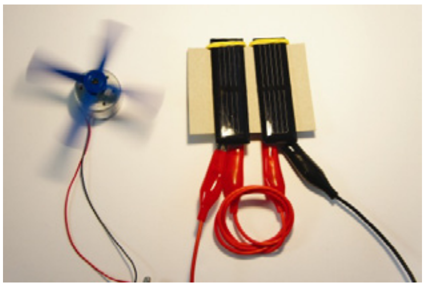

Fig. 11: Motor operation with series circuit

3.4 Observation

Write down a summary of your observations.

3.5 Analysis

When you use two solar cells, twice the electrical energy is generated from the light. Actually, you would expect that the solar motor would clearly rotate faster with two solar cells than with one, regardless of the type of connection. Why is it that a different amount of the energy flows to the motor depending on the connection? (Tip: internal resistance of the solar cell)

3.6 Questions

a) Why does the solar cell's power output differ for parallel and series connections?
b) How do two AA batteries behave when connected in parallel or in series, compared to solar cells?

4 Current and voltage with solar cells connected in series and in parallel

This subexperiment is a continuation of subexperiment 3, but in this case you will measure the current and voltage.

4.1 Apparatus and materials

- Cardboard
- 4 connecting cables, alligator clip to alligator clip
- 1 digital multimeter
- 1 halogen lamp, 20 W*
- 1 measuring cable assembly, banana plug to alligator clip, red and black for each
- 2 rubber bands
- 2 solar cells, 0.5 V/150 mA

*You can also conduct the experiment in direct sunlight.

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

4.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.
Halogen light bulbs become very hot. Do not touch them.

4.3 Conducting the experiment

- Move a solar cell to a distance of 10 cm from the lamp (or into bright sunlight). Measure the short-circuit current and the no-load voltage of the single solar cell.
- Now connect two solar cells in parallel. Measure the short-circuit current and no-load voltage of the parallel connection.
- Repeat the measurement for a series connection of two solar cells.

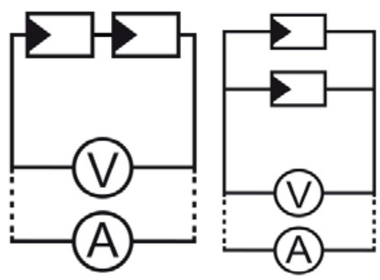

Fig. 12: Circuit diagrams for series (left) and parallel (right) circuits.

4.4 Observation

- Create a table using the template below and enter the values you measure:

	Voltage [V]	Current [A]
Single cell		
2 cells in parallel		
2 cells in series		

- How would you approximately describe the behavior of current and voltage of two solar cells connected in parallel and in series compared with that of a single solar cell?

4.5 Analysis

Compare the results of this subexperiment with the results of subexperiment 3
(What happens when you connect solar cells in series or in parallel?) and explain the differences.

4.6 Questions

Why is the product of the short-circuit current multiplied by the no-load voltage not equal to the actual power output of the solar cell?

5 How do solar cells connected in series or in parallel behave when shaded?

For this subexperiment, use the same solar cells mounted on cardboard that you used for subexperiments 3 and 4.

5.1 Apparatus and materials

- Cardboard
- 4 connecting cables, alligator clip to alligator clip
- 1 digital multimeter
- 1 halogen lamp, 20 W*
- 1 measuring cable assembly, banana plug to alligator clip, red and black for each
- 2 rubber bands
- 1 sheet of paper, black, DIN A4
- 2 solar cells, 0.5 V/150 mA

*You can also conduct the experiment in direct sunlight.

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

5.2 Safety information

The materials may be used only as instructed by your teacher or as described in the experimentation instructions.
Halogen light bulbs become very hot. Do not touch them.

5.3 Conducting the experiment

- Connect two solar cells in parallel. Move them to a distance of about 10 cm from the lamp.
- Measure the short-circuit current and no-load voltage of the parallel connection.
- Cover half of both solar cells with the black paper (see drawing in Fig. 14).

Fig. 13: Partial shading of one of the two solar cells.

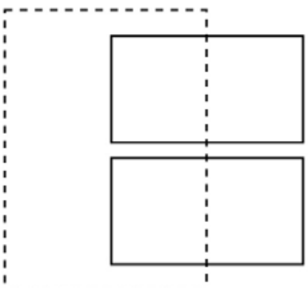

Fig. 14: Partial shading of both solar cells.

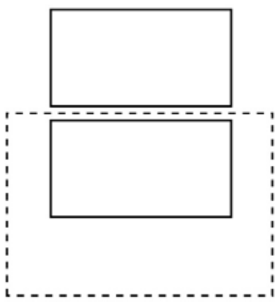

Fig. 15: Shading of only one solar cell.

- Now completely cover one of the two solar cells (see drawing in Fig. 15). Compare the results.
- Repeat the measurements for a series connection of two solar cells.

5.4 Observation

Create a table using the template below and enter the values you measure:

	Parallel circuit		**Series circuit**	
	U [V]	**I [mA]**	**U [V]**	**I [mA]**
Uncovered				
Both half covered				
One completely covered				

5.5 Analysis

Calculate the product of the short-circuit current multiplied by the no-load voltage for each measurement.

5.6 Questions

a) Why are solar cells connected in series for the production of solar modules and then why are the solar modules connected in parallel? Explain your answer.
b) The following sentence appears on a website about solar technology: “For a series connection, the weakest module determines the total power output.”
What is meant by that? Write a corresponding sentence for a parallel connection.
c) Tina would like to participate in a solar competition. She must build a boat that is driven by a fan. She may use a maximum of four solar cells (0.5 volts, 100 mA). The motor has a starting voltage of 0.6 volts and a starting current of 25 mA. How would you advise her to connect the solar cells so that the boat reaches maximum speed? Explain your answer.

6 Optimizing the power output of solar cells

Since only one digital multimeter is available for each group, the groups must work in pairs for this subexperiment.

6.1 Apparatus and materials

- 6 connecting cables, alligator clip to alligator clip
- 2 digital multimeters
- 1 halogen lamp, 20 W*
- 2 measuring cable assemblies, banana plug to alligator clip, red and black for each
- 1 potentiometer, 470 ohms
- 1 solar cell, 0.5 V/150 mA

*You can also conduct the experiment in direct sunlight.

Attention: After you have completed the experiment, return the materials or dispose of them properly as instructed by your teacher.

6.2 Safety information

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Halogen light bulbs become very hot. Do not touch them.

6.3 Conducting the experiment

Note: The potentiometer is a variable resistor. A sliding contact picks up the desired value along a resistor.

- Set up a circuit according to the circuit diagram in Fig. 16. Use a second digital multimeter so that you can measure the current and voltage simultaneously.

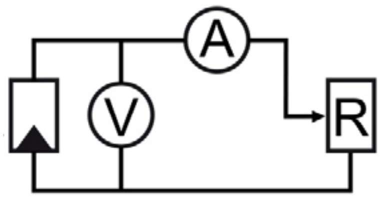

Fig. 16: Circuit diagram for measuring the power output of a solar cell. The lower resistance, the more electricity should flow at a constant voltage. But does the voltage remain constant?

- Move the solar cell to a distance of approx. 5 cm from the lamp.
- Change the resistance by turning the potentiometer until the maximum voltage is indicated. (Normally greater than 0.5 volts.)
- Now read the associated current.
- Then reduce the voltage by approx. 0.1 volt by turning the potentiometer and measure the associated current again. Repeat this process until the voltage is zero.

Fig. 17: Connection to a potentiometer via an outside terminal and the middle terminal.

6.4 Observation

Create a table using the template below and enter the values you measure:

Measurement	Voltage [V]	Current [A]	Resistance [Ω]	Power output [W]
1				
2				
...				

6.5 Analysis

a) Plot a current – voltage graph.
b) For each individual measured value, you can determine the resistance of the potentiometer as well as the electrical power delivered by the solar cell at the resistor. Enter the values in another column of the table.
c) Determine the measuring point at which the maximum power was drawn. This point is called the maximum power point (MPP).

6.6 Questions

The maximum power is drawn when a device's resistance is just as high as the solar cell's internal resistance. The internal resistance is not constant, but depends on the lighting. Therefore, in order to draw the maximum power in poor lighting conditions, you must change the resistance. Create an experiment to prove whether a device's resistance must be increased or decreased when the lighting conditions change.