International Baccalaureate

PHYSICS EXTENDED ESSAY

How does the panel angle of solar panel affect the voltage output?

Word Count: 3000

1. Introduction

Solar panels are one of the most important ways for generating renewable energy. Solar panels convert the energy in the sunlight into electrical energy which everyone uses in their daily lives. Starting from the simplest lightbulb in houses into charging phones and laptops require electricity. More common ways of generating electricity generally produces harmful gasses and pollutants which is slowly but surely corrupting and poisoning our planet. To prevent this, renewable energy like solar panels must replace the current ways of generating energy. Although solar panels are a great invention to produce renewable energy, they need special set ups to work properly and there are situations where they work less efficiently. In this investigation the effect of solar panel angle to the generated electricity in voltages will be examined to determine the conditions to achieve more electricity through solar panels.

During my childhood years, my family and I went on trips often. In one of our trips, I saw a huge amounts of solar panels in a field. I was interested in how a couple of blue panels turned sunlight into electricity we used. Later I experimented with solar panels in sciences classes during science projects. I also learned how they placed these solar panels in different orientations and angles. I thought about how this change in panel angle would affect the product of solar panels as sunlight energy can change if it hits the surface in different angles. These memories pushed me into investigating solar panels and in this study I aim to find how the panel angle of solar panels affect the produced electricity of solar panels.

2. Background Information

2.1 Solar Panels

Solar panel is a device that uses sunlight to produce electricity by using photovoltaic (PV) cells. Photovoltaic cells are made of materials that produce excited electrons when exposed to light. These excited electrons then flow through a circuit to produce direct current electricity. This direct current electricity then can be used to power devices or stored in batteries.

Solar panels are used for a source of more environmentally friendly energy source as they provide lower electricity bills for households and reduce greenhouse gases in the air. On the other hand, they have some dependances like the availability of sunlight of having high initial costs. Solar panels are widely used around the world in many areas because of these advantages.

2.2 Construction of solar panels

Solar panels contain photovoltaic modules in them. Photovoltaic modules contain many solar cells and use photon from the sunlight to create electricity using this photovoltaic effect. Usually, modules use crystalline silicon cells which is water based or thin film cells. Cells must be protected from mechanical damage and moisture. These cells are generally connected electrically in series one to another to the desired voltage, and then connected in parallels to increase current. The power of the module overall is calculated by multiplying the voltage with the current and power depends on the electrical load and the amount of light the module is receiving. One solar module is only capable of producing little electricity by itself. For that reason, most installations have multiple modules connected to each other to add up their currents and voltage.

2.3 Placement of Solar panels

There are several placement techniques used for solar panels depending on the intended usage or the space available. One of the placement techniques is ground placement. In this way the solar panel is directly set on the ground through foundation or poles and the electric connection is usually made underground. This type of placement is usually preferred in large scale set ups where all solar panels are connected together.

Apart from placements, there is also portable solar panels available. These portable solar panels can be set up anywhere with sunlight but provide enough current to charge devices. This type of solar panel is made for travels where city electricity is inaccessible.

2.4 Energy in solar panels

As mentioned before, solar panels generate electricity by absorbing sunlight. The amount of light absorbed by solar panels depends on the angle of incidence of the sunlight that hits the surface of the solar panel. This is partly because the number of photons that hit the surface of solar panel increase as the angle of sunlight gets closer to perpendicular. To maximize the output, modules are oriented in different directions depending on where it is in the world. This change is south in the Northern Hemisphere and north in the Southern Hemisphere. There is another technology named solar tracking that moves the solar panel in the direction of the sun but that is not considered in this investigation. Solar panels are often coated with an anti-reflecting coating for the same goal of maximizing the output. Anti-reflecting coating absorbs more light thus increasing the output.

In terms of current, Solar modules have inverters that convert direct current (DC) into alternating current (AC). Maximum power point (MPP) of the solar panel includes MPP voltage and MPP current. Performing maximum power point tracking, a solar inverter samples the output (I-V curve) from the solar cell and applies the proper electrical load to obtain the maximum power.

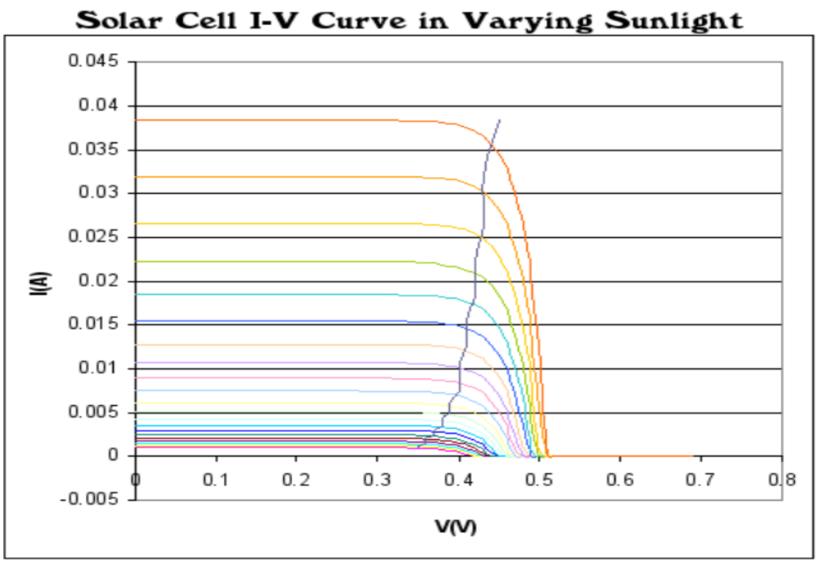

Figure 1: Graph of the solar cell I-V curve in varying sunlight

2.5 Solar module interconnections

Solar module electrical connections are made with conducting wires that take the current off the modules and sized accordingly to the current it is carrying. Solar panels are normally connected in series of one or more panels to form strings of modules to achieve a desired output voltage, and these strings of modules can be connected in parallels to provide the desired current capability of the system. In string connections, the voltages of the modules add but the current is determined by the lowest performing module in the string. This is also known as the "Christmas light effect". In parallel connections the voltages will be the same, but the currents will add up. ("Solar Panel")

2.6 Efficiency of Solar Panels

Each module of solar panels is rated by its direct current output power under standard test conditions so the on-field output may vary. Output power usually ranges from 100 to 365 Watts. The efficiency of a module determines the area of a module given the same rated output. For example, a 10% efficient 200W module will have twice the area of a 20% efficient 200W module. Some commercially available solar modules exceed 24% efficiency. Currently, the best achieved solar module efficiency is around 21.5% in new commercial products typically lower than the efficiencies of their cells in isolation. ("Solar Panel")

3. Methodology

To do the experiment, I bought a small solar panel and started planning the experiment. The experiment is planned to be done at exactly midday to achieve better results. The trials will be done in a 30-minute time interval to get better data as the sun will rotate throughout the day. So, the data is collected according to this plan.

3.1 Hypothesis

As stated before, I will investigate the change in solar panel outcome depending on the angle of the sunlight incoming to the solar panel. According to my background information and research, I predict the bigger angle to produce the most electricity because the energy sunlight gives more energy when the angle it hits a surface is 90 degrees. I am expecting my experiment to match my hypothesis.

3.2 Variables

Independent Variable	Dependent Variable
Solar Panel Angle (30, 40, 50, 60, 70degrees)	Solar Panel Output (generated electricity in voltages)

Table1: Independent and Dependent variables

Controlled Variables	Method of Control
Sunlight Angle	The experiment will be done in a short time interval so the sunlight angle will be constant change.
Atmospheric Absorption	Atmospheric Absorption will be constant in the simulation
Sunlight intensity	Sunlight intensity is constant in the simulation
Placement of solar panel	The solar panel won't be moved during the experiment
Environment around the solar panel	The area around the solar panel will stay the same throughout the experiment.

Table2: Controlled variables and method of control

3.3 Materials

- Solar panel
- Protractor ($\pm$ 0.5 degrees)
- Support handles for solar panel
- Voltmeter ($\pm$ 0.01 volts)
- Cables

3.4 Procedure

1) Place the solar panel in solid ground where all parts of the solar panel will get sunlight.
2) Use the protractor to set the solar panel to desired angle.

3) Record the current with voltmeter after waiting one minute.

4) Do this for five minutes and total of 5 trials.

5) Repeat for other variables.

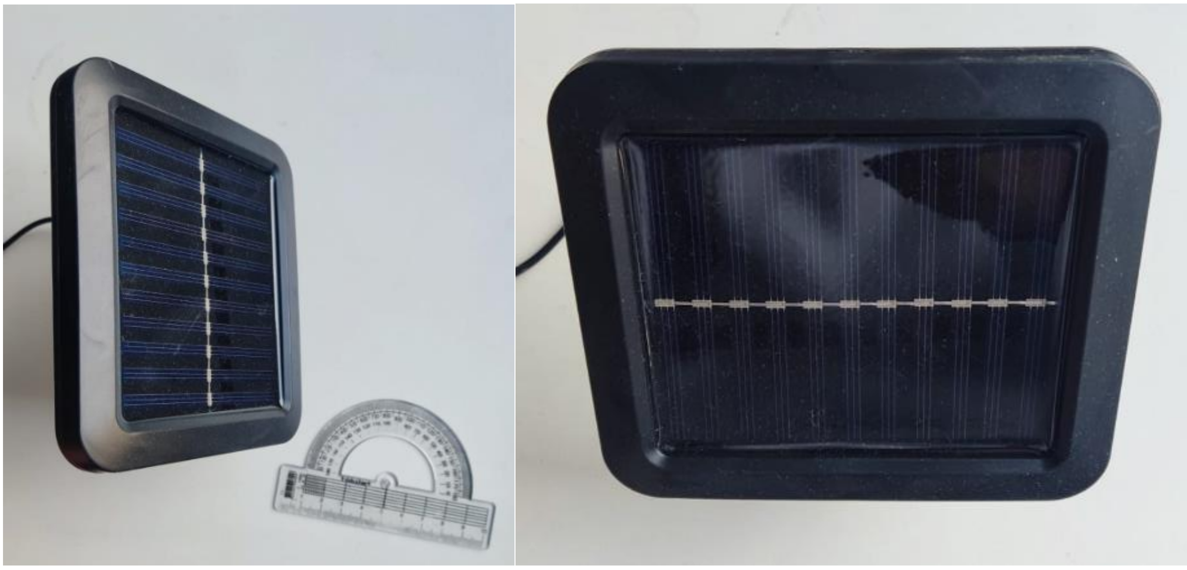

Figure2: Photo of the solar panel used in the experiment

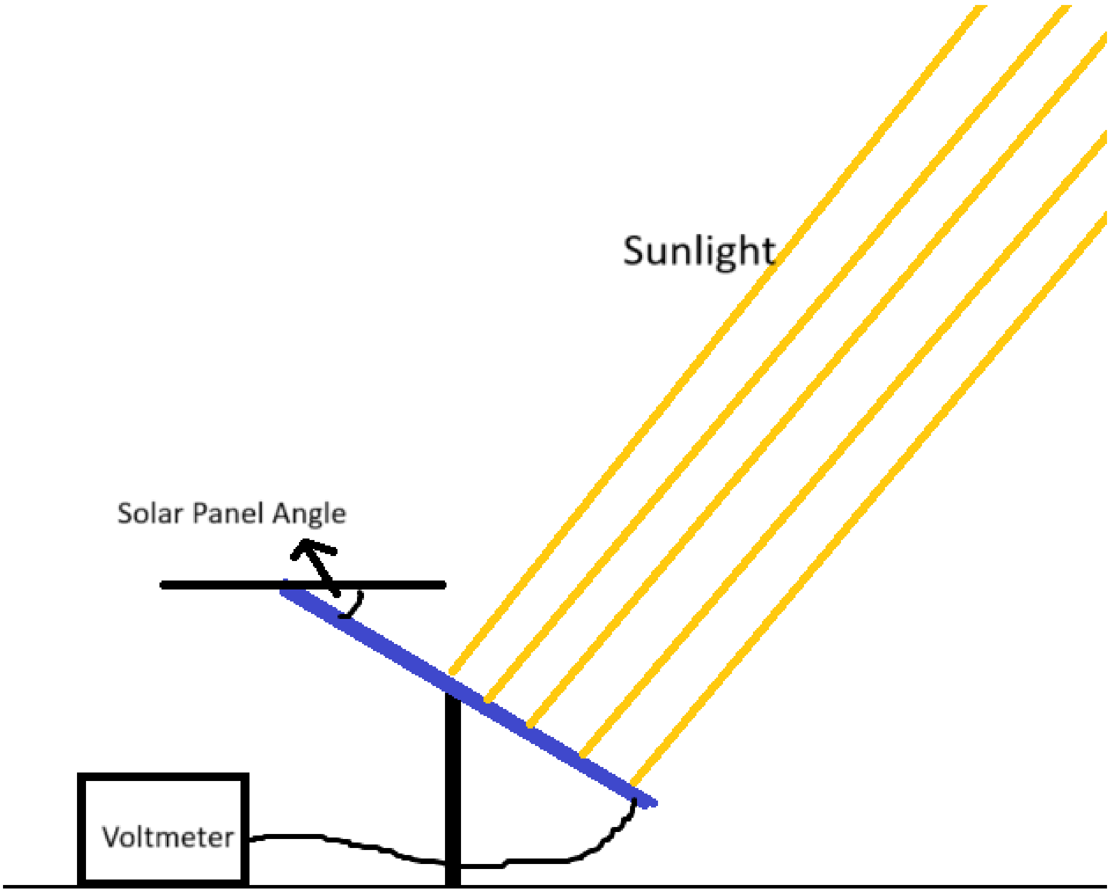

Figure3: Figure of the experiment

3.5 Safety, Environmental and Ethical Issues

This experiment has no safety and environmental issues as the experiment is safe and the equipment used can't harm the environment. The solar panel or voltmeter can't harm anyone during the experiment as a small solar panel won't produce a lethal current. The equipment used in the experiment also can't harm the environment as solar panels don't contain pollutants or have any features that can harm the environment in any way. This experiment also doesn't have any ethical issues as it is completely safe and doesn't concern the wellbeing of any organisms.

4. Data and Analysis

4.1 Raw Data Table

Angles ($\pm$0.5 degrees)	70.0 ($\pm$0.5)	60.0 ($\pm$0.5)	50.0 ($\pm$0.5)	40.0 ($\pm$0.5)	30.0 ($\pm$0.5)
Trial 1 (V) ($\pm$0.01)	0.91	1.05	1.15	1.06	0.93
Trial 2 (V) ($\pm$0.01)	0.92	1.03	1.17	1.04	0.89
Trial 3 (V) ($\pm$0.01)	0.88	0.98	1.18	1.01	0.92
Trial 4 (V) ($\pm$0.01)	0.92	1.04	1.19	0.99	0.93
Trial 5 (V) ($\pm$0.01)	0.93	1.02	1.16	1.03	0.90

Table3: Table of the angle and the output voltage data values of the experiment

Before making the graph of the data I decided to get the means of each variable as it will be clearer in the graph, and it will be easier to analyze. So, I added up all 5 trials and created a new table.

Angle (degrees) ($\pm$0.5)	70 ($\pm$0.5)	60 ($\pm$0.5)	50 ($\pm$0.5)	40 ($\pm$0.5)	30 ($\pm$0.5)
Mean of trials (V) ($\pm$0.05)	0.912	1.024	1.17	1.026	0.914

Table4: Table of means of voltage output values

The uncertainty of the means of trials are calculated as $\pm$0.05 because when the means are calculated all the respective trials were added up so the uncertainties are also added up to $\pm$0.05.

After calculating the means and creating the new table, I decided to create a graph from the means. This graph is created in the program LoggerPro3. The link to the site is https://www.vernier.com/downloads/logger-pro-demo/ . The graph will allow me to analyze and comment on the data.

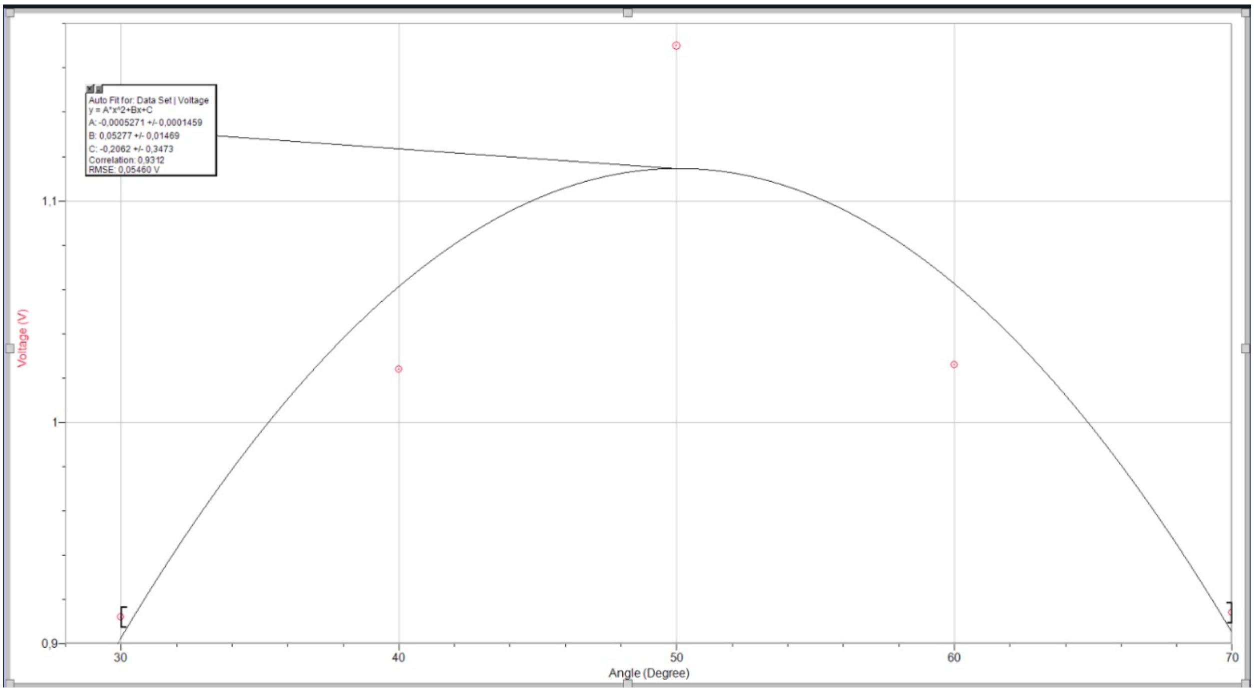

Figure4: Graph of angle versus mean voltage output with best curve fit

4.2 Analysis

It is seen on the graph that the generated electricity is at its peak at 50 degrees, and the fit curve for the data is quadratic and the values are close to each other at 60 and 40 degrees, and at 70 and 30 degrees. This quadratic relationship shows that 50 degrees is the best angle for the solar panel in these conditions. The values that are equally distant from 50 degrees being nearly equal states that in this experiment means that at 50 degrees solar panel will have the peak value and the generated electricity will decrease as the solar panel angle changes from 50 degrees. To investigate this, there are figures created to examine the situation of the solar panel better. The first figure is the figure of the 50-degree solar panel angle.

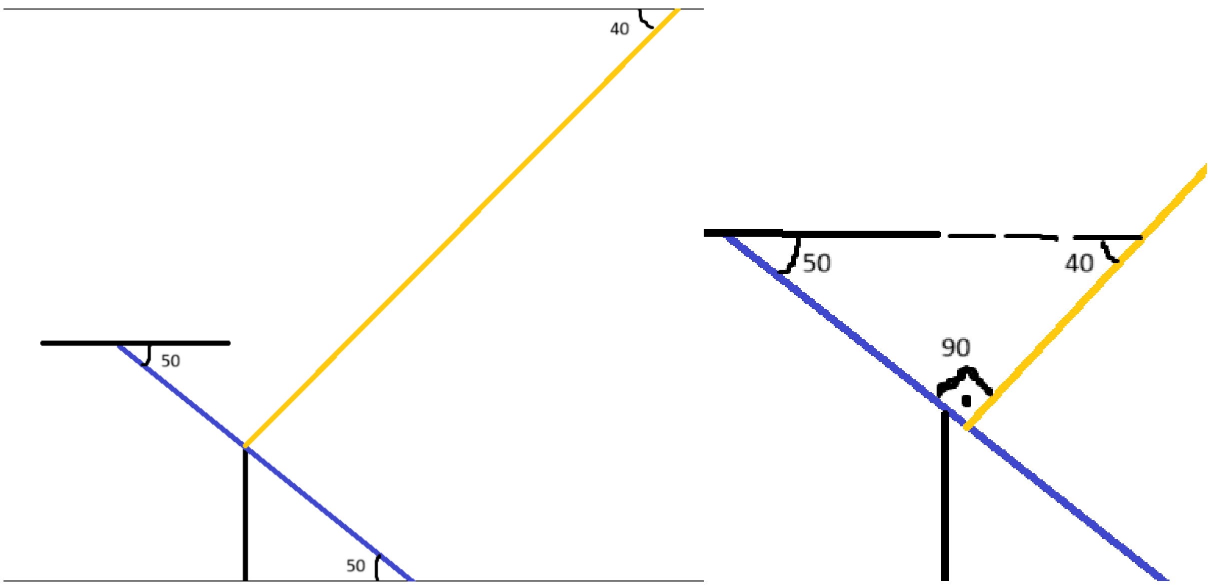

Figure5: Figure of the variable 50 degrees and its examination with sunlight angle

In this figure it is clearly seen that the 50-degree solar panel angle gives the most voltage output because the solar panel makes a 90-degree angle with the sunlight that hits the panel directly. This is because the sunlight in the examination area is known to have a 40-degree angle of sunlight. So, with this information the both angles were carried into an imaginary triangle and found out that the point where the sunlight hits the solar panel is 90 degrees. As stated in the background information the solar panel produces most electricity when the angle of incidence is zero which in this case means that the sunlight hitting the solar panel perpendicularly. Then the next part of the investigation was to examine why the degree values that are equally separated from the angle 50 had very similar voltage outputs. So, I made more figures for 60 and 40 degree variables.

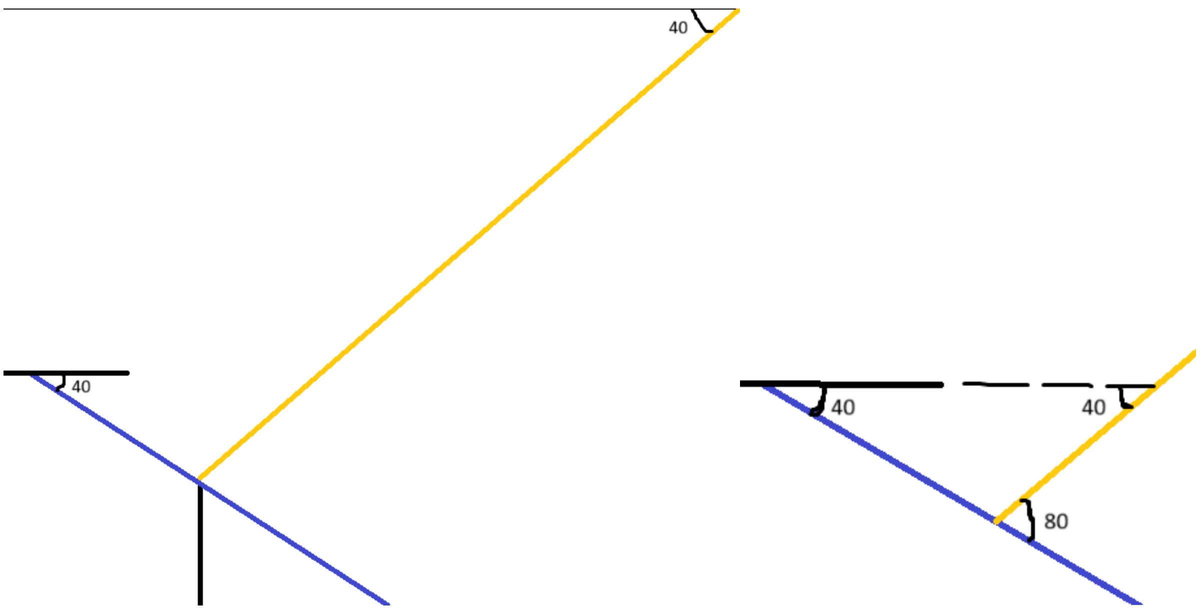

Figure6: Figure of the variable 40 degrees and its examination with sunlight angle

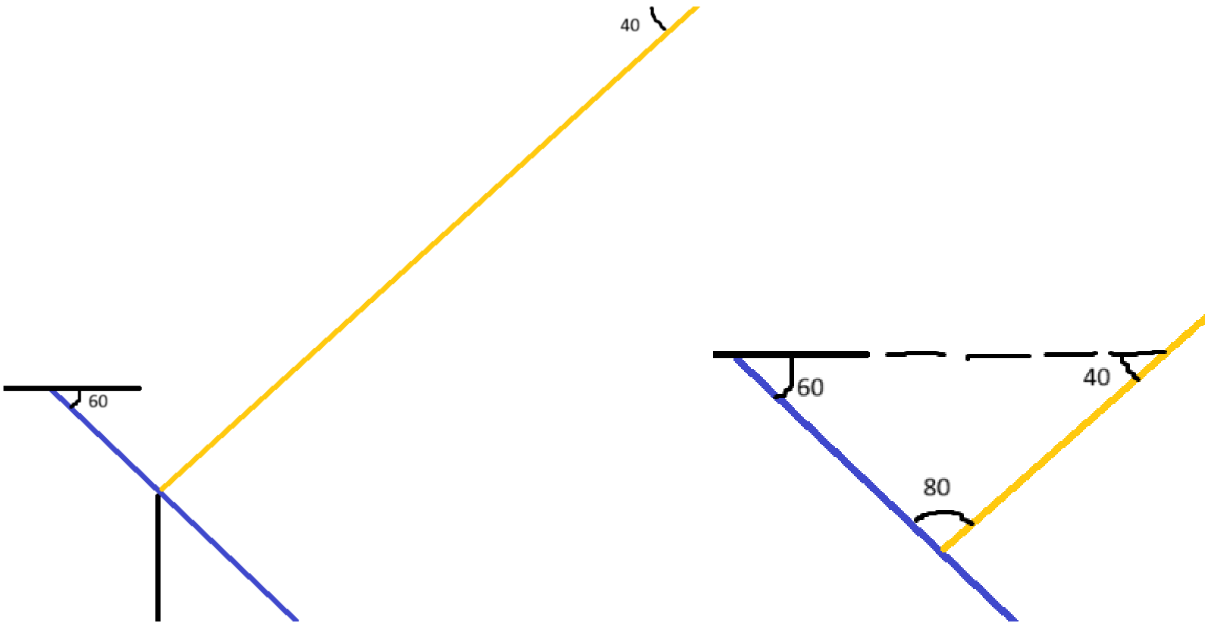

Figure7: Figure of the variable 60 degrees and its examination with sunlight angle

As I made these figures, I realized that I should examine the angles like I did with the 50-degree angle. So, I carried the angles into an imaginary triangle like before and found out that both angles have the same angle of incidence. This is because different angles make up to the same angle of incidence from opposite sides. The output of solar panels doesn’t change based on the side of the angle of incidence, so it is similar values. After this examination I decided to verify my results by investigating the remaining two variables with figures.

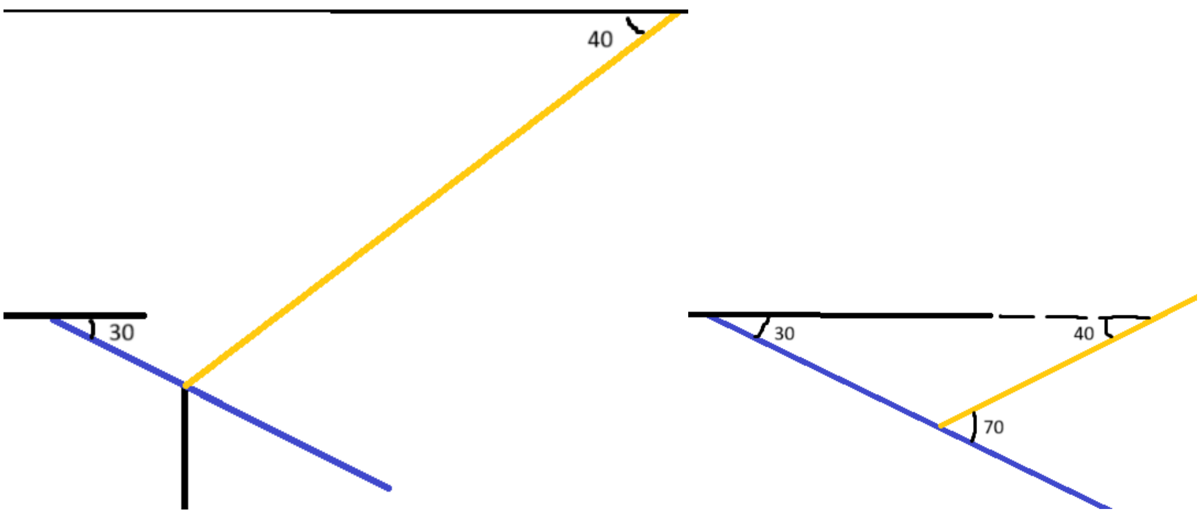

Figure8: Figure of the variable 30 degrees and its examination with sunlight angle

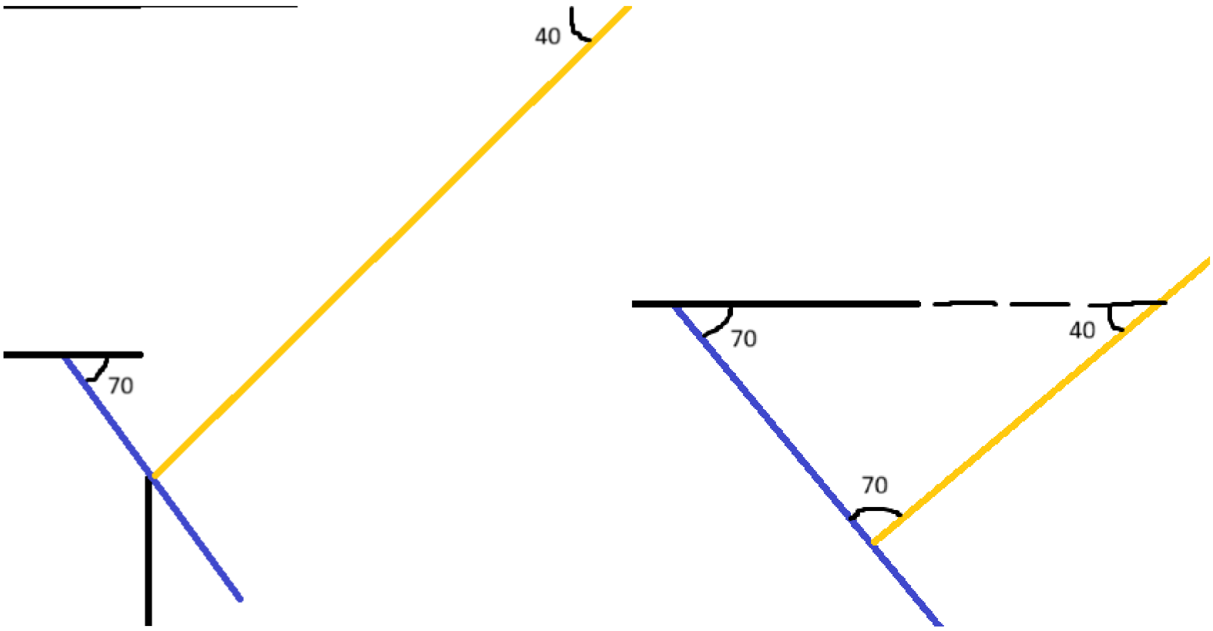

Figure9: Figure of the variable 70 degrees and its examination with sunlight angle

The results of these last two figures are parallel to my results from before. The variables 70 and 30 degrees have the same angle of incidence from opposite sides. So, these variables produce very similar results. And this examination overall proves my hypothesis was wrong. My hypothesis was false because I assumed that the electricity generated would increase as the angle of solar panel decreased because I thought more the solar panel was directed to the sky the more near perpendicular the sunlight will come. The experiment falsified my hypothesis by showing that the angle of incidence was also connected the angle of sunlight.

5. Further Investigation

To have a better understanding of the topic and further investigate my experiment, I planned to use a simulator to recreate my experiment with more scientific data. I found a simulator online for this purpose. The simulator I used is at the site https://archive.manylabs.org/lesson/124/solarPanelSimulation/ . I aim to use this simulator to examine the experiment better and back up the results.

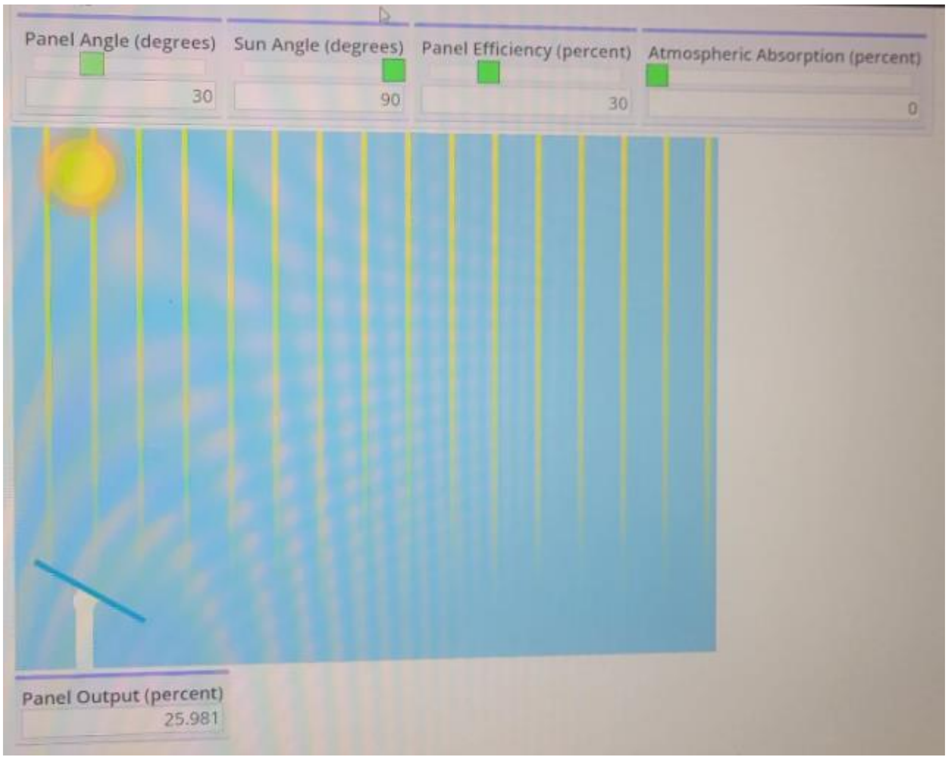

Figure10: Photo of the simulation

The variables in this simulation will be the same as the variables in the main experiment. So, the angle of sunlight will be set to 40 and the solar panel angle will be shifted through 70, 60, 50, 40 and 30 while all other available variables stay constant. Although using the same variables, the simulation gives only one output per variable so there will be only 5. The simulation doesn't have uncertainty so the table wont also have uncertainty.

Angle	70	60	50	40	30
Output voltage of solar panel	26.016	27.670	30.230	27.670	26.016

Table5: Table of voltage output data from the simulation

After obtaining these data from the simulator, I made a graph like the main experiment with LoggerPro to compare both graphs on how they shape to verify the results.

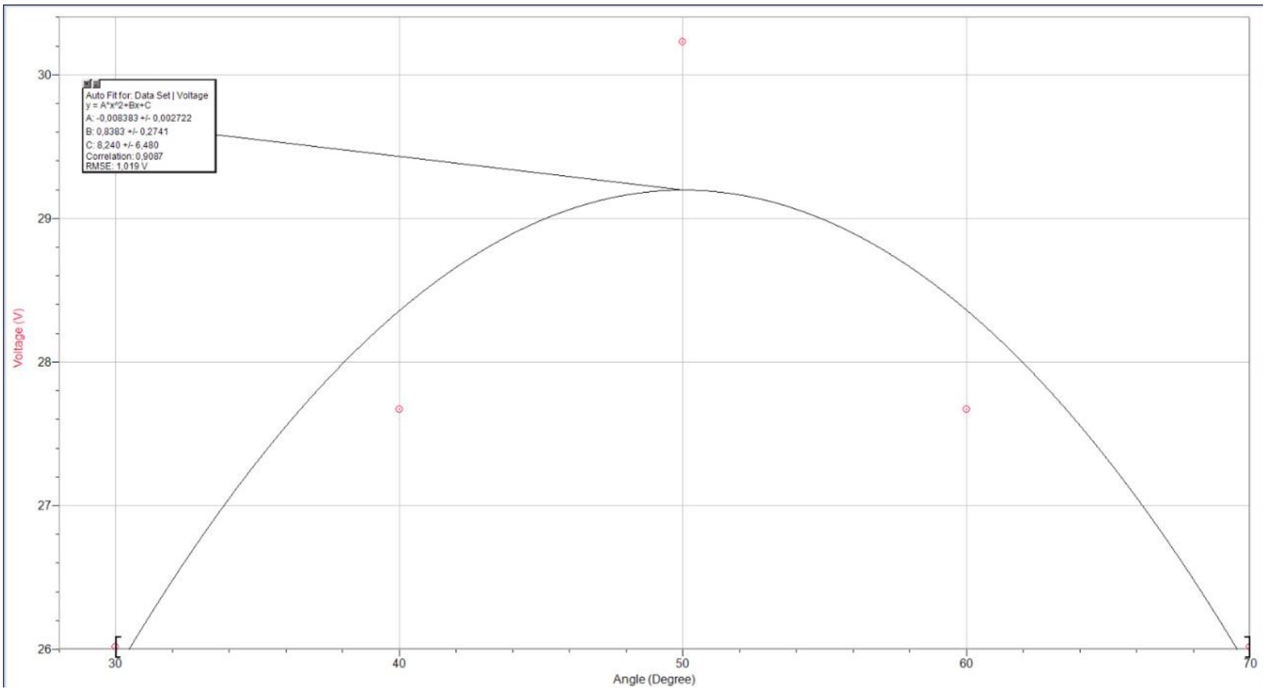

Figure11: Graph of angle versus simulation voltage output with best curve fit

After analyzing the graph, it is seen that the highest voltage output is at 50-degree solar panel angle like before and the variables equally separated from the 50-degree angle is the exact same. This is possibly because mathematically the angle of incidence does not change so the output wouldn't change. In the end, the data from the simulation backs up my analysis of the main experiment and further disproves my hypothesis.

6. Conclusion and evaluation

This investigation is about the research question “How does the panel angle of solar panel affect the voltage output?”. This research question is examined in this extended essay and these I hypothesized about it before my experiment. In the end of the experiment my hypothesis is falsified by the results of the experiment and the correct evaluation were put forward. In this research paper I investigated the output of solar panels when their angle with respect to ground is changed with one independent variable being the angle. It was observed that the output changed with the angle and had a quadratic relationship with the output of the solar panel in voltages. The peak value was achieved at the variable 50-degree angle and the values equally separated from that had very similar outputs. For example, variables 40- and 60-degree angles had very similar results and they were each 10 degrees away from the 50 degrees angle. In my examination I found that this was because the sunlight hit the surface of the solar panel in a 90-degree angle in the variable 50-degree angle and solar panels generate the most energy when receiving sunlight perpendicularly. And the separation of variables with similar angles were possible because even though angles were different they created the same angle of incidence. For further examination I used an online simulator to verify my examination. This simulation data was used to repeat the same steps as the main experiment to check if the results were similar or not. Then the simulation data were used as a scientific context. The simulation can be addressed as scientific context as it doesn’t have an uncertainty and uses absolute values. When considering the results of the simulation as scientific context, the main experiments results align with the results from the simulation. This further confirms the accuracy of my examination and supports the investigation of this research paper.

As for limitations, there are some limitations due to the real-life factors that could slightly change the outcome of the experiment. In first glance, the inevitable waiting when doing the experiment could have the sunlight to change angle a little and it could have altered the outcome of the experiment, but to avoid this the experiment is made is the fastest way possible. Another limitation is the weather conditions, I have selected a day when the sky is clear, but a small cloud could have gotten into way while the experiment is ongoing and change the intensity of sunlight slightly. Even though there are limitations, all the variables have data like each other, so it is safe to say that there is little to no random errors in this experiment. There may be systematic errors due to the equipment and electronics but is all the data shifted in the same amount the conclusion wouldn't change.

While working on this experiment and investigation, I encountered some difficulties regarding the experiment. First, apart from the experiment, time and place was an issue because it was hard to find the correct time and place that will have good and clear sunlight. To do this I first tried doing it in a park but at there were many obstacles and objects that could block sunlight, so I decided to do it from the balcony. Another thing was that the simulation I used included a different sized solar panel for measurement and the size of solar panel was unchangeable in the simulation so I couldn't use that data as theoretical value instead I compared the result graphs and behavior of the pattern. Another reason why I couldn't use the simulation as theoretical value was that I didn't have access to a larger solar panel. Overall, if these conditions were better and the experiment was made in a more intended environment, the achieved results from the better experiment would have given a clearer result and there would be a better outcome from the experiment.

Apart from the weaknesses, this experiment also has a couple of strengths. The simpler setup of the experiment has its advantages as it has low chance to has mistakes as the initial set up is easy. Also, the procedure of experiment is uncomplicated and a straight process. This makes it easy to complete the experiment without obstacles. The procedure of the experiment was easy to follow and smooth for me as I got all the data without any major errors.

7. Works Cited

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