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Investigating the Effect of Light Intensity on Voltage Produced by Solar Cell

Name of Candidate: Ata Gün Aksu

Number of Candidate: 001129-0092

Name of Supervisor: Enis Cihanoğlu

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Abstract

In this study, it was aimed to show the effect of light intensity on voltage produced by the solar cell. According to the research question: 'How does voltage produced by the solar cell change when the light intensity changes?', an experiment was done by using a light source, standard solar cell, transformator, light meter and voltmeter.

In the experiment, the solar cell is placed under the light source and voltmeter is connected to it. Light meter is placed near the solar cell to measure the light intensity. Light source is connected to the transformator and intensity of the light source is changed by using the transformator. Voltage and intensity of the light values are measured in each intensity. Increase in intensity of light means increase in number of photons. Thus the total energy of the photons increase and more electrons are emitted from the solar cell. After all, potential of the cell increases.

In the result of the experiment, it is found out that there is a logarithmic relation between light intensity and the voltage produced. After an intensity value, increasing rate of voltage decreases due to the characteristic property of the solar cell. Also, it is found out that light intensity is directly proportional to the fifth power of the voltage. As the intensity of light increased, the power in the solar cell will increase due to the increase in voltage.

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Introduction

The scope of this investigation is to find out the relation between the light intensity and the voltage produced by the solar cell. Due to the increasing cost of coal, oil and natural gas, renewable energy sources are becoming more popular and their usage is increasing day by day. The sun is a source of energy, which is unlimited; most of it is wasted but it still provides us millions of kilowatts of power and keeps us warm. Solar energy is safe and pollution free energy. The source of solar energy is the fusion reactions in the sun. Under high temperatures some elements, such as hydrogen, undergo fusion reactions and give large amounts of energy.

Applications of Solar Energy

- **Solar heaters**

  Also known as solar panel, captures thermal energy and heats water for the use of domestic. The surface of the panel is usually flat and covered by glass for protection. To reduce reflection, glass should be coated. Blackened surface below the glass collects sunlight and water circulating in the pipes gets heated. This hot water can be used for household purposes, like bathrooms, or with the help of a pump it can circulate through the house to provide heating.

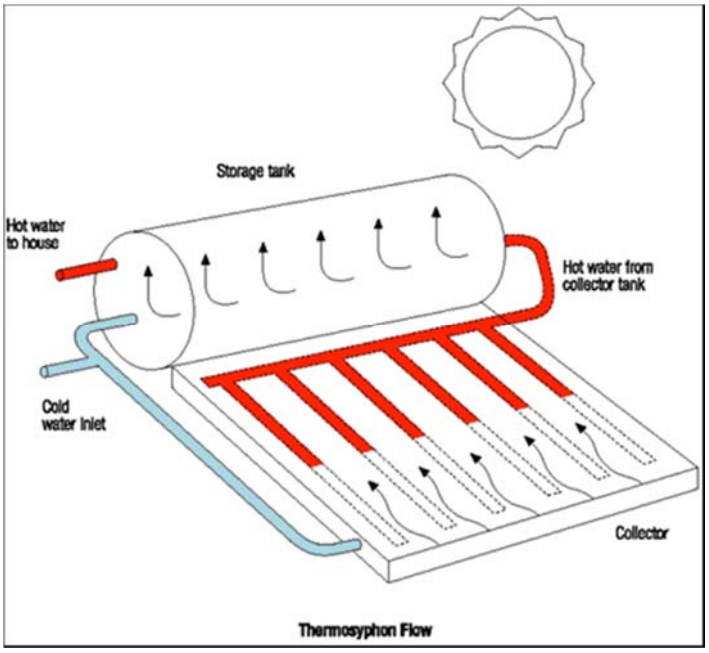


Figure 1: A device for collecting sunlight. The water in the pipes become heated and stored in storage tank.[1]

More sophisticated collectors include a concentrator system, which the incoming solar radiation is focused before it falls on the collecting surface. These systems can heat water to higher temperatures than a simple flat collector. These heated water turn into steam, which can drive a turbine to produce electricity.

- **Solar greenhouses**

  Solar energy is used in greenhouses. Construction of this system is easy thus it is widely used in many countries. Solar greenhouses prevent the crops from freezing and many vegetables and crops are raised two or three time per year in these houses.

- **Solar furnace**

  Solar energy can heat a lot more than water and it is used as a furnace in research

[1] http://d3ux6s8yj4izvp.cloudfront.net/wp-content/uploads/2009/03/solar-water-heating-system.gif

and industry.

- **Solar cell**

The solar cell was developed in 1954 and it is used in many different areas such as space programs. It converts sunlight into DC current, electrical energy. Workings of the photovoltaic cell depend on the physics of semiconductors. The PV effect is directly related to the photoelectric effect.

Photovoltaic systems become more dominant in electricity production as their price decreases.

Figure 2: The solar cell, which is used in the experiment.

Photoelectric effect is the effect whereby if light is shone onto a metal surface, electrons are emitted. Electrons are only emitted if the light is above the threshold frequency. If frequency is less than this value then photoelectric effect cannot be seen. Threshold frequency values depend on the material used. There are some

other factors, which affect the photoelectric effect if the frequency is above threshold frequency.

- The number of photoelectrons affects the photoelectric effect. It depends on the intensity of light and if the intensity of light increases, number of photoelectrons increase and the photoelectric current increases.
- Kinetic energy of photoelectrons also has an effect on the photoelectric effect. Photoelectrons emitted have a range of kinetic energies up to a maximum value, which depends on the metal used, and the frequency of light.

The work function, ϕ, of the metal is the minimum energy required to release an electron from a metal. Electron gains energy when a photon, light particle, hits to it and the energy of each photon depends on the frequency of light. The energy of a photon is given by the equation $E = hf$, where E is the energy, h is the Planck's constant and f is the frequency of light.

- If the work function, ϕ, of the metal is greater than the photon energy no photoelectrons will be emitted.
- If the frequency is greater than the threshold frequency of the metal then photoelectrons will be emitted.

  Since a photon gives up all its energy to the electron then if the photon energy is greater than the work function, energy required to release electron, electron will also have kinetic energy. The kinetic energy will be equal to the energy absorbed by the photon, over and above the energy required to release it. This is the maximum kinetic energy of the electron since work function is the minimum energy required for an electron to escape.

$$Ek_{max} = hf - \phi$$

$$hf = \phi + Ek_{max}$$

This equation was derived by Einstein who made use of Planck's theory to explain the photoelectric effect as above.

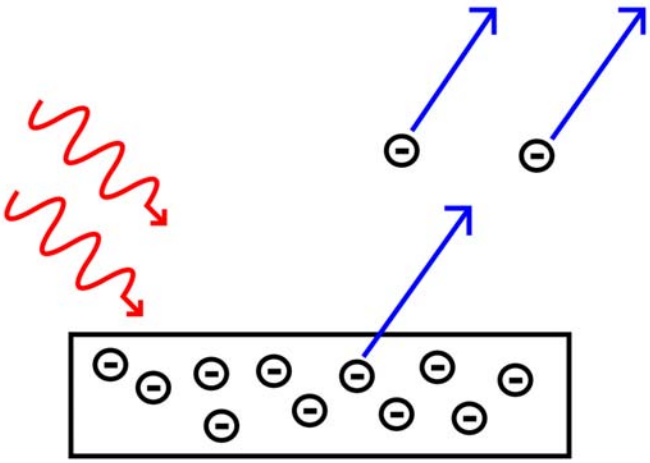


Figure 3: Diagram showing the photoelectric effect

Light Intensity

Intensity is the rate at which light spreads over a surface of a given area from a source and in the SI system, its unit is watt per metre squared (Wm^{-2}). It varies with the power of the source and the distance from the source. Power, which is a property of the light source, describes the rate at which light energy is emitted by the source. It is often expressed in units of watts. Different light bulbs have different power values. If the light intensity increases, number of photons increase, which increases the total energy and increases the number of electrons emitted.

Light Meter

Light meter is a device, which is used to measure the light intensity. Most of them detect the light with photoresistors, photodiodes or photomultipliers. It may measure the light after is has passed through a filter to analyze the light.

Figure 4: The lightmeter, which is used in the experiment.

Voltage

Voltage is the amount of potential energy between two points in a circuit. One point has more charge than the other one and this potential difference is called voltage. In the SI system, its unit is volt (V), which is joules per coulomb.

Voltmeter

Voltmeter, also known as voltage meter, is a device used for measuring potential difference between two points in a circuit. Some of them are designed for use in direct current and others are designed for alternating current.

Figure 5: The voltmeter, which is used in the experiment.

Design and Method

Aim of study

The output power of a solar cell vary with different external factors, like frequency of light, light intensity, etc… The aim of this study is finding the relationship between the light intensity of light source, and the voltage produced by the solar cell.

Research Question

How does changing the light intensity of light source affects the voltage produced by the solar cell, whilst environmental conditions (temperature and pressure), distance between the light source and the solar cell are kept the same?

Hypothesis

It is expected to see that as the light intensity of the light source increase, the voltage produced by the solar cell will also increase. Because, increased light intensity means more number of photons from the light. In photoelectric effect one photon interacts with one electron thus it should increase the number of emitted electrons and the potential difference, voltage, will increase. However, after a time increasing rate of the voltage will slow and it will not increase anymore. Because the solar cell has a maximum power output which it cannot produce more than it due to its characteristic properties.

Dependent and Independent Variables

Power produced by the solar cell is dependent upon different factors including the type of the solar cell, frequency of the light, intensity of the light. In this experiment only light

intensity is changed by changing the power of the light source by using a transformator. All readings were taken by performing the experiment on the same solar cell and voltage produced by that solar cell measured using a voltmeter for each light intensity value.

Controlled Variables

For the accuracy of the results, some factors are kept constant throughout the experiment. The most important controlled variable is the power efficiency and the type of the solar cell. Same solar cell used during the experiment which has the properties: brand: Sefun Solar, model: SF-10M, Pm: 10 W, weight: 1.4 kg, dimensions: 24.0 cm x 36.0 cm. Also, some external factors like air friction, atmospheric pressure and temperature are kept constant. Since external factors can affect the voltage produced by the solar cell, they must be kept constant. The experiment is held in Hacettepe University Department of Physics Engineering in Ankara, Turkey. The external factors of that place can be known beforehand. Temperature, air friction and pressure would be same during the experiment day. However, the temperature of the room where the experiment is conducted is still kept constant with an air conditioner as 21℃. Distance between the light source and the solar cell is kept constant during the experiment. Angle of incidence of light is also kept constant. Also, the resistance of the circuit is kept constant. Because of the Ohm's Law, V=I.R, where V is the potential difference, I is the current, R is the resistance of the circuit, resistance can affect the current thus it must be kept constant. To keep the frequency of light same, same light source is used.

Material and Equipment

- Solar cell to produce electrical energy from the light energy (brand: Sefun Solar, model: SF-10 M, Pm: 10 W, weight: 1.4 kg, dimensions: 24.0 cm x 36.0 cm)
- One voltmeter, which is sensitive to 0.01 V, to measure the voltage, potential difference, produced from the solar cell (TT T-ECHNI-C VC97)
- Light source (105 W, yellow light)
- Transformator to change the intensity of light source
- Cables with alligator clips
- Ruler, which is sensitive to 0.1 cm, to measure the distance between the light source and the solar cell
- Light meter, which is sensitive to 0.1 Wm^{-2}, to measure the light intensity
- Air conditioner, to keep the room temperature same

Method

Firstly, solar cell is placed horizontally on the table and light source is placed on the center of mass of the solar cell with a distance of 33.5 cm between panel and the source. Voltmeter is connected to the solar cell using crocodile cables. It is made sure that every other light source in the room turned off and the experiment room darkened in order to solar cell only absorb the light from single source. Light source is connected to the transformator and transformator is connected to socket. Light meter should be placed in the center of the solar cell but it is impossible to do that during the experiment so, it is put near the solar cell. Then, the light source is turned on. Light intensity of the light source is changed by using the trasformator and light intensity is measured using the light meter. Voltage produced by the solar cell is read from the voltmeter in each intensity value. Data

collection is continued until the light intensity of the source reached maximum. The whole process is carried out with constant temperature and pressure as it is carried out on the same location. For the accuracy of results obtained, this method was carried out for one more trial. The experimental setup can be seen from Figure 6 and the realization of the setup can be seen from Figure 7.

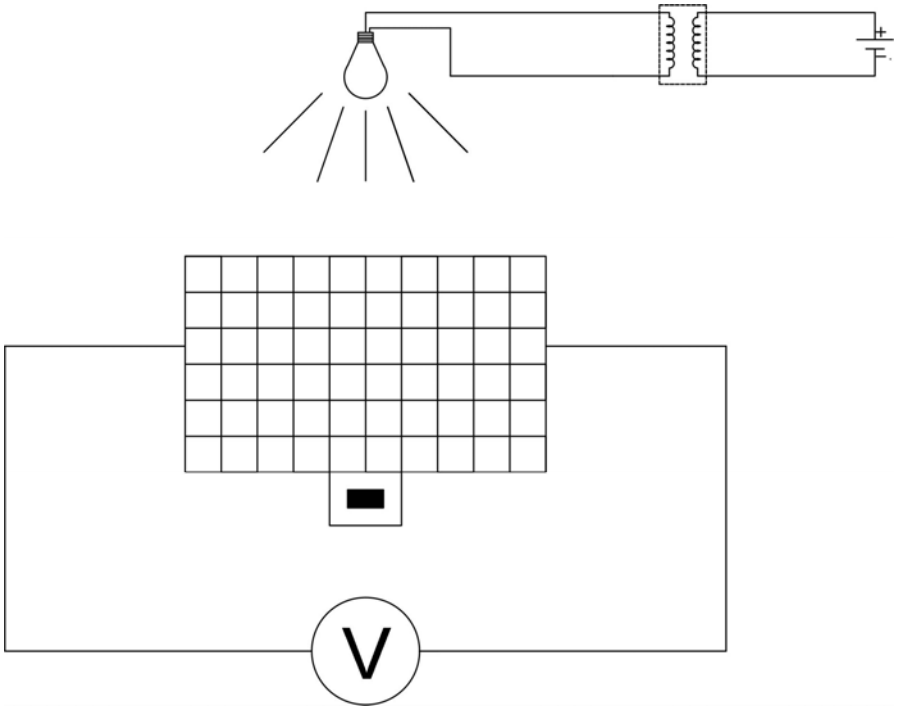


Figure 6: Diagram showing the experimental setup. Solar cell connected to voltmeter; light meter, with the black sensor, placed near the solar cell; light source connected to transformator and transformator connected to power source.

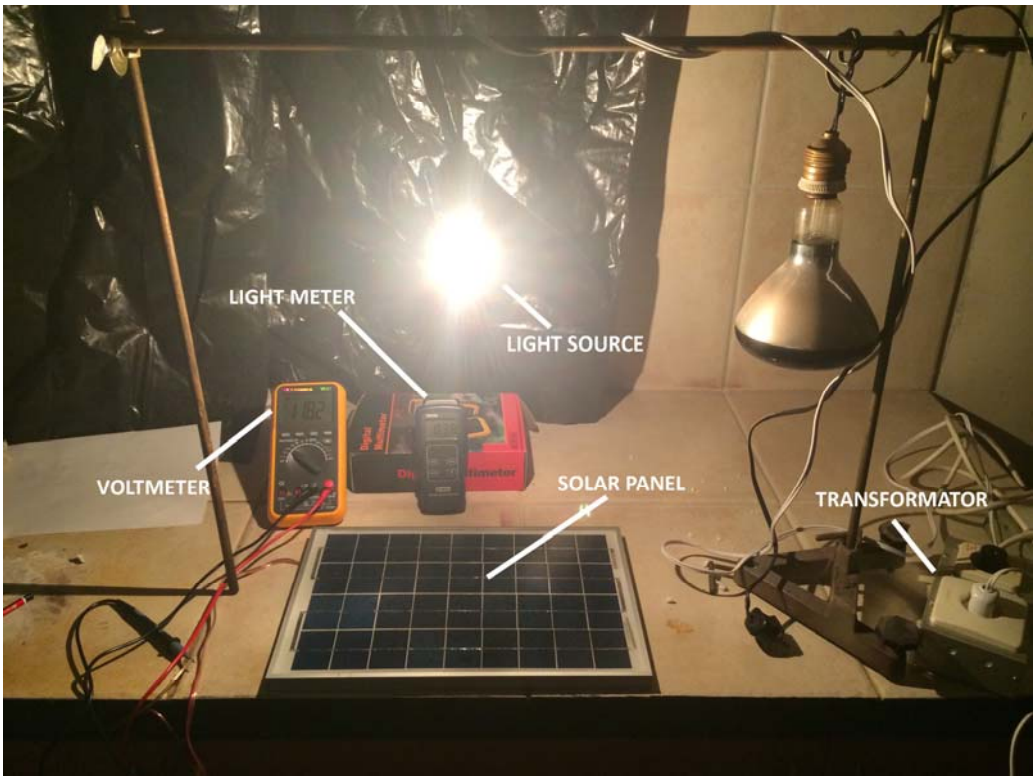


Figure 7: Realization of the experimental set-up. Light source is connected to the transformator and voltmeter is connected to the solar cell. However, light source was not in the place it is seen on the figure during the experiment.

Data Collection and Processing

Primary data, which has been collected throughout the experiment, is given in the following tables.

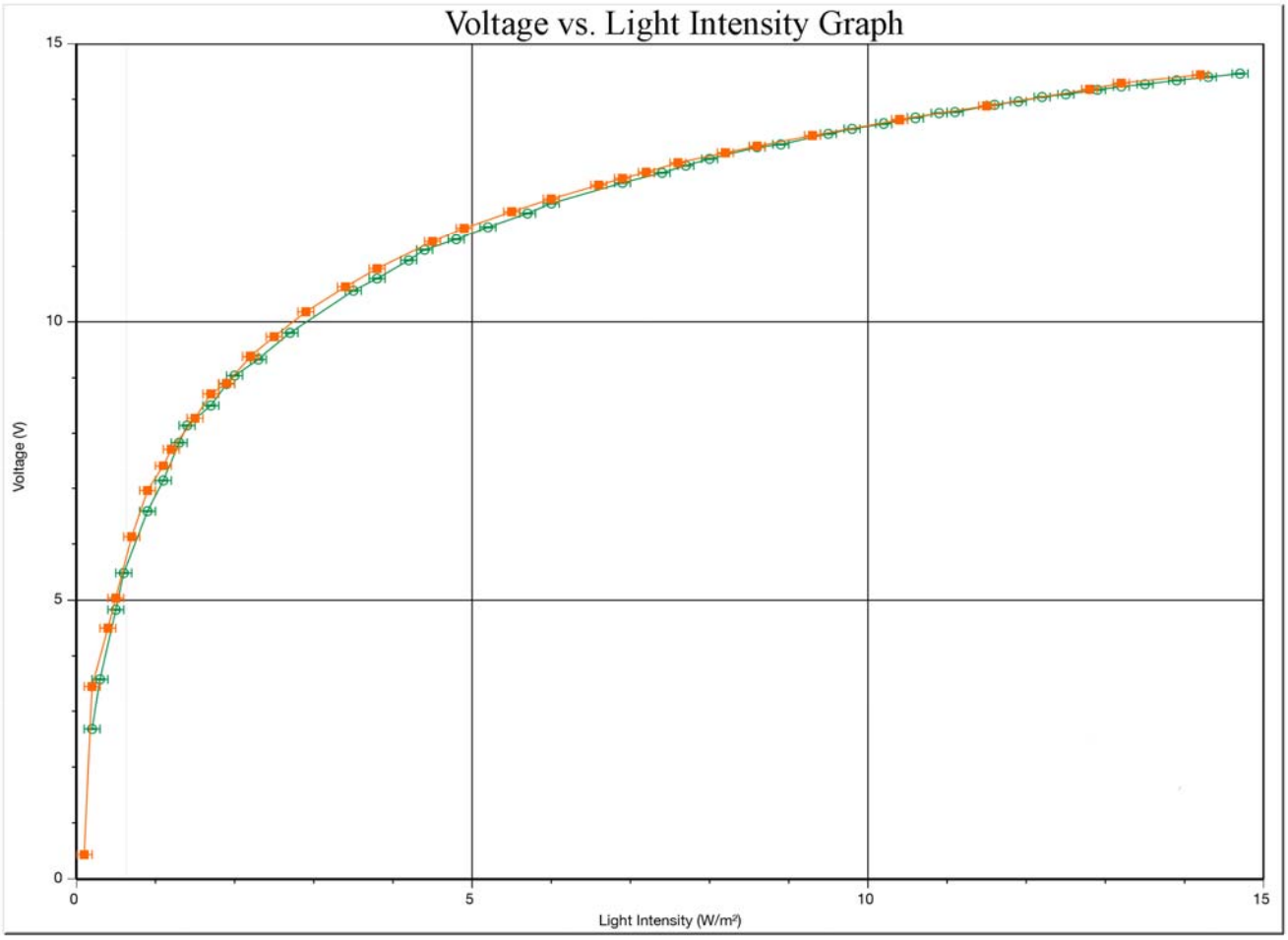
Light Intensity (±0.1 Wm^{-2})	Voltage (±0.01 V)
14.2	14.44
13.2	14.29
12.8	14.18
11.5	13.88
10.4	13.64
9.3	13.36
8.6	13.17
8.2	13.05
7.6	12.87
7.2	12.70
6.9	12.59
6.6	12.47
6.0	12.22
5.5	11.99
4.9	11.69
4.5	11.45
3.8	10.96
3.4	10.63
2.9	10.18
2.5	9.73
2.2	9.38
1.9	8.90
1.7	8.71
1.5	8.27
1.2	7.71
1.1	7.41
0.9	6.96
0.7	6.13
0.5	5.04
0.4	4.50
0.2	3.45
0.1	0.44

Table 1: Illustration of the raw data of first trial obtained from the investigation. Uncertainty comes from the sensitivity of the voltmeter and the light meter. Uncertainties were the smallest decimal digit on these devices.

Light Intensity (±0.1 Wm^{-2})	Voltage (±0.01 V)
14.7	14.46
14.3	14.40
13.9	14.34
13.5	14.27
13.2	14.23
12.9	14.17
12.5	14.09
12.2	14.04
11.9	13.96
11.6	13.90
11.1	13.77
10.9	13.75
10.6	13.67
10.2	13.57
9.8	13.48
9.5	13.39
8.9	13.20
8.6	13.15
8.0	12.94
7.7	12.82
7.4	12.69
6.9	12.51
6.0	12.14
5.7	11.96
5.2	11.71
4.8	11.49
4.4	11.30
4.2	11.11
3.8	10.78
3.5	10.56
2.7	9.80
2.3	9.33
2.0	9.04
1.9	8.89
1.7	8.50
1.4	8.14
1.3	7.83
1.1	7.14
0.9	6.59
0.6	5.48
0.5	4.83
0.3	3.58
0.2	2.68

Table 2: Illustration of the raw data of second trial obtained from the investigation. Uncertainty comes from the sensitivity of the voltmeter and the light meter. Uncertainties were the smallest decimal digit on these devices.

As the relevant data were harvested, it is now pretty much possible to see the relation between light intensity of the light source and the voltage produced by the solar cell via a graph.



Graph 1: Voltage vs. light intensity graph, with the uncertainty bars, where orange line shows the data of the first trial and green line shows the data of the second trial.

As seen, the relation between the light intensity and the voltage is logarithmic. It would be possible to observe a directly proportional and linear relation if the powers of the voltage values are computed. First the square of the voltage values are computed and it is seen that there is not a linear relation between square of the voltage and light intensity. Other powers of voltage values are computed and finally it is seen

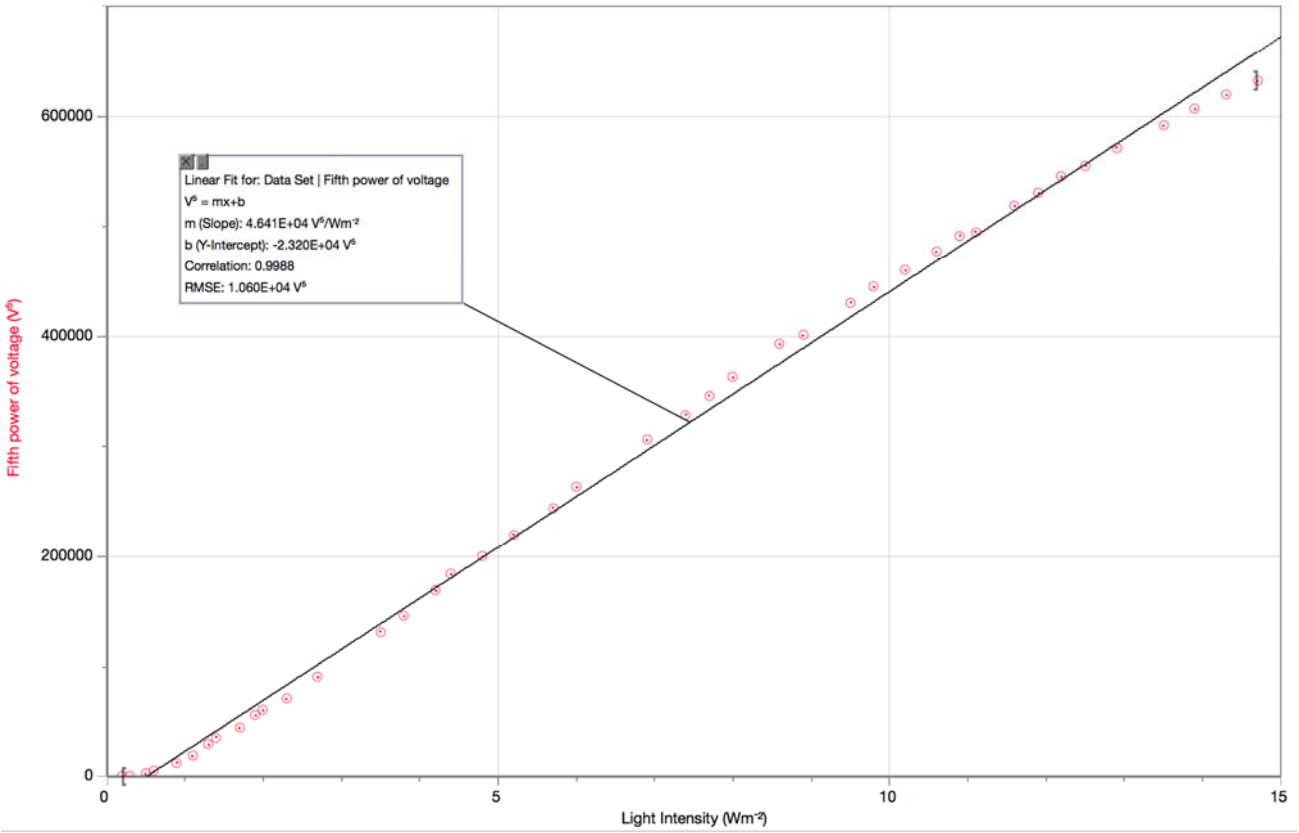
that there is a linear relation between fifth power of the voltage values and light intensity.

Light Intensity (±0.1 Wm^{-2})	**Fifth Power of Voltage (V^5)**
14.2	627821.184800000
13.2	595883.203600000
12.8	573298.960400000
11.5	515166.163600000
10.4	472141.147900000
9.3	425630.058400000
8.6	396213.140400000
8.2	378488.386700000
7.6	353095.948600000
7.2	330383.694100000
6.9	316321.455700000
6.6	301531.207900000
6.0	272493.426200000
5.5	247796.926600000
4.9	218309.460200000
4.5	196801.060000000
3.8	158144.018700000
3.4	135727.022700000
2.9	109329.884700000
2.5	87209.581290000
2.2	72612.968550000
1.9	55840.594490000
1.7	50129.200140000
1.5	38683.659130000
1.2	27244.063900000
1.1	22340.404890000
0.9	16332.256730000
0.7	8655.703525000
0.5	3252.016064000
0.4	1845.281250000
0.2	488.759796600
0.1	0.016491622

Table 3: Table, which shows the processed data, fifth power of voltage and light intensity values of the first trial.

Light Intensity (±0.1 Wm^{-2})	Fifth Power of Voltage (V^5)
14.7	632181.037400000
14.3	619173.642200000
13.9	606381.239800000
13.5	591724.928100000
13.2	583478,019900000
12.9	571280.304100000
12.5	555334.897400000
12.2	545551.229600000
11.9	530184.578700000
11.6	518888.447000000
11.1	495073.523900000
10.9	491488.647500000
10.6	477356.205700000
10.2	460149.800700000
9.8	445091.664400000
9.5	430430.348900000
8.9	400746.424300000
8.6	393213.811700000
8.0	362803.427800000
7.7	346290.140000000
7.4	329085.017600000
6.9	306398.439100000
6.0	263689.862500000
5.7	244712.356000000
5.2	220183.350200000
4.8	200262.735200000
4.4	184243.517900000
4.2	169266.219600000
3.8	145577.348200000
3.5	131316.588300000
2.7	90392.0796800000
2.3	70698.177550000
2.0	60372.915960000
1.9	55527.587460000
1.7	44370.531250000
1.4	35737.323580000
1.3	29431.256950000
1.1	18556.286060000
0.9	12428.739140000
0.6	4942.000584000
0.5	2628.667488000
0.3	588.051190100
0.2	138.252811000

Table 4: Table, which shows the processed data, fifth power of voltage and light intensity values of the second trial.



Graph 2: Fifth power of voltage vs. light intensity graph, of first trial.

Equation of the graph:

$$V^5 = mI + b$$

where;

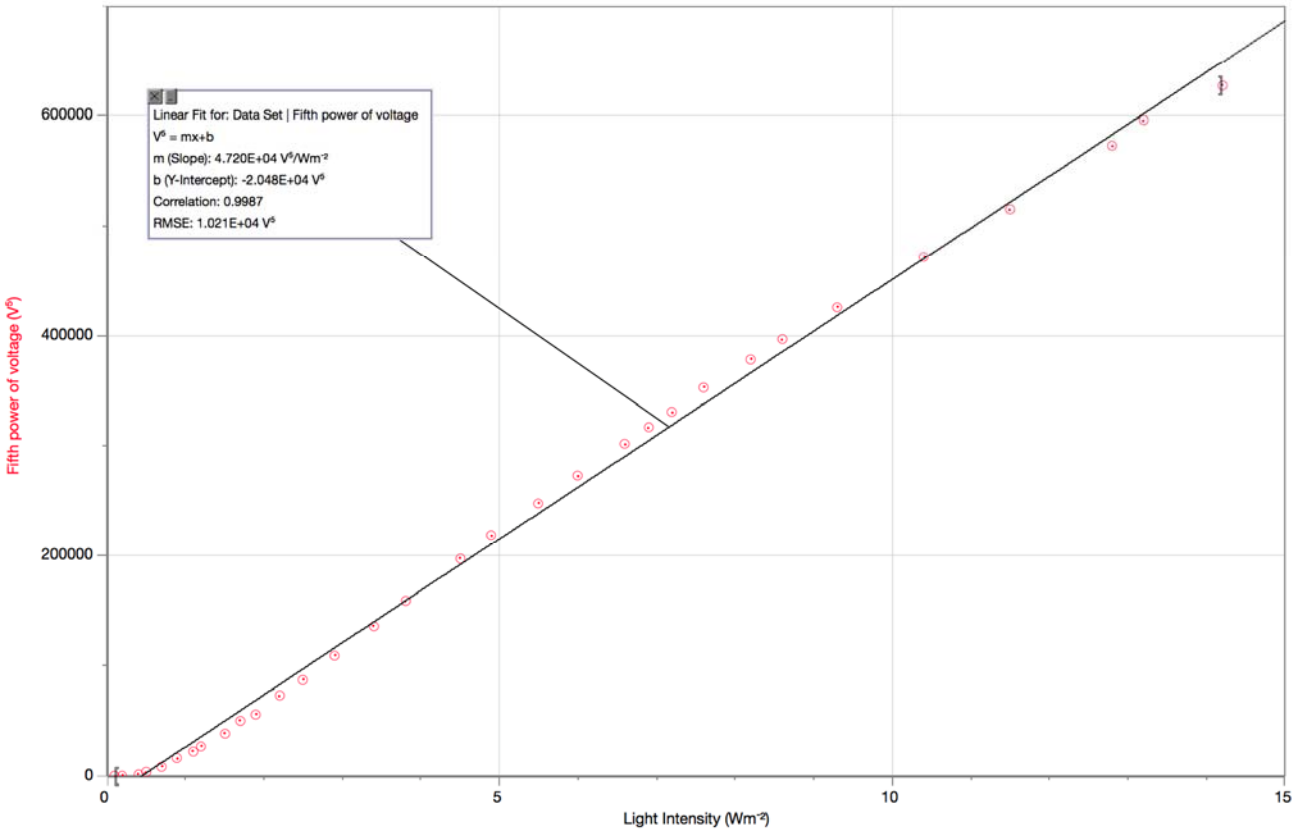
V is the voltage

m is the slope of the line

I is the light intensity

b is the interception point of the line with y-axis

$$V^5 = (4.641x10^4)\, I + (-2.320x10^4)$$



Graph 3: Fifth power of voltage vs. light intensity graph, of second trial.

Equation of the graph:

$$V^5 = mI + b$$

$$V^5 = (4.720x10^4)\ I + (-2.048x10^4)$$

Conclusion and Evaluation

The main purpose of this experiment was to observe the relation between light intensity and the voltage produced by the solar cell. The hypothesis suggested that as the light intensity increases, voltage produced by the solar cell would also increase because increasing the light intensity also increases the number of photons. Since one photon interacts with one electron, it should increase the number of emitted electrons.

The electric current is the number of charges, passing through a cross-sectional area per unit time. So, the potential difference will also increase. However, there is a maximum power output of the solar cell because of its characteristic properties as the manufacturer mentioned in the back of the solar cell. In my opinion, this increase will not be continuous since there are not enough electrons in the outer level of the solar cell to react with the increasing number of photons. To prove the hypothesis, we changed the power of the light source using a transformator, which changes the light intensity of the source and voltage produced by the solar cell, potential difference between the two points of the circuit, measured. When the graph of these measured values [Graph 1] were sketched, it is seen that there is a logarithmic relation between light intensity and voltage produced. To find a formulaic relation between light intensity and voltage, a linear relation had to be found. After trying the powers of voltage it is found out that there is a linear relation between fifth power of voltage and light intensity. Graph 2 and Graph 3 were sketched using these processed data. These graphs obtained, showed an almost-perfect linear relation and they helped to find an algebraic relation between light intensity and voltage. From the simple equation of the linear function, y = mx + b, and the values obtained, we obtained an equation for the voltage with respect to light intensity: $V^5 = (4.720x10^4)\, I + (-2.048x10^4)$ and $V^5 = (4.641x10^4)\, I + (-2.320x10^4)$. However, these equations cannot be used in all intensity or voltage values because after a certain intensity value voltage stops increasing and stays same. That means these equations can be used only in the range where voltage changes.

If we look at the slopes and the y-intercept points of the equations, it is pretty much seen that the difference is not too high. Also, when we look at the Graph 1, we can easily see that the two curves are almost coincident except some parts of the curve.

However, the distance in these lines are too small and this difference may be caused by some random errors. Also, when we look at the Graph 2 and Graph 3, it is seen that the lines are not passing through the origin, (0,0). It also shows us some systematic and random errors occurred in the experiment. In addition, there were some limitations in the experiment, which are caused by the instruments used in the experiment. Better results would be obtained if these limitations were prevented.

One of the greatest limitations in the experiment was the transformator used. An analog transformator was found in the laboratory and power of the light source is changed by hand thus the light intensity values differ in each trial. If a digital transformator was used, each trial could be done with the same intensity values and mean of the voltage values could be calculated. So more accurate results would be obtained.

Another great limitation was the light source used. There is not enough energy obtained from a solar cell in an indoor place, under an artificial light. Even a light source with high power used, it was not enough to see the maximum voltage value which solar cell can produce. In greater scale, the results can be much better thus it is logical to try this system in long term with a more powerful light source.

One of the error sources in the experiment was the place that the light meter was located. It would be much better if the light meter was put in the center of the solar cell but it was impossible, which is also explained in the design part. I located the light source near the solar cell. It did not affect the preciseness of the results. Also, taking the solar cell and measuring the light intensity in each intensity value is impossible because it would take too much time and the distance between the solar cell and the light source might change.

Another error source of the experiment is the writings on the light source. There were some writings on the bulb, as seen on the figure below, which avoid light to scatter to each point on the solar cell in same amount. Even it is not a big error cause; using a light source without any writings could prevent it.

Figure 8: The light source used in the experiment with the writing on it.

Controlling external conditions such as atmospheric conditions and temperature were not really possible. In order to get better results and to make this experiment better, it should be done under completely controlled conditions.

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