Experimental project II

Experiment 3.

Solar Cells

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1 Introduction

Solar cells, also known as photovoltaic cells, play a pivotal role in harnessing clean and renewable energy from the sun. These devices convert sunlight directly into electricity through the photovoltaic effect, providing a sustainable alternative to conventional energy sources. Understanding the principles behind solar cell operation is essential for exploring and optimizing their efficiency.

Therefore, the objectives of the experiment can be summarized as follows:

- Adjusting the prism spectrometer.
- Calibrating the prism spectrometer with an He-lamp.
- Measuring an "unknown" line spectrum.
- Identifying the "unknown" light source.

2 Principles

Solar cells based on semiconductors are inherently straightforward devices. Semiconductors possess the ability to absorb light and transfer a portion of the absorbed photon's energy to carriers of electrical current, namely electrons and holes.

A simplified and conventional solar cell structure is illustrated in Figure 2.

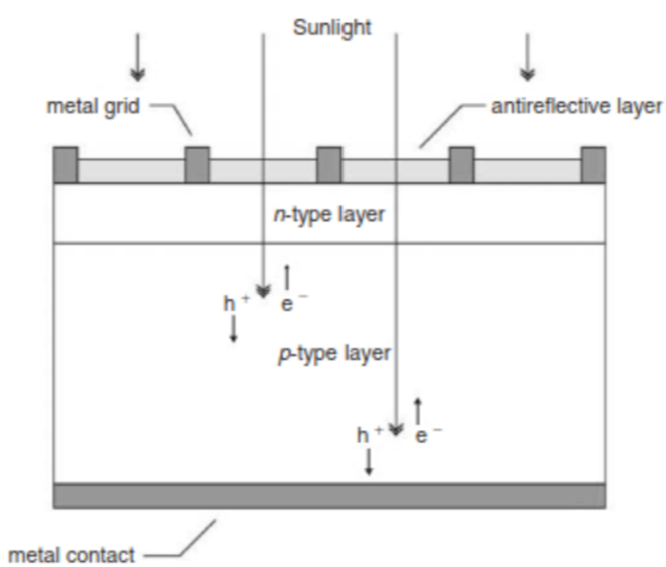


Figure 1: A schematic of a simple conventional solar cell. Creation of electron-hole pairs (e^-, h^+).

2.1 Fundamental properties of semiconductors

Solar cells can be manufactured using various semiconductor materials, with silicon (Si) being the most prevalent choice, available in crystalline, polycrystalline, and amorphous forms. Additionally, solar cells can be produced from alternative semiconductor materials like GaAs, GaInP, $Cu(InGa)Se_2$, and CdTe.

Solar cells have crystalline structures. Thus, atoms are arranged in a periodic lattice (body-centered cubic (bcc), face-centered cubic (fcc), among others). To determine the properties, it is necessary to describe the characteristic parameters of the lattice (first Brillouin zone, length, occupation, etc.).

The dynamics of electrons forming semiconductors can be described by the Time-Independent Schrödinger Equation (TISE):

$$\nabla^2\Phi + \frac{2m}{\hbar^2}(E - U(\vec{r}))\Phi = 0 \tag{1}$$

where m is the electron mass, $\hbar$ is the reduced Planck constant, E is the energy of the electron, and $U(\vec{r})$ is the periodic potential energy inside the semiconductor.

2.2 Electron-Hole Conduction

Electrons are subatomic particles with a negative electric charge that orbit the nucleus of an atom in energy levels. In conductive materials, electrons can move freely, contributing to electrical conduction.

On the other hand, a hole is the absence of an electron in a valence band energy level; when an electron moves to a higher band, leaving behind a hole, it behaves as a positively charged particle.

Band theory (Figure **??**) explains how electrons fill energy levels in solid materials, and in semiconductors, electrical conduction can occur through electron movement in the conduction band or hole movement in the valence band. Applying an external electric field causes electrons to move in the opposite direction of the field, contributing to electric current, and similarly, holes can move in the direction of the electric field, also contributing to current.

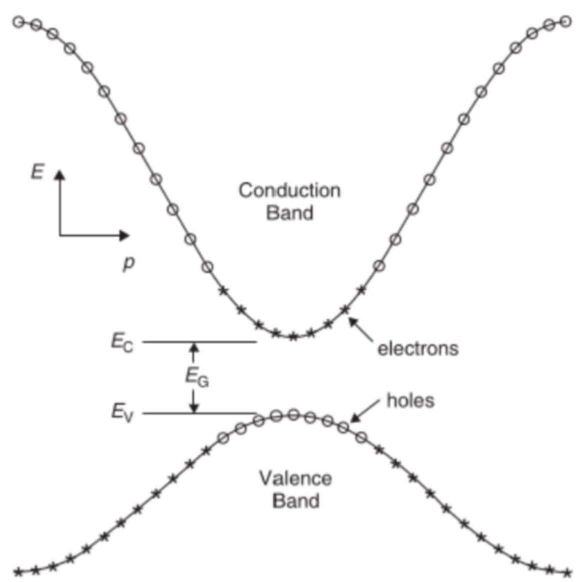


Figure 2: A schematic of a simple conventional solar cell. Creation of electron-hole pairs (e^-, h^+).

3 Experimental Procedure and Calculations

The experiments and subsequent calculations will be carried out taking into account the instructions of the student book. Specifically, experiments 2 and 3 will be conducted, as well as one chosen from among experiments 4 to 15.

3.1 Experiment 2

In **experiment 2**, the model is built so that the lamp arm is in the south position, the brightness regulator is at level 10 and there is no shading screen.

The results obtained from the change in polarity of the solar cell connection cables, the adjustment of different irradiation intensities and the observation of the electric motor will be analyzed.

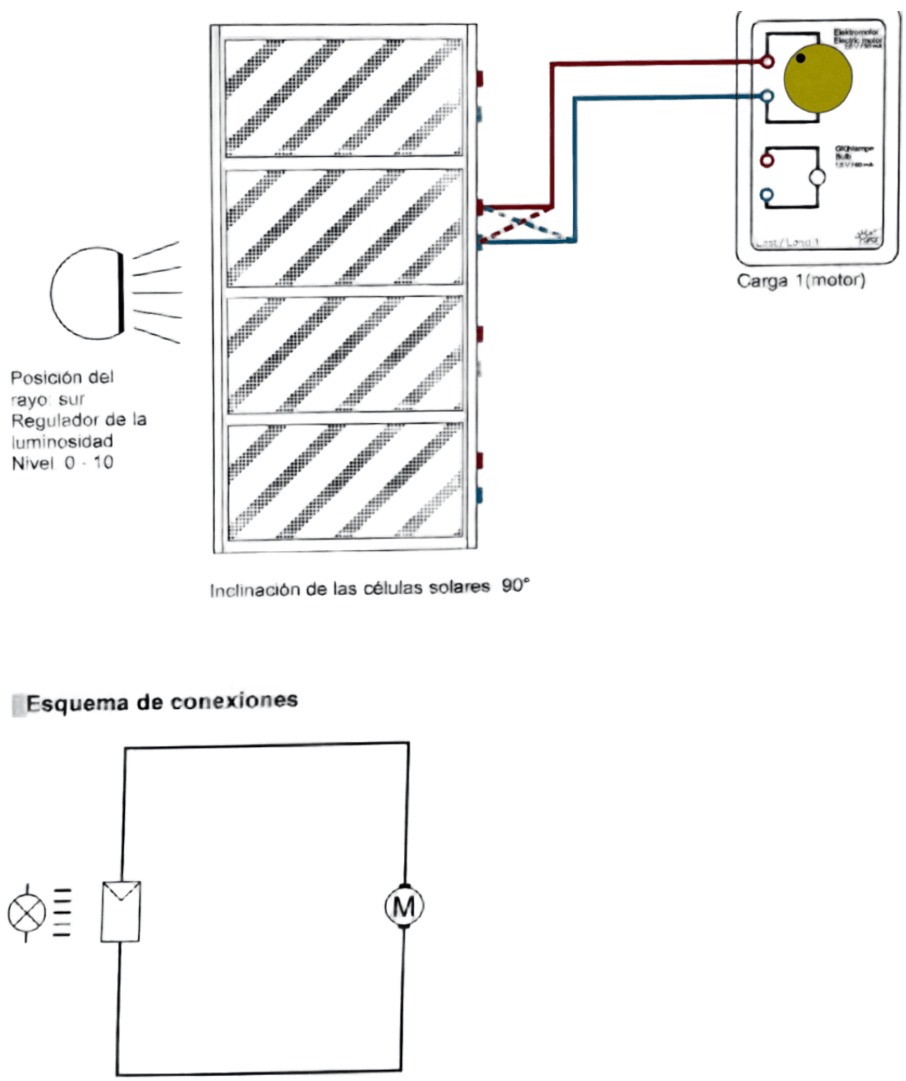


Figure 3: Scheme of experiment 2 .

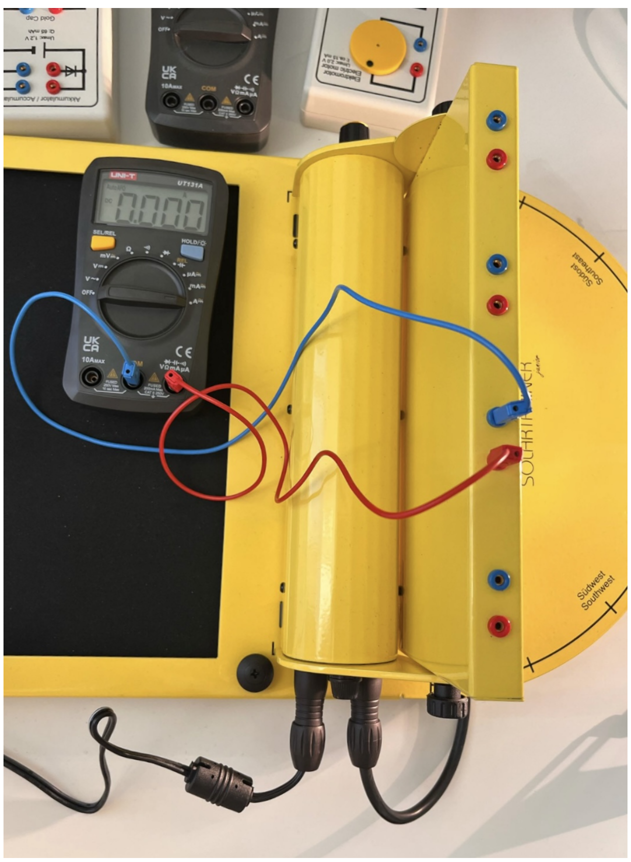
A: What happens when the polarity of the solar cell connection cables is changed?

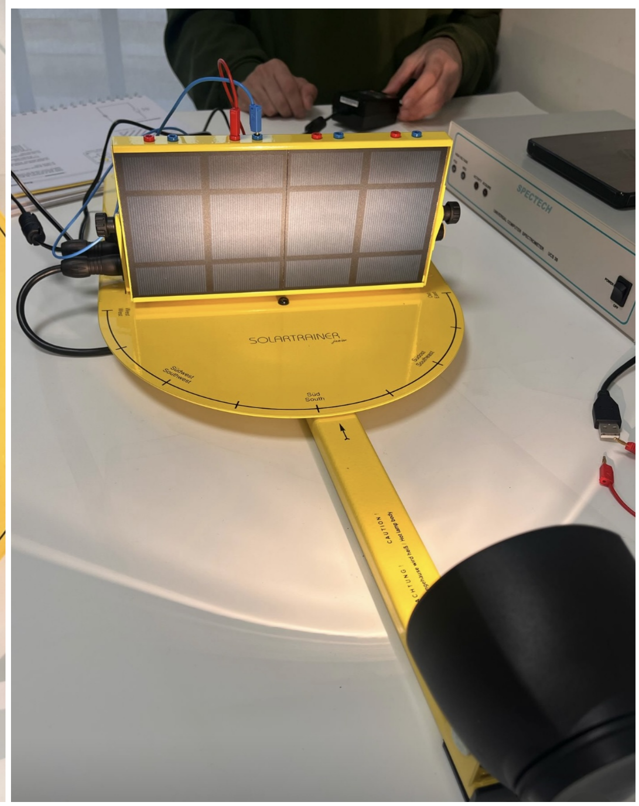
When we firstly started the experiment and had all the instructions followed by the model, we could confirm that the electric engine spinned in a clockwise direction. Then, we changed the polarity of the solar cells and this direction changed, so it started spinning counterclockwise.

B: On the brightness regulator, adjust different irradiation intensities and observe the electric motor.

After setting up different irradiation intensities, we could easily observe that as we increase the intensity, the velocity increases too. So the strongest the intensity is, the fastest the engine is.

C: State the energy conversions that take place in the solar cell and the electric motor. Light energy is created in the light bulb and it is transformed into electrical energy in the solar cell. Lastly, it turns into kinetic energy. This last energy is the one that makes the engine twirl. The higher the intensity, the most electrical energy that is transformed.





3.2 Experiment 3

In **experiment 3**, the experiment is constructed according to the representation. The experiment is divided into two, first without a shading plate and then with a shading plate.

The range selection switch of the multimeter as an ammeter must be set to position A (DC) (1A = 1000 mA)

At first, the solar cell is operated without shading plates. With the lamp arm in the South position and the brightness regulator at level 10. Next, the solar cell connections are exchanged and the results are observed. Finally, the experiment is carried out again but with a cover plate and without irradiation.

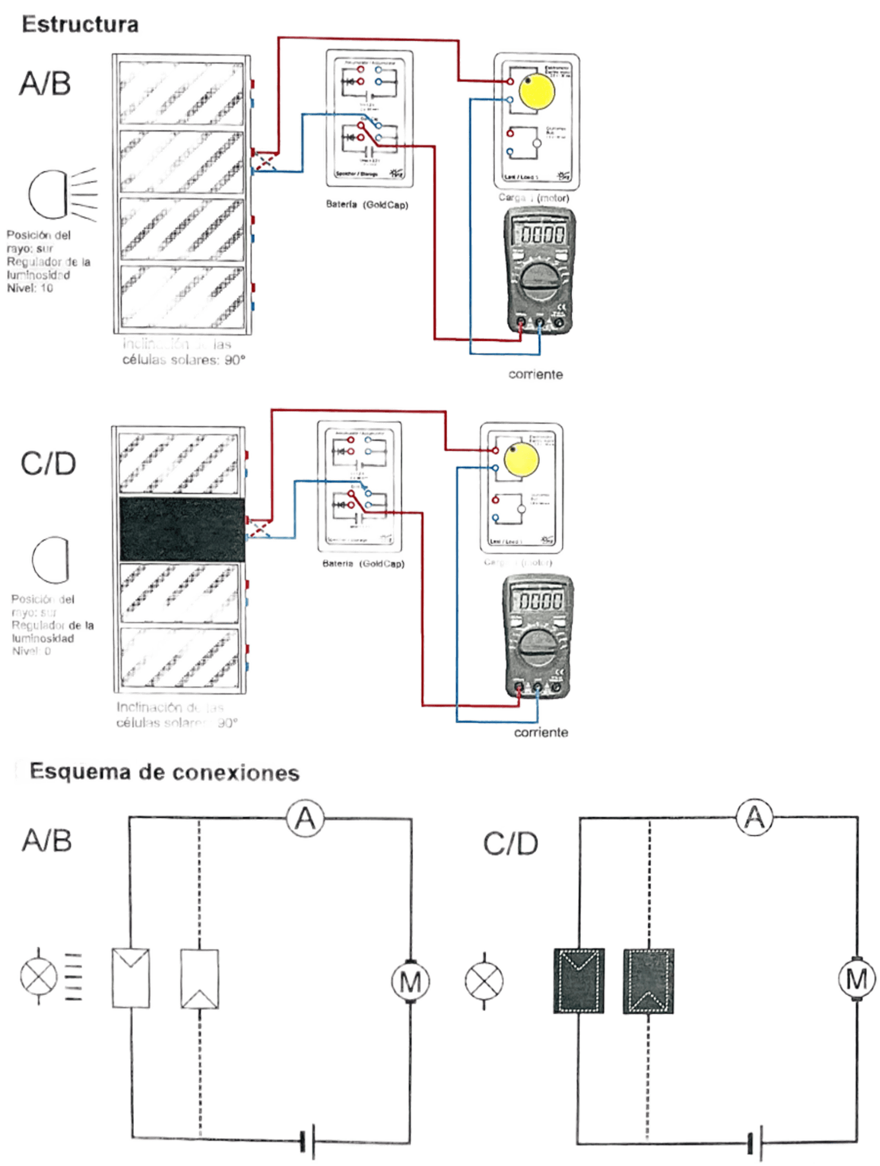


Figure 4: Scheme of experiment 3 .

A: Without shading plates, what observation can be made?

The engine twirls in a clockwise direction. It spins slower. There was supposed to flow approximately 11mA in the electric circuit. However, we got to measure 9mA. As we know; 1A = 1000mA.

B: By changing the connections to the solar cell, what observation can be made?

In this set up (exchanging the wiring), we observe the opposite of the A part. It spins counterclockwise and it twirls faster. There flows approximately 14mA in the electric circuit.

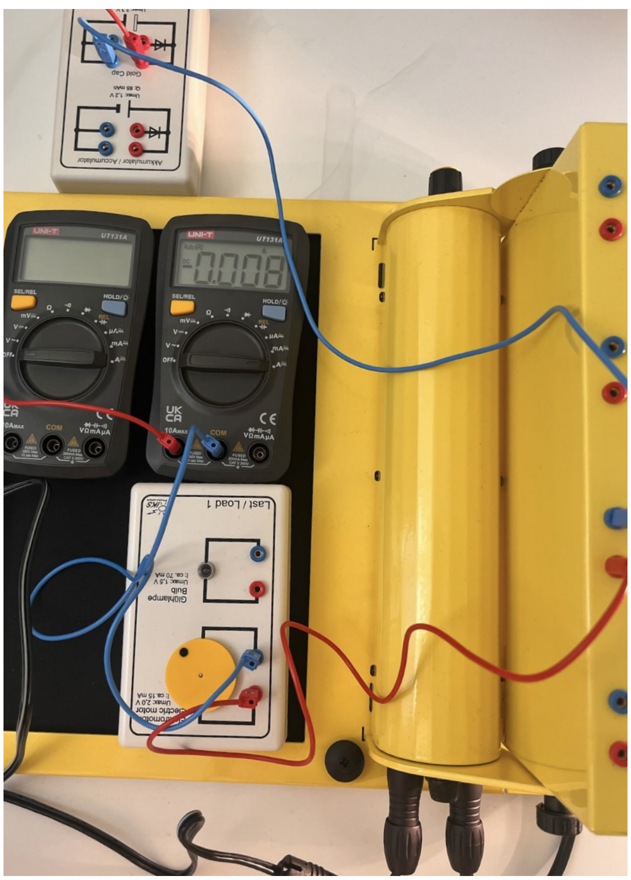
C/D: With the plate covered and without irradiation, what observations can be made?

Firstly, in the C (the red wire in its correspondence color and the same for the blue one), we covered the cell and the light was off, so there wasn't any radiation. As we could guess, the engine doesn't twirl and we measure 0 mA.

On the other hand, it could happen that when placing the shading plate and turning off the bulb, a small voltage could still be detected due to residual light or leaks.

Therefore, if 14 mA were previously detected, now a lower but not null voltage could be detected, however when carrying out the experiment the voltmeter read 0 mA.

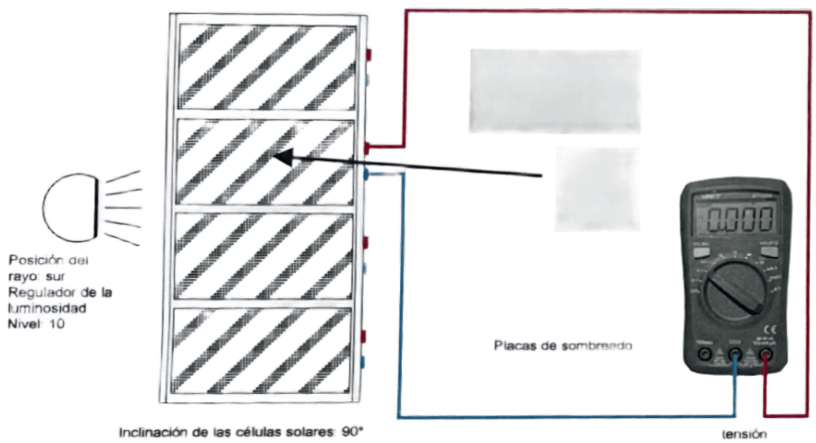
In the D set up (exchanging the wiring) , we also cover the cell but there is radiation, we set the intensity in the higher level (10), but we measured 0 mA.



3.3 Experiment 4

In **experiment 4**, the lamp arm is placed in the South position and the brightness regulator is placed at level 10. The range selection switch of the multimeter as a voltmeter must be set to the V (DC) position (1 V = 1000 mV).

Completely cover the solar cell with the 1/1 shading plate (temporarily set the regulator to 0 for this shading), measure the open circuit voltage and enter the value in the table. Continue with position 10 of the regulator, with half covered, with $\frac{1}{4}$ covered and one uncovered and measure the tension in each case. Enter the measured values in the table and connect the measurement points with lines.



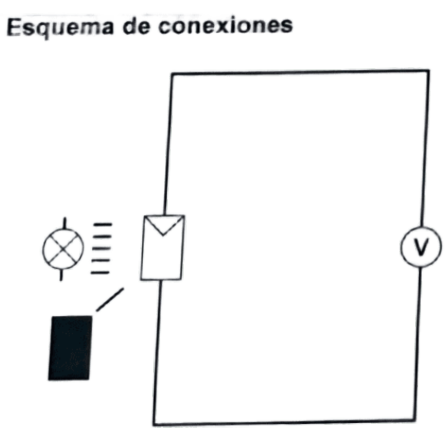


Figure 5: Scheme of experiment 4

Before answering the A question, we need to explain the data that we measured during this experiment. In the first case, we covered all the cell that we were studying, the tension was 0,547V

Then, we covered half of it, and we measured 0,542V.

Next, 3/4 parts of it was covered, and the tension measured was 0,525V.

Lastly, when there wasn't any coverage at all, and we got 0,550V.

We confirm that 0,547V = 54mV

0,525V = 525mV

0,542V = 542mV

0,545V = 550mV

The mV refers to open-circuit voltage.

A: What knowledge is obtained from measurement?

We decided to plot all the previous information to see and analyze the results.

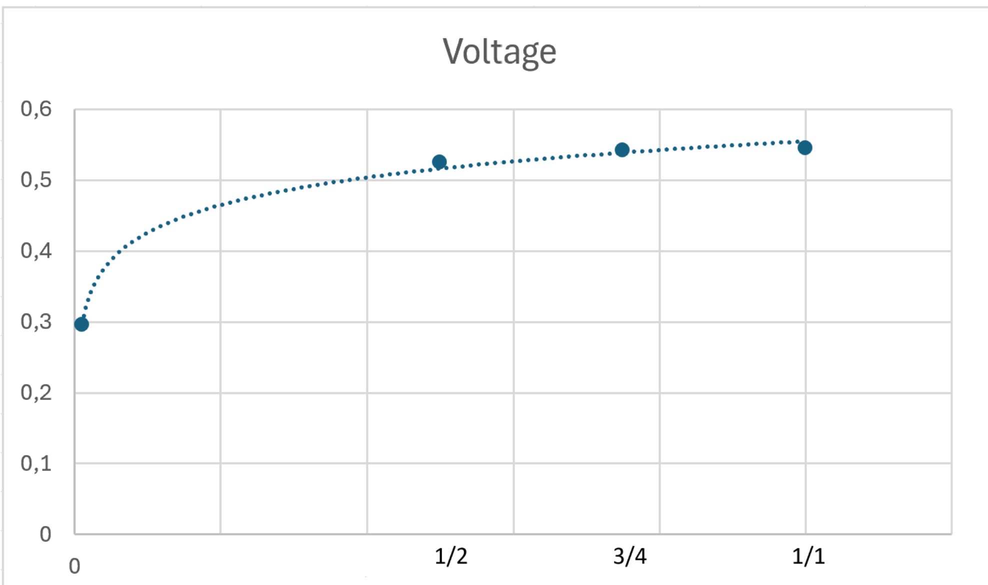
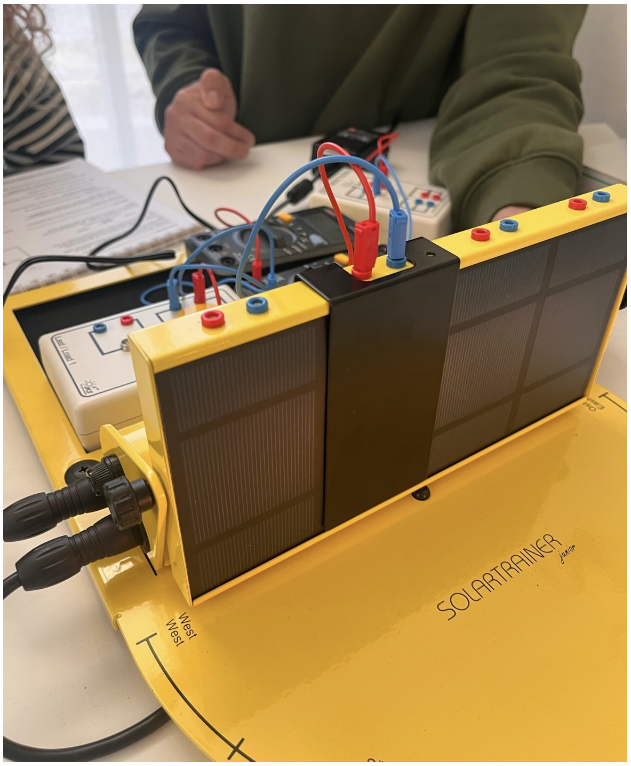


Figure 6: Voltage.

After studying this graph, we confirm that even if a small part of the solar cell receives light, the open-circuit voltage remains similar to the maximum voltage that would be reached if the entire cell were illuminated. This is because the voltage increases logarithmically with the intensity of the light, as seen in the graph, where the trend line that best fits the data is displayed.

In other words, the open-circuit voltage does not increase proportionally with the illuminated surface area but instead quickly reaches a value close to its maximum, even if only a fraction of the cell is exposed to light.

This happens because the open-circuit voltage of a solar cell depends more on the material quality and the potential barrier between the semiconductor layers rather than the total amount of absorbed light. However, if the cell were completely shaded, the voltage would drop significantly.



4 Discussion and Evaluation

- **What are the key steps in the manufacturing of solar cells used in this photovoltaic energy experiment?**

  A solar cell is a PN junction diode used to transform light energy into electrical energy. A diode is a semiconducting electronic element whose conductivity depends on the direction of the current. Thus electric current can only flow in one direction.

  The PN junction is the fundamental structure of solar cells, so there is a p-type material with holes that act as mobile positive charges, and another n-type material with free electrons that act as mobile positive charges. The material in both cases is silicon.

  Electrons from the N side begin to move to the P side, where they combine with holes. This leaves behind fixed charged ions and produces an electric field.

  When light falls on the solar cell, the photons excite electrons, generating electron-hole pairs. The electric field separates these pairs so that the electrons are directed towards the N region and the holes are directed towards the P region. This generates a potential difference that allows obtaining an electric current

- **How does the efficiency of converting solar energy to electricity vary based on the intensity of incident light on the solar cells?**

  The efficiency of conversion of solar energy into electricity in solar cells varies with the intensity of the incident light, but the relationship is not necessarily linear as we have seen in experiment 4 where a logarithmic increase is observed. Even so, it is concluded that the greater the intensity, the greater the current generated, which is why a higher voltage is detected.

Therefore, the greater the intensity of the light incident on the solar cell, the greater the efficiency when converting solar energy into electricity.

- **How does ambient temperature affect the performance of solar cells, and what measures can be taken to optimize their efficiency under various conditions?**

Ambient temperature affects the performance of solar cells in the following way: an increase in temperature decreases the voltage which reduces the efficiency of the light-to-electricity conversion process. However, the current may increase.

To optimize their efficency under various conditions, like high temperatures, we could use materials suitable for the process that have lower thermal absorption to counteract the heat, or the implementation of a cooling system. Likewise, the panels must be located in the optimal direction and inclination and with sufficient space between them.

- **What is a perovskite? What chemical structure does it have? Explain physically why it is such a promising material for photovoltaic cells.**

Perovskite is a mineral whose chemical formula is $CaTiO_3$. It crystallizes with an orthorhombic structure.

In the context of solar cells, perovskite refers to a more general group of crystals with the same structure and with a chemical formula that follows the ABX_3 structure, with A a large cation, B a metal cation, and X an anion. Therefore, an example of this type of materials would be Methylammonium lead iodide $CH_3NH_3PbI_3$, used in solar cells.

Perovskite is a promising material for solar cells since it has a high light absorption coefficient, has high electron and hole mobility, and allows the manufacture of flexible solar cells.