Solar Cells

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YOUR TASK: You will be given a small solar cell to use in your experiment.

- Design an investigation that utilizes a solar cell to investigate the current or power produced by the solar cell. Be careful to choose an independent variable that is quantitative (measurable). For example, color is not measurable, so it is not acceptable. We can brainstorm some examples of quantitative factors for your IV that you may choose from that affect the DV which is power or current.
- You need to design an experiment that will measure the impact of your independent variable on the power or current of the solar cell.
- Collect and graph data, then produce a full lab report following the MYP Lab Report Guidelines.

R.Q. How does the brightness of a lamp from 50 to 25,600 lux affect the amount of power produced by a solar cell?

1 Introduction

I'll be testing how the brightness of a lamp will impact the amount of power produced by a solar panel. I will also compare this to the amount of light energy being emitted by the lamp to test how the efficiency of the solar cell changes at different brightnesses. I will be testing this by altering the brightness of the lamp and then measuring the power output from the solar panel and calculating the efficiency and whether or not it changes. The maximum possible luminous efficacy is approximately 683 lumens/watt[5]. Using that I can find the efficiency of the solar cell.

1.1 Background research

Photovoltaic (PV) devices, commonly referred to as solar cells, are devices that convert sunlight directly into electricity using the photovoltaic effect. They work by converting the energy coming from the sun into electrical energy. Sunlight is composed of photons, which are particles of solar energy with different amounts of energy depending on the wavelength of the particle. PV cells are made of semiconductor material. When photons hit the PV cell, they can either reflect off, pass through or be absorbed by the semiconductor material. Absorbed photons generate energy that dislodges electrons from the material's atoms. The dislodged electrons can then move towards the surface of the cell, creating an electric current. This current is extracted through conductive metal contacts on the solar cell.[2]

The efficiency of a PV cell is the ratio of electrical power output to the amount of light energy absorbed. The efficiency of a solar cell depends on many different variables, such as the light's intensity, wavelengths, and the properties of the PV cell itself. Though PV technology has evolved significantly, with advancements in materials and manufacturing processes that have led to increased efficiency and decreased costs, most PV cells only have an efficiency of around 30%.[1]

1.2 Hypothesis

I believe that as the brightness of the lamp increases, so will the amount of power being produced by the solar panel. I believe it will follow a fairly linear relationship until at extremely high brightnesses, much brighter than can be produced by a lamp, the panel will start turning the photonic energy into thermal energy into electrical energy due to the materials in the panel not being able to handle the extreme energy. I also believe that the efficiency will be fairly constant except for at low brightness, I think there will be a drop in efficiency, as well as at very high brightnesses, but I doubt that I'd be able to reach these high brightnesses with a lamp. At lower brightnesses, I believe the photons won't carry enough energy to cause the electrons to break free and create an electric current. This is because the electrons won't get enough energy from the photons to cross the bandgap, the amount of energy to free the electrons from the atoms.

2 Method

2.1 Variables

2.1.1 Independent Variable (I.V.)

The brightness of the lamp (lux)

I will measure the brightness of the lamp using a lux meter connected to my laptop. I will change the brightness of the lamp by adjusting the amount of electrical power going to the lamp.

2.1.2 Dependent Variable (D.V.)

The amount of power produced by the solar panel (W)

I will measure the amount of power produced by the solar panel by measuring both the voltage and current produced by the solar panel using an ammeter and a voltmeter. To get the power, I multiply these two values together.

2.1.3 Controlled Variables

Control Variable	Why should it be controlled	How can it be controlled
The color of light produced by the lamp	To avoid accidentally having different colors which could impact efficiency and power produced by the solar cell	Use either the same lamp for all trials and brightnesses or use the same kind of bulb/light source
The source of light (LED vs incandescent)	Different sources of light could contribute to higher or lower solar panel power production because even though they might be the same brightness, they could be producing different wavelengths of light which could impact the amount of electrical power produced by the solar panel.	Use the same lamp for all trials or at least use the same kind of light source, either use just LEDs or incandescent bulbs
The distance of the lamp from the solar panel	Different distance would mean different amounts of light are directed at the panel, meaning a different power output	Keep the lamp a set distance from the solar panel (0.1m)
Size of solar panel	Different sized solar panels would be able to produce different amounts of electrical energy which would impact results	Either use the same solar panel for each trial or use the same sized panel (17cm by 30cm or $0.051m^2$)
The environment the experiment is conducted in	Different brightnesses in the environment could impact power being produced	Conduct all the trials in the same environment

2.2 Safety precautions

- Avoid shining light directly into eyes
- Keep solar cell clean

2.3 Materials

- 1 Solar Cell (Approximately 15cm by 30cm)
- 1 Ammeter
- 1 Voltmeter
- 1 Lamp with brightness control (Single incandescent bulb)
- 1 Lux meter (Capable of measuring up to approximately 30,000 lux)
- 4 Wires

2.4 Procedure

1. Set the lamp 0.1 meters away from the solar cell
2. Point the lamp at the solar cell
3. Turn on the lamp and measure the brightness using the lux meter
4. Measure the power being produced by the solar cell using the voltmeter and ammeter
5. Repeat for 9 other brightnesses, or until reach brightest lamp setting, doubling the brightness each time

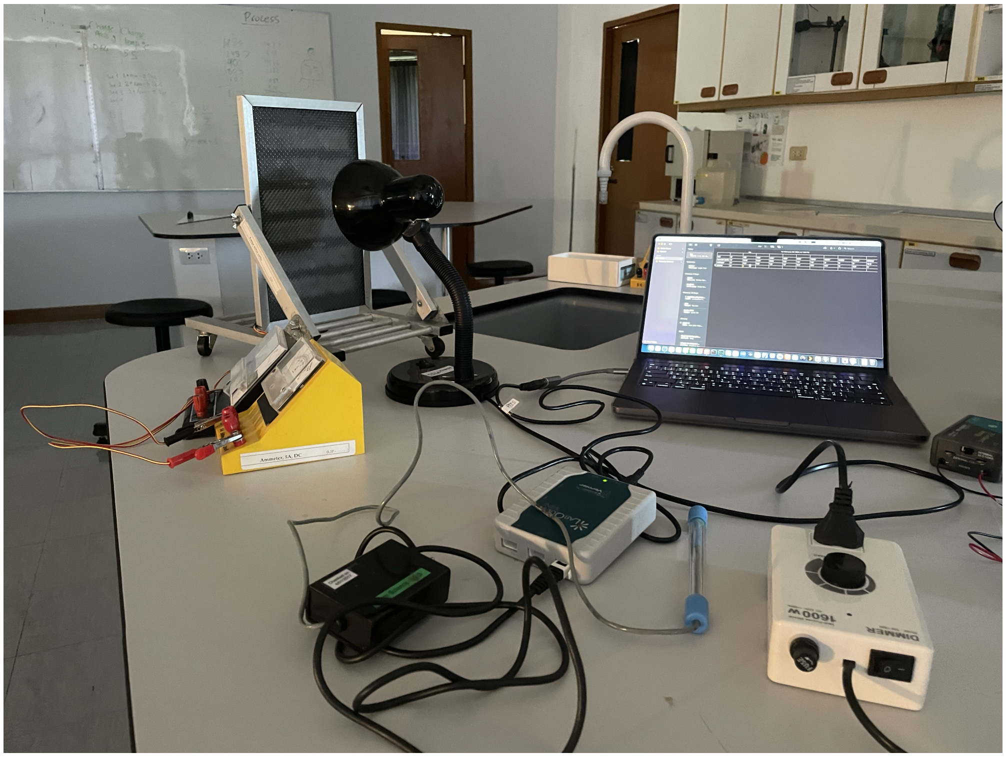


Figure 1: Example of setup used

3 Results

3.1 Raw data

Raw data collection - Trial 1

I.V. - Brightness (lx)	0	50	100	200	400	800	1600	3200	6400	12800	25600
D.V. - Current (mA)	0	0.12	0.22	0.51	0.78	1.2	1.9	3.8	5.1	8.2	12.3
D.V. - Voltage (V)	0	0.42	0.51	1.2	1.6	2.4	3.5	4.5	4.9	5.5	5.8

Raw data collection - Trial 2

I.V. - Brightness (lx)	0	50	100	200	400	800	1600	3200	6400	12800	25600
D.V. - Current (mA)	0	0.1	0.21	0.51	0.75	1.2	1.9	3.8	5.1	8.2	12.6
D.V. - Voltage (V)	0	0.4	0.51	1.3	1.5	2.4	3.6	4	5	5.4	6.2

Raw data collection - Trial 3

I.V. - Brightness (lx)	0	50	100	200	400	800	1600	3200	6400	12800	25600
D.V. - Current (mA)	0	0.14	0.2	0.52	0.87	1.1	1.8	3.8	4.8	7.6	12.6
D.V. - Voltage (V)	0	0.38	0.48	1.1	1.8	2.3	3.7	4.5	5.1	5.6	6

3.2 Calculations

To calculate the power that is being produced by the solar panel, we use the formula for electrical power:

$$P = IV$$

Where P is the power, I is the current, and V is the voltage. To then get the power, we simply multiply the current by the voltage to get the power in watts. Using the 25,600 lux case as an example, we first convert the current in mA into amps by multiplying the 12.5 mA by $\frac{1}{1000}$ which gives 0.0125. The voltage at 25,600 lux was 6V, so then using the formula:

$$\begin{aligned} P &= IV \\ P &= (0.0125)(6) \\ P &= 0.075W \end{aligned}$$

So we get the at 25,600 lux, the solar panel was producing 0.075 watts of power.

To get efficiency, we can use the formula:

$$Efficiency = \frac{E_{out}}{E_{in}}$$

Where E_{out} is the energy output, and E_{in} is the energy in. We already know the power out from the previous calculation. We can get the power in as it's the power of the light going into the solar panel, which can be calculated by first taking the lux being produced by the light and converting it into lumen. The formula for this is[3]:

$$Lumens = Lux \cdot m^2$$

Where m^2 represents the amount of area the light is hitting, which I'll be using the area of the solar panel for, $0.051m^2$. To convert 25,600 lux to lumens:

$$\begin{aligned} Lumens &= Lux \cdot m^2 \\ Lumens &= (25,600)(0.051) \\ Lumens &= 1305.6lm \end{aligned}$$

To then get efficiency, we must divide the power of the light by the power being produced by the solar panel. To get the power of the light, we can use the formula[4]:

$$Power = \frac{Luminosity}{\eta}$$

Where η is the luminous efficacy, which is how much power there is per lumen. The maximum possible luminous efficacy is 683 lumens/watt. Using 25,600 lux as an example:

$$Power = \frac{Luminosity}{\eta}$$
$$Power = \frac{1305.6}{683}$$
$$Power = 1.91W$$

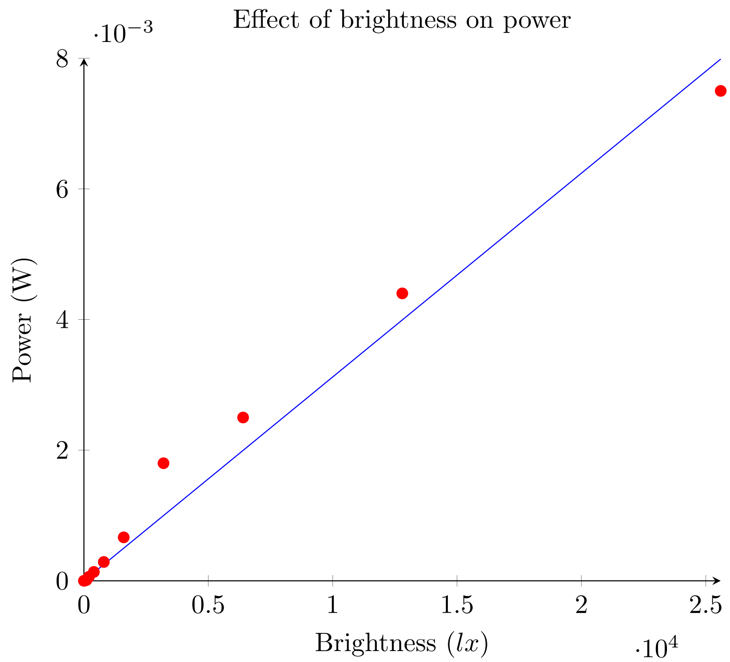
To finally get the efficiency:

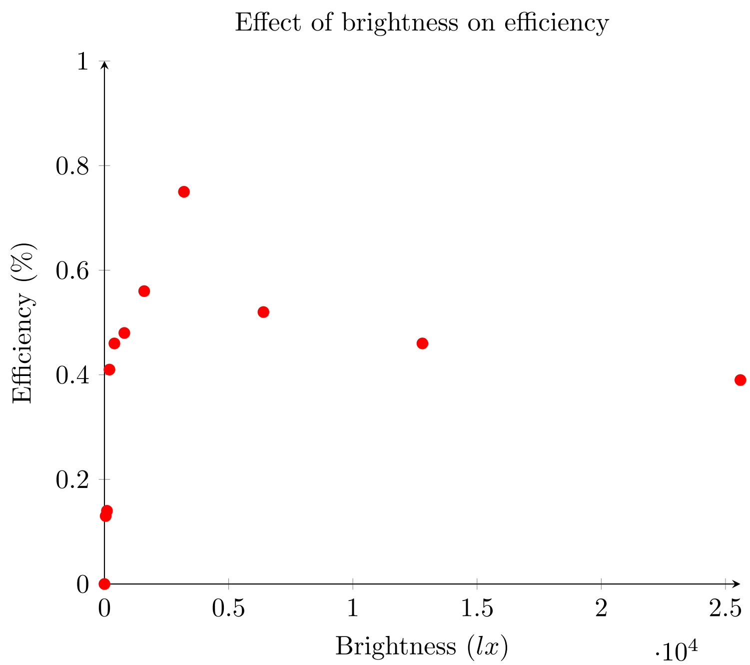
$$Efficiency = \frac{E_{out}}{E_{in}}$$
$$Efficiency = \frac{0.0075}{1.91}$$
$$Efficiency = 0.39\%$$

3.3 Processed data

Processed data table

Brightness (lx)	Current (mA)	Voltage (V)	Power (W)	Lumen (lm)	Power from light (W)	Efficiency
0	0	0	0	0	0	0.00%
50	0.12	0.4	$4.8 \cdot 10^{-6}$	2.55	0.0037	0.13%
100	0.21	0.5	$1.1 \cdot 10^{-5}$	5.1	0.0075	0.14%
200	0.51	1.2	$6.1 \cdot 10^{-5}$	10.2	0.015	0.41%
400	0.8	1.7	$1.4 \cdot 10^{-4}$	20.4	0.030	0.46%
800	1.2	2.4	$2.9 \cdot 10^{-4}$	40.8	0.060	0.48%
1600	1.9	3.5	$6.7 \cdot 10^{-4}$	81.6	0.120	0.56%
3200	4	4.5	$1.8 \cdot 10^{-3}$	163.2	0.239	0.75%
6400	5	5	$2.5 \cdot 10^{-3}$	326.4	0.478	0.52%
12800	8	5.5	$4.4 \cdot 10^{-3}$	652.8	0.956	0.46%
25600	12.5	6	$7.5 \cdot 10^{-3}$	1305.6	1.912	0.39%





4 Discussion

From my data, I can see that as the brightness increases, so does the power being produced by the solar panel. This is because as more energy from the photons hit the solar cells, more electrons are able to be freed, adding to the electrical power being produced by the panel. However, the data I received for the efficiency of the panel doesn't seem to follow any sort of trend. There appears to be a peak at around 3200 lux. I believe this is due to the fact the as the brightness of the lamp increased, more and more of the light that being was being produced by the lamp wasn't directed at the solar panel and didn't hit the solar panel. I tried to minimize this by having my lamp fairly close to the panel, only 10cm apart, but some light was still able to miss the panel and not contribute to the power produced by the panel.

There does appear to be a linear relationship between the brightness of the lamp and the power produced by the panel. This is expected because as the lux increases, more photonic energy is reaching the panel which means more energy that can be converted to electrical power. At low brightnesses, the efficiency of the panel is quite low as there isn't enough energy in the photons that reach the panel to free electrons, to be converted into electrical power. The efficiency of the panel decreases as higher brightnesses due to the fact that most of the light isn't directly hitting the panel and instead goes in other directions.

5 Evaluation

Weakness/limitation	Impact on result	Suggested improvement
A lot of the light being produced by the lamp wasn't directly hitting the panel	Impacted the efficiency of the system, more energy was being lost and less power was able to be produced by the solar panel	Either use a larger panel that could have all the light directed towards it, use a light source that was more directed, or have the light source even closer to the panel
Hard to get exact lux values, would fluctuate	Made it hard to get exact lux values, meaning values could fluctuate more and hard to get exact results	Do more trials to try and remove fluctuations and inaccuracies from results
Environmental factors, such as light from other sources could impact results slightly	Could vary results, leading to inaccurate results.	Do experiment in a more controlled environment where other sources of light can't impact results

6 Conclusion

In conclusion, as the brightness of the lamp increases, so does the amount of power being produced by the solar panel. This supports my original hypothesis *"I believe that as the brightness of the lamp increases, so will the amount of power being produced by the solar panel. I believe it will follow a fairly linear relationship."* My results answer my research question *"How does the brightness of the lamp affect the amount of power produced by the solar cell?"* as they show a correlation between the brightness of the lamp and the amount of power being produced by the solar panel. My results show a near-linear relationship between the two, as the brightness of the lamp increases so will the amount of power being produced by the solar panel.

The amount of photonic power is proportional to the amount of power being produced by the solar panel, meaning that as the amount of photonic power, or brightness of the lamp increases, so will the amount of the energy and power that's going into the material of the solar panel or cells. As more photonic energy goes into the panel, more electrons can be freed, meaning more energy is converted into electrical energy, meaning more electrical power. This agrees with my test results. As the brightness of the lamp increased, so did the amount of power being produced by the solar panel.

However, my test results don't support my hypothesis regarding the efficiency of the solar panel. From my test results, there seems to be a peak at 3200 lux, and then slowly decreases from there. I believe this is due to the light not completely hitting the solar panel, with lots of light not being directed exactly at the panel. However, the first part of my hypothesis was correct, that the efficiency would drop at low brightnesses as the photons wouldn't have enough energy to dislodge the electrons in the material of the solar cell to create an electrical current.

These results show that to get the most optimal production of electrical power, one has to set up the solar panels so that they are receiving the most efficient amount of light per solar panel and maximizing the amount of photonic energy that can be turned into electrical power. Maximizing brightness would be ideal as it allows the panels to produce more electrical power. However, using lenses to spread out or direct the photonic energy to maximize the efficiency of all the panels could mean the least energy lost which could also be useful in some use cases such as where photonic energy isn't widely available, though this case is not likely use case on Earth.

References

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