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INFLUENCE OF JANUS GREEN- B PHOTOSENSITIZER AZO DYE IN PHOTOGALVANIC CELL FOR SOLAR POWER GENERATION AND STORAGE

Chemistry

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ABSTRACT

Molecular formula of Janus Green-B photosensitizer is C30H31ClN6. In present work A tentative mechanism has been proposed for the generation of the photocurrent. In this regard for conversion of solar energy into electrical energy we use A photogalvanic cell composed with Ganus Green-B, Ascorbic Acid and Sodim laurylsulphate reagents as photosensitizer, reductant and surfactant respectively. Surfactant not only increase conversion efficiency but also increases storage capacity. The photopotential, photocurrent, power at power point, fill factor (η), conversion efficiency and cell performance (t0.5) at light intensity 10.4 mWcm-2 have been observed of the order of 806.0 mV, 775 µA, 122.55 µW, 0.1961, 1.17% and 130 minutes respectively. The impact of various parameters like concentration of photosensitizers, reductant and micelles, variation of pH, light intensity and diffusion path length were observed at different conditions.

KEYWORDS

Ganus Green-B, Ascorbic acid, Sodium Lauryl Sulphate (SLS), Photogalvanic effect (PGE), Fill factor, Power point.

INTRODUCTION:

Climate change is not only a major global environmental problem, but is also an issue of great concern to a developing country like India. Energy is the basic need of human being in our society and the need of energy is rising faster day by day due to increase in industrial, agricultural and developmental activities. The solar energy is one of the most important and practically unlimited sources of regenerative energy. It has been understood that development and implementation of cheap and functional system for efficient solar energy conversion and storage is of crucial importance for the humanity. Solar cell converts solar energy into electricity directly. Among such solar cells, the photogalvanic cells are unique as these are only solar cells that are capable of doing solar power generation and storage simultaneously.[1] Solar energy is a universal, decentralized, non-polluting, freely available source of energy and necessary for every kind of living organism. A photogalvanic cell is an important device that provides a desirable pathway for converting solar energy into electrical energy. It is the 3rd type of photoelectrochemical cell that is used to convert solar energy.[2] The Brilliant Cresyl Blue dye as photosensitizer, Fructose as reductant and NaOH as alkaline medium have been studied for enhancing the solar energy conversion and storage capacity of the photogalvanic solar cells. In this study, the observed values of electrical parameters like maximum potential, maximum photocurrent, short-circuit current, power at power point, and conversion efficiency are 1115 mV, 785 µA, 590 µA, 183.3 µW, and 1.9586%, respectively.[3] Thin-films have the potential to revolutionise the present cost structure of photovoltaics by eliminating the use of the expensive silicon wafers that alone account for above 50% of total module manufacturing cost. The strengths and weaknesses of the contending thin-film photovoltaic technologies and the current state of commercial activity with each are briefly reviewed.[4] In photogalvanic cell (PG) two inert electrodes are used and An electron transfer occurs between the excited dye molecules and electron donor or acceptor molecules added to the electrolyte. A photovoltage develops between two electrodes if light is absorbed by the electrolyte.Accordingly, the photogalvanic cell is essentially a concentration cell and is based on some electrochemical reactions, which gives rise to high energy products on excitation by a photon.

This energy product loose energy electrochemically lead to generate the electricity called as a photogalvanic effect. First of all the photogalvanic effect was observed in equilibrium of Ferrous ferric iodine iodide but this effect was systematically investigated in Thionine-Iron system.[5-7] The experiment was carried out employing solar cell simulator with varying cell temperature in the range 25–60 °C at constant light intensities 215–515 W/m^2. The results show that cell temperature has a significant effect on the photovoltaic parameters and it controls the quality and performance of the solar cell. The open circuit voltage, maximum power, fill factor and efficiency are found to be decreased with cell temperature. The reverse saturation current increases with cell temperature and a slight increment is observed in the short circuit current. The relative changes are found from −0.0022/°C to −0.0025/°C, 0.002/°C, −0.0013/°C and −0.002/°C for open circuit voltage, short circuit current, fill factor and maximum output power respectively.[8] Depending on the polymer-dye ratio, a bathochromic shift is observed as compared to the spectrum of free thionine. Photogalvanic potential is found to depend strongly on the polymer-dye ratio.[9] The conversion efficiency of the EDTA-TB photogalvanic cell has been estimated to be about 0.0022%. The electrochemical behaviour of toluidine blue in the presence of all the reducing agents has been examined by cyclic voltametry.[10]

We analyse the progress in cells and modules based on single-crystalline GaAs, Si, GaInP and InP, multicrystalline Si as well as thin films of polycrystalline CdTe and $CuIn_xGa_{1-x}Se_2$. In addition, we analyse the PV developments of the more recently emerged lead halide perovskites together with notable improvements in sustainable chalcogenides, organic PVs and quantum dots technologies.[11] A system with their maximum photovoltages are: thionine-ferrous ion aqueous system 250 mV, proflavine-EDTA aqueous system 476 mV and tolusafranine-EDTA aqueous system 844 mV. Authors have reported a photovoltage 615 mV in a redox system consisting of phenosafranine and EDTA in aqueous medium and this value increases with increasing temperature attaining 870 mV.[12] Photogalvanic cells using toluidine blue diethylenetriamine penta aceticacid (TB - DTPA) and Methylene blue-EDTA have been developed. The effects of different parameters like pH, concentration, temperature, electrode area, diffusion length etc on the electrical output of the cell were observed. Current-voltage (i-v) characteristics and performance of the cell were determined.[13-14]

Gangotri et al have increased the power output as well as storage capacity up to reasonable mark by using various photosensitizers with micelles in photogalvanic cell.[15-16] The accumulation of dust particles deteriorates the performance of solar cells and results in appreciable losses in the generated power due to the sun irradiance scattering effects on the surface of the solar panel. The deposition of the dust on the surface of the photovoltaic solar modules showed a reduction in both the short circuit current (I_{sc}) and the output power compared to the same parameters of the clean module. The average degradation rate of the efficiencies of the solar modules exposed to dust are; 6.24%, 11.8% and 18.74% calculated for exposure periods of one day, one week and one month.[17] In this system all possible (55) combinations of binary mixed dyes of different 11 dyes have been studied, in order to select stable mixed dye combination that can absorb wider range of solar spectrum and retains λ_{max} value of both dyes. Out of all these mixed dyes combinations, MB+BCP absorbs broadest visible wavelength (431.0–664.0 nm) followed by AB+BCP (431.0–645.0 nm), TB+BCP (431.0–628.0 nm) and lowest by BCB+BCP (431.0–625.0 nm). The MB+BCP absorbs the widest visible solar spectrum and retain λ_{max} value of both dyes.[18]

Photogalvanic effect was invented in a photogalvanic cell containing SLS, Ascorbic acid and Azur A as a surfactant, reductant and photosensitizer, respectively. The photopotential (770mV), photocurrent (160μA) and the effect of different parameters on the electrical output of the cell were observed and i–V characteristics of the cell have also been studied. The observed conversion efficiency and storage capacity for this system were 0.5461 and one hour fifty minutes respectively.[19] Genwa and Singh have reported reasonable values of electrical output with different photosensitizers (Brilliant Blue-FCF, and Lissamine green-B) in photogalvanic cells for solar energy conversion and storage.[20-21]

This article presents efficient solar cells suitable as top cells for tandem devices and highly active photocathodes for solar hydrogen evolution using CGSe photoabsorber layers with modified p–n heterointerfaces. Rb-doping during the last stage of CGSe film growth effectively improves the photovoltaic performance, and solar cell efficiency of >10% with a high fill factor (FF) of 74.6% is obtained. The half-cell solar-to-hydrogen conversion efficiency reaches 8% with the use of a photocathode composed of a CGSe film grown in an identical growth batch. Interface modification with i) a Cu-deficient layer, ii) alkali-metal doping, and iii) an n-type buffer layer formed on the CGSe film surface is found to a be key to control the energy conversion device parameters, such as the FF and open circuit voltage of solar cells and the onset potential of photoelectrochemical cells, due to the suppression of interface recombination.[22] The photogalvanic behaviour of Xylidine ponceau dye was studied in Xylidine ponceau–Tween 60–Ascorbic acid system. Cell generates maximum power of 68.77 μW in ideal conditions. Conversion efficiency was calculated by photopotential and photocurrent values at power point.[23] Modified photogalvanic cell for enhancing the solar power generation and storage have studied with EDTA, Safranine-O and SLS chemicals.This cell showed greatly enhanced performance in terms of charging time (40 min), initial generation of photocurrent (260 μA min^{-1}), equilibrium photocurrent (1700 μA), power (364.7 μW) and efficiency (8.93%).[24] Photogalvanic effect also observed in spinach extract as photo-sensitizer for sun light conversion and storage. The observed cell performance (charging time 18 min, Open-circuit potential 1050 mV, Short-circuit current 1750 μA, storage capacity as half change time 44 min and efficiency ≈ 9.22%) was very encouraging to photogalvanics.[25] A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a p-n junction. With regard to the development of sustainable energy, such as solar energy, in this article we will Study types of solar cells and their applications.[26]

The study of photogalvanics of Aniline blue dye (photo-sensitizer)-Ascorbic acid(reductant)-Sodium Lauryl Sulfate (surfactant) has been done in basic medium. The solar conversion efficiency, fill factor, cell performance (as t1/2), power at power point, open circuit potential and equilibrium current at 10.4 mWcm-2 have been observed of the order of 2.31%, 0.2445, 130 min, 240.24 □W, 1485 mV and 750□A respectively.[27] The PV module P-V curve was evaluated in each observed test to analyze the output power performance before and after the activation of the proposed hot spot mitigation technique. One PV module affected by hot spot was tested. The output power increased by approximate to 3.6□ W after the activation of the hot spot mitigation technique. Additional test has been carried out while connecting the hot spot PV module in series with two other PV panels. The results indicate that there is an increase of 3.57□ W in the output power after activating the hot spot mitigation technique.[28] A feasible ZnO/MoS_2/CZTS structure where the classical CdS buffer layer is replaced by a molybdenum disulfide buffer layer. This proposed solar cell is investigated thereafter using SCAPS code so as to determine the optimal value of each layer thickness constituting the cell of interest. The different photovoltaic parameters are determined versus each layer thickness. Our solar cell shows a conversion efficiency of about 23.69%. This corresponds to optimal thicknesses of 0.1 μm for ZnO window layer, 0.2 μm for MoS_2 buffer layer and 1 μm for CZTS absorber layer and common doping concentrations of 10^{18} cm^{-3} for each layer. This conversion efficiency compares reasonably with those previously quoted in the literature.[29]

Now in present work, Janus Green B is a basic azo dye and vital stain used in histology. The indicator Janus Green B changes colour according to the amount of oxygen present. When oxygen is present, the indicator oxidizes to a blue colour. In the absence of oxygen, the indicator is reduced and changes to a pink colour.

The scientific society has used different photosensitizers, surfactants, reductants in PG cells for conversion of solar energy into electrical energy but no one has been paid to the use of an azo dye as photosensitizer Ganus Green-B . So the our system contain Ganus Green-B azo dye Photosensitizers as energy material to increase the electrical output and performance of the PG cell was planned. Therefore, the present work was undertaken to obtain better performance and commercial viability of the PG cell.

RESULT AND DISCUSSION:

A. Effect of variation of Ganus Green- B dye, Ascorbic acid and SLS concentration:

A PG cell composed with Photosensitizer, reductant and surfactant. The impact of variation of an Ganus Green-B, ascorbic acid and SLS concentration are given in table 1. Variation of dye concentration studied by using solution of different molar concentration of dyes. It was observed that the photopotential, photocurrent and power enhanced with increasing in concentration of Ganus Green-B photpsensitizer. A maximum value (at 806 mV, 775 μA and 624.65 W) was obtained for a fix value of dyes concentration (1.8×10^{-5}M), above which a decrease in electrical output of the cell was observed. Low electrical output observed at the minimum concentration range of dye due to limited number of dye molecules to absorb the major part of the light in the path, while higher concentration of dye again resulted in a decrease in electrical output because intensity of light reaching the molecule near the electrode decrease due to absorption of the major portion of the light by the dye molecules present in the path. Therefore corresponding downfall in the electric output, with the increase in concentration of the reductant Ascorbic acid, the photopotential, photocurrent and power were found to increase till it reaches a maximum value at 1.6×10^{-3} M. On further increase in concentration of ascorbic acid, a decrease in the electrical output of the cell was observed. The fall in power output was also resulted with decrease in concentration of reductant due to less number of the molecules available for electron donation to the cationic form of dye. On the other hand, the movement of dye molecules hindered by the higher concentration of the reductant to reach the electrode in the desired time limit and it will also result in to a decrease in electrical output. The electrical output of the cell was increased on increasing the concentration of surfactant-SLS. A maximum result was obtained at a certain value (2.4×10^{-3}M) of concentration of SLS. On further increasing the surfactant concentration it react as a barrier and major portion of the surfactant photobleach the less number of dye molecules so that a down fall in electrical output was observed.

Table-1. Effect of variation of Ganus Green-B, Ascorbic acid and SLS concentrations

Light Intensity = 10.4 mW cm^{-2}, Temperature = 303 K, pH = 11.80			
Concentrations	Photopotential (mV)	Photocurrent (μA)	Power (W)
Ganus Green-B × 10^{-5} M			
1.2	550.0	515.0	283.25
1.4	628.0	590.0	370.52
1.8	806.0	775.0	624.65
2.0	660.0	574.0	378.84
2.2	570.0	427.0	243.39
[Ascorbic acid] x 10^{-3} M			
1.2	575.0	440.0	255.30
1.4	672.0	564.0	379.01
1.6	806.0	775.0	624.65
1.8	668.0	540.0	360.72
2.8	570.0	441.0	251.37
[SLS] x 10^{-3} M			
2.0	532.0	434.0	230.89
2.2	627.0	623.0	390.62
2.4	806.0	775.0	624.65
2.6	734.0	632.0	463.89
2.8	610.0	512.0	312.32

B. Variation of Potential With Time:

The photogalvanic cell was placed in dark till it attained a stable potential and then the Pt-electrode was exposed to light. It was observed that potential changes on illumination and it reached a constant value after a certain period. When the light source was removed, the direction of change in potential was reversed and a stable potential are again obtained after sometime. The variation of potential in Ganus Green-B-Ascorbic acid-SLS System with respect to time is graphically represented in figure 1 and table-2.

Table.2 Variation of Potential with Time

[Ganus Green-B] = 1.8 x 10^{-5} M Light Intensity = 10.4 mW cm^{-2} [Ascorbic acid] = 1.6 x 10^{-3} M Temperature = 303 K [SLS] = 2.4 x 10^{-3} M pH = 11.80	
Time (Min.)	Photopotential (mV)
0 Dark	100
5	204
10	256
15	297
20	343
30	366
40	407
50	443
60	615
70	723
80	754
85	906
100	906
110	906
115	906
120 Light off	906
125	892
130	882
135	882
140	842
145	831
150	825
160	820

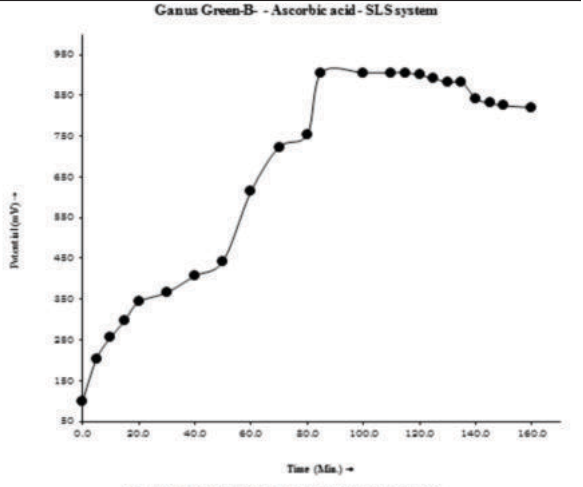


Fig 1. VARIATION OF POTENTIAL WITH TIME

C. Variation of Photocurrent With Time:

It was observed that there was a rapid rise in photocurrent of Ganus Green-B-Ascorbic acid-SLS System on illumination and it reaches a maximum value within few minutes. This value is denoted by i_{max} (Maximum Photocurrent). Then the current was found to decrease gradually with the period of illumination finally reaching a constant value at equilibrium. This value is represented as i_{eq} (Photocurrent at equilibrium). The photocurrent was found to decrease on removing the source of illumination. The variation of photocurrent in Ganus Green-B-Ascorbic acid-SLS system with respect to time is shown in figure 2.and table-3.

Table-3. Variation of Photocurrent with time

[Ganus Green-B] = 1.8 x 10^{-5} M Light Intensity = 10.4 mW cm^{-2} [Ascorbic acid] = 1.6 x 10^{-3} M Temperature = 303 K [SLS] = 2.4 x 10^{-3} M pH = 11.80	
Time (Min.)	Photocurrent (A)
0.0	0
1.0	172
3.0	245
5.0	270
7.0	367
9.0	389
11.0	401
15.0	466
20.0	498
30.0	527
40.0	575
50.0	638
60.0	767
70.0	797
80.0	820
90.0	810
100.0	775
110.0	775
115.0 light off	775
125.0	765
130.0	760
140.0	754
150.0	750
160.0	744
170.0	742
180.0	740

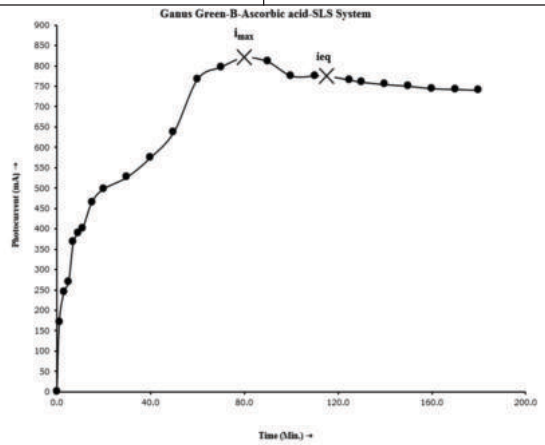


Fig 2. VARIATION OF PHOTOCURRENT WITH TIME

D. Effect of Light Intensity:

The effect of light intensity was studied by using intensity meter (Solarimeter model-501). It was found that photocurrent showed a linear increasing order with the increase in light intensity whereas photopotential increases in a logarithmic manner. This increase in number of photons with increase in light intensity. The effect of variation of light intensity on the photopotential and photocurrent is represented in table 4.and graphically in fig.3.

Table- 4. Effect of light intensity

Ganus Green-B-Ascorbic acid-SLS System	Light Intensity (mW cm^{-2})				
	3.1	5.2	10.4	15.6	26.0
Photopotential (mV)	846.0	835.0	806.0	767.0	743.0
Photocurrent (A)	768.0	770.0	775.0	777.0	781.0
Log V	2.9274	2.9217	2.9063	2.8848	2.8710

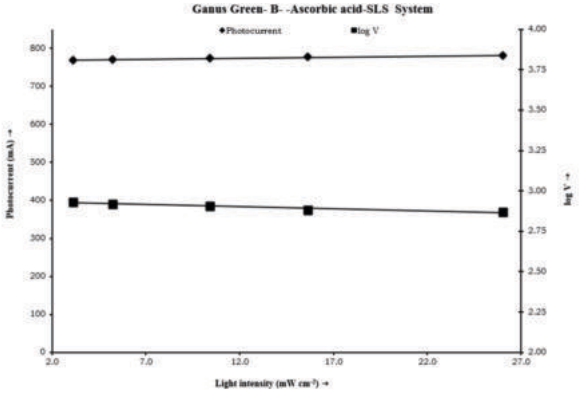


Fig. 3. VARIATION OF PHOTOCURRENT AND log V WITH LIGHT INTENSITY

E. Current-voltage (I- V) Characteristics Of The Cell:

The short circuit current (i_{sc}) 775 µA and open circuit voltage (V_{oc}) 806 mV of the photogalvanic cell were measured with the help of a microammeter (keeping the circuit closed) and with a digital pH meter (keeping the circuit open), respectively. The current and potential values in between these two extreme values were recorded with the

help of a carbon pot (log 470 K) connected in the circuit of multimeter, through which an external load was applied. The i-V characteristics of the photogalvanic cells containing Ganus Green-B – Ascorbic acid–SLS system is graphically shown in Fig. 4 and summarized in table 5. It was observed that i-V curve deviated from its regular rectangular shape. A point in the i-V curve, called power point (pp), was determined where the product of curve of current (i_{pp}) 430 µA and potential (v_{pp}) 285 mV was maximum. With the help of i-V curve, the fill-factor was calculated as 0.1761 using the formula:

$$\text{Fill factor}(\eta) = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}}$$

Table-5. Current-voltage (I-V) Characteristics Of The Cell

Current-Voltage (i-V) characteristics of the cell					
S.No.	Potential (mV)	Photocurrent (A)	S.No.	Potential (mV)	Photocurrent (A)
1.	906	0	21.	440	270
2.	901	5	22.	421	280
3.	892	10	23.	417	285
4.	862	15	24.	385	315
5.	853	20	25.	375	323
6.	842	25	26.	360	330
7.	831	30	27.	345	340
8.	747	40	28.	315	375
9.	742	50	29.	309	388
10.	725	60	30.	285	430
11.	709	75	31.	270	440
12.	659	95	32.	250	465
13.	641	105	33.	241	480
14.	620	115	34.	228	505
15.	597	125	35.	906	580
16.	565	135	36.	901	610
17.	538	155	37.	892	620
18.	515	170	38.	862	720
19.	501	180	39.	853	750
20.	488	210	Fill factor (η) = 0.1961		

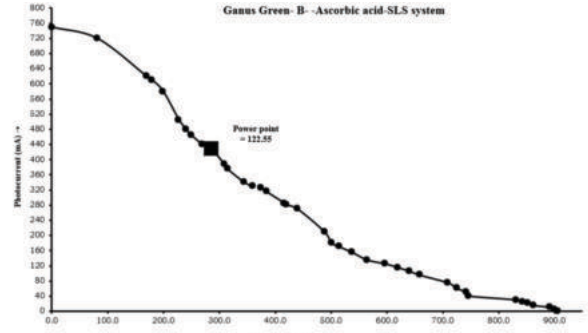


Fig.4. CURRENT VOLTAGE (I-V) CURVE OF THE CELL

F. Cell Performance And Conversion Efficiency:

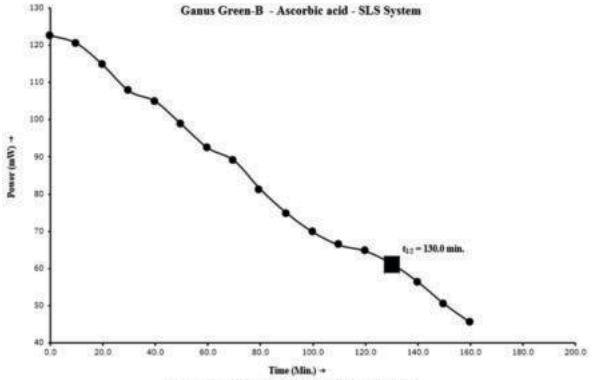


Fig. 5. TIME-POWER CURVE OF THE CELL

The performance of the photogalvanic cell was observed by applying an external load (necessary to have current at power point) after termination the illumination as soon as the potential reaches a constant value. The performance was determined in terms of $t_{1/2}$, i.e., the time required in fall of the output (power) to its half at power point in dark. It was observed that the cell containing Ganus Green-B –Ascorbic acid–SLS system can be used in dark for 130.0 minutes. With the help of current and potential values at power point and the incident power of radiations, the conversion efficiency of the cell was determined as 1.17% using the formula. The results are graphically represented in time-power curve (Fig.5).

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

G. Mechanism :

When certain dyes are excited by the light in the presence of electron donating substance (reuctant), the dyes are rapidly changed into colorless form. The dye now acts as a powerful reducing agent and can donate electron to other substance and reconverted to its oxidized state. On the basis of earlier studies a tentative mechanism in the photogalvanic cell may be proposed as follows:

Illuminated chamber: On irradiation, dye molecules get excited. The excited dye molecules accept an electron from reductant and converted into semi or leuco form of dye, and the reductant into its excited form.

At Platinum Electrode: The semi or leuco form of dye loses an electron and converted into original dye molecule.

Finally leuco/semi form of dye and oxidized form of reductant combine to give original dye and reductant molecule. This cycle of mechanism is repeated again and again leading production of current continuously. The scheme of mechanism is shown in Fig.6.

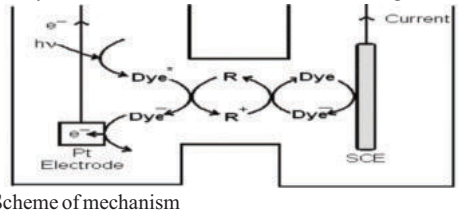
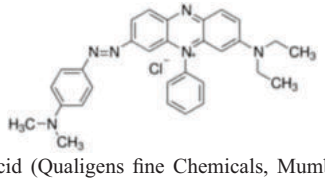


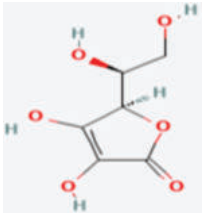
Fig.6. Scheme of mechanism
SCE = Saturated calomel electrode D = Dye (Photosensitizer)
R = Reductant/ Reducing agent D = Semi & Leuco form

H. MATERIALS AND METHODS

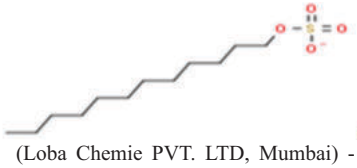
(i) Ganus Green-B- (Loba Chemie PVT. LTD, Mumbai) - Used as (dye) photosensitizer



(ii) Ascorbic acid (Qualigens fine Chemicals, Mumbai), - Used as reductant



(iii) NaLS (Loba Chemie PVT. LTD, Mumbai) –Used as surfactant



(iv) NaOH (Loba Chemie PVT. LTD, Mumbai) - Used as basic medium

Ganus Green-B , Ascorbic acid , NaLS and NaOH were used in the present work. Solutions of ascorbic acid, Ganus Green-B, SLS and NaOH (1N) were prepared in double distilled water (conductivity 3.5×10^{-5} Sm^{-1}) and kept in amber coloured containers to protect them from sun light.

A mixture of solutions of dyes, reductant, surfactant and NaOH was taken in an H–type glass tube which was blackened by black carbon paper to unaffected from sun radiation. A shiny platinum foil electrode

($1.0 \times 1.0\ cm^2$) was immersed in one limb of the H–tube and a saturated calomel electrode (SCE) was immersed in the other limb. Platinum electrode act as a working electrode and SCE as a counter electrode. The whole system was first placed in the dark till a stable potential was attained, then the limb containing the platinum electrode was exposed to a 200 W tungsten lamp (Philips). A water filter was used to cut off thermal radiation. Photochemical bleaching of the dye was studied potentiometrically.

A digital multimeter (HAOYUE DT830D Digital Multimeter) was used to measure the potential and current generated by the system respectively. The current voltage characteristics were studied by applying an external load with the help of Carbon pot (log 470 K) connected in the circuit the photogalvanic cell set-up is shown in Figure 5.

I. CONCLUSIONS:

The photogalvanic cell have inbuilt storage capacity and stored energy can be used in absence of light whereas photovoltaic cell needs extra hardware as battery for energy storage, photogalvanic cells are favourable than photovoltaic cells because low cost materials are used in these cells. The conversion efficiency, storage capacity, power at power point and fill factor are recorded as 1.17%, $t_{1/2}$ 130.0 min, 122.55µW and 0.1761 respectively in Ganus Green-B –Ascorbic acid–SLS system.

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