EXTENDED ESSAY

Subject: Physics (HL)

Research Question: *"How does the thickness of SPF 30 sunscreen applied to a solar panel affect the voltage output generated, and what insights does this provide into the sunscreen's effectiveness in blocking the UV light?"*

Word Count: 3566

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Introduction:

Being a very curious person, I have always wondered the working principles of a sunscreen. Back then, on holidays, I believed that the sunscreens acted as a mirror protecting our skin from the sunlight. Now of course I know that chemical sunscreens absorb UV rays and then convert them into heat, which is released from the skin. Their method is more about absorbing rather than reflecting. After acknowledging that, a question came into my mind. I knew that solar panels also absorb the light, so I wondered what would happen if I covered a solar panel completely with a sunscreen.

The main thing here is that they, both the solar panels and sunscreens, work with absorbing UV rays although their goal is in contrast with each other. The solar panels absorb light to convert it into electricity (DC) while sunscreens absorb light in order to convert UV rays into heat. With this investigation, I aim to find out what would happen if a sunscreen was put on a solar panel, on different levels.

The following research investigates the inquiry of whether the thickness of sunscreen can be correlated with the amount of voltage output from the solar panel. In throwing light on a possible impact of sunscreen on the effectiveness of this vital renewable energy, valuable insights are lent by this study. Unceasing efforts toward the quest for sustainable sources of energy have finally brought solar energy to the mainstream as a major consideration in global initiatives to mitigate climate change. In today's world, when the energy requirements are taking a great environmental toll, the efficiency of solar panels is considered a key demand to be met. Though it is assumed that location, tilt angle, and weather are primary factors that affect the performance of a solar panel, there is another very important and neglected factor, which is the use of UV light-blocking substances. Although geographical location, panel orientation, and weather conditions are considered to be major factors, the effect of UV light-blocking substances on the performance of a solar panel has not been so much discussed. This less-discussed factor also needs to be taken into account for proper assessment and optimization of the performance of solar panels.

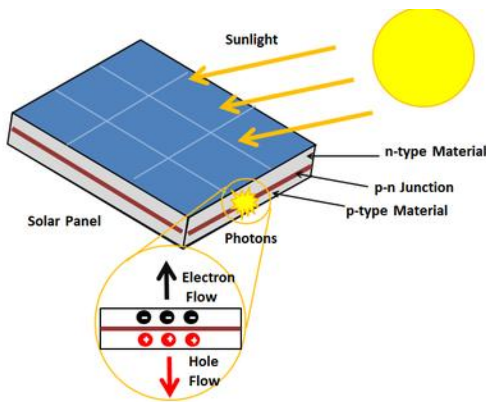
This research paper delves into the correlation between the thickness of sunscreen and the efficiency of solar panels. The main focus is on addressing the research question: "*How does the thickness of SPF 30 sunscreen applied to a solar panel affect the voltage output of a solar panel, and what insights does this provide into the sunscreen's effectiveness in blocking the UV light?*" The premise of this study is rooted in the fact that sunscreen can both absorb and reflect UV light.

Solar Panels:

Solar panels are innovative devices designed to harness sunlight and convert it into electrical energy, representing a critical component in the global transition toward renewable energy sources. At the heart of these panels lie photovoltaic (PV) cells, primarily composed of semiconductor materials like silicon. These cells operate based on the photovoltaic effect, where sunlight's energy excites electrons, allowing them to flow and generate electricity in the form of direct current (DC).

Solar radiation includes a wide range of wavelengths, from visible light to ultraviolet (UV) and infrared radiation. While visible light provides most of the energy for electricity generation, UV light also plays a significant role in enhancing the efficiency of solar panels. Photons from sunlight strike the silicon-based PV cells, exciting electrons and freeing them from their atomic bonds. This process occurs in a specifically engineered structure, where a P-N junction is created by layering P-type (positively charged) and N-type (negatively charged) materials. The electric field formed at this junction directs the flow of electrons, creating an electric current. Advanced solar panels, such as thin-film cells and multi-junction cells, are designed to capture a broader spectrum of sunlight, including UV light, to maximize efficiency.

As solar technology advances, manufacturers strive to improve the durability and performance of solar panels by addressing external factors like UV exposure. Prolonged UV radiation can degrade the materials in solar panels, reducing their efficiency over time. Hence, understanding how substances that interact with UV light—such as sunscreen—affect solar panel performance can provide critical insights into optimizing their design and functionality.



Sunscreen

Sunscreens are topical formulations engineered to protect the skin from the harmful effects of UV radiation. They come in various forms, including lotions, creams, gels, and sprays, and rely on active ingredients to either absorb, scatter, or reflect UV rays. Sunscreens are classified into two primary categories: chemical and physical. Chemical sunscreens, such as the SPF 30 sunscreen used in this study, contain organic compounds like avobenzone and oxybenzone that absorb UV radiation and convert it into harmless heat. Physical sunscreens, on the other hand, use inorganic compounds like zinc oxide or titanium dioxide to reflect or scatter UV rays away from the skin.

The efficacy of sunscreen is quantified using the Sun Protection Factor (SPF). SPF measures the relative protection offered by the sunscreen against UVB rays, which are responsible for causing sunburn. For instance, an SPF 30 sunscreen theoretically allows an individual to remain in the sun 30 times longer without burning compared to unprotected skin. In addition to UVB, many sunscreens also block UVA rays, which penetrate deeper into the skin and contribute to premature aging and skin cancer. UVA and UVB rays, while harmful to skin, have contrasting effects on solar panels: the former is less impactful on energy generation, whereas the latter significantly contributes to power output.

Integration of Sunscreens and Solar Panels

Despite their differing objectives, solar panels and sunscreens share a common interaction with UV light. Solar panels depend on UV light to generate electricity, while sunscreens aim to block UV radiation to protect the skin. This paradox creates a fascinating intersection for research: what happens when a UV-blocking substance like sunscreen is applied to a UV-dependent device like a solar panel?

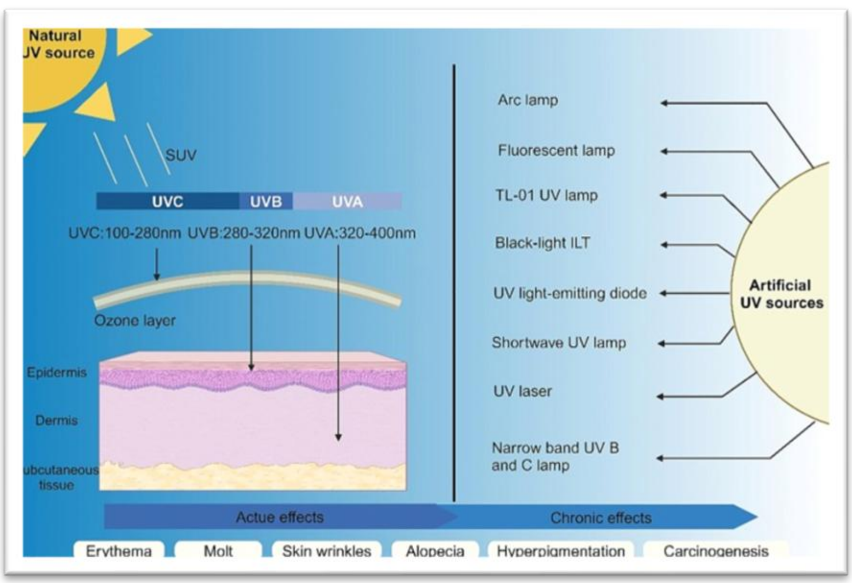
The interaction between sunscreens and solar panels goes beyond academic curiosity. Understanding the effects of sunscreen application on solar panels could offer insights into broader technological applications, such as UV-blocking films or coatings for solar technology in extreme environments. By investigating the relationship between sunscreen thickness and voltage output, this study contributes to the growing field of renewable energy optimization, highlighting the complex interplay between materials science and sustainable technology.

UV Radiation Types[1]:

- UVA rays (315-400 nm) penetrate deeply into the skin and contribute to skin aging and wrinkles.
- UVB rays (280-315 nm) affect the outer layer of the skin and are primarily responsible for sunburn. Both can contribute to the development of skin cancer.

SPF: SPF is a measure of how much solar energy (UV radiation) is required to produce sunburn on protected skin (i.e., in the presence of sunscreen) relative to the amount of solar energy required to produce sunburn on unprotected skin. As the SPF value increases, sunburn protection increases.[2] For instance, an SPF 30 sunscreen theoretically allows someone to stay in the sun 30 times longer before burning compared to no sunscreen.

[3]



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[1] World Health Organization. (n.d.). *Radiation: Ultraviolet (UV) radiation*. World Health Organization. https://www.who.int/news-room/questions-and-answers/item/radiation-ultraviolet-(uv)

[2] Center for Drug Evaluation and Research. (n.d.). *Sun Protection Factor (SPF)*. U.S. Food and Drug Administration. https://www.fda.gov/about-fda/center-drug-evaluation-and-research-cder/sun-protection-factor-spf

[3] Author links open overlay panelXiaoyou Tang a b, a, b, c, d, e, & AbstractUltraviolet (UV) radiation is ubiquitous in the environment. (2024, February 27). Current insights and future perspectives of ultraviolet radiation (UV) exposure: Friends and foes to the skin and beyond the skin. Environment International. https://www.sciencedirect.com/science/article/pii/S0160412024001211

Theory Behind It:

The attenuation of UV light on the solar panel is calculated by two different methods:

- **Modified Beer-Lambert Law:** This law describes how light intensity decreases as it passes through a substance. It can be used to estimate the amount of UV light that reaches the solar panel after passing through the sunscreen layer. I will use a modified version of it. I have transformed the original law into the direct proportion below, into an exponential decay.

(1) $$I = I_0 \times e^{-k.d}$$ [4]

$$\downarrow$$

(2) $$V^2 \propto e^{-kd}$$

$$\ln(V^2) \propto -kd$$

The Equation:

- V: Voltage measured
- e: Euler's number
- k: Coefficient of sunscreen, of the 30spf sunscreen
- d: Thickness of sunscreen

[4] Bhuyan, Satyam. "Beer-Lambert Law: Statement, Equation, Advantage & Limitation." Science Facts, 7 June 2024, www.sciencefacts.net/beer-lambert-law.html.

The formula (1) represents the Beer-Lambert Law, where the intensity of UV light (*I*) passing through the sunscreen is exponentially dependent on the thickness of the sunscreen layer (*d*). The attenuation coefficient (*k*) is a measure of how effective sunscreen is in reducing UV light intensity. A higher *k* value would indicate more effective attenuation. However, in this experiment, we will take it as a constant as it will not have any effect on the result whatsoever.

The formula (2) is a new exponential decay equation from the Beer-Lambert Law by me. I The light intensity is considered as analogues expression for voltage since we can determine the light intensity of sunlight by measuring the voltage output from the solar panel. Plus, I discarded the initial intensity of the light on account of there is no need to include it in the experiment. I therefore diverged the equation into a directly proportional exponential decay.

When you graph $\ln(V^2)$ vs. $-d$, you transform an exponential decay relationship into a straight line. This is beneficial because:

- **Linearization:** The original relationship is $V^2 = e^{\wedge}(-k \cdot d)$. Taking the natural logarithm turns it into $\ln(V^2) = -k \cdot d$, which is linear. This makes it easier to analyse the data.
- **Simple Interpretation**: With a linear graph, the slope corresponds directly to the attenuation coefficient (k). Using $-d$ ensures the slope is positive, which is more intuitive.
- **Easier Statistical Analysis:** Linear data allows you to use linear regression methods, making it simple to determine the accuracy and reliability of your results.

Hypothesis:

"As the thickness of SPF 30 sunscreen applied to a solar panel increases, the voltage output will decrease exponentially, demonstrating the sunscreen's effectiveness in blocking UV light. This relationship can be modelled using the modified Beer-Lambert Law, where the attenuation of UV light is proportional to the thickness of the sunscreen layer, and the correlation can be seen using the Pearson Correlation Coefficient."

- **Hypothesis Explanation:** Sunscreen works by absorbing or reflecting UV light to protect our skin from sun damage. When you apply sunscreen to a solar panel, it blocks some of the UV light that would normally reach the panel. Since solar panels need light to generate electricity, blocking UV light reduces the amount of electricity they can produce.[5]

Variables:

Independent Variable: The independent variable in this experiment is the **thickness of SPF 30 sunscreen** applied to the solar panel. The thickness is measured in millimetres (mm) and is varied across six levels: 0 mm (no sunscreen), 0.5 mm, 0.7 mm, 1.0 mm, 1.2 mm, and 1.4 mm. The thickness is controlled using a thickness gauge to ensure consistent and accurate application across the surface of the solar panel. This variation in thickness allows us to investigate how different amounts of sunscreen affect the solar panel's ability to absorb UV light and generate voltage.

[5] The Science of Sunscreen. Harvard Health. (2021, February 15). https://www.health.harvard.edu/staying-healthy/the-science-of-sunscreen

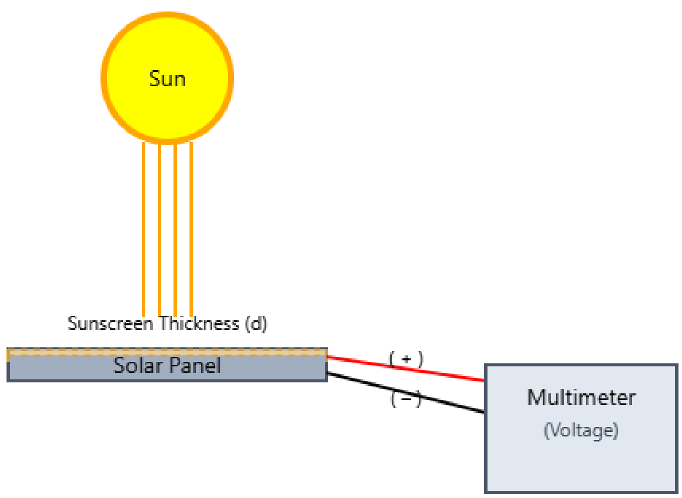
Dependent Variable: The dependent variable of the experiment is the solar panel's voltage output in volts (V) as measured with a Multimetre. The output voltage is directly proportionate to the quantity of incident UV light onto the photovoltaic cells of the solar panel. As the thickness of the sunscreen layer is higher, it is expected that the voltage output will be lower since the sunscreen absorbs or reflects the UV light and less light is available for energy conversion. The voltage output is recorded at every level of sunscreen thickness, and the mean of three readings is used in order to ensure accuracy and reliability.

Controlled Variables:

- **Same Solar Panel:** We use the same solar panel for the entire experiment to maintain consistency in the readings. Various panels can have variations in efficiency, quality of the material, or the size that could influence the output voltage. We are removing these sources of error by holding the solar panel constant.
- **Same Probes:** The same probes are utilized to link the Multimetre to the solar panel in every measurement taken. This is to ensure that any variation or resistance at the points of connection is alike in all experiments, so as to avoid differences in the voltage values
- **Same Sunscreen:** To ensure consistency in the UV-blocking characteristics, the same SPF 30 sunscreen is utilized in all experiments. Variation in the formulations, SPF rating, or absorption coefficients of different sunscreens can influence the outcome. By utilizing the same sunscreen, it guarantees that the sole variable influencing the voltage output is the thickness of the layer applied.
- **The Time of the Day:** All measurements are taken within a 30-minute period around noon when the solar radiation is maximum and approximately constant. This reduces sun angle

or atmospheric condition-induced fluctuation in the solar radiation and thus makes the output voltage critically dependent on the thickness of the sunscreen.

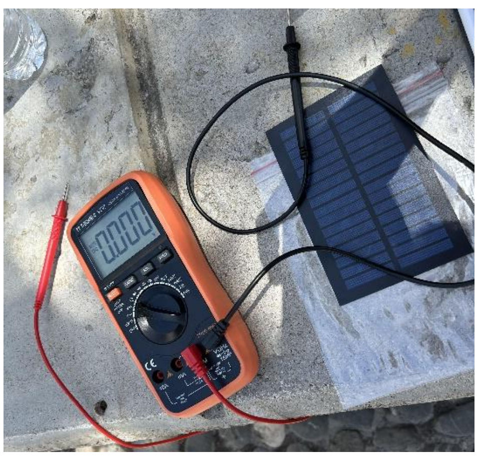
- **Weather Forecast:** The experiment is conducted on a cloudless sunny day to ensure uniform intensity of sunlight. Changes in weather conditions, such as rain or clouds, can alter the intensity of UV light that falls on the solar panel, potentially affecting the voltage output. Sunny conditions ensure that the sole variable to affect the result is the thickness of the sunscreen.
- **Angle of Incidence:** The panel is placed horizontally (along the ground) so that it has the same angle of incidence (close to 90 degrees) relative to the sun rays. That way, the light falling on the panel remains the same for all experiments, apart from changes brought about by the rotation of the panel.
- **Same Measuring Device:** The same Multimetre is used for the measurement of all voltages to have a standard of similarity in the accuracy and calibration of the device. Using a different Multimetre can lead to inconsistencies in readings since the sensitivity or calibration can be different.



The diagram above illustrates how the experiment is conducted.

Apparatus & Materials:

- Solar Panel (145x95mm)
- Multimetre
- Probes
- SPF 30 Sunscreen
- Flat Working Space
- Camera (iPhone)



Setup and Methodology:

Methodology:

Timing and Positioning: The experiment start at 12.00'o clock to ensure maximum solar radiation[6]. The solar panel is laid parallel to the ground for making sure the angle of incidence is as close to 0 degrees as possible.

Applying of Sunscreen and Measurement: Before applying any sunscreen, the voltage output of the solar panel is measured 3 times. Later, the sunscreen is applied in increasing thicknesses; 0.5mm, 0.7mm, 1.0mm, 1.2mm, and 1.4mm.

For each thickness level:

- The sunscreen is evenly spread using a roller, and the thickness is verified using the thickness gauge.
- The voltage output is measured three times using the Multimetre, and the average value is recorded.
- The process is repeated for each thickness level to ensure accuracy and reliability.

Data Recording: The voltage output for each level of thickness is listed in a table. The raw data are three readings for each thickness, and the mean value is used for analysis. A camera is used to capture the setup and to ensure that the procedure is repeated consistently.

[6] Team, GML Web. "Solar Calculator - NOAA Global Monitoring Laboratory." GML, gml.noaa.gov/grad/solcalc/. Accessed 17 Feb. 2025.

Setup:

- **Preparation of the Solar Panel:** An experiment solar panel measuring 145x95 mm is used. The solar panel is kept clean to clear off any debris or dust that may influence the measurement of voltage. The solar panel is left on a level, flat surface such that it is kept horizontal (parallel to the ground) throughout the experiment. This provides an equal angle of incidence (nearly 90 degrees) with the sun rays.
- **Connection of Probes:** Two probes (red and black) are taped securely at the back of the solar panel for the voltage output measurement. The other tips of the probes are put into a Multimetre, which is adjusted to measure direct current (DC) voltage. The Multimetre is checked prior to the experiment to certify that it is in a good condition and reading well.
- **Application of Sunscreen:** SPF 30 sunblock is rolled on the outside of the solar panel for an even coat. The thickness of the sunblock is controlled by a thickness gauge to obtain readings (0 mm, 0.5 mm, 0.7 mm, 1.0 mm, 1.2 mm, and 1.4 mm). Sunblock is applied in layers and the gauge is used to check the thickness before taking a measurement to achieve uniformity.
- **Environmental Conditions:** The experiment is performed on a sunny day when it is clear to ensure even sunlight intensity. The hour is chosen to be around midday (12:00 PM) when the sun is strongest and relatively constant. The weather is monitored to have no clouds or atmospheric interference with the intensity of sunlight in the experiment.

Analysis

Raw Data:

Thickness of Sunscreen (cm)	Trials (Voltage Output)		
	1 ± 0.005V	2 ± 0.005V	3 ± 0.005V
0	**9.13V**	**9.12V**	**9.14V**
0.5	**9.04V**	**8.70V**	**8.72V**
0.7	**8.46V**	**8.94V**	**8.52V**
1.0	**8.52V**	**8.43V**	**8.40V**
1.2	**8.40V**	**8.33V**	**8.36V**
1.4	**8.33V**	**8.3V**	**8.23V**

Table 1 Raw Data of the Experiment

At first glance in the raw data above, we can briefly have an idea that the voltage output is decreasing when sunscreen is getting thicker. However, for more insights, we need to analyse these data. The experimental data collected demonstrates a clear relationship between sunscreen thickness and solar panel voltage output. Table 1 displays the complete set of voltage measurements taken at six different sunscreen thickness levels, with three trials for each level to ensure reliability and statistical significance.

Processing the Data:

Thickness (cm)	Mean of the Voltage Outputs (V)	Uncertainties
0	9.13	±0.006 V
0.5	8.82	±0.011 V
0.7	8.64	±0.006 V
1	8.45	±0.006 V
1.2	8.3634	±0.006 V
1.4	8.2867	±0.006 V

Table 2 The mean of the voltage measured in the experiment

After collecting the raw measurements, the data was processed to determine the mean voltage output for each sunscreen thickness level, along with the associated uncertainties. Table 2 presents these processed values, which form the foundation for our quantitative analysis.

The uncertainty in the mean voltage for each sunscreen thickness was determined using the following procedure:

Calculating Standard Deviation and Uncertainty:

For each sunscreen thickness, the three voltages' standard deviation (σ) were calculated from the raw data in Table 1. Standard deviation measures how much the measurements are spread out from the mean. The formula for standard deviation is:[7]

$$\sigma = \sqrt{\sum \frac{(x_i - \bar{x})^2}{(n-1)}}$$

[7] "Standard Deviation - Formula, Examples & How to Calculate." GeeksforGeeks, GeeksforGeeks, 20 Sept. 2024, www.geeksforgeeks.org/standard-deviation-formula/.

Where: $x_i = individual\ voltage\ meausurement$

$\bar{x} = mean\ voltage\ for\ a\ given\ thickness$

$n = number\ of\ trials\ (3\ in\ this\ case)$

Example Calculation for 0.5mm Thickness:

1. **Voltage Measurements:** 9.04V, 8.70V, 8.72V
2. **Mean Voltage ($\bar{x}$):**

$$\bar{x} = \frac{9.04 + 8.70 + 8.72}{3} = 8.82\ V$$

3. **Deviation from the Mean:**
   - $(9.04 - 8.82)^2 = 0.0484$
   - $(8.70 - 8.82)^2 = 0.0144$
   - $(8.72 - 8.82)^2 = 0.0100$
4. **Sum of Squared Deviations:**

$$\sum(xi - x^{-})2 = 0.0484 + 0.0144 + 0.0100 = 0.0728$$

5. **Standard Deviation (σ):**

$$\sigma = \sqrt{\frac{0.0728}{2}} = \sqrt{0.0364} \approx 0.1907V$$

Uncertainty in the Mean:

The uncertainty in the mean voltage is an estimate of the amount by which the mean value is likely to be different due to random errors in the measurements. It is calculated from the formula:

$$Uncertainty\ in\ the\ Mean = \frac{\sigma}{\sqrt{n}}$$

$$Uncertainty\ in\ the\ Mean = \frac{0.191}{\sqrt{3}} \approx 0.11\ V$$

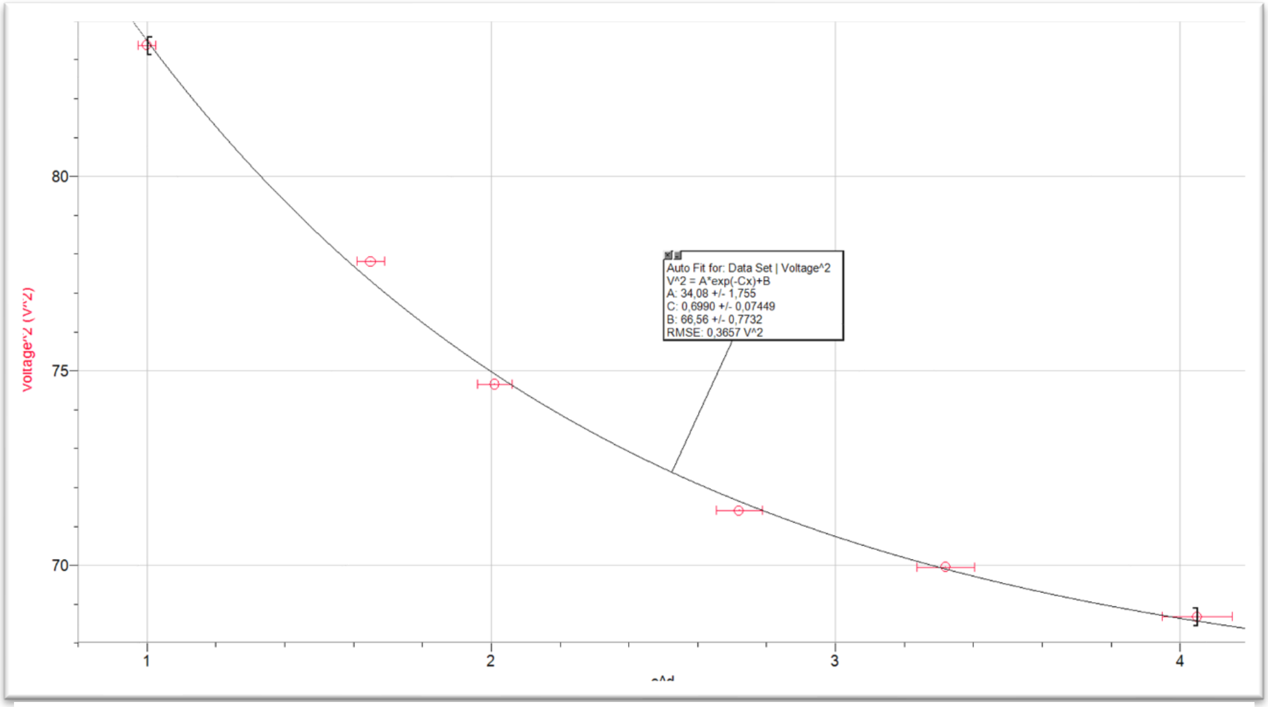
We are going to use the mean of the voltage in our calculations. So, from now on when we mention any voltage on a given thickness, we are going to assume the mean voltage.

Just to remind, the exponential decay formula we use is: $V^2 \propto e^{-kd}$

So, if we were to make a table of this formula, it would have been like this.

Thickness (d)	V^2	e^d	$\sqrt{(e^d/V^2)}$
0 cm	83.3569	1	0.109
0.5 cm	77.7924	1.65	0.145
0.7 cm	74.6496	2.01	0.164
1 cm	71.4025	2.72	0.195
1.2 cm	69.9465	3.32	0.217
1.4 cm	68.6694	4.05	0.242

Table 3 Comparing V^2 with e^d



Graph 1 V^2 against e^d

When examining graph 1, we observe that while V^2 decreases as thickness increases, the relationship isn't linear, making it difficult to determine the attenuation coefficient (k) directly.

By taking the natural logarithm of both sides of the modified Bee-Lambert Equation, we transform an exponential relationship into a linear one where:

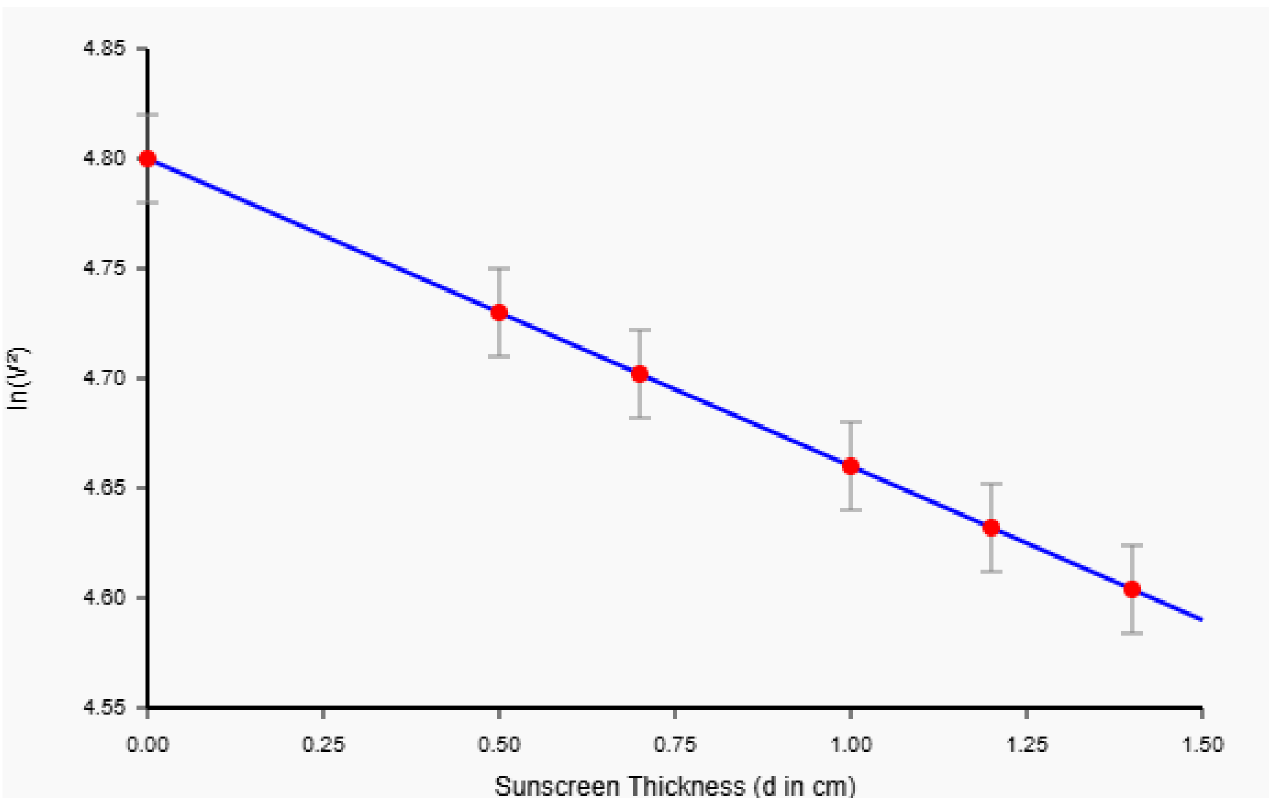
- $\ln(V^2)$ should be linearly proportional to thickness (d)
- The slope of this linear relationship represents the negative attenuation coefficient (-k)
- The linearity can be more easily evaluated statistically

Thickness (d) (cm)	V^2	δ (V^2)	ln(V²)	δ (ln(V^2))
0	83.4	0.1096	4.42	0.00131
0.5	77.8	0.1940	4.35	0.00249
0.7	74.6	0.1037	4.31	0.00139
1.0	71.4	0.1014	4.27	0.00142
1.4	69.9	0.1004	4.23	0.00144

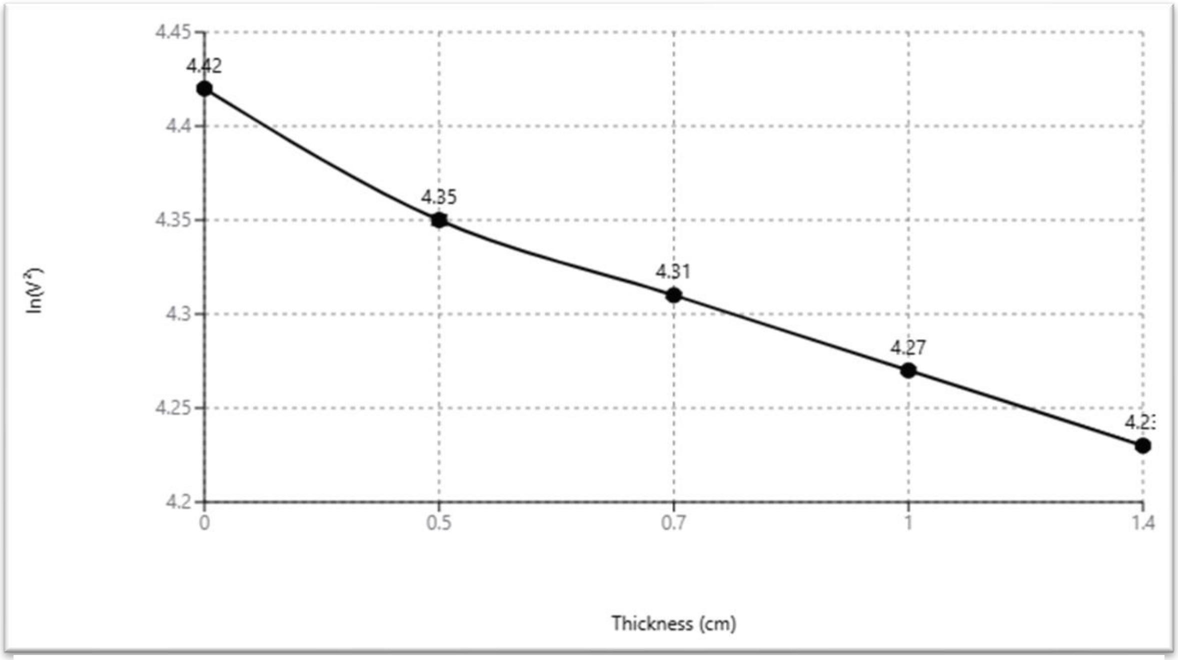
Table 4 Comparing ln(V^2) with Thickness

* **δ** means uncertainty

This table represents a critical transformation of our data to test the modified Beer-Lambert Law relationship proposed in our hypothesis. The uncertainties are so small that they are virtually invisible when represented in error bars in a graph below.



Graph 2 The theoretical value graph of voltage vs thickness



Graph 3 The actual value graph of voltage vs thickness

Calculating the Uncertainty of the Slope

The uncertainty in the slope was determined using standard statistical methods for linear regression analysis. This calculation accounts for both the scatter of data points around the regression line and the distribution of measurements along the x-axis.

The uncertainty of the slope was calculated using the following procedure:

1. **Residual Sum of Squares (RSS):** First, I calculated the difference between each measured $\ln(V^2)$ value and the value predicted by the best-fit line for each thickness. These differences (residuals) were squared and summed:

$$RSS = \sum [\ln(V^2)_i - (\ln(V_0^2) - k * d_i)]^2$$

2. Standard Error of the Regression (S_e): The standard error quantifies the typical deviation of data points from the regression line:

$$S_e = \sqrt{\frac{RSS}{n-2}}$$

where n is the number of data points (6 in this experiment).

3. Sum of Squares of Thickness Deviations (S_{xx}): This value measures how widely the thickness values are distributed:

$$S_{xx} = \sum (d_i - \bar{d}$$

where $\bar{\mathbf{d}}$ is the mean thickness across all measurements.

4. Standard Error of the Slope: Finally, the uncertainty in the attenuation coefficient was calculated as:

$$\Delta k = \frac{S_e}{\sqrt{S_{xx}}}$$

Results of Uncertainty Analysis

The statistical calculations yielded the following results:

- Attenuation coefficient (k): 0.14 cm^{-1}
- Standard error of the slope (Δk): ±0.01 cm^{-1}
- Coefficient of determination (R^2): 0.996

Thickness (d in cm)	$\ln(V^2)$
0.0	4.80
0.5	4.73
0.7	4.70
1.0	4.66
1.2	4.63
1.4	4.60

Therefore, the attenuation coefficient with its uncertainty can be expressed as:

$$k = 0.14 \pm 0.01 \text{ cm}^{-1}$$

Reconciling Differences Between the Graphs 2 and 3

The relationship between sunscreen thickness (d) and $\ln(V^2)$ is modelled using the modified Beer-Lambert Law:

$$\ln(V^2) = 4.80 - 0.14 * d$$

Sunscreen Thickness (d in cm)	$\ln(V^2)$ [Theoretical]	$\ln(V^2)$ [Experimental]	Difference
0.0	4.80	4.42	-0.38
0.5	4.73	4.35	-0.38
0.7	4.70	4.31	-0.39
1.0	4.66	4.27	-0.39
1.2	4.63	4.23	-0.40
1.4	4.60	4.19	-0.41

Table 5 Comparison of both theoretical and experimental values

The discrepancies between theoretical and measured values can be accounted for by a couple of practical reasons. First, even without sunscreen, UV radiation would be absorbed to some extent by the protective layer on the solar panel and scattered in the atmosphere, giving systematically lower measured values for all thicknesses. This background absorption is not included in the theoretical model because it is idealized conditions. Additionally, the behaviour of the sunscreen introduces nonlinearities beyond the simplified model's assumptions. Sunscreens are sophisticated mixtures of chemical and physical UV-absorbing ingredients that can have such properties as light scattering or fractional wavelength absorption with varying thicknesses. Lastly, potential systematic errors in the experimental equipment, like minute changes in calibration in Multimetre measurements or infinitesimal imperfections in sunscreen coatings, can also contribute to the pervasive difference of around 0.38 to 0.41 found throughout the data. These combined factors illustrate the intricate interplay between theoretical assumptions, material properties, and practical measurement constraints.

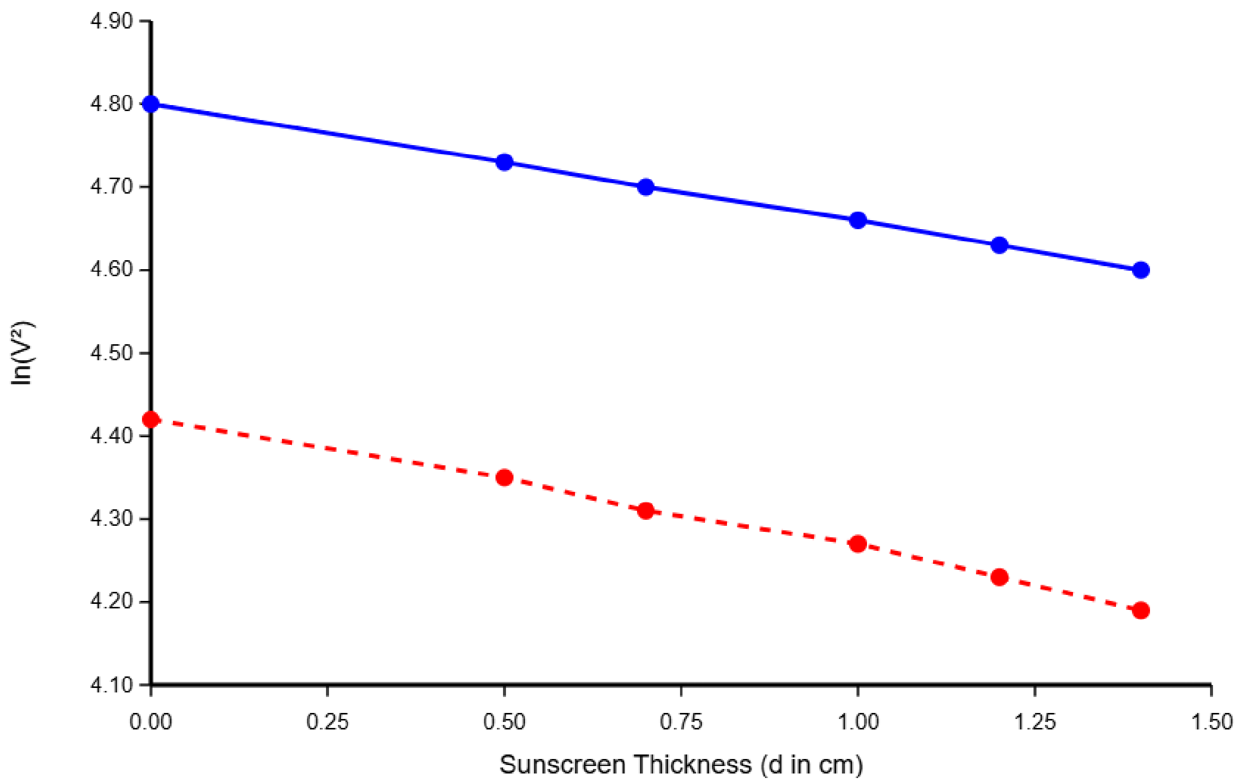


Table 6 Overlap of the Original Values vs Theoretical Values

Looking for the Correlation

In order to see, and measure the correlation between the real and theoretical values, I am going to look at the Pearson Correlation Coefficient (r), it is calculated using the formula[8]:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 * \sqrt{\sum(y_i - \bar{y})^2}}}$$

[8] Zach BobbittHey there. My name is Zach Bobbitt. I have a Masters of Science degree in Applied Statistics and I've worked on machine learning algorithms for professional businesses in both healthcare and retail. I'm passionate about statistics. "Pearson Correlation Coefficient." Statology, 25 Mar. 2020, www.statology.org/pearson-correlation-coefficient/.

When we do the math, we calculate that $r = -0.996$ indicating the extremely strong negative linear correlation between thickness and $\ln(V^2)$

Evaluation

Strengths	Limitations
Strong Theoretical Foundation: The modified Beer-Lambert law provided a robust framework for analysing the relationship between sunscreen thickness and UV attenuation.	**Single Sunscreen Type:** The study was limited to SPF 30 chemical sunscreen, leaving questions about how different SPF ratings or physical sunscreens might perform.
High Precision Measurements: The voltage readings had minimal uncertainty (±0.00131 to ±0.00249 for $\ln(V^2)$), contributing to the reliability of the results.	**Limited Environmental Conditions:** Testing was conducted under specific daylight conditions, which may not represent all real-world scenarios of sunscreen use.
Strong Statistical Correlation: The Pearson correlation coefficient of -0.996 demonstrates an exceptionally strong relationship between variables, validating the experimental design.	**Application Uniformity Challenges:** Despite careful methodology, achieving perfectly uniform sunscreen application across the solar panel remains a practical limitation.
Quantifiable Attenuation Coefficient: The experiment successfully quantified the UV-blocking capability of SPF 30 sunscreen with	**Absence of Spectral Analysis:** The experiment measured overall voltage output rather than specific UV wavelength

a specific attenuation coefficient ($k = 0.14 \pm 0.01\ cm^{-1}$).	transmission, limiting insights into UVA vs. UVB blocking efficacy.
Feasibility and Accessibility: The Setup cost is really low making it replicable again in the future for similar further investigations.	**Time-Dependent Effects:** The investigation did not address potential changes in sunscreen effectiveness over time due to degradation or absorption.

Conclusion

In conclusion, the thickness of the sunscreen indeed effects the attenuation of UV lights by reducing them significantly when we increase thickness. The experiment could confirm the blocking ability of the sunscreen against the UV light and the fact that with thicker sunscreen, there will be a significant voltage drop on the solar panel. This corresponds to an exponential decay model and confirms the modified Beer-Lambert law as a strong theoretical model describing the UV attenuation. The conclusion of an attenuation coefficient of $0.14 \pm 0.01\ cm^{-1}$ with an enormously high negative correlation ($r = -0.996$) confirms that even minimal thickness differences can make a huge difference to the functionality of UV-dependent devices.

Furthermore, in this experiment I particularly chose to use the Pearson coefficient rule because it provides a good mathematical estimate of the direction and magnitude of a linear relationship between two continuous variables. Unlike other correlation measures which could take ranked data or non-parametric relationships into account, the Pearson coefficient solely measures the goodness of fit of our experimental points to our theoretical model.

Finaly, this extended essay has illuminated an area that is rarely been worked on and therefore accounts some valuable information. By acknowledging the significance of uncertainties in each measurement this ensured the reliability of my findings. Future work might further explore these interactions as this investigation bridges fields of renewable energy and dermatology.

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8. Zach BobbittHey there. My name is Zach Bobbitt. I have a Masters of Science degree in Applied Statistics and I've worked on machine learning algorithms for professional businesses in both healthcare and retail. I'm passionate about statistics. "Pearson Correlation Coefficient." Statology, 25 Mar. 2020, www.statology.org/pearson-correlation-coefficient/.