2024年【科學探究競賽-這樣教我就懂】

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題目名稱： 二氧化鈦溶液濃度對太陽能電池安倍效率的影響 **Different Concentration of TiO_2 Solution Effect on Solar Cell Efficiency Measured in Amperage**

一、摘要

如今，非再生能源因相對便宜而被廣泛使用，對環境的損害卻不可彌補。有效應用以太陽光為能源等再生能源能夠減少非再生能源對環境的影響。然而，太陽能電池板安裝成本高且使用壽命有限，透過優化太陽能板的效率來彌補高昂的安裝成本，並解決壽命有限而低效率的問題。因此，本實驗將研究如何透過控制二氧化鈦溶液的濃度來提高太陽能電池的效率。此實驗比較了不同濃度（1g/ml、3g/ml、5g/ml）的二氧化鈦溶液對太陽能電池電流效率的影響。實驗人員利用鋁箔紙製作帶有二氧化鈦塗層的太陽能電池，並添加了乙醇、花草茶、石墨和碘溶液等材料，各具有幫助完成電路的作用。實驗數據表明，隨著TiO_2溶液濃度的增加，電流的安培數隨之增加，意味著太陽能轉換效率更高。這是由於添加更多的二氧化鈦能夠吸收更多光子，產生更多可以導電的電子電洞對。然而，一旦二氧化鈦濃度超過最佳量，太陽能電池的效率便開始下降。其原因為二氧化鈦層厚度的增加，導致 二氧化鈦表面和電極之間的距離增加，更多的電子電洞對被捕獲並隨後複合、降低效率。

二、探究題目與動機

Research Question: How do different concentrations, 1g/ml, 3g/ml, and 5g/ml, of TiO_2 solution, affect the efficiency of the solar panel in terms of amperage?

Objective: This experiment aimed to investigate the effect of TiO_2 on the efficiency of solar cells, finding the most suitable concentration of TiO_2 solution that can optimize the efficiency of solar cells.

Research Background and Motivation

Non-renewable energy, generated by burning fossil fuels such as coal, oil, and natural gas, has been one of the main sources of greenhouse gas emissions. According to the United Nations, non-renewable energy accounts for more than 75% of global greenhouse gas emissions. This results in health issues including respiratory infections, and lung diseases, killing approximately 7 billion people (United Nations, 2023). Nevertheless, despite detrimental impacts on humanity and the environment, fossil fuel energy is responsible for 80% of global energy needs, highlighting humanity's heavy dependence on fossil fuels (United Nations). Thus, one possible solution is to apply renewable energy to gradually reduce the reliance on fossil fuels energy (United Nations). Considering solar panels' limited operational lifespan of 30 to 35 years and declining efficiency after years of operation, the experimenters seek to optimize the efficiency of solar panels. We specifically choose TiO_2, an n-type semiconductor used in solar cells that acts as an electron transport layer (ETL), for three reasons: environmental friendliness, the ability of electron transfer, and long-time stability in perovskite solar cells (American Chemical Society)

三、探究目的與假設

Hypothesis: If the concentration of TiO_2 in alcohol increases, then the ampere of the electric current will increase, meaning higher solar energy conversion efficiency, as TiO_2 helps facilitate electron transport and passivate surface recombination sites (Auger, P et al., 2023).

Objectives:

1) Investigate the effects of different concentrations of TiO_2 on the overall efficiency of solar cells, with a focus on electron transport and recombination rates within solar cells.
2) Determine the optimal TiO_2 concentration for maximizing electron transport and minimizing recombination, thereby enhancing solar cell efficiency.
3) Assess the correlation between TiO_2 concentration, electron mobility, and conductivity to elucidate their role in solar cell performance.
4) Explore the relationship between TiO_2 layer thickness and protection against moisture-induced

recombination, aiming to optimize protective layers for improved efficiency.

四、探究方法與驗證步驟

Table 1. Experimental variables and how they are manipulated.

Independent Variable: Concentration of TiO_2 solution (in g/ml) ● 1 g/ml ● 3 g/ml ● 5 g/ml	How to prepare? The TiO_2 solution will contain TiO_2 and alcohol, with different grams of TiO_2 (10g, 30g, 50g) and the same volume of alcohol (10ml), creating different concentrations of TiO_2 solution (1g/ml, 3g/ml, 5g/ml). The grams of TiO_2 will be measured with a digital scale, which is an accurate instrument with an uncertainty of ±0.05 g. Each concentration will be tested at least three times to ensure the reliability of the data.
Dependent Variable: Energy conversion efficiency of the solar cell (ampere)	How to measure? The efficiency of a solar cell would be measured by a multimeter, in terms of ampere (A).

Controlled Variables	How to control it?
Heating Time of the solar cell	The heating time of the solar cell will be set to 15 minutes for every trial. It is important to keep it constant as it is a process that burns off the organic solvents (the ethanol) on the cell.
Staining time of the cells with tea	The staining time of the cells with tea will be set to 30 minutes for every trial. This will allow the anthocyanins to have enough time to bind to the surface of the solar cells and ensure absorbance.
Source of light	The source of light will apply the same desk lamp throughout all trials, as it emits the same amount of light. The mol of electrons is essential when measuring the amperage of the solar cells.
Amount of alcohol	The amount of alcohol should be kept at 10 mL in every trial. The amount of alcohol will be measured by a 50 ml beaker to ensure the accurate amount is the same throughout all trials.

Table 2. List of Materials and Quantities Needed for this Experiment

Materials	Quantity	Materials	Quantity	Materials	Quantity
Aluminum foil roll	1	Digital scale (±0.05g)	1	Iodine solution	200ml
Lab Pasteur	1	Stirring rod	1	Titanium dioxide (TiO2)	300 g
Heatproof dish	1	Heat-safe dish	1	Adhesive tape	100 cm
Multimeter	1	Hibiscus tea bag	9	Ethyl alcohol (C2H6O)	100 ml
Hotplate	1	Ruler	1	Water	1000 ml

Penicl	1	Cups	3	Alligator clips	2

Safety Precautions

Titanium dioxide (TiO_2): Be aware not to inhale, ingest, or contact TiO_2 directly. Inhalation of TiO_2 could lead to discomfort or irritation; ingestion of TiO_2 could lead to irritation, vomiting, or discomfort; direct contact with TiO_2 could lead to skin irritation. If this happens, seek further medical support and advice if needed.

Iodine: Experimenters should avoid ingestion, inhalation, or direct skin contact and eye contact with iodine. Ingestion may cause burns to the digestive tract, inhalation may cause severe respiratory tract irritation, and direct skin or eye contact would lead to skin or eye irritation, even possible burns on the skin. If this occurs, seek medical advice.

Experimental Procedures:

1) Using a stirring rod, mix 10 ml of alcohol with 10g, 30g, and 50g of TiO_2 in three beakers.
2) Cut 3 pieces of 5cmx8cm rectangular aluminum foil and cut them into 5cmx4cm size. (each concentration will need two pieces of rectangular aluminum foil)
3) Use a marker to label each two pieces of aluminum foil with the corresponding concentration.
4) Put a layer of tape around three sides of the aluminum foil pieces to control the coating.
5) Using a pipette, drop two drops of the TiO_2 solution onto the surface of 3 pieces of aluminum foil, each piece with a different concentration of TiO_2 solution.
6) Ensure the TiO_2 solution is spread evenly on the surface of aluminum foil (thin coating)
7) Put the 3 pieces of solar cells (with TiO_2 solution) into a heatproof dish, then cook the cells on a hotplate for 15 minutes until they turn brown.
8) While heating, distribute 300 ml of brewed herbal tea into three cups, each with 100 ml.
9) After heating, stain each cell (with TiO_2 solution) with a cup of herbal tea (bind anthocyanins) for 30 minutes.
10) Using a pencil, coat the other 3 aluminum foil pieces (without TiO_2 solution) with graphite (counter-electrode).
11) Mix the iodine solution with alcohol with a 3:1 ratio by a stirring rod, then spread a thin coating of the solution on the surface of the aluminum foil with graphite.
12) Place each aluminum foil coated with TiO_2 solution onto the ones covered with graphite.

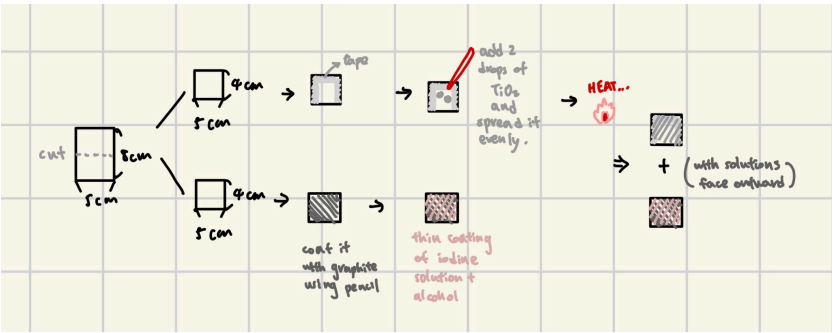

Figure 1. Step 2 to Step 12 procedures with 1 piece of 5cmx8cm rectangular aluminum foil being shown (3 pieces will need to be used according to Step 2).

13) Using alligator clips, hold the aluminum foil stack together.
14) Under the desk lamp light, use a multimeter to measure the electric current of the solar cells with different TiO_2 concentrations.
15) Repeat steps 1-14 for two more trials to ensure the data reliability.
16) Record the data on how TiO_2 concentrations affect the efficiency of the solar cells.

五、結論與生活應用

Table 3. Data of 1g/ml, 3g/ml, and 5g/ml of TiO_2 effect on the efficiency of the solar panel, measured in terms of amperage

	Trial 1	**Trial 2**	**Trial 3**	**Average**
Amperage (A) for 1g/ml TiO_2	0.082	0.079	0.042	0.068
Amperage (A) for 3g/ml TiO_2	0.459	0.356	0.289	0.368
Amperage (A) for 5g/ml TiO_2	0.274	0.272	0.238	0.261

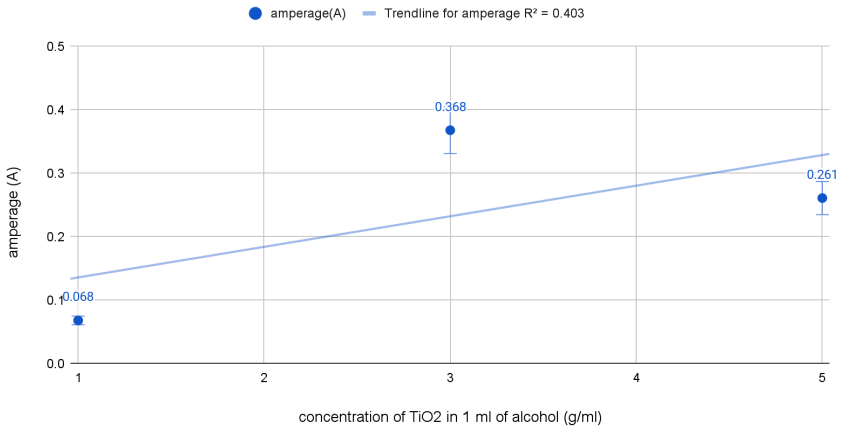

Figure 2. Graph of the average of three trials of how different concentrations of TiO_2 in alcohol, 1g/ml, 3g/ml, and 5g/ml, affect the efficiency of the solar panel, measured in terms of amperage.

Data Analysis & Hypothesis Evaluation

The data collected does not fully support the hypothesis, demonstrating that the amperage of the solar cell does not increase correspondingly as the concentration of TiO_2 in alcohol increases (1g/ml to 3g/ml to 5g/ml). While the highest amperage corresponds to 3g/ml, indicating increased efficiency, further concentration increases do not proportionately elevate amperage (explained in the following paragraph). The addition of TiO_2 enhances photon absorption, generating more electron-hole pairs and consequently increasing amperage. This is evidenced by the rise in amperage from 1g/ml to 3g/ml TiO_2 concentration. Furthermore, TiO_2 supplementation reduces surface recombination, minimizing the loss of photogenerated charge carriers (Park, 2013).

Nonetheless, the amperage started to decrease (from 0.368 in 3g/ml to 0.261 in 5g/ml) when the grams of TiO_2 kept on increasing to 5 grams, indicating that our data does not fully support our hypothesis. The lower amperage being measured for the solar cells that have 5 grams of TiO_2 suggests that, after surpassing the optimal gram of TiO_2, the addition of TiO_2 will start to reduce the efficiency of solar cells. This could be caused by several reasons.

1. First, the function of TiO_2 increases the light absorption capacity of the photoanode up to a certain point (Salim, 2023). Beyond the optimal point, the absorption of light becomes saturated, which stops increasing the energy conversion efficiency (Salim, 2023).
2. Second, the thick TiO_2 layer could increase the distance between the TiO_2 surface and the electrodes, resulting in more electron-hole pairs being trapped and later recombining (Pesci, 2013). This increases the efficiency-suppression recombination rate of electron-hole pairs, which reduces the efficiency of the solar cell (Pesci, 2013).

After the optimal concentration is met, factors such as light absorption, charge transport, and recombination might stop or decrease the energy conversion efficiency of the solar cell.

Evaluating Random and Systematic Errors

Figure 5. 50g of TiO_2 in 10 ml of Ethyl alcohol.

1. **Material:** Aluminum foil has a rough surface, leading to the TiO2 solution not being able to spread evenly across the surface of the aluminum foil. This happened in all trials, making it a systematic error. The uneven spread on the rough surface of aluminum foil can lead to an uneven distribution of absorbed light that results in fewer photons being absorbed, causing less electrons generated, therefore generating less electric current. In the experiment, for every aluminum foil folded for different concentrations of TiO2 solution, there may be variations in the smoothness or roughness of the surface, creating inaccurate results when measuring the efficiency of solar cells.
2. **Imprecise optimal point:** The data results suggest that there is an optimal point for TiO_2 to maximize the efficiency of solar cells. However, the difference between each value of the independent variable is too big to find the exact optimal point. With a difference of 2 grams of TiO_2, it is difficult to figure out the optimal point to maximize the efficiency when the data only present that it is between 3 g/ml and 5 g/ml. Further testing is required to find out the optimal concentration of TiO_2 that can increase the solar energy conversion efficiency of solar cells.

Improvements to the lab

1. **Material:** Experimenters could replace aluminium foil with a material that has a smoother surface. Common materials for self making solar panels includes conductive glass, which is also electrically conductive. In this way, the solar panel could also efficiently transport electric current and increase the overall efficiency of solar panel, but having a smooth surface that eliminates the systematic error that causes inaccurate results.
2. **Imprecise optimal point:** Experimenters could make the difference between each independent variable smaller, meaning each independent variable's value is closer to the other. The experimenters suggested a concentration of 1 g/ml, 1.5 g/ml, 2 g/ml, 2.5 g/ml, 3 g/ml, 3.5 g/ml, and 4 g/ml. By reducing the original difference of 2 g/ml to 0.5 g/ml between each independent variable, it is easier to figure out the optimal concentration of TiO_2 to reach the maximum efficiency of a solar cell. This can help increase the accuracy of the experiment data and solve the problem of solar cell's low efficiency of solar effectively.

Conclusion and Application

Referring to the purpose of this experiment, this experiment has demonstrated the function of TiO_2 in increasing solar energy conversion efficiency. The data of 3 g/ml, 5 g/ml, to 1 g/ml indicates that there is an optimal concentration of TiO_2 in alcohol to maximize the efficiency. The experiment highlighted the importance of TiO_2 coating in solar cell's performance, which contributes to environmental improvement. By improving the efficiency of solar cells, society can reduce the demand and reliance on fossil fuels energy. Moreover, applying our experimental results, the improved efficiency highlights the possibility of using renewable energy to support energy needs, reducing the emission of greenhouse gasses from non-renewable sources, which helps mitigate global warming problems and environmental damage. According to Taiwan

Insight, several environmentalists oppose the establishment of renewable facilities, fearing the loss of trees and natural habitats (United Nations). With the improvement in the efficiency of solar panels, the number of solar energy facilities installed could also be reduced, alleviating the environmental damage including land use and habitat disruption. Moreover, in 2022, only 8.3 percent of all electricity produced was renewable (United Nations). If the efficiency of solar cells is improved, renewable energy could help reduce Taiwan's current heavy reliance on fossil energy. In essence, solar panels should be more effectively used to generate electricity, promoting sustainable and environmentally friendly electricity consumption.

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