2022

AP® CollegeBoard

AP® Research Academic Paper

Sample Student Responses and Scoring Commentary

Inside:

Sample C

☑ Scoring Guidelines

☑ Student Samples

☑ Scoring Commentary

The Response…				
Score of 1 **Report on Existing Knowledge**	**Score of 2** **Report on Existing Knowledge with Simplistic Use of a Research Method**	**Score of 3** **Ineffectual Argument for a New Understanding**	**Score of 4** **Well-Supported, Articulate Argument Conveying a New Understanding**	**Score of 5** **Rich Analysis of a New Understanding Addressing a Gap in the Research Base**
Presents an overly broad topic of inquiry.	Presents a topic of inquiry with narrowing scope or focus, that is NOT carried through either in the method or in the overall line of reasoning.	Carries the focus or scope of a topic of inquiry through the method **AND** overall line of reasoning, even though the focus or scope might still be narrowing.	Focuses a topic of inquiry with clear and narrow parameters, which are addressed through the method and the conclusion.	Focuses a topic of inquiry with clear and narrow parameters, which are addressed through the method and the conclusion.
Situates a topic of inquiry within a single perspective derived from scholarly works **OR** through a variety of perspectives derived from mostly non-scholarly works.	Situates a topic of inquiry within a single perspective derived from scholarly works **OR** through a variety of perspectives derived from mostly non-scholarly works.	Situates a topic of inquiry within relevant scholarly works of varying perspectives, although connections to some works may be unclear.	Explicitly connects a topic of inquiry to relevant scholarly works of varying perspectives **AND** logically explains how the topic of inquiry addresses a gap.	Explicitly connects a topic of inquiry to relevant scholarly works of varying perspectives **AND** logically explains how the topic of inquiry addresses a gap.
Describes a search and report process.	Describes a nonreplicable research method **OR** provides an oversimplified description of a method, with questionable alignment to the purpose of the inquiry.	Describes a reasonably replicable research method, with questionable alignment to the purpose of the inquiry.	Logically defends the alignment of a detailed, replicable research method to the purpose of the inquiry.	Logically defends the alignment of a detailed, replicable research method to the purpose of the inquiry.
Summarizes or reports existing knowledge in the field of understanding pertaining to the topic of inquiry.	Summarizes or reports existing knowledge in the field of understanding pertaining to the topic of inquiry.	Conveys a new understanding or conclusion, with an underdeveloped line of reasoning **OR** insufficient evidence.	Supports a new understanding or conclusion through a logically organized line of reasoning **AND** sufficient evidence. The limitations and/or implications, if present, of the new understanding or conclusion are oversimplified.	Justifies a new understanding or conclusion through a logical progression of inquiry choices, sufficient evidence, explanation of the limitations of the conclusion, and an explanation of the implications to the community of practice.
Generally communicates the student's ideas, although errors in grammar, discipline-specific style, and organization distract or confuse the reader.	Generally communicates the student's ideas, although errors in grammar, discipline-specific style, and organization distract or confuse the reader.	Competently communicates the student's ideas, although there may be some errors in grammar, discipline-specific style, and organization.	Competently communicates the student's ideas, although there may be some errors in grammar, discipline-specific style, and organization.	Enhances the communication of the student's ideas through organization, use of design elements, conventions of grammar, style, mechanics, and word precision, with few to no errors.
Cites **AND/OR** attributes sources (in bibliography/ works cited and/or in-text), with multiple errors and/or an inconsistent use of a discipline-specific style.	Cites **AND/OR** attributes sources (in bibliography/ works cited and/or in-text), with multiple errors and/or an inconsistent use of a discipline-specific style.	Cites **AND** attributes sources, using a discipline-specific style (in both bibliography/works cited **AND** in-text), with few errors or inconsistencies.	Cites **AND** attributes sources, with a consistent use of an appropriate discipline-specific style (in both bibliography/works cited **AND** in-text), with few to no errors.	Cites **AND** attributes sources, with a consistent use of an appropriate discipline-specific style (in both bibliography/works cited **AND** in-text), with few to no errors.

Academic Paper

Overview

This performance task was intended to assess students' ability to conduct scholarly and responsible research and articulate an evidence-based argument that clearly communicates the conclusion, solution, or answer to their stated research question. More specifically, this performance task was intended to assess students' ability to:

- Generate a focused research question that is situated within or connected to a larger scholarly context or community;
- Explore relationships between and among multiple works representing multiple perspectives within the scholarly literature related to the topic of inquiry;
- Articulate what approach, method, or process they have chosen to use to address their research question, why they have chosen that approach to answering their question, and how they employed it;
- Develop and present their own argument, conclusion, or new understanding while acknowledging its limitations and discussing implications;
- Support their conclusion through the compilation, use, and synthesis of relevant and significant evidence generated by their research;
- Use organizational and design elements to effectively convey the paper's message;
- Consistently and accurately cite, attribute, and integrate the knowledge and work of others, while distinguishing between the student's voice and that of others;
- Generate a paper in which word choice and syntax enhance communication by adhering to established conventions of grammar, usage, and mechanics.

Investigating the effects of carbon-based RF aerogels on DSSCs with the purpose of increasing cell efficiency

Word Count: 4312

Abstract:

With increasing concerns and demands for clean energy, solar cells seem to be one of the most practical solutions. The sun delivers ample amounts of energy to the Earth, and while conventional solar cells are capable of converting some of the energy from the sun, they are severely limited by their inability to function properly at high temperatures. Given that they have to be in direct sunlight to convert light into electrical energy, solving the heating issue would be an effective step towards a cleaner and more sustainable future. Being composed of a micro-fibrous structure, Aerogel is a very good insulator and would serve well as an integrated cooling solution to the solar panel without requiring external maintenance. A particular type of aerogel - carbon aerogel - shows promise as a solution as it does not only demonstrate the insulating properties of silica aerogel but also increases the photovoltaic properties of Titanium Dioxide (TiO_2), the main chemical in dye-sensitized solar cells (DSSCs). DSSCs were assembled using TiO_2 as one of the main chemicals, anthocyanin dye sourced from raspberries, and other chemicals. Half of the cells were treated with the Aerogel by incorporating it into the cell in contact with the TiO_2. The control cells that contained no aerogel performed as expected and showed substantial drops of efficiency with temperature, dropping by 70% in one hour, while the aerogel treated cells showed only a 12% drop in efficiency over the same period, serving as promising results for future integration of carbon aerogel in solar cells.

Introduction:

Solar cells are poised to become a main source of energy production in the near future and improving their efficiency continues to be an active field of research. A particular type of photovoltaic cell (solar cell) will be the focus of this investigation: a DSSC (Dye-Sensitized Solar Cell). DSSCs (also called Grätzel cells after their inventor) are appealing because they are relatively inexpensive and simple to assemble. DSSCs can be assembled without access to the specialized equipment that is required to get silica crystals to the near-perfect structure necessary for acceptable solar energy conversion in silicon solar cells [2][11][13][14]. The main component of DSSCs is TiO_2 (Titanium Dioxide), a relatively safe and accessible chemical [2][14]. Photoexcitation - the process by which a material gains energy after absorbing a photon - of TiO_2 with the help of a dye provides the necessary energy to release an electron which will travel by diffusion [5] through the outside of the cell, through a load, and back to the counter-electrode forming a circuit. The dye regenerates the electron through a redox reaction with the iodine electrolyte and counter electrode who in turn is regenerated by the electron completing the circuit [2][11]. Due to their low production cost and photovoltaic properties, DSSCs are a good model for other types of photovoltaic cells such as monocrystalline silicon, polycrystalline silicon, and perovskites among others.

A problem with most kinds of solar cells is their drop in efficiency after temperature increases past their optimal temperature[10][16]. A lot of work has been done to address the problem of temperature and research on water sprays, coolants, TEGs (thermoelectric generator), TECs (thermoelectric cooler) and other methods have been conducted [1][10]. This research paper focuses on a solution integrated within the photovoltaic cell that does not require external additions to minimize the maintenance required, maintenance cost, and complexity. The solution proposed involves incorporating carbon aerogel into the TiO_2 suspension in an effort to minimize the heating rate of the panel while allowing for electrical conductivity inside the cell and increasing the photovoltaic properties of TiO_2 [6].

Aerogels' unique physical properties enable them to act as excellent insulators despite their low density. Being composed of almost 99% air, it is the porous nanostructure that lends it most of its properties [17]. Silica aerogels are fairly common, but specialized gels can combine the chemical properties of a base material with the insulative properties of aerogel. One such specialized aerogel is a carbon-based aerogel. Apart from the thermally insulative properties, carbon aerogel is also able to conduct some electricity and has been shown to enhance the photovoltaic properties of TiO_2 [6]. In a previous investigation I conducted, silica aerogel showed some promise in increasing voltage output in cells by decreasing heat gain. It is possible that the specialized carbon aerogel may provide the insulative advantages of silica aerogel with the addition of increased conductivity and voltage due to its interactions with TiO_2. In the previous year's research, I was able to incorporate the fibrous silica aerogel into the DSSCs and run two trials with the aerogel cells and the controls without aerogel. Due to limited time constraints, no overall results were reached but individual results from groups were promising. One of the trials showed significant improvement in voltage output between the cells treated with the fibrous silica aerogel and the control cells which lacked the aerogel. The incorporation of a more specialized aerogel like carbon aerogel would provide clearer and more pronounced results.

Dye-sensitized solar cells are unique in their architecture regarding the conversion of light into electrical potential. According to Nazeeruddin, Baranoff, & Grätzel, DSSCs generally contain a glass support coated with transparent conductive oxides, a semiconductor film, TiO_2, or a similar semiconductor, a sensitizer absorbed onto the surface of the semiconductor, an electrolyte, and a counter electrode capable of regenerating the electrolyte [11]. This project uses FTO (Fluorine-doped Tin Oxide) glass as the transparent conductive oxide, TiO_2 as the semiconductor, anthocyanin dye from raspberries, Iodine solution as the electrolyte, and the carbon byproduct of unclean wax combustion to achieve a thin counter electrode. The dye in the cells is generally a ruthenium-based complex that provides stability to the cells [12][15], but for simplicity and low production cost, the organic anthocyanin dye sourced from raspberries was used. Figure 1 represents a functional dye-sensitized solar cell with the materials and a typical electron path.

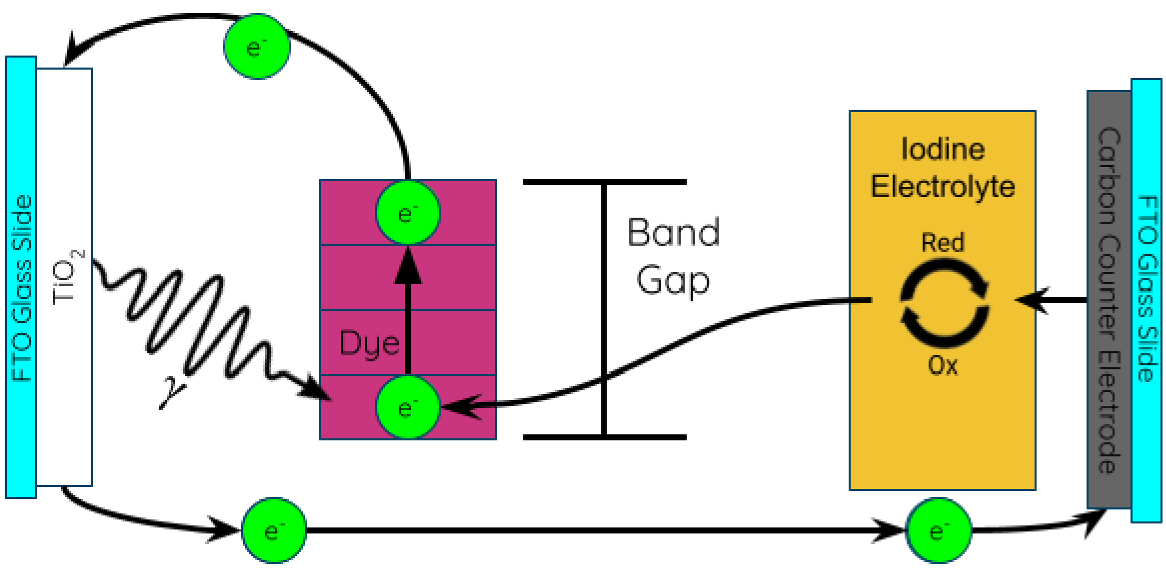

Fig. 1: General pathway of electron transport in DSSCs

Currently, there have been papers that have achieved over 10% efficiency with DSSCs [4]. The goal of this research is not to compete with those efficiencies, rather provide a 'proof of concept' for the potential of aerogel integration in DSSCs. To demonstrate the potential of aerogel, the experimental cells must perform better than control cells of the same caliber in order to demonstrate that carbon aerogel might be able to mitigate the negative effects of temperature on solar cell efficiency while also increasing the photocatalytic properties of TiO_2.

Methods:

Several key steps are required in the production of a single DSSC including preparing the TiO_2 suspension, preparing the FTO slides, coating each of the two slides either with TiO_2 or carbon, preparing the iodine electrolyte, assembling the cells, and incorporating the carbon aerogel into the experimental cells. The testing procedure involves maintaining a controlled environment where the cells are exposed to high-intensity visible light as well as infrared radiation.

1. Preparing the TiO_2 suspension

The titanium dioxide suspension consists of a fine TiO_2 powder (Flinn Scientific, T0081) suspended in vinegar and held in place by a small amount of dishwasher detergent acting as a surfactant. The detergent acting as a surfactant increases the time it takes for the vinegar and TiO_2 to disassociate. To begin the making of the suspension, 6g of TiO_2 powder were measured with a digital scale and placed in a mortar. To incorporate the TiO_2 into a workable solution, 1mL increments of vinegar were added to the TiO_2, making sure to grind the suspension after each addition to assure the smallest possible size for the TiO_2 particles and ensure a homogenous mixture. The process of adding vinegar was repeated until a total of 10mL had been added to the TiO_2. Depending on the size of the batch, the entire procedure would then be repeated to make a total of 12g of TiO_2 suspended in 20mL of vinegar. One drop of the dishwashing detergent was added to act as a surfactant and the solution was transferred to a container for storage and let rest.

2. Preparing the semiconductor FTO slide:

For each dye-sensitized solar cell produced, one semiconductor FTO slide must be prepared. A pre-purchased FTO slide (Arbor Scientific #P6-2100-17) must be cleaned with isopropyl alcohol (MG Chemicals) to remove contaminants from the slide and ensure the TiO_2 adheres properly to the slide. Since the FTO slide is only conductive on one side, a multimeter set to measure resistance is necessary to determine which of the two sides is conductive. The slide measured about 50Ω corner to corner on the FTO coated side (the conductive side). Once the correct side was identified, the doctor-blade method [7] was used to evenly distribute three drops of the titanium dioxide suspension on the slide. The doctor blade method is a process to ensure an even coating by passing a blade a specific distance above the surface to be coated and scraping off the excess material. To ensure the slide did not move during the application, clear tape was used to restrain the slide to the table. The tape covered a band approximately 0.2cm on each side of the slide. This band lacked the TiO_2 covering and would be later used to connect the photovoltaic cell to the multimeter when testing. The coating is then left to dry. If making more than one slide at a time, then the slides were placed side by side and all taped down together on two opposite sides. Three drops of the TiO_2 per slide in the group were added on top and spread out using the doctor-blade method [7]. From there they were left to dry in the same manner as the individual ones for at least 15 minutes. Figure 2 shows the band covered by the tape and the arrangement of the slides.

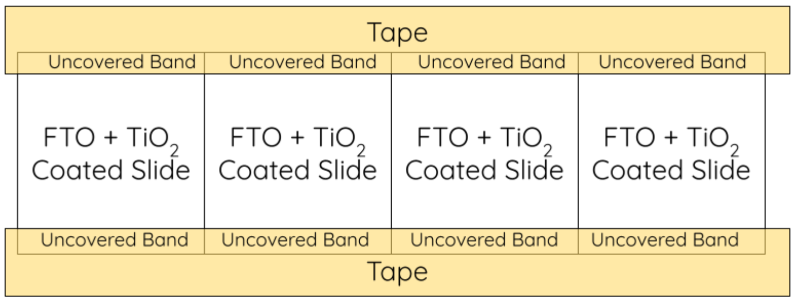

Fig. 2: Diagram of FTO slides taped to countertop for TiO_2 application

3. Preparing the Counter Electrode:

Similar to the semiconductor slide, the counter electrode must be wiped down with isopropyl alcohol to ensure proper contact with the carbon layer. The carbon layer was applied on the slide by the accumulation of carbon residue from a wax combustion reaction. Effectively, the slide must be placed over a candle using tongs and maintained for as long as is needed to make the slide entirely opaque. The tongs left a band at the bottom of the cell approximately half a centimeter wide but the rest of the area was covered with carbon residue. The uncovered band would serve as a place to connect the slide to the multimeter later, much like the bands on the TiO_2 slides. Having a controlled distance from the candle was crucial or else the flame singed the slide, rendering the singed area incapable of the redox reaction necessary to maintain the flow of electrons.

4. Annealing the TiO_2-coated semiconductor slide:

To ensure that the TiO_2 is able to perform its photoelectrochemical process inside of the DSSC, a primitive convection oven was created inside of a fume hood (Fisher Scientific, FH3943810244) to evenly heat the slides. A DeWalt hot air gun (D26960) was set up vertically underneath a ring stand (~1cm apart). On top of the ring stand, the semiconductor slides were placed on a wire mesh to allow airflow. Aluminum foil was then placed around the slide and extended to the edge of the hot air gun muzzle. This was done to maintain the slides in contact with the hot air for as long as possible. The temperatures followed in the procedure were adapted from Ito, Seigo et. al [4] who also used hot air flow to anneal their slides. A low airflow at 300 °C was maintained for 5 min. followed by 350 °C for 5 min. The airflow was then switched to high and left at 450 °C for 15 min. and finally at 500 °C for 15 min. The entire procedure took exactly 40 min. The gradual increase of temperature was to ensure there was no damage to either the slide or the coating by rapid change in temperature. The slide was extracted and allowed to cool at ambient temperature. The annealing process did two things: it evaporated the vinegar and detergent used to maintain the titanium dioxide in a suspension while also ensuring a high efficiency later on as higher annealing times have been shown to present higher efficiencies [3].

5. Extracting and Applying the Anthocyanin Organic Dye:

The dye is necessary to artificially lower the bandgap of the TiO_2 enough for electron flow to become feasible under normal circumstances. A bandgap is just the separation of the valence and conduction bands, and lowering the bandgap results in less energy being required for an electron to move from the valence band to the conduction band. Generally, ruthenium-based complexes are used for the dyes [14] but due to unavailability and cost, an organic dye was used in this project. The dye was extracted from raspberries by placing 10 berries in cheesecloth in a mortar & pestle and physically extracting the juice while separating the solid part of the berry using a cheesecloth. Approximately 30mL of juice was able to be extracted from every batch of 10 berries, but the amount of dye was much smaller than that since it was dissolved in the juice. In order to maintain a consistent quality of the dye, the liquid extracted from the berries is kept stirred with a magnetic stir bar to ensure homogeneity. While the liquid was stirred, 160μL of the juice was pipetted out on the top of the FTO coated slide using a micropipette. The micropipette was set to 20μL and used eight times, ensuring that the entire surface was exposed to the liquid by pipetting the liquid in a specific pattern seen in Figure 3. The TiO_2 absorbs the dye fairly slowly so it is left overnight to absorb and dry. The time allows for the dye to be absorbed by the TiO_2 and for the water to evaporate, leaving only the dye on the slide. Using the magnetic stirrer, much more even coverings are achieved from the starting and ending slides. Before using the magnetic stirrer, the first slides assembled looked visibly discolored while the later slides were the desired dark pink color they should be. Hypothesizing that the mixture was not homogeneous and that the dye was sinking to the bottom the magnetic stirrer was introduced and solved the situation.

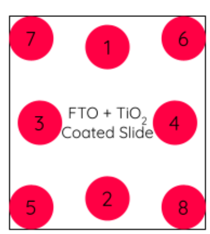

Fig. 3: TiO_2 slide with the order for dye application. 20μL per application location.

6. Preparing the Iodine electrolyte solution:

The iodine/potassium iodide electrolyte solution is necessary to facilitate the movement of charges within the cell and allow the internal circuit to be closed. A volumetric flask of 10mL was partially filled with ethylene glycol and 0.119g of Iodine crystals (I_2) were added. To that, 0.831g of potassium iodide crystals (KI) were added. The volumetric flask was then filled with ethylene glycol to the 10mL mark. The contents were mixed by gently swirling. The iodine solution was stored in darkness to prevent spontaneous decomposition.

7. Final Assembly of control cells:

The final assembly of the control cells combines the annealed and dye-coated TiO_2 slides with the carbon counter electrode, as well as with the iodine solution. Using a dropper, three drops of the electrolyte solution were applied to the TiO_2 slide. Should the electrolyte have been added to the counter electrode, the carbon layer would have come off and rendered the cell useless. Since the control cells only require the iodine solution in between the slides, the carbon-coated slide was then pressed on top of the TiO_2 and held in place using two metal clips. The carbon counter electrode must be out of phase (See Fig. 4) with the other slide to leave a small exposed band of glass on either slide. These are the bands described in methods sections 2 and 3 for the TiO_2 and counter electrode slides respectively. The excess iodine solution that was pressed out from between the slides was cleaned with a q-tip to allow proper contact to be made with the FTO coating. A final diagram of the cell is shown in Figure 5.

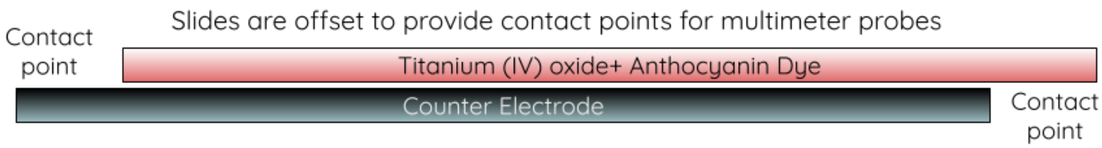

Fig. 4: Assembled cell side view diagram with exposed contact points

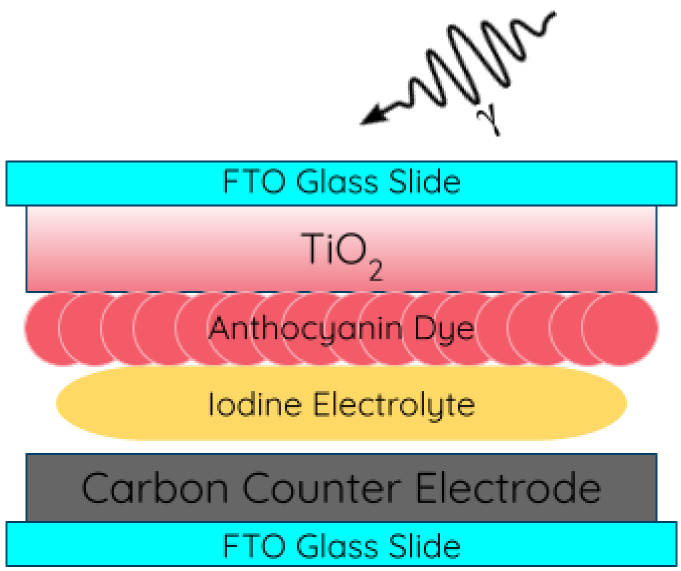

Fig. 5: Diagram of Control Cell

Unsuccessful Incorporation of the RF carbon aerogel:

The carbon-aerogel treated cells were assembled in the same manner as the control except when nearing the final assembly of the cell. Up to the addition of the iodine electrolyte, the procedure is identical for control and aerogel cells, and the only variation after the electrolyte is the addition of the carbon aerogel to the titanium dioxide slide before sealing the cell with the metal clips. The incorporation of the carbon aerogel into the cells was a lengthy process involving several failed attempts and a final working solution.

Several attempts were made to incorporate the aerogel into the cells, the first of which was incorporating aerogels that were approximately 0.0135g into the cell. This was done by crushing the aerogel into a very fine powder in a mortar and pestle and layering it on top of the iodine electrolyte. The cells assembled in this manner failed to produce any voltage and the procedure was discarded. It is possible that the result could be explained due to the large quantity of the aerogel incorporated. The final incorporation of aerogel required less than a quarter of the amount aforementioned. Another possible explanation for the failure of the cells was the excessive pulverization of the aerogel, rendering its structure useless. Since the structure of the aerogel is what provides the physical properties, aggressive handling of the aerogel might have failed to yield desirable results.

The second failed incorporation of the aerogel involved introducing the aerogel to the electrolyte before application. This was achieved by crushing approximately 0.0145g in a mortar and pestle and adding 120μL of the electrolyte to the powder. A viscous paste resulted from the addition of the electrolyte that was added to the titanium dioxide slide before sealing. The cell had no output voltage and the technique was deemed futile and discarded. A possible explanation for the failure of the paste was that there was insufficient contact between the layers causing there to be a break within the cell.

Successful Incorporation of the RF Carbon Aerogel:

Ultimately, a solution was found to incorporate the aerogel into the cells. With the tentative explanations for the failures for the previous two attempts at incorporation, a third method was implemented which built off the previous two failures. A localized application of approximately 0.0030g of the carbon aerogel yielded functional cells. To achieve this, approximately 0.0030g of the carbon aerogel was placed in a mortar and pestle and gently tapped with the pestle to break pieces off the aerogel. Careful repetition of the tapping continued to ensure small enough aerogel size while also preserving as much of the structure as possible. Three drops of the electrolyte solution were added to the TiO_2 slide as discussed in the *Final Assembly* section, and the aerogel was localized to the center of the cell by funneling the aerogel as closely to the center as possible. The cell was closed, sealed, and cleaned and produced adequate results to proceed with testing. A diagram showing the aerogel cell is shown in Figure 6.

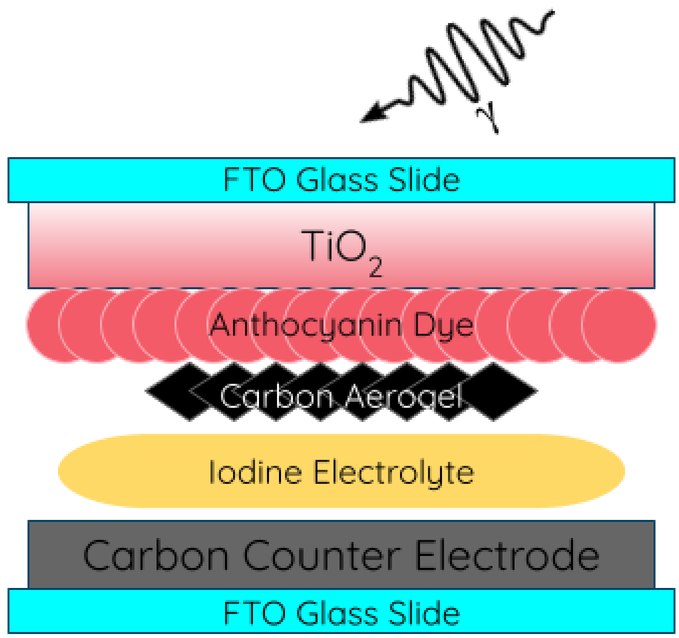

Fig. 6: Diagram of Carbon Aerogel Treated Cell

Testing Setup:

To collect data, four testing groups (A, B, C, D) were created. Each group had four functional cells, two of which were control cells and two that were carbon aerogel treated cells. All four groups were assembled simultaneously up until the final assembly. When testing on a group, the selected group underwent final assembly and was tested on the same day. The final assembly of the groups on the day of testing ensured the best performance of the cells, as they deteriorated within a week of their final assembly date. They are, however, quite stable before final assembly which is why they were left incomplete, but ready for final assembly up to the day of testing.

When cells were assembled and ready for testing they were positioned beneath a fluorescent light source and near a strong heat source that was able to surpass 40℃. An Agilent (U1252A) multimeter was used to measure the voltage of the cells every five minutes for one hour under direct heat. A wireless Bluetooth PASCO thermometer was connected to its respective PASCO data collection program on a laptop and air temperature immediately around the cells was recorded. Figure 7 shows an image of the testing setup. The nomenclature for referring to a specific cell is [Group Letter, **C**ontrol/**A**erogel, Cell #]. For example, cell AC2 would be the second control cell in group A. Figure 8 shows the positioning of cells from an overhead perspective where cells labeled #2 were closer to the heat lamp than cells labeled #1. Even though there were cells that were closer to the heat source than others, the difference between them was small and there was symmetry in the cells' positioning that meant similar conditions for all the cells.

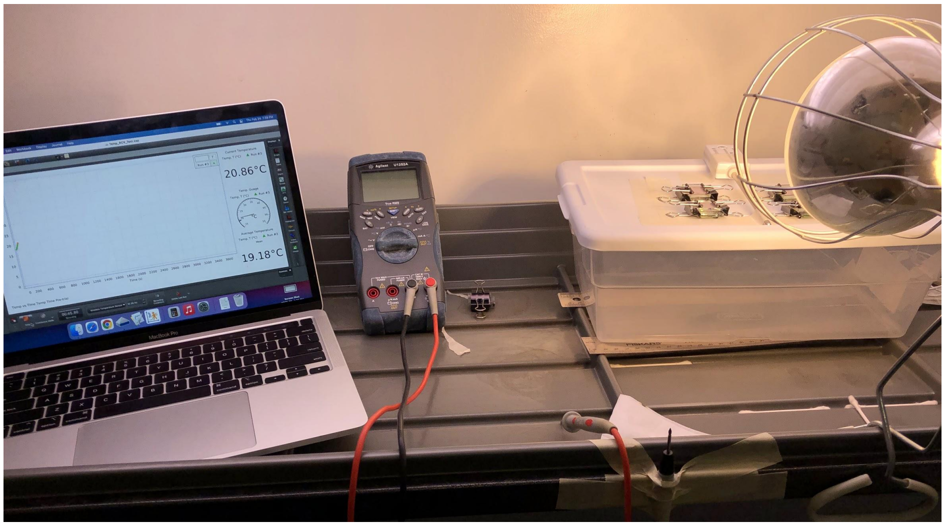

Fig. 7: Testing setup including 4 cells, multimeter, laptop computer, and heating element.

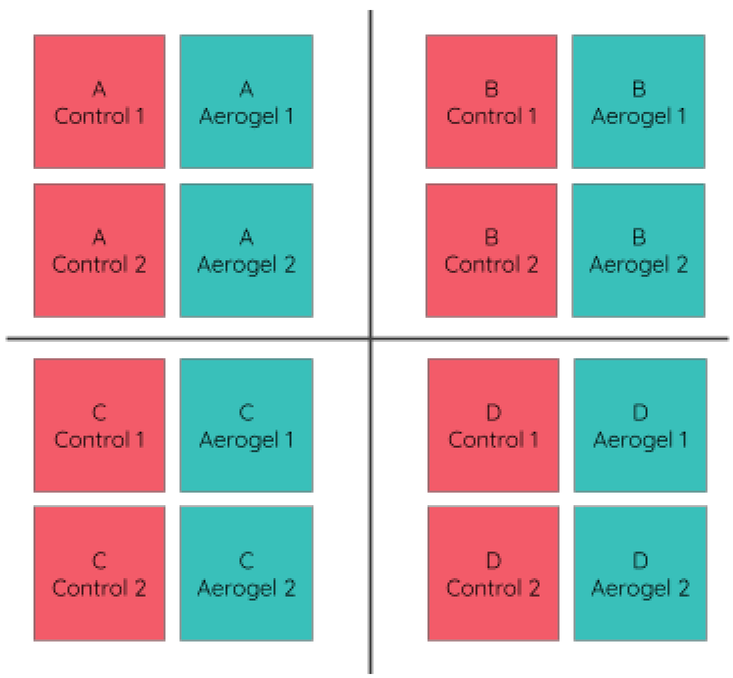

Fig. 8: Diagram of Cell Groups

Data:

All voltage data in 5-minute increments for all cells in all four groups are shown in Tables 1 through 4 in the appendix. To analyze the data, all points for control cells and carbon aerogel treated cells were each averaged together between groups at each instance in time to produce an average voltage over time graph for control and aerogel cells (Fig. 9). The graph shown in Figure 9 clearly shows a higher voltage for aerogel cells over their untreated control counterparts, showing the photocatalytic properties of carbon aerogel. To see whether the aerogel mitigated the negative effects of temperature on the cells, Fig. 10 shows the average voltage drop of the cells taking the final voltage value from the initial voltage. The graph demonstrates a 12% drop in voltage for carbon aerogel cells in comparison to the 71% drop seen in control cells. To calculate error in the graph shown in Fig. 10, a Pythagorean method for combining Standard Error of the Mean formula was utilized where the square of the new error was the sums of the squares of the individual errors from two previous groups: $E_C^2 = E_1^2 + E_2^2$

This method for calculating error, by its very nature, ensured that the combined error (E_c) was always larger than the two errors from which it came from (E_1 & E_2). The resulting error after combining four groups of data becomes increasingly large but provides very high confidence when no overlap is seen. To increase the confidence in the results an unpaired t-test was performed to assess the significance of the results. The t-test compares the means of exactly two groups and the results of the t-test run on the data for the average voltage drop show significant results where the p-value is less than 0.05 showing that there is less than a 5% chance that the results achieved were due only to chance.

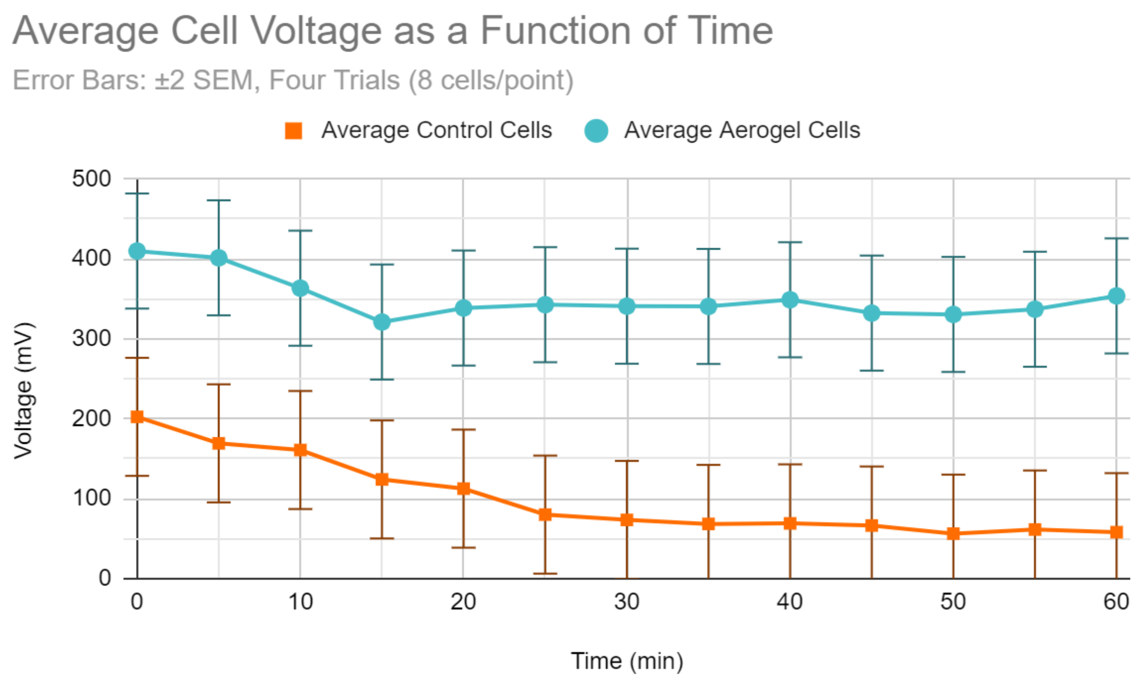

Fig. 9: Average Cell Voltage as a Function of Time

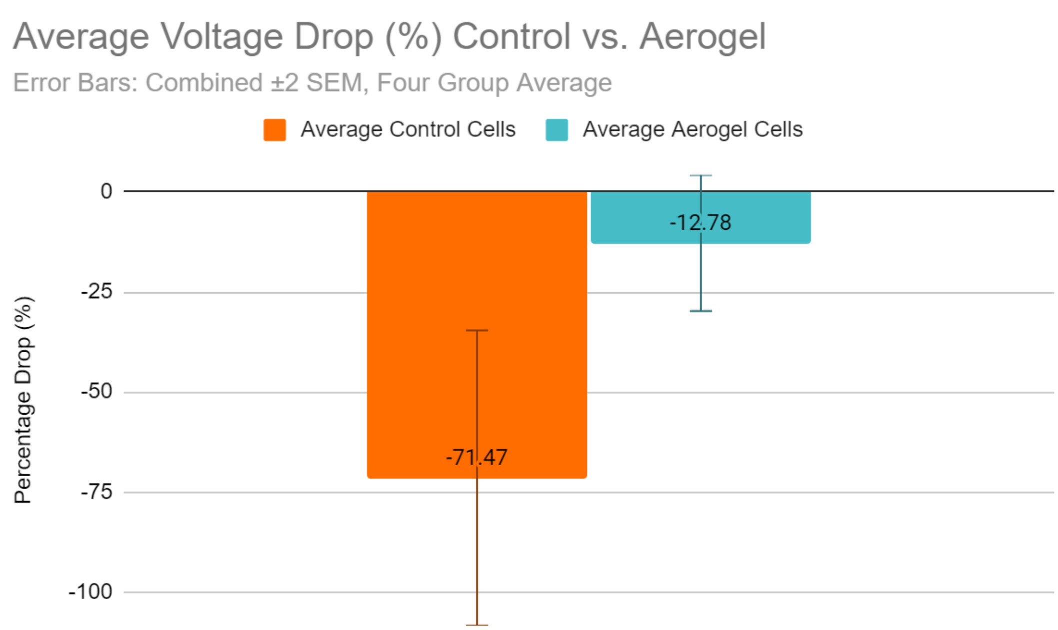

Fig. 10: Average Voltage Drop (%) in Control vs. Carbon Aerogel Cells

Limitations:

The study conducted had its limitations in terms of the scope of the data. The cells assembled were not mass-produced, which means that the cells could not be guaranteed to be within a very specific range of each other. All the groups ultimately showed a very positive and similar result for the carbon aerogel so it is unlikely that the variations were too large, however. Another limitation of the project was the materials used in the assembly of the cell. As previously explained, ruthenium-based sensitizers are traditionally used in the assembly of dye-sensitized solar cells but due to cost anthocyanin dye was used, which gave consistent results but not at the higher voltages expected from the synthetic dyes. Overall the biggest limitation and the most promising area for future research is that the dye-sensitized cells were meant to serve as a model for solid-state cells with the intent of future incorporation of the carbon aerogel into the solid-state cells.

Conclusion:

The results from the voltage drop seen in Fig. 10 combined with the statistical analysis from the t-test very strongly suggest that carbon aerogel could serve as a viable alternative to external cooling systems. An integrated solution would require significantly less maintenance than an external solution and was the goal of the research conducted. Given the consistently higher voltages for the aerogel treated dye-sensitized solar cells compared to the untreated control cells it is likely that the photocatalytic properties of aerogel improved the base voltage while simultaneously decreasing the voltage drop associated with a temperature increase past optimal operating conditions. Overall, the carbon aerogel seemed to perform in a very promising manner which might encourage the continuation of its application even further as the manufacturing cost of aerogels eventually decrease with time.

Future research on carbon aerogel would include varying the amount of the aerogel applied and integration of the carbon aerogel into solid-state photovoltaic cells. Solid-state cells could include monocrystalline silicon cells, polycrystalline silicon cells, or perovskite cells. Other investigations could be conducted regarding the longevity of cells treated with the aerogel compared to untreated cells to see how effective an integrated solution is in reducing required maintenance without compromising the longevity of the cell.

Should carbon aerogel be found to be significantly adept at increasing the operating range of photovoltaic cells, it would greatly impact the advancement of clean energy infrastructure and provide greater versatility in the use of solar cells in both commercial and industrial applications.

Appendix:

Time	AC1 (mV)	AC2 (mV)	AA1 (mV)	AA2 (mV)
0	234	171	458	516
5	206	107	519	417
10	185	174	350	300
15	153	102	264	245
20	158	117	355	412
25	73	98	341	403
30	57	101	406	384
35	86	72	346	415
40	76	65	320	471
45	63	82	298	359
50	62	39	335	326
55	74	43	364	335
60	62	52	370	417

Table 1: Voltage Over Time for Group A

Time	BC1 (mV)	BC2 (mV)	BA1 (mV)	BA2 (mV)

0	180	203	328	273
5	164	178	413	372
10	154	112	341	360
15	133	129	330	358
20	95	80	246	284
25	70	88	253	284
30	84	69	258	243
35	71	73	249	263
40	78	77	265	284
45	74	72	281	277
50	67	64	285	274
55	69	63	290	276
60	63	67	284	281

Table 2: Voltage Over Time for Group B

Time	CC1 (mV)	CC2 (mV)	CA1 (mV)	CA2 (mV)

0	206	221	422	463
5	196	165	321	367
10	168	173	447	383
15	146	82	384	346
20	175	51	382	353
25	104	48	359	417
30	98	32	361	394
35	75	34	383	388
40	78	41	379	375
45	71	37	392	387
50	70	36	401	363
55	68	52	387	371
60	64	41	399	372

Table 3: Voltage Over Time for Group C

Time	DC1 (mV)	DC2 (mV)	DC3 (mV)	DC4 (mV)

0	183	204	456	472
5	164	197	446	481
10	147	183	447	477
15	149	161	435	501
20	138	140	393	469
25	140	135	387	463
30	133	119	383	455
35	118	94	379	444
40	95	86	372	446
45	76	83	381	462
50	74	76	373	450
55	69	61	368	453
60	53	55	371	461

Table 4: Voltage Over Time for Group D

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Academic Paper

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Sample: C
Score: 4

This paper earns a score of 4. The topic of inquiry is presented on pages 2-3: “This research paper focuses on a solution integrated within the photovoltaic cells that does not require external additions to minimize the maintenance required, maintenance cost, and complexity.” The topic of inquiry is focused and clearly stated and is addressed throughout the methods and conclusions. This topic is situated within relevant scholarly work about solar cells, specifically DSSCs, and ways to improve them as seen on pages 2-4. A gap in the literature is presented on page 5 of the paper: “The goal of this research is not to compete with those efficiencies, rather provide a ‘proof of concept’ for the potential of aerogel integration in DSSCs.”

The methods are logically defended on pages 5-14, including the preparation of the TiO2 suspension, FTO slides, preparing the counter electrode, annealing the TiO2-coated semiconductor to the slide, extracting and applying the organic anthocyanin dye, preparation of the iodine electrolyte solution, assembling controls, and more. One example of this logical defense occurs on page 6 where the paper describes why the slide must be cleaned, stating “A pre-purchased FTO slide (Arbor Scientific #P6-2100-17) must be cleaned with isopropyl alcohol (MG Chemicals) to remove contaminants from the slide and ensure the TiO2 adheres properly to the slide.” Several other examples of this logical defense of choices throughout the methods section exist.

The results of the paper can be found on pages 12-18. The paper discusses how some attempts were unsuccessful (page 12), and some were successful (page 13). The paper concludes that the analysis results “strongly suggest that carbon aerogel could serve as a viable alternative to external cooling systems” on page 18.

This paper is not a 3 because the topic of inquiry is focused and narrow on solar cells and an easy way to improve them (see pages 2-3). This paper connects a topic of inquiry within scholarly works with clear connections of DSS compositions and ways to improve the efficacy. The research methods are replicable and aligned to the topic of inquiry, as evidenced on pages 5-14. The methods are thoroughly explained, detailed, and justified.

This paper is not a 5 because the implications to the community of practice discussed on page 19 are more hyperbolic and are not hypercritical. This is seen on page 19, “should carbon aerogel be found to be significantly adept at increasing the operating range of photovoltaic cells, it would greatly impact the advancement of clean energy infrastructure and provide greater versatility in the use of solar cells in both commercial and industrial applications.” The explanation of the figures (pages 4-17) was not detailed enough and thus did not enhance communication. Finally, the limitations (discussed on page 18) were a discussion of the limits of the method and not of the conclusion.