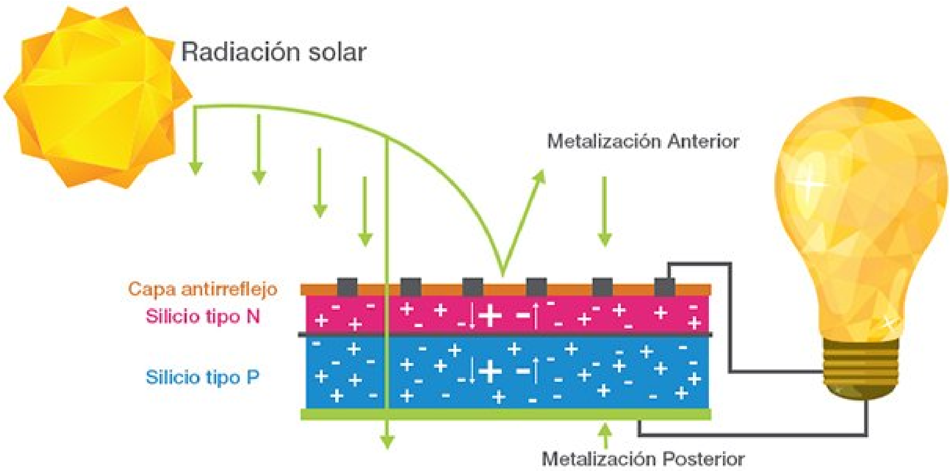
Experiment 3:
Solar Cells



3rd Year of the Degree in Physics

Experimental Project

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1 Introduction

In this experiment we aim to observe the generation of electrical energy by the photovoltaic effect. We will be using a solar cell connected to different kind of electronical equipments so we can see how artificial light brings them energy.

The structure of the document is as follows. First, the theoretical principles behind this experiment will be explained. It will be followed by the experimental procedure and the results with their analysis. Finally, there will be the conclusions of the experiment, and we will answer some questions related to the experiment.

2 Theoretical Fundaments

The phenomenon of photovoltaic energy is described by the theory of semiconductor electronic bands. Electronic bands are a quantum feature of the atomic model. The electronic structure of a single atom consists of an amount of quantified energy levels in which the electrons can travel depending on their kinetic and potential energy.

Therefore, when a great number of atoms bond together, these energy levels are so close to each other that they can be considered as continuous levels. These continuous levels are called energy bands; in a semiconductor, these bands are distinguished according to the Fermi Energy μ_F, which is the highest energy level occupied at 0 kelvin. The energy band below μ_F is called the Valence Band and the one above is the Conduction Band.

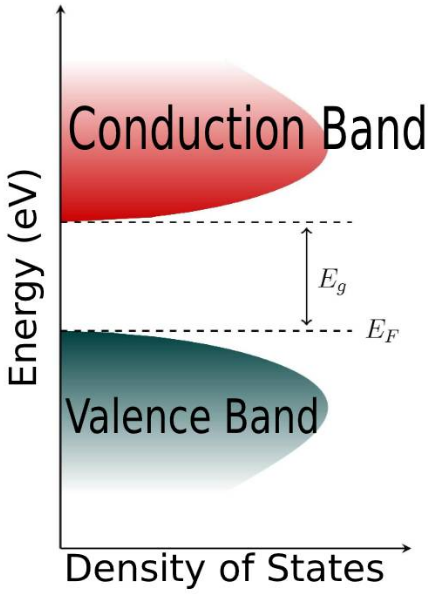

Figure 1: Energy bands of a semiconductor material

The main difference between both bands is the population of holes and electrons, the holes being a quasi-particle that represents an empty electronic state in the valence band and they are positively charged. With this being explained, the photovoltaic phenomenon is produced when a photon excites an electron from the Valence Band; the photon is absorbed and makes the electron promote to the Conduction Band. When this phenomenon of absorption happens with a lot of electrons, it produces an electric current. If the semiconductor is connected to an electronic device, it will provide it with a voltage which will power it up.

3 Experimental Procedure

The material required for this experiment is basically an irradiance device, which can be used to adjust the luminosity and the angle of the light, a grid of photovoltaic cells whose angle towards the light is also variable, and finally a voltmeter, amperemeter and a electric motor.

After connecting and adjusting every parameter and component we need to choose and implement every component needed for each experiment. There are a total of 3 different experiments that require different components for it to work.

Finally, we write down the results and data to obtain conclusions for every experiment.

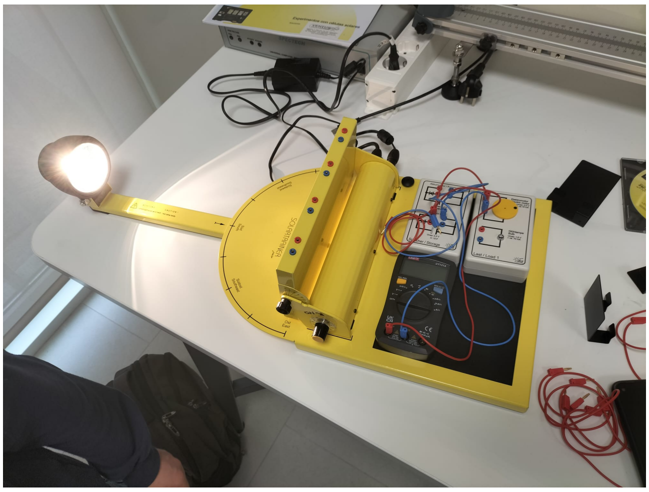

Figure 2: Experimental Set-up

4 Experiment Data and Final Results

4.1 Experiment 1

The experimental conditions for this experiment are described as it follows:

- Irradiation device on south direction.
- Only one photovoltaic cell connected and inclined 0 degrees.
- A motor connected to the cell.

What happens when the polarity of the cables connected to the power cell are changed?

When we change the polarity of the cables the sense of spin of the motor changes. When the cables are connected positive to positive the motor spins clockwise and when are connected positive to negative the motor spins anticlockwise.

Change the intensity of the light and observe the electric motor.

When increasing the intensity of the light the motor spins faster.

Indicate the energy conversions that take place on the solar cell and the electric motor.

Fist the energy of the photons is absorbed by the electrons whose mechanical movement create a current that we describe as electric energy, this current arrives to the motor that transforms that energy into mechanical energy by spinning in some direction.

4.2 Experiment 2

The experimental conditions for this experiment are described as it follows:

- Irradiation device on south direction
- Only one photovoltaic cell connected and inclined 0 degrees

- One pole connecting the solar cell to the battery and the other connecting the solar cell to the motor. The battery and the motor are both connected by one pole to the voltmeter.

At first the solar cell operates without shading plates. What observations can be made?

The amperemeter shows an intensity of current that changes with the light intensity

Now change the conexions to the solar cell. What observations can be made?

Depending on the polarization defined by the cables the motor can spin or not spin as well as the direction of change of the intensity of current can increase or decrease. We think that the reason of the motor not spinning is that the amperemeter serves as a resistence so the intensity that arrives to the motor isn't enough to make the motor spin.

Now repeat the other two experiments but with the shading plate. What observations can be made now?

Due to the low irradiance capacity of the lamp and the little time we had, the plate is not able to get enough current to see the desired effects in the experiment. Although if we had disposed of the resources needed we would see that even after shading the solar cell the system would still run for a short time.

4.3 Experiment 3

The experimental conditions for this experiment are described as it follows:

- Irradiation device on south direction
- Only one photovoltaic cell connected with variable inclination depending on the measure
- The solar cell is only connected to the amperemeter.

Wich relations can be derived between the irradiance angle and the intensity of the current?

Angle (º)	Current (mA)
0	0,02
15	0,44
30	0,98
45	1,28
60	1,42
75	1,5
90	1,52

Table 1: Chart of the measured Current intensity vs Angle of the solar cell

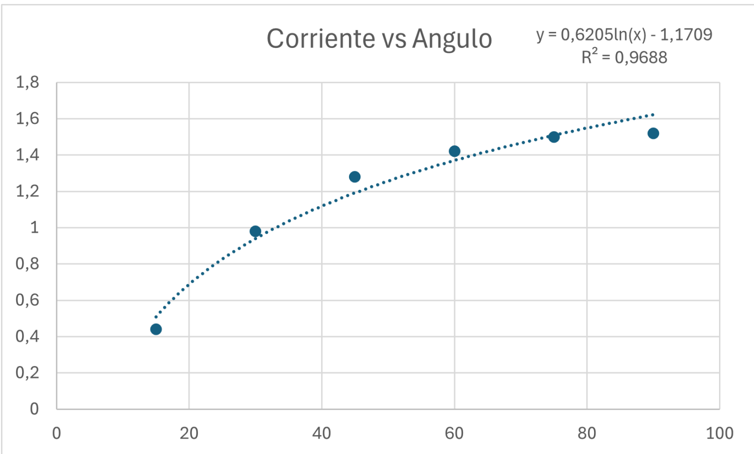

Figure 3: Dispersion plot - Angle (º) vs Current Intensity (mA)

We can see that the relation between the angle and the current is logarithmic.

5 Discussion and Evaluation

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

Solar cell manufacturing begins with extracting and purifying silicon, which is then cut into thin wafers. The wafers are doped to create a p-n junction and coated with an anti-reflective layer. Metal contacts are added, and the cells are encapsulated and assembled into solar panels.

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

When you increase the intensity of light, you are increasing the amount of photons in the beam. This doesn't raise the kinetic energy of the electrons but the number of electrons excited. That will increase the electric current, following Ohm's law $IR = V$ the voltage produced by the light will be higher and the efficiency of the conversion in solar energy will be better.

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

In a semiconductor material, the energy levels of the electronic bands vary with the temperature following the Fermi statistical distribution:

$$f(E) = \frac{1}{1 + e^{\frac{E-E_F}{KT}}} \tag{1}$$

Using this function we can describe the population of electrons,n_o in a semiconductor as:

$$n_o = \int_{E_c}^{\infty} f(E)N(E)dE \tag{2}$$

Where $N(E)$ is the concentration of electrons in the semiconductor. We can see that as the temperature increases, the occupation of states will rise. This results in a greater number of electrons being thermally excited to the conduction band, which affects the electrical properties of the semiconductor, including the efficiency of solar cells.

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

Perovskite is a mineral composed of oxygen, titanium and calcium($CaTiO_3$). It's also a kind of geometrical structures that crystals can follow, that is named after the mineral in which as the name says the atoms are distributed in a cube form. These atoms are placed in the corners, the centre and the centre of the faces.

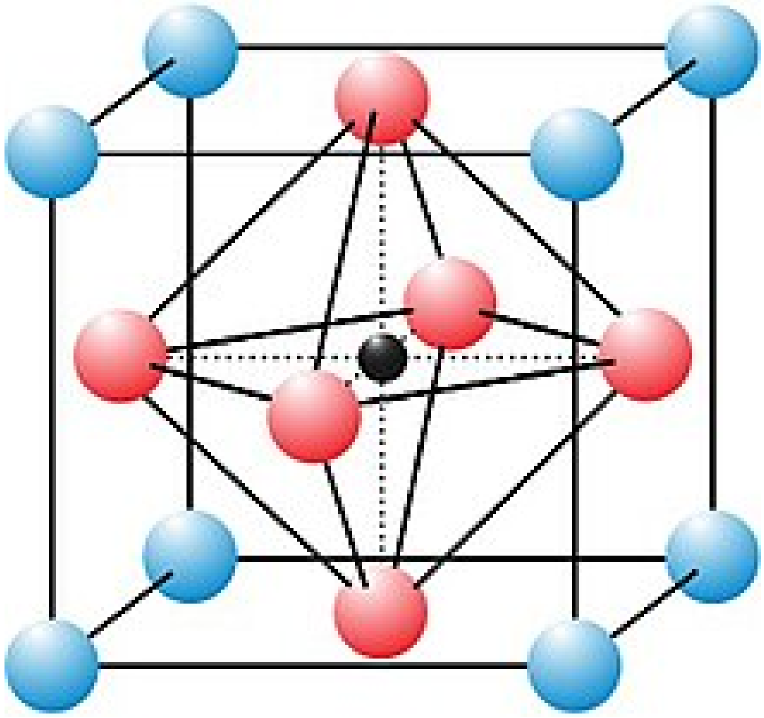

Figure 4: Perovskite structure

This structure has been widely used in the development of solar cells, they have achieved an efficiency of a 26.9% in 2024. Their high efficiency, low cost, and ease of fabrication make them a promising alternative to traditional silicon-based photovoltaic cells.