Use Of Indigo Carmine Dye, Ascorbic Acid And Sodium Lauryl Sulphate Chemicals In Photogalvanic Cell For Simultaneous Solar Power Generation And Storage

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ABSTRACT:

We need energy to heat our houses, cook our meals, travel, communicate with one another, power our companies, and carry out a variety of other growth activities; the need for energy throughout the globe is growing at an alarming rate. Solar power is quickly becoming one of the most promising forms of alternative energy for the 21st century. The use and storage of solar energy using indigo carmine- ascorbic acid- sodium lauryl sulphate photogalvanic cells is the focus of this research project. The purpose of the photogalvanic cell, as detailed in the current study effort, is to build a suitable photogalvanic energy device that can simultaneously be used for the production of solar power and the storage of that power. Additionally, optimal cell conditions were shown to exist for the viability of photogalvanic cells. At 10.4 milliwatts per square centimetre, the efficiency of solar energy conversion, fill factor, power storage capacity ($t_{1/2}$), power at power point (Pp), photopotential (Voc), and equilibrium current (Isc) were observed to be on the order of 1.27 percent, 0.2269, 140 minutes, 132.27 milliwatts, 894 millivolts, and 724 micro ampere, respectively.

Keywords: Photogalvanic effect (PGE), Sodium lauryl sulphate (SLS), fill factor (FF), power point, conversion efficiency (CE).

INTRODUCTION:
One third of the world's total greenhouse gas emissions are caused by fuels used to generate electricity. These fuels include oil, natural gas, and coal. Increasing access to electricity that is both clean and reliable is critical to raising overall living standards. As a result of the implementation of economic development plans, India is experiencing an increase in the country's energy demand. The availability of additional energy is a necessary condition precedent to the expansion of a nation's economy. Solar energy is an abundant source of energy that is not only decentralized but also environmentally friendly, easily accessible, and free of cost. It is necessary for all types of life. Photogalvanic cells are essential pieces of equipment for converting solar energy into electrical energy and storing it for later use. The conversion of solar energy is accomplished with the help of this third type of dye-sensitized concentrating photo electrochemical cell. Chemical reactions that result in the production of high-energy products are the foundation of photogalvanic cells. These reactions are excited by photons. The photogalvanic effect is the name given to this process, which involves the loss of energy while simultaneously producing electricity (PGE). PGE was first discovered as an effect of light on the equilibrium of iron, iodine, and iodide, but it was systematically studied in the thionin-iron system. [2-3] Murthy and Reddy conducted research on

the behaviour of photoelectron chemical cells that contained methylene blue along with a variety of different reducing agents. [4] In addition, a significant photopotential and photocurrent have been found. The EDTA - methylene blue photogalvanic cell is estimated to have a conversion efficiency of less than 0.04 percent, which corresponds to the output solar power. Tamilarasan and Natarajan produced water-insoluble films by condensing thionine with poly (N-methylolacrylamide). These films were coated on platinum electrodes, and when irradiated with a tungsten lamp, they produced an open-circuit photopotential of 32 millivolts and a short-circuit current of 3.7 micro amperes. [5] In an aqueous medium, Rohatgi-Mukherjee et al.[6] found that a redox system made up of phenosafranin and EDTA had a photovoltage of 615 millivolts when the temperature was 298 degrees kelvin. A photogalvanic cell that included chemicals such as thionine and EDTA was utilised in the study carried out by Ameta et al. [7] A photoelectron chemical cell containing a methylene blue-NLS-EDTA system was used to investigate the photoelectric effect. Both the system's potential and its current, which were measured, came out to be 654 millivolts and 190 micro amperes, respectively. [8] Sodium lauryl sulphate, tetradecyl trimethyl ammonium bromide (TTAB), and Brij-35 surfactants were used for photogalvanics by Ameta et al[9] in a cell that contained azur A and glucose. The photocurrent and potential that were generated by the tergitol-7-toluidine blue-glucose system were, respectively, 70 micro ampere and 315 millivolt. [10] In the toluidine blue-CTAB-glucose system, the photocurrent was measured at 35 micro amperes, the photopotential was measured at 175 millivolts, and the power measured at 6.26 micro watts. [11] The photogalvanic effects that were seen in a cell that contained a combination of the dyes methylene blue and toluidine blue together with EDTA. The efficiency of converting solar energy into usable form was measured at 0.5398 percent, while the power output was measured at 81.62 micro watts. [12] PGE was seen in a photoelectrochemical cell that had the photosensitizers methylene blue and Azure B in it. The efficiency of the conversion was measured at 0.1165 percent, and the maximum output power measured at 51.24 milliwatts. Both of these figures were found at the power point. In a photogalvanic cell containing nitrilotriacetic acid (NTA)-Azur B, sodium lauryl sulphate (NLS), cetyl pyridinium chloride (CPC), and Tween 80 were used to study PGE. Both the cell's efficiency and its capacity for storage were observed to be 0.4053% and 0.2177% after 105 minutes, 31 minutes, and 74 minutes respectively. [14]PGE was investigated in dye-sensitized cells that also contained thionine, methylene blue, and EDTA. The conversion efficiency is 0.43%, while the power at the power point is 67.68 W, and the cell can be used in the dark for a period of 30 minutes. [15] Gangotri and Pramila used a photogalvanic cell that contained the safranin-mannitol-NLS system in their experiment. [16] In order to conduct research on the photogalvanic effect. After conducting research on the current voltage characteristics of a dye-sensitized cell containing a dioctyl sulfosuccinate-mannitol-safranine system, researchers found that the conversion efficiency, fill factor, and performance of this cell were respectively 0.7603%, 0.50, and 40.0 minutes. [17] The Tween-80-EDTA-Safranine-O cell was observed to have a conversion efficiency of 0.9769%, a fill factor of 0.34, a storage capacity of 60 minutes, and a maximum power output of 235.50 W respectively. [18] Both Gangotri and Bhimwal have made use of a photogalvanic cell that was constructed using eosin and arabinose to facilitate the transformation of solar energy into electrical energy. [19] The conversion efficiency (CE) was found to be 0.7026%, and the fill factor was found to be 0.2856. This cell can function normally for a total of 85.0 minutes when it is completely dark. A combination of two reducing agents, EDTA and dextrose, in addition to Azure A, which Gangotri and Indora use [20] in photogalvanic cells, which are used in the generation of solar power. The power point of the cell was determined to be 10.87 W, and its CE and FF were measured to be 0.1045% and 0.1942 respectively. Chemicals such as brilliant cresyl blue and fructose have been incorporated into photogalvanic solar cells in order to improve the efficiency of the conversion of solar energy and the capacity for storage. [21] In order to boost the electrical output and power of a photogalvanic cell, a system consisting of safranin, SLS, and D-xylose was utilised. At the cell power point, it was found that the cell's CE and FF, respectively,

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were 0.68% and 0.32, respectively. [22] In order to raise the amount of electricity produced by the cells, rhodamine B and fructose were added to the basic medium. In terms of photopotential, photocurrent, short-circuit current (Isc), power, capacity, and efficiency, the observed cell performance was 1071 millivolts, 1049 micro ampere, 972 micro ampere, 244.02 micro watts, 7.58 percent, and 3.6 hours, respectively. [23] Chemicals such as tergitol-7, EDTA, and Azur-B are utilised in photogalvanic cells for the purpose of converting and storing solar energy. The photogenerated values of photopotential, photocurrent, and CE are observed to be 778.0 mili Volt, 45.0 micro amperes, and 0.14 percent, respectively. The FF value is observed to be 0.3170. [24] The photogalvanic behaviour of xylidine ponceau dyes was investigated using a system consisting of xylidine ponceau, tween 60, and ascorbic acid. [25] Nile Blue has been used in conjunction with arabinose in photogalvanic cells as a photosensitizer in order to achieve the highest possible rate of conversion of solar energy into electrical energy. [26] The photogalvanic effects of Tween-80 containing toluidine blue and EDTA were used in an experiment to study the conversion and storage of solar energy. This system had a photopotential of 430 millivolts, a photocurrent of 50 micro amperes, and a storage capacity of 60 minutes, respectively. [27] In order to convert solar energy into electrical energy, the scientific community has used a variety of photosensitizers, surfactants, and reducing agents in photogalvanic cells. However, no attention has been paid to the use of Indigo Carmine dye in combination with ascorbic acid and sodium lauryl sulphate (SLS) as an energy material to increase the electrical output and performance of the cell. As a result, efforts are currently being made to improve the efficiency of photogalvanic cells and ensure their continued viability in the commercial market.

RESULT AND DISCUSSION:

Effect of variation of Indigo Carmine, ascorbic acid and SLS concentration:

The results of experimenting with different levels of indigo carmine, ascorbic acid, and SLS are presented in Table 1. We used solutions of indigo carmine with varying concentrations so that we could study the effects of changes in dye concentration. It was observed that the photopotential, photocurrent, and power all increased as the concentration of the dye [Indigo Carmine] increased. At a particular value of dye concentration (2.5×10^{-5} M), a maximum value of 894 millivolts, 724 microamperes, and 582.82 microwatts was obtained. Once this value of dye concentration was exceeded, a decrease in cell output power was observed. A low electrical output was observed at the lower concentration range of dye due to the finite number of dye molecules that could absorb the major portion of the light in the path. On the other hand, higher concentrations of dye again resulted in a decrease in electrical output because the intensity of light reaching the molecule near the electrode decreased due to the absorption of the major portion of the light by the dye molecules that were present in the path. This was the case because higher concentrations of dye resulted in more dye molecules. Therefore, there has been a corresponding decrease in power. We found that the photopotential, photocurrent, and power output all increased as the concentration of the reducing agent (ascorbic acid) increased, until they reached their maximum value of 2.6×10^{-3} M. This was the case until the maximum concentration was reached. These numbers add up to 894 millivolts, 724 microamperes, and 582.82 microwatts, respectively. It was found that the concentration of ascorbic acid in the cell caused the electrical output of the cell to decrease as the concentration was raised further. Because there are fewer molecules available to donate electrons to the cationic form of the dye, reducing agent concentrations tend to be lower, which is another factor that contributes to the lower output. On the other hand, when there is a high concentration of reducing agent, the migration of dye molecules is slowed down, preventing them from reaching the electrode within the allotted amount of time. This results in a decrease in the amount of electrical output. The amount of electricity that was produced by the cell increased as the concentration of the surfactant did. One value of SLS concentration produced the best results (894 millivolts, 724 milliamperes, and 582.82 microwatts), which were obtained at their maximum (2.4×10^{-3} M). As the concentration of the

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surfactant was increased even further, it began to act as a barrier and a significant portion of the surfactant photobleached a smaller number of dye molecules, which led to a decrease in the amount of electrical output.

Table -1. Effect of varying indigo carmine, ascorbic acid, and SLS concentrations Light Intensity = 10.4 mW cm^{-2} , Temperature = 303 K , pH = 11.70			
Concentrations **[Indigo Carmine]$\times 10^{-5}$ M**	**Photopotential (mV)**	**Photocurrent (µA)**	**Power (µW)**
2.0	651.0	507.0	330.05
2.2	704.0	583.0	410.43
2.5	805.0	724.0	582.82
2.7	738.0	590.0	435.42
2.9	657.0	501.0	329.15
[Ascorbic acid] x 10^{-3} M			
2.2	572.0	432.0	247.10
2.4	712.0	573.0	407.98
2.6	805.0	724.0	582.82
2.7	753.0	642.0	483.43
2.9	664.0	442.0	293.49
[SLS] x 10^{-3} M			
2.1	532.0	434.0	230.89
2.3	729.0	625.0	455.63
2.4	805.0	724.0	582.82
2.6	736.0	634.0	466.62
2.8	589.0	459.0	270.35

Effect of diffusion length:

Using H-type cells of variable dimensions, an investigation was conducted into the impact that changing the diffusion length had on the cell's current characteristics (imax, ieq, and the initial rate of photocurrent production). The diffusion length is the distance between the two electrodes. It has been found that there is a discernible rise in the photocurrent during the first few minutes after the onset of illumination. Because of this, the maximum photocurrent, also known as imax, rises as the diffusion length grows. This is because there are now more paths for photochemical reactions to take place, which is something that has not been shown in experiments. It has been found that there is a discernible rise in the photocurrent during the first few minutes after the onset of illumination. Because of this, the maximum photocurrent, also known as i_{max}, rises as the diffusion distance grows. This is because there are now more paths for photochemical reactions to take place, which is something that has not been shown in experiments. On the other hand, there was a linear drop in the amount of equilibrium photocurrent (i_{eq}). Therefore, we are able to draw the conclusion that the most significant electroactive species are the leuco-type dyes, also known as photosensitizers, in both the light chamber and the dark chamber, respectively. The sole role that the reducing agent and its oxidation products play along this path is that of electron carriers. Table 2 provides a concise summary of the findings.

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Table- 2 Effect of Diffusion Length (DL)			
[Indigo Carmine] = 2.5 x 10^{-5} M		Light Intensity = 10.4 mW cm^{-2}	
[Ascorbic acid] = 2.6 x 10^{-3} M		Temperature = 303 K	
[SLS] = 2.4 x 10^{-3} M		pH = 11.70	
Diffusion Length DL (mm)	Maximum Photocurrent i_{max} (µA)	Equilibrium Photocurrent i_{eq} (µA)	Rate of initial generation of current (µA min^{-1})
35	773.0	732.0	20.34
40	775.0	728.0	20.39
45	778.0	724.0	20.47
50	780.0	722.0	20.53
55	782.0	618.0	20.58

Effect of light intensity:

An intensity metre was used in order to evaluate the influence of the light's intensity (Solarimeter Model-501). It was discovered that the photocurrent rose in a linear fashion whereas the photopotential increased in a logarithmic manner with increasing levels of light intensity. This is the rise in the number of photons that occurs when the light intensity is increased. Figure 1 presents a graphical representation of the influence that changes in light intensity have on photopotential and photocurrent.
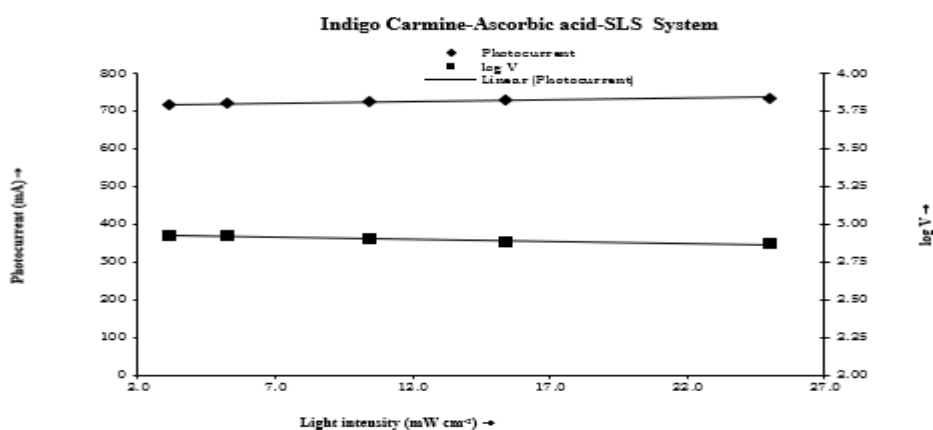

Fig. 1 VARIATION OF PHOTOCURRENT AND log V WITH LIGHT INTENSITY

Cell current-voltage (i-V) characteristics:

The short-circuit current (isc) of the cell was measured to be 724 micro ampere, and the open-circuit voltage (Voc) was measured to be 805 mili volt. These values were obtained from the cell by using, respectively, a microammeter (closed circuit) and a digital pH metre (open circuit). Using a carbon pot (log 470 K) that was linked in circuit with a multimeter and to which an external load was applied, current and potential values that fell somewhere in the middle of these two extremes were measured and recorded. Figure 2 shows a graphical representation of the i-V properties of a photogalvanic cell that contains indigo carmine, ascorbic acid, and SLS. It was discovered that the i-V curves did not have the typical rectangular form that is expected of them. We found the point on the i-V curve that maximizes the product of the curves of current (i_{pp}) 325 A and potential (v_{pp}) 407 mV. This point is referred to as the power point (pp). We determined the fill factor by applying the formula 0.2269 to the i-V curve in order to do the calculations.

$$\text{Fill factor}\left(\eta\right) = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}}$$
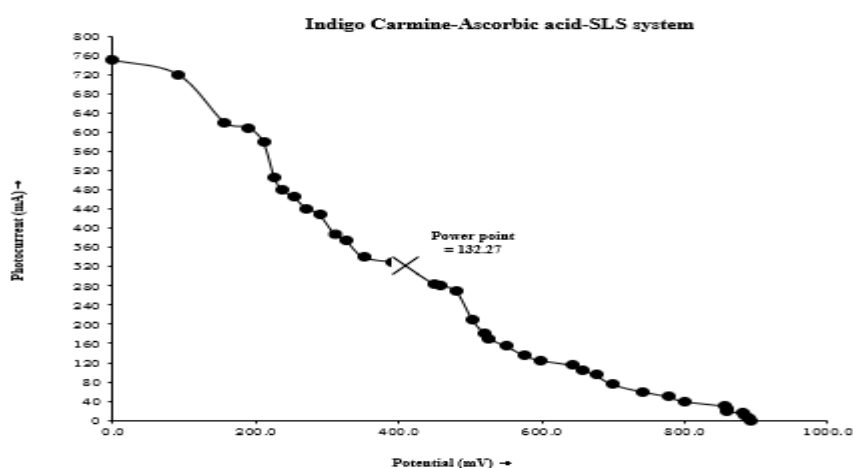
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Fig. 2 CURRENT VOLTAGE (i-V) CURVE OF THE CELL

Cell performance and conversion efficiency:

The efficiency of the photogalvanic cell was evaluated by providing an external load, which necessitated the flow of current via the power point. This was done after the light was turned off when the potential reached a certain threshold. The performance was measured in proportion to $t_{1/2}$, which is the amount of time it takes for the output (power) to decrease to half the power point when it is completely dark. In the dark, it was possible to employ cells that contained indigo carmine-ascorbic acid-SLS for a total of 140.0 minutes, as was seen. Utilizing the formula, we were able to establish that the cell had a conversion efficiency of 1.27 percent by using the current and potential values at the power point together with the incident radiant power. A time-power curve is graphed to display the results (Figure 3)

$$\text{Conversion efficiency} = \frac{V_{pp} \times i_{pp}}{A \times 10.4 mWcm^{-2}} \times 100\%$$
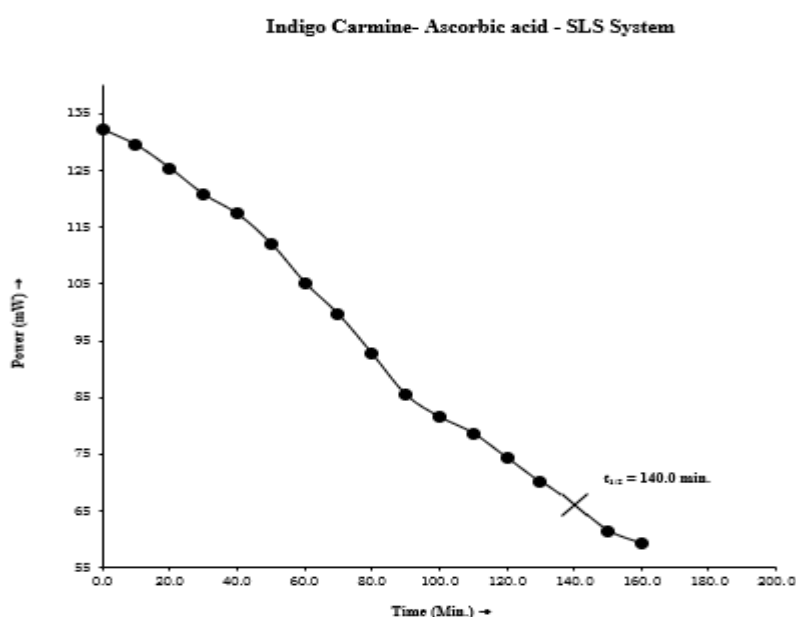

Fig. 3. TIME-POWER CURVE OF THE CELL

Mechanism:

When some dyes are exposed to light in the presence of electron-donating compounds (reducing agents), the dyes undergo a fast transformation into a form that lacks colour. Dye compounds are capable of donating electrons to other molecules, therefore restoring them to an oxidised state. Dye

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compounds are powerful reducing agents. According to the findings of prior research, the following is one possible mechanism that may underlie photogalvanic cells.

lluminated chamber:

$$D \xrightarrow{h\upsilon} D^* \qquad\qquad (i)$$
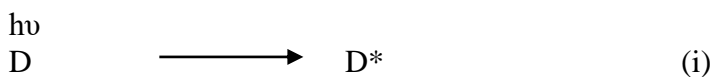
During this process, the excited dye molecule gives up an electron to the reducing agent in order to change into the leuco form of the dye, and the reducing agent also changes into the excited form of itself.

$$D^* + R \longrightarrow D^-(\text{semi or leuco}) + R^+ \qquad\qquad (ii)$$
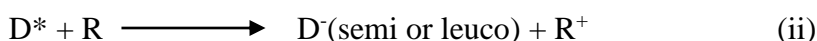
At platinum electrode:

The leuco-form of the dye loses an electron and converts to the original dye molecule.

$$D^- \longrightarrow D + e^- \qquad\qquad (iii)$$

Dark Chamber:

At counter electrode:

$$D + e^- \longrightarrow D^- (\text{Semi or leuco}) \qquad\qquad (iv)$$
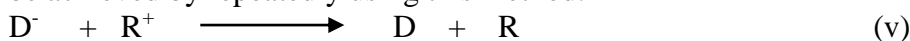
The leuco form of the dye and the oxidised form of the reducing agent eventually unite to produce the molecules of the original dye and reducing agent. Continuity in the production of electricity may be achieved by repeatedly using this method.

$$D^- + R^+ \longrightarrow D + R \qquad\qquad (v)$$

Here D, D*, D⁻, R and R⁺ are the dye, its excited form, leuco form, reductant and its oxidized form, respectively. The mechanism is shown in scheme 1
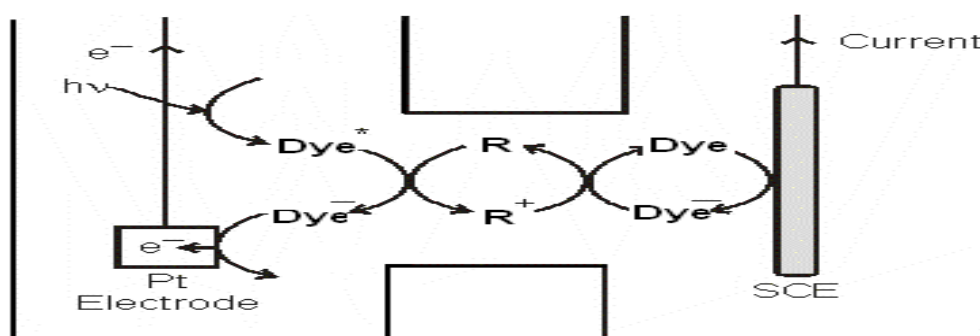
Scheme: 1tentative mechanism in the photogalvanic cell

SCE = Saturated calomel electrode   D = Dye (Photosensitizer)

R = Reductant   D⁻ = Leuco form

MATERIALS AND METHODS:
This investigation made use of indigo carmine, sodium lauryl sulphate (provided by Sisco Research Laboratories in Mumbai), ascorbic acid (provided by Ases Chemical in Jodhpur), and sodium hydroxide (provided by RFCL in New Delhi). After being made in double-distilled water, solutions containing ascorbic acid, indigo carmine, SLS, and NaOH (1N) were placed in amber-colored containers for storage. These containers were kept out of direct sunlight. The indigo carmine dye is

a dark blue crystalline powder that is stable at normal temperatures and pressures. It is soluble in alkaline environments. The chemical formula of this substance is $C_{16}H_{10}N_2O_2$, and its molecular weight is 262.27 g/mol. A combination of dye, reducing agent, surfactant, and NaOH solution was put in an H-shaped glass tube that had been blackened with black carbon paper to protect it from being impacted by sun radiation. This was done in order to keep the mixture from being stained by the dye. A saturated calomel electrode (SCE) was put into one leg of the H tube, and a brilliant platinum foil electrode measuring one centimetre by one centimetre was dipped into the opposite leg of the H tube. The Pt electrode acts as the working electrode, while the SCE performs the function of the counter electrode. After the complete system was initially left in the dark until a stable potential was obtained, the leg that contained the platinum electrodes was then subjected to light from a tungsten lamp with a power output of 200 watts (Philips). In order to prevent the transmission of heat radiation, a water filter was used. It was determined that a digital multimeter, specifically a HAOYUE DT830D digital multimeter, was necessary in order to measure both the system's potential and the current that it produced. A straightforward illustration of the photogalvanic cell construction as seen in Scheme 2.
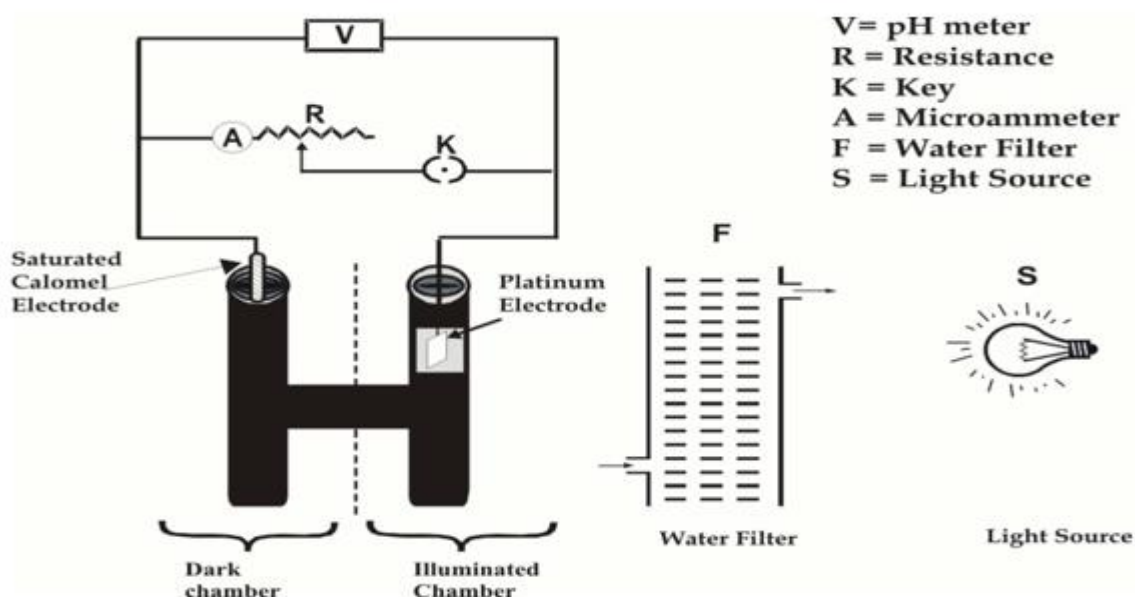
Scheme.2 Simple schematic diagram of the photogalvanic cell set-up

CONCLUSIONS:

The photogalvanic cells have an internal storage capacity and can use the stored energy even when there is no light, in contrast to the photovoltaic cell, which requires additional hardware in the form of a battery in order to store energy; photogalvanic cells are more advantageous than photovoltaic cells due to the low cost of the materials used to construct these cells. The Indigo Carmine - Ascorbic Acid - SLS system has conversion efficiency (CF) of 1.27 percent, a storage capacity of 140.0 minutes, a power point of 132.27 micro watts, and a fill factor (FF) of 0.2269 accordingly. These figures were reported for the conversion efficiency.

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