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Comparative study of Photogalvanic Cells on the Conversion and Storage of Solar Energy

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Abstract: Photogalvanic (PG) cells are energy storage devices that utilise solar electricity. These cells represent a promising technique for converting solar energy into electrical energy through various chemical reactions. This research reports on the electrical output and analysis of Bismark brown-based PG cells. The current study examines the electrical output of photosensitiser-reductant systems through comparative analysis. The findings demonstrate that dye-based PG cells can generate electricity, aligning with previously published studies. Furthermore, this research focuses on the electrical output of PG cells concerning solar energy conversion and storage via photochemical methods. This article reviews the latest advancements in PG cell devices that convert light energy into electrical energy through photochemical reactions. The work primarily addresses developments in materials science, including charge generation, photochemical processes, stability, and efficiency concerns. Various chemicals—such as dyes, reductants, and surfactants—are crucial components of PG cells and significantly contribute to electrical output. The study investigates three types of PG cells: the PG1 System, which combines Bismark brown and ascorbic acid; the PG2 System, which uses Bismark brown and EDTA; and the PG3 System, which incorporates Bismark brown and glucose. The open-circuit voltage (Voc) and power point (PP) values for the PG1 system were recorded at 1055.00 mV and 576.00 mV, respectively. For

the PG2 system, the Voc and PP values were recorded at 985.00 mV and 390.00 mV, respectively. The PG3 system's Voc and PP values were noted at 538.00 mV and 278.00 mV, respectively.

Keywords: Bismark brown, PG cell, Fill factor, Reductant, Surfactant, Electrical output.

Introduction: Energy is one of the basic building blocks of all human activity. Fossil fuels have been the main energy source for industrial advancement for a long time. But currently there is a universal consensus that these conventional energy sources have their own disadvantages and further research is required to find more efficient sources of energy. Thus, the development of renewable energy sources is relevant. Solar energy is one of the important renewable energy sources, as it provides an infinite amount of energy to each planet. Humans have been using solar energy since the 17th century B.C. The earliest known usage of sunlight was by ancient civilisations such as Rome and Greece who used mirrors to light holy lamps. Early structures often employed passive solar design, using sunshine to heat and light interior areas. They are over-using their natural resources and are so rapidly diminishing them – coal, kerosene, timber and other commodities. However, fossil fuels have its own disadvantages such as expensive extraction processes and the danger of environmental damage.

The promise for the future lies in the fundamental aspects of solar energy generated by photochemical processes, such as photosynthesis and the photolysis of water, which are sustainable and promising [1]. This includes studies on the performance of photogalvanic cells [2], comparative studies on sunlight-induced surfactant systems [3], innovative approaches for enhancing the performance of photogalvanic cells [4], insights into the necessity of complete electrolytes for photogalvanics, and the contributions of thermal and photochemical nature [5].

Additionally, there are surfactant-based photogalvanic cells for solar energy conversion and storage [6], comparative studies of various alkali materials in transparent H-cell designs [7], and explorations of photogalvanics using aluminum metal and aluminum alloy working electrodes for solar power generation with dual modes of storage [8].

The use of natural surfactants, such as fenugreek (Trigonella foenum-graecum) seeds, in photogalvanic cells [9], along with a histological/biological stain-based device that can be charged in light for solar power generation and storage through the photogalvanic effect [10], further illustrates this potential. Photogalvanics involving the lactic acid reductant, Carmoisine A photosensitizer, and CAPB surfactant electrolyte [11]; the photo-stability of chrysoidine 'R' dye in the presence of lactic acid, cocamidopropyl betaine surfactant, and NaOH [12];photogalvanics of dodecyltrimethylammonium bromide, quinoline yellow, and alkali [13]; Tropaeline O, oxalic acid, and benzalkonium chloride photogalvanic cells for solar energy conversion and storage [14]; innovations in progressive studies for prospective energy sources through photogalvanic systems [15]; innovative studies in renewable energy sources through mixed surfactant systems for an eco-friendly environment [16]; studies on the micellar effect on photogalvanics, focusing on solar energy conversion and storage using EDTA, Safranine O, and the DSS system [17]; the study of KOH as an alkali to enhance the performance of photogalvanic cells in a transparent cylindrical cell design [18]; photogalvanics of copper and brass working electrodes in the NaOH, Allura Red D, galactose, and DDAC electrolyte for solar power generation [19]; and graphite counter electrode modified Tropaeolin-O photosensitized photogalvanic cells for solar power and storage [20]. Sudan-I dye and fructose-based photogalvanic cells for electrochemical solar energy conversion and storage under low and artificial sunlight intensity[21]; enhancing the efficiency of Fast Green FCF–fructose photogalvanic solar cells through the use of surfactants in natural

sunlight[22]; natural sunlight-irradiated Rhodamine B dye sensitised and surfactant-enhanced photogalvanic solar power and storage[23]; simultaneous electrochemical solar power generation and storage using metanil yellow-formic acid as a new sensitiser-reductant couple in photogalvanic cells[24]; the significance of aniline blue in liquid-phase dye sensitised photogalvanic cells for solar power generation and storage using ascorbic acid and sodium lauryl sulphate[25]; photogalvanics of the platinum working electrode in the Allura Red D-galactose-didecyl dimethyl ammonium chloride-NaOH electrolyte[26]; studies on the effect of heterocyclic dyes in photogalvanic cells for solar energy conversion and storage: NaLS-ascorbic acid system[27]; comparative study of the photogalvanics of Sudan-I, Rhodamine B, Fast Green FCF, Brilliant Cresyl Blue, Naphthol Green B, and Chlorophyll 'A' photosensitisers under natural sunlight illumination intensity[28]; study on the performance of photogalvanic cells for solar energy conversion and storage: Brilliant Cresyl Blue—D-xylose—sodium lauryl sulphate system[29]; solar energy conversion and storage: Fast Green FCF-fructose photogalvanic cell[30].

Solar power is the direct conversion of sunlight into electricity, achieved through solar cells that utilise the photovoltaic effect. When a photosensitizer absorbs light, it generates energy-rich species in an electrolyte solution, which forms the foundation of PG cells. These solar cells can be constructed with either a single layer of light-absorbing material (single junction) or various physical structures (multi-junctions) to optimise different absorption and charge separation processes [Fig. 1].

Research has investigated various aspects of photogalvanic cells, including: The contribution of chemical components in the photogalvanic electrolyte to the potential, power, and current of photogalvanic cells [31]. The use of sodium lauryl sulphate as a surfactant in photogalvanic cells for solar energy conversion and storage, particularly in a sodium lauryl sulphate-methylene blue-

mannose system [32]. The conversion efficiencies of different sugars as reducing agents for the photosensitiser eosin in photogalvanic cells [33]. The performance of photogalvanic cells for solar energy conversion and storage in a methyl orange–D-xylose–NaLS system [34]. Solar energy conversion and storage in a rhodamine B-fructose photogalvanic cell [35]. The use of naphthol green B dye as a photosensitiser in photogalvanic cells for solar energy conversion and storage [36]. High energy throughput through photogalvanic solar techniques and environmentally benign chemical systems, as discussed in the Journal of Photochemistry and Photobiology [37]. The photocurrent response of phloxin B-cetyltrimethylammonium bromide photogalvanic cell devices [38]. The performance of photogalvanic cells for solar energy conversion and storage in a rose bengal–D-xylose–NaLS system [39], and the optimum conversion efficiency in the Nile blue-arabinose system using photogalvanic cells [40].

Low solar-to-ammonia efficiency and high overpotential are significant challenges in photoelectrochemical ammonia generation, which impede the bias-free operation of sustainable photoelectrochemistry [Fig. 2]. Solar energy can be harnessed to produce hydrogen, a clean fuel, through the photoelectrochemical (PEC) water splitting process. The following studies have investigated various approaches to electrochemical solar energy conversion and storage: Sudan-I Dye and Fructose Chemicals Based Photogalvanic Cells for Electrochemical Solar Energy Conversion and Storage at Low and Artificial Sun Intensity [41]. Studies of the Micellar Effect on Photogalvanics: Solar Energy Conversion and Storage in an EDTA−Safranine O−Tween-80 System, Energy Fuels [42]. PG system Cell for Conversion of Solar Energy into Electricity: Safranine–Arabinose–Sodium Lauryl Sulphate System [43]. Photochemical Characterisation of Safranine–Fructose–Sodium Lauryl Sulphate System in a PG system Cell [44]. Exploratory Insights into Dye-Sensitised and Ethylenediaminetetraacetate Photoreduced PG system Systems

[45]. Study of Electrical Output in PG system Cells for Solar Energy Conversion and Storage: Lauryl Glucoside-Tartrazine-D-Fructose System [46]. Use of Mixed Dyes in PG system Cells for Solar Energy Conversion and Storage: EDTA-Methylene Blue and Azur-B System, Energy Sources [47].

Beetroot's Crude Aqueous Extract Photosensitiser-Formic Acid-Sodium Lauryl Sulphate PG system Electrolyte: Solar Power and Storage, Bioresource Technology Reports [48]. PG system Effect of Natural Photosensitiser (Crude Spinach Extract) in Artificial Light for Simultaneous Solar Power Generation and Storage [49]. Use of Mixed Dyes in PG system Cells for Solar Energy Conversion and Storage: EDTA-Methylene Blue and Thionine System, Proceedings of the Institution of Mechanical Engineers [50].

Bio-photoelectrochemical cells (BPECs) are advanced systems that integrate biological processes and photoelectrochemical technologies for energy and environmental applications and have attracted increasing attention in recent years. Energy Conversion and Storage Potential of PG system Cells Based on Mixed Dyes System: Ethylene Diaminetetraacetic Acid—Toluidine Blue—Thionine, Env Prog and Sustain Energy [51], Role of Surfactants in PG system Cells for Solar Energy Conversion and Storage [55], Study the Performance of PG system Cells for Solar Energy Conversion and Storage: Toluidine Blue-D-Xylose-NaLS System [53], Dye Sensitized PG system Solar Cells: Studies in a Methyl Green-NaLS System in View of Energy Conversion [54], Scalability and reproducibility of electrical output of photo-galvanic cells through assembly formation [55], Dye-Sensitized Solar Cells: Fundamentals and Current Status [56], Halochromic effect/transitions and their role in the efficiency of chromotrope 2B-based photo-galvanic cells [57], PG systems for Solar Energy conversion and storage [58], and Use of $NaHCO_3$ as the Alkali

Component in PG system Cells [59]. PG system cells are electrochemical cells that use dye-sensitized materials [56] to convert and perform PG systems.

Recently improved PG cells have been reported [3-12, 55-59], including studies on enhanced PG system performance for solar energy. Notable contributions include those by Lal and Gangotri [3], Lal [4], Reetoo et al. [5], Mohan et al. [6], Dheerata et al. [7], Saren et al. [8], Jonwal et al. [9], Panwar and Koli [10], Charan et al. [11], Koli and Charan [12], Koli and Panwar [55], Sharma et al. [56], Ritika and Koli [57], Lal et al. [58], and Dheerata et al. [59]. These studies address the fundamentals and current status of solar energy PG systems, focusing on storage capacity, solar power generation, and the performance of PG systems [2,30,40, 54], as well as comparative studies [3,29].

2 METHODOLOGIES

2.1 Solution preparations: To ensure the results are applicable, distilled water (DW), Bismarck brown, ascorbic acid, ascorbic acid EDTA, and mannitol were utilised in the experiment. Each test series was standardized to an alkaline medium using oxalic acid. All these compounds are stored in amber-coloured vials to protect them from light exposure.

2.2 Methodology: The H-shaped PG system (PG) system has been extensively utilized in experimental work [Fig.3], (Lal and Gangotri [3], Lal [4], Reetoo et al. [5], Mohan et al. [6], Dheerata et al. [7], Saren et al. [8], Jonwal et al. [9], Panwar and Koli [10], Charan et al. [11], Koli and Charan [12], Koli and Panwar [55], Sharma et al. [56], Ritika and Koli [57], Lal et al. [58], Dheerata et al. [59]), including studies on the performance of PG systems [2, 30, 40, 54] and methodologies related to PG cells [3, 29].

3 RESULTS AND DISCUSSION

3.1 Variation of dye: Dyes and photosensitisers are important in the working of PG system cells since they absorb solar light and initiate the reactions eventually leading to electron transfer. Table 1-3 shows that many plant-based dyes have been utilised as photosensitisers in PG cells to capture sun energy. Thus, an appropriate light harvesting substance which is photostable should be used as a photosensitiser. To be able to have photochemical reactions, the dye must be at a certain concentration. The lowering of the photopotential and the photocurrent was due to the lower concentration of photosensitiser molecules accessible for excitation and subsequent electron donation to the platinum electrode. This is because the interactions between light and dye molecules are controlled by the Stark-Einstein law, and both light and dye molecules are particles in nature. Moreover, the PG system cells are diffusion-controlled, thus at greater concentrations much light is absorbed by dye molecules. At increased concentration, the injected electrons and dye may recombine more quickly. In the present work, the changes in the concentration of dye have been studied for Bismarck brown with three different system. The electrical output is increased by the presence of a specific surfactant that stabilises the dye and enhances its solubility in water. The electrical output of the dye increases, reaching a peak before starting to decline. Since the dye is hydrophobic, there is less Bismarck brown available to absorb light, resulting in a relatively low electrical output. A significant number of Bismarck brown molecules accumulate on the surface of the absorbent, along with a greater quantity of dye molecule. The ideal light source can reach the molecule closest to the electrode and initiate photochemical reactions, as the most effective molecules are present at the optimal concentration. There are three varieties of PG cells: the PG1 System, which is a combination of Bismark brown and ascorbic acid, the PG2 System, which uses Bismark brown and EDTA, and the PG3 System, which contains Bismark brown and glucose. The Voc and PP values of the PG1 system were noted to be 1055.00 mV and

576.00 mV, respectively. The Voc and PP values for the PG2 system were found to be 985.00 mV and 390.00 mV, respectively. The Voc and PP values for the PG3 system were 538.00 mV and 278.00 mV, respectively. Numerous dye systems were reported for solar energy conversion and storage [12, 21, 23, 25, 27, 41, 45, 47, 50, 54, 56].

3.2 Variation of reductant: In this study, we examined the changes in dye concentration across three different systems: ascorbic acid, EDTA [17,42,47, 50], and D-glucose. The presence of a specific surfactant increases the electrical output by stabilizing and enhancing the solubility of dye molecules in water. In the PG system, the electrical output rises with increasing concentrations of Brilliant Yellow, reaching a peak before starting to decline. The hydrophobic nature of the dye means that less Brilliant Yellow is available for light absorption, which results in a comparatively low electrical output when using Bismark Brown. At higher concentrations, a significant number of Brilliant Yellow molecules accumulate on the surface of the absorbent. An optimal light source can effectively reach the molecules nearest to the electrode, initiating photochemical reactions, particularly when the most effective molecules are present at the ideal concentration of Brilliant Yellow.

3.4 Variation of pH Range: In this study, the amount of hydrogen ions has been investigated. For the A, B, and C systems, the measured parameters include PP, PC, maximum PC, and equilibrium PC at the nature of alanine. As the basic composition (pH) increased, the PG system decreased, while the other parameters gradually increased, reaching a maximum value within certain limits. At a pH range of 12.77 to 12.85 and above, unsatisfactory results were obtained. However, better results were observed in the moderate pH range. This phenomenon is attributed to the fact that photochemical reactions are more suitable for dye molecules. pH-sensitive hydrogels, which are intelligent polymer materials, include anionic polymers (polyacrylic acid), cationic polymers

(chitosan), and smart block copolymers. These materials can dynamically sense changes in ambient pH and subsequently trigger corresponding physical or chemical responses.

3.9 Effect of variation of light intensity:

3.10 MECHANISMS: The PG cell technique uses two electrodes. The working electrode, usually platinum or Pt, is exposed to the light, while the counter electrode, usually a saturated calomel electrode, or SCE, is kept in the dark. The gap between electrodes is filled with alkaline solution comprising photosensitiser (species that absorb photons), reductant (species that give electrons) and surfactant (agent that promotes efficiency). Net volume of electrolyte is 25 ml. The working electrode in PG cells is where the exchange of electrons between the external circuit and the semi/leuco-reduced sensitizer molecule occurs. Experimental set-up of PG cell for solar energy conversion and storage (Figs. 1, 2, 3, 4 and 5). The chemical reaction occurring in a laboratory demonstrates the movement of electrons through the cellular circuit. The counter electrode closes the circuit and carries current [5], [7], [6] [7], [8], [9], [10], [12], [14], [19], [27], [32], [43], [54], and [65].

Illuminated Chamber: When light is received, the dye absorbs a photon and is excited. The excited dye is converted to a semi- or leuco-form on gaining an electron from the reductant.

$$\text{Dye} \longrightarrow \text{Dye}^*$$

$$\text{Dye}^* + \text{Red} \longrightarrow \text{Dye}^- \text{ (semi or leuco)} + \text{Red}^+$$

At the platinum electrode: When the semi-leuco form gives an electron to the platinum electrode, the original form of the dye becomes available.

$$\text{Dye}^- \longrightarrow \text{Dye} + e^-$$

Dark Chamber- After the dye takes an electron from the SCE, it becomes the semi-leuco form. The same process is repeated to synthesise the original dye and reductant molecules when the oxidised form of the reductant combines with the leuco/semi form of the dye. The end result is an electron stream which converts light into electricity [3], [4], [5] [6], [7], [65], [8], [9], [10], [12], [56], [57], [58], [149], and [59].

$$Dye + e^- \longrightarrow Dye^- \text{ (semi or leuco)}$$

$$Dye^- + Red^+ \longrightarrow Dye + Red$$

STORAGE CAPABILITIES OF PG CELLS: The capability of the cell to store power and the stability of the power at the cell power point have been studied in 2 lab environments, one without light and another with light. Study of the power storage capacity (half change time) of the cell in dark conditions after illumination: The half change time (t0.5) has been used to study the power storage capability of the cell. The half change time is the time in the dark for the power to fall to half its initial value. The cell must be completely charged to measure the power storage capacity. At that time the power is governed by the i-v characteristics. Then the resistance of the circuit is fixed and the cell is powered up to a specified point. The illumination is cut off and the cell is kept in the dark. The power output is recorded at different times. Half change time is the time length (from the lighting cut-off point) when power output reduces to 0.5 of the power point. Then the half-time was measured in the dark or without light when the illumination was switched off for this study (Table 1-3 and Fig. 1-3). Tests have been performed to study the half change time in an effort to understand the relation between the half change time and the power point value.

Investigation of the power storage capacity of the cell (half change time) under illumination: The relationship between the half change time and the power at power point value has been investigated by two trials and the half change time is shown in Table. An interesting feature of power decay is that the power decay rate is higher with higher initial power. In the experiment the half change time is longer because of the lower initial power. The power decay is of non-zero and non-first order decay. The power decay with time trend shows that half change time is inversely related to the beginning power. Also, it is noted that the speed of present decline is relatively higher than the speed of potential decline.

PG cell stability: Charging and discharging the cell was used to measure the power stability of the power point. Circuit is fixed for restoring power point after the cell gets charged and power at point is monitored. The value of the power output was recorded at different times after switching off the illumination. If no electricity is forthcoming the cell is exhausted. This process is called the first recharge of the battery. Then the cell was illuminated again to charge it again. The power was then recorded until the power reached zero and again the power at the power point was recorded.

Dark potential (V_{Dark}): The entire system is first maintained in the dark until it reaches its stable potential. This constant potential is known as dark potential. It is referred to as V_{Dark} and is given in V or mV. Vmax: maximum potential; potential increases when the platinum electrode is lit after the measurement of the dark potential. Vmax is the maximum potential that has been observed. The open circuit voltage (Voc) is the greatest voltage that can be generated by a solar cell when no current is flowing through it. Voc, measured in V or mV. Photopotential (ΔV): The photopotential is determined using the below equation.

$$\Delta V = V_{oc} - V_{Dark}$$

Short circuit current (isc): The short-circuit current is the highest current flowing through a solar cell when there is no voltage across it (or when the cell is shorted). isc is its representation and is measured in A or mA.

Maximum current (i_{max}): The initial few minutes of illumination resulted in a rapid increase of the photocurrent to a maximum value. This quantity is known as the maximal photocurrent. It is denoted by i_{max}.

Equilibrium current (ieq): following the highest photocurrent, the current gradually dropped under illumination before reaching a steady-state. When this photocurrent is equilibrium state it is called as equilibrium photo current. It is denoted by Ieq. The point at which the cell produces the highest electricity is called the maximum power point (Ppp). Ppp is the mathematical statement for its calculation and its symbol.

$$P_{pp} = V_{pp} \times i_{pp}$$

The power point voltage (Vpp) is the maximum potential at the power point. Maximum current at power point. It is denoted by ipp and is given by ipp.

Fill Factor (FF) The fill factor is the most significant parameter to evaluate the performance of a solar cell. It is found by multiplying the short circuit current by the ratio of maximum power to open circuit voltage. All observed results are reported in Table 3.

$$FF = \frac{P_{pp}}{V_{oc} \times i_{sc}} = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}}$$

Conversion efficiency: The most essential characteristic of a PG cell in demonstrating its potential is the conversion efficiency (CE). It is the ratio of electrical power input (energy from the rays of the sun) to output. All observed results are reported in Table 3.

$$CE\ (\%) = \frac{V_{pp} \times i_{pp} \times FF}{P \times A} \times 100\%$$

Storage capacity ($t_{1/2}$): To determine the storage capacity of the PG system cell, apply an external load (current at power point) after cessation of illumination when the potential tends to become constant. The storage capacity is determined by means of t1/2, i.e. the time required for the output (power) to fall to half its power point in the dark. All observed results are reported in Table 2.

It can also be stated as a percentage of the charging time (charging time = tVmax-tVillum).

Information on the stability of the cell: The photo-stability of the cell has been studied by long-term observation of the potential, current and power values. This stability is considered to be due to the stability of the dye in the electrolyte. The dye sensitizer is an important material for the creation of photo-galvanic cells since it is the material which absorbs sunlight. Stability of the dye substance so influences the performance of the cell. When the photo-stability of the dye is increased, the cell will be more stable and robust. In the present work, the stability of the dye was studied using spectroscopy. For stable dye absorbance of the main band (at wavelength maxima) will not shift sharply. That is, the height of the main band will be not dependent on time and the dye will be constant.

Limitations: A significant challenge for PG system cells is improving their efficiency, particularly regarding recombination losses that diminish overall energy conversion rates. Photovoltaic/thermal (PV/T) systems represent an advancement over traditional PV systems, as they cool the PV cells and harness solar radiation to generate both thermal and electrical energy. Typically, PG system cells exhibit lower solar energy conversion efficiency compared to

conventional photovoltaic cells, which limits their potential for large-scale power generation for the grid. The energy storage capacity of a PG system cell is directly related to the volume of the electrolyte solution, resulting in a lower energy storage density compared to batteries. Additionally, the long-term stability and operation of PG system cells can be challenging due to issues such as electrode corrosion and electrolyte degradation. Furthermore, the commercial scalability of PG system cells is constrained by the high cost of materials and production processes. A solid-state photothermal (PT) energy storage film has been developed using norbornadiene (NBD) molecules, which can undergo photoisomerization to convert solar energy into chemical energy and subsequently release it as thermal energy when heated.

4 CONCLUSIONS: This article is essential for understanding future trends and state-of-the-art technologies that promote PG cells as a viable option in the solar energy sector. The purpose of this research is to enhance the conversion of solar energy into electricity and its storage using PG cells. There are three varieties of PG cells: the PG1 System, which is a combination of Bismark brown and ascorbic acid, the PG2 System, which uses Bismark brown and EDTA, and the PG3 System, which contains Bismark brown and glucose. The Voc and PP values of the PG1 system were noted to be 1055.00 mV and 576.00 mV, respectively. The Voc and PP values for the PG2 system were found to be 985.00 mV and 390.00 mV, respectively. The Voc and PP values for the PG3 system were 538.00 mV and 278.00 mV, respectively. **Highest Output:** The **PG1 System** (Bismark brown + ascorbic acid) delivers the strongest overall performance, achieving both the highest open-circuit voltage and the highest potential at the power point. **Moderate Output:** The **PG2 System** (Bismark brown + EDTA) produces a high open-circuit voltage close to PG1, but experiences a larger potential drop under load at the power point). **Lowest Output:** The **PG3 System** (Bismark brown + glucose) shows the lowest electrical output across both metrics. The

PG1 System (Bismark brown + ascorbic acid) is the best-performing cell based on our findings. Performance Evaluation: PG1 (Bismark brown + Ascorbic acid): Superior overall electrical performance. PG2 (Bismark brown + EDTA): Exhibits a favourable open-circuit potential, although experiences a more pronounced voltage decline when subjected to load. PG3 (Bismark brown + Glucose): Minimal performance in both parameters.

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Ethical Approval: All authors approved that this study is non-human subject research, and no need for informed consent.

Consent to Participate: Not applicable

Consent to Publish: Not applicable

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations section: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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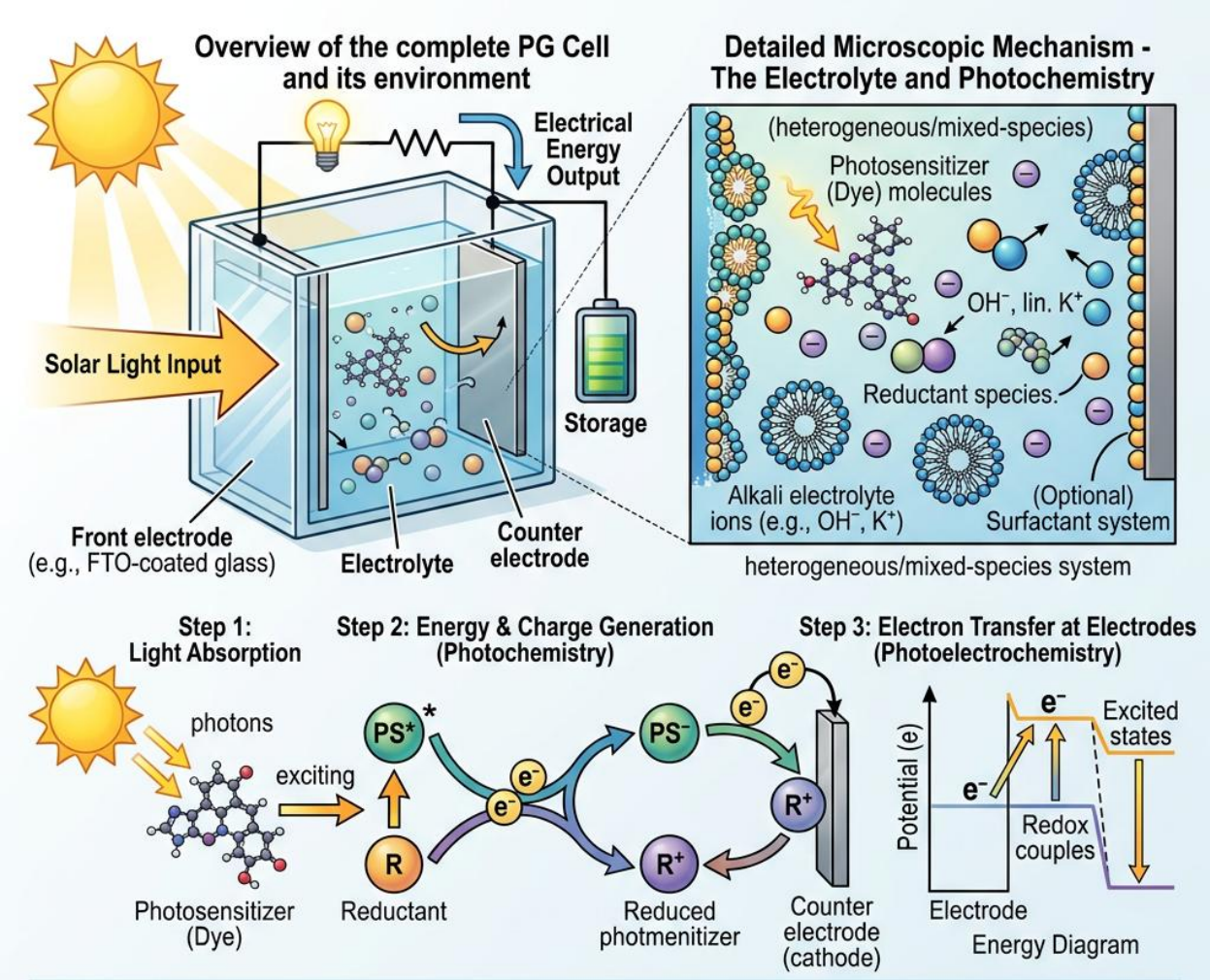


Fig. 1. Series assembly representation of solar cells

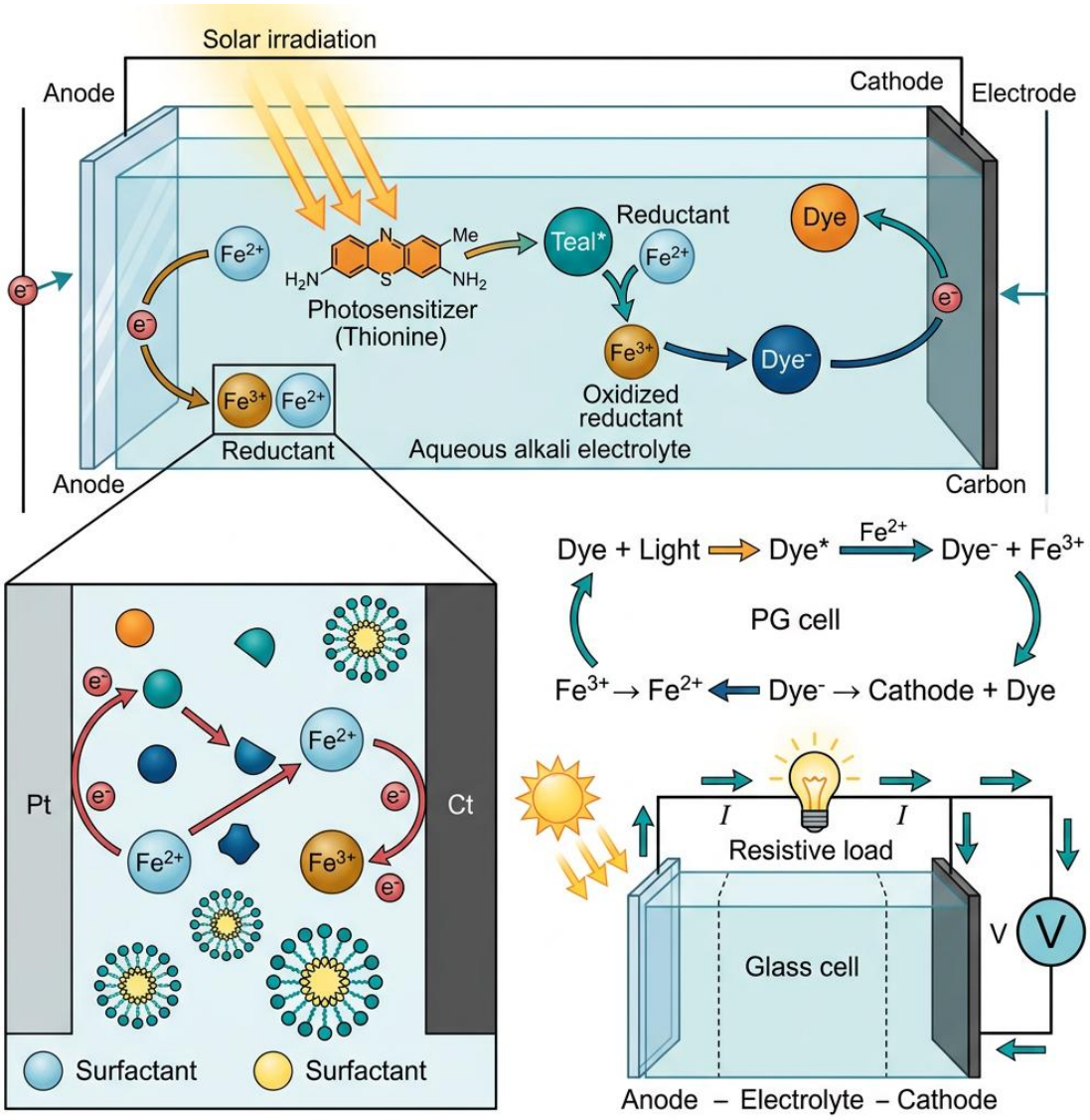


Fig. 2 Solar cell: Schematic diagram

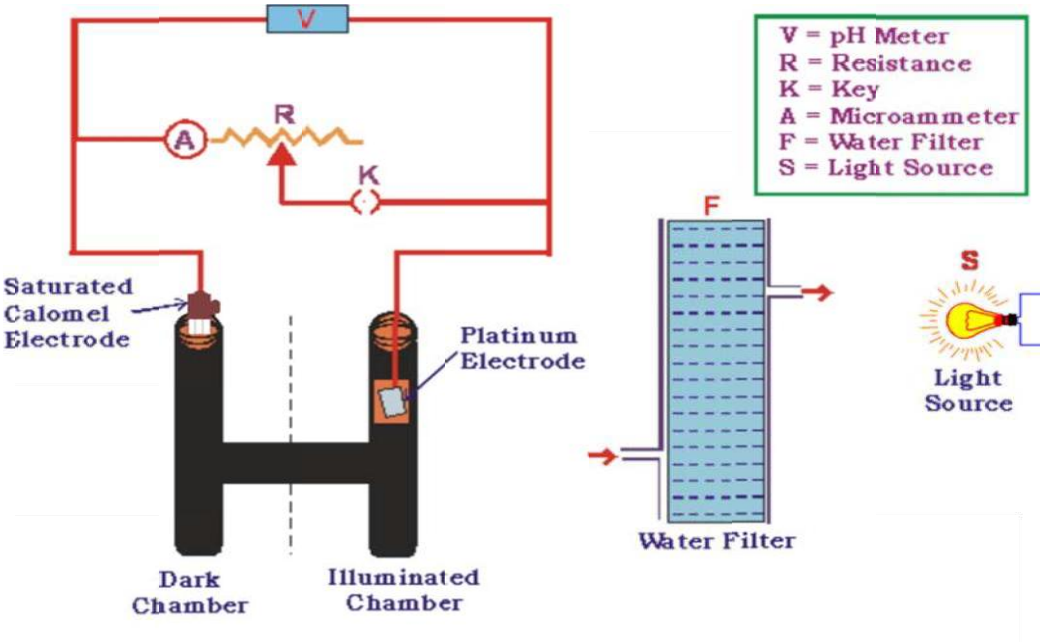


Fig 3. Experimental setup for PG cell

Table 1. i-v characteristic of PG cell

S.No.	PG System	Voc	isc	Vpp	ipp	ŋ
1.	Bismark brown and ascorbic acid [PG1]	1055.0 mV	175.0 µA	576.0	120.0	0.3743
2.	Bismark brown and EDTA[PG2]	985.0 mV	145.0 µA	390.0	80.0	0.3658
3.	Bismark brown and Glucose [PG3]	538.0 mV	70.0 µA	278.0	40.0	0.3518

Table 2. Performance of PG cell

S.No.	PG System	Power	T1/2
1.	Bismark brown and ascorbic acid	141.75 µW	35.0 Min.
2.	Bismark brown and EDTA	112.95 µW	40.0 Min.
3.	Bismark brown and Glucose	20.44 µW	35.0 Min.

Table 3. conversion efficiency and sunlight light conversion data of PG cell

S.No.	PG System	FF	CE	Photopotential	Photocurrent
1.	Bismark brown and ascorbic acid	0.3743	0.6646 %	1620.0 mV	700.0 µA
2.	Bismark brown and EDTA	0.3658	0.5027%	1558.0 mV	580.0 µA
3.	Bismark brown and Glucose	0.3518	0.1274%	584.0 mV	280.0 µA

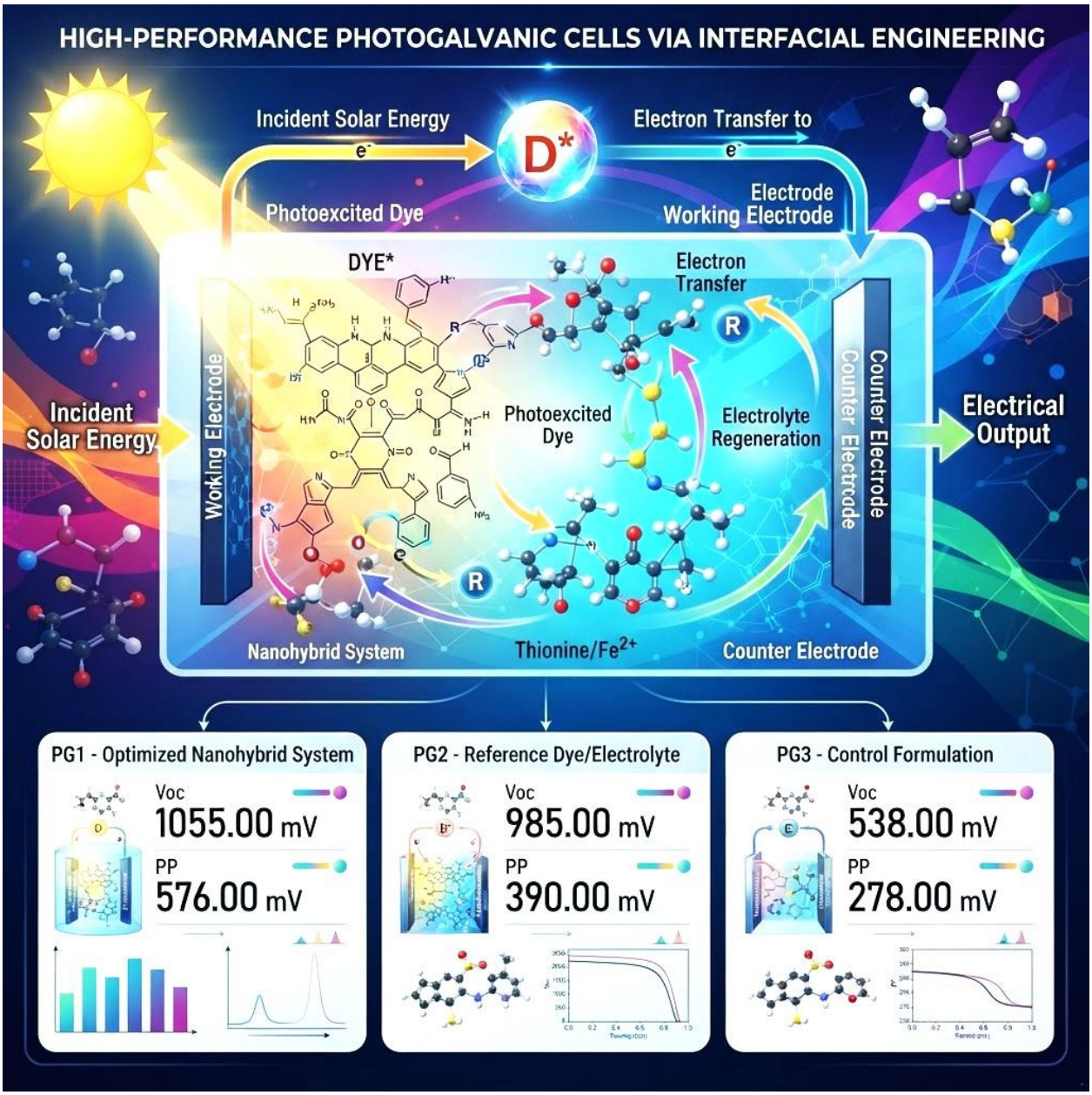


Fig: Graphical abstract of Photogalvanic Cells for Conversion and Storage of Solar Energy