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EXPLORATORY INSIGHT INTO THE LONG-TERM PHOTOSTABILITY OF THE BRILLIANT CRESYL BLUE BASED ELECTROLYTE SOLUTION OF PHOTOGALVANIC CELLS[**]

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Photogalvanic cells have been studied with respect to the photostability of the brilliant cresyl blue (BCB) dye sensitizer Fructose reductant sodium lauryl sulfate surfactant NaOH alkali electrolyte solution and the consequent electrical output over a long time period. It is observed that BCB dye photosensitizer molecules undergo photodecay, but despite this decay, the cell, even with the photodecayed electrolyte, has a promising capacity to produce power with storage. The observed characteristics (spectral and electrical data) of the electrolyte are quite indicative of the stability of the BCB dye photosensitizer-based photogalvanic cell.

Keywords: *photostability of electrolyte, photogalvanic cell, solar energy conversion, power storage capacity, UV-visible spectra.*

ДОЛГОВРЕМЕННАЯ ФОТОСТАБИЛЬНОСТЬ РАСТВОРА ЭЛЕКТРОЛИТА НА ОСНОВЕ БРИЛЛИАНТОВОГО КРЕЗИЛОВОГО СИНЕГО ДЛЯ ФОТОГАЛЬВАНИЧЕСКИХ ЭЛЕМЕНТОВ

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Для фотогальванических элементов проведены исследования фотостабильности раствора электролита на основе красителя бриллиантового крезилового синего (BCB), восстановителя фруктозы, поверхностно-активного вещества лаурилсульфата натрия, NaOH и электрической мощности в течение длительного периода времени. Показано, что молекулы фотосенсибилизатора BCB подвергаются фотораспаду, однако, несмотря на это, элемент даже с фотораспадающимся электролитом обладает способностью производить и накапливать энергию. Спектральные и электрические характеристики электролита свидетельствуют о стабильности фотосенсибилизатора на основе красителя BCB.

Ключевые слова: *фотостабильность электролита, фотогальванический элемент, преобразование солнечной энергии, аккумулирующая способность, УФ-видимый спектр.*

Introduction. Energy is unavoidable for all individual and organizational activities. It is only solar energy that has the potential to meet this energy need forever. Solar energy can be harvested indirectly or directly by various solar power techniques [1–4]. Photogalvanic cells (PG cells) are also one of the promising solar cell technologies [5–11]. PG cells are able to convert solar energy directly into solar electricity with the added advantage of power storage. PG cells are composed of two electrodes dipped in the photosensitive electrolyte material consisting of the alkali medium (NaOH), water solvent (single or double distilled), pho-

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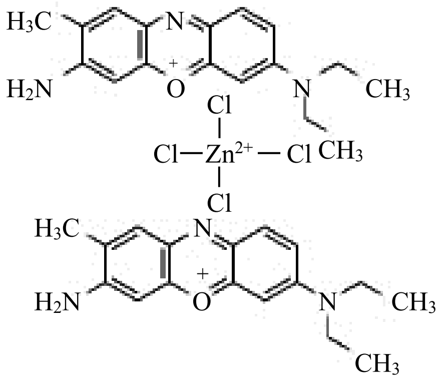
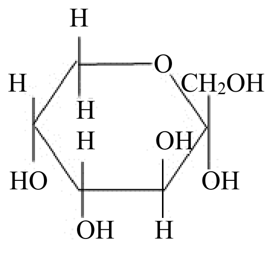
to-sensitizer (dye or pigment), reductant (inorganic or organic), and surfactant (polar or non-polar). The published work on PG cells has focused exclusively on the enhancement of the electrical output by manipulating one or more cell fabrication variables (like concentrations and nature of the chemicals, nature and size of the electrodes, cell diffusion lengths, illumination intensity, etc.) [12–16]. The author has also reported photogalvanic cells based on the Brilliant Cresyl Blue (BCB) dye sensitizer-Fructose reductant-NaOH alkali electrolyte solution [17]. Recently, the impressive electrical output has been reported for the modified PG cells fabricated of modified electrodes (Pt of the miniaturized size with the combination electrode) and the modified BCB dye sensitizer-Fructose reductant electrolyte by adding the Sodium lauryl sulfate surfactant [18]. But herein the point is that the energy needs are of durable and sustainable nature. Therefore, any solar cell device including the PG cell has to be capable of being used for over a long time period in a sustainable manner. Therefore, from this viewpoint, having PG cells with a good electrical output only would not be sufficient for realizing durable solar cell devices, but these cells have to show long term stability with commensurate capacity also to produce power over a long period of time. It is a research gap considered in this paper. The aim of our study is to have an exploratory insight on the relative photo-stability of the BCB dye sensitizer (present in the BCB dye sensitizer-Fructose reductant Sodium lauryl sulfate surfactant-NaOH alkali electrolyte solution of the PG cell) with the consequent electrical output of the cell over a long time period. In the present work, as part of a series of studies with a similar aim, the exploratory spectroscopic study on the photo-stability of the BCB dye sensitizer-Fructose reductant Sodium lauryl sulfate surfactant-NaOH alkali electrolyte solution of the photogalvanic cell based on the synthetic BCB dye sensitizer has been reported. It is observed that the BCB dye sensitizer molecules definitely undergo photo-decay in the electrolyte, but such an electrolyte having photo-decayed sensitizers' molecules is also capable of producing solar power with storage in the long term.

Materials and methods. The BCB dye purchased from the market was used as the dye photo-sensitizer material. The characteristics of the BCB, a basic dye, are class oxazine, M.F. $C_{17}H_{20}ClN_3O.0.5\ ZnCl_2$, M.W. 385.96, λ_{max} (nm) 622, UV-visible spectrum [at a concentration of 0.005 g/L in 50% ethanol, E 626 (±3 nm) $\geq$ 40,000, E 250 (±3 nm) $\geq$ 15,000, E238 (±3 nm) $\geq$ 15,000], solubility 1 mg/mL H_2O (clear to opaque, blue solution) and color index No. 51010.



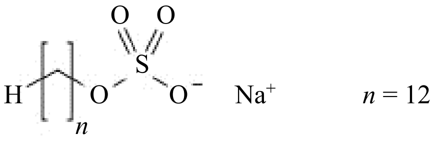
BCB

The α-fructopyranose, i.e., fructose (99.8% assay), purchased from the market was used as the reductant material. Its IUPAC name is 1,3,4,5,6-pentahydroxy-2-hexanone.



D(-)Fructose

Sodium lauryl sulfate (IUPAC name, sodium dodecyl sulfate) purchased from the market was used as the surfactant material. It is a water-soluble white powder. Its characteristics are: a negatively charged surfactant, M.F. $C_{12}H_{25}SO_4Na$, M.W. 288.3 g/mol, purity (active matter) 94% minimum (impurity of chloride, sulfate, moisture, un-reacted oil, etc.), pH (of 10% solution) 7.5–9.5 at 25°C, density 1.01 g/cm^3, melting point 206°C, and CAS registry number 151-21-3.



Sodium Lauryl Sulfate

All the solutions were prepared in singly distilled water. The stock solutions of all the chemicals were prepared by direct weighing and kept in the dark to protect them from sunlight.

The solutions, M/500 BCB dye (M.W. 385.96) aqueous solution (50 mL), M/100 fructose (M.W. 180.16, 99.8% purity) aqueous solution (50 mL), M/10 sodium lauryl sulfate (M.W. 288.3, 94% purity) aqueous solution (50 mL) were prepared by dissolving 0.038 g of the solid dye in 50 mL of water, dissolving 0.090 g of solid fructose in 50 mL of water, and dissolving 1.53 g of solid sodium lauryl sulfate in 50 mL of water. The 2.5 M NaOH (M.W. 40) (100 mL) solution was prepared by dissolving the excess amount (>10 g) of NaOH pellets in 100 mL of water followed by standardization with the 2.5 N standard oxalic acid solution.

Ultraviolet-visible spectra were taken by a single-beam UV-visible spectrophotometer-108 (Systronics, Ahmedabad, India). The cuvette cells used (Optiglass, U.K.) have transmissions 82.3% (at 200 nm), 84.3% (at 220 nm), and 85% (at 85 nm). The accuracy of determining the band positions in the observed spectra from this spectrophotometer is ±0.5 nm.

Results and discussion. *The combined effect of the reductant, surfactant, and alkali on the absorption spectra of the BCB (pre-illumination spectra of the BCB in the electrolyte of the PG cell).* The study of the combined effect of the fructose reductant, SLS surfactant, and NaOH alkali on the light absorption property of the BCB dye sensitizer (pre-illumination spectra of the BCB dye sensitizer in the electrolyte of the PG cell) was carried out by making two solutions, i.e., the blank solution and the sample cell. The blank solution (total solution 10 mL) is made of a mixture of 1 mL of 2.5 M NaOH (resultant pH 13.39), 1 mL of M/100 fructose (resultant concentration 1.0×10^{-3} M), 1 mL of M/10 SLS (resultant concentration 1.0×10^{-2} M), and 7 mL of singly distilled water. The sample solution (total solution 10 mL) is made of a mixture of 1 mL of 2.5 M NaOH (resultant pH 13.39), 1 mL of M/100 fructose (resultant concentration 1.0×10^{-3} M), 1 mL of M/10 SLS (resultant concentration 1.0×10^{-2} M), 1 mL of the M/500 BCB dye (resultant concentration 0.2×10^{-3} M), and 6 mL of singly distilled water.

The electrolyte was scanned for UV-visible spectra from 205 to 850 nm manually with the help of the UV-visible spectrophotometer-108 (Systronics) and cuvettes (width 1 cm). There are three bands in the observed spectra 240 (0.41), 340 (0.22), and 630 nm (1.21). Further, the observed absorbance beyond 690 nm (toward the lower energy side) is negligibly small (Table 1, Fig. 1). These bands have position and intensity as primary main absorption band maxima at wavelength 630 nm (absorbance $A = 1.21$, molar extinction coefficient $\varepsilon = 6.05\times10^3$ L/M · cm), absorption band at wavelength 340 nm ($A = 0.22$, $\varepsilon = 1.1\times10^3$ L/M · cm), and absorption band at wavelength 240 nm ($A = 0.41$, $\varepsilon = 2.05\times10^3$ L/M · cm). Here, the value of ε was calculated from Lambert–Beer's law ($A = \varepsilon cb$), where the c and b are the concentration of the solute (in M/L; in the present study, the concentration of the BCB dye is 0.2×10^{-3} M/L), and the width of the cuvettes (in cm, in the present study, the width is 1 cm).

The observed UV-visible spectra of the pre-illuminated electrolytes in the present study can be interpreted with the help of the already published work:

(i) Well-defined absorption maxima of the BCB dye are reported at $\lambda_{max} = 520$ nm ($A = 0.64$) with one more band at 270 nm ($A = 0.62$) in the methanol solvent. Further, the observed absorbance beyond 690 nm (toward the lower energy side) is reported to be negligibly small (i.e., absorbance 0.005) [19].

(ii) An absorbance maximum $\lambda_{max} = 624.5$ nm is at the laboratory temperature, and the λ_{max} value shifts toward a higher wavelength 644.5 nm with the SLS surfactant for the BCB dye in an aqueous medium. It is also reported that the BCB dye forms a complex with SLS, creating a stable dye–surfactant complex [20].

(iii) UV-visible spectra of the BCB dye in 50% ethanol [at a concentration of 0.005 g/L, (1.29×10^{-5} M)] are reported to be $\lambda_{max} = 622$ nm [E 626 (±3 nm) ≥ 40,000 ($A = 0.518$)], E 250 (±3 nm) ≥ 15,000 ($A = 0.194$), and E 238 (±3 nm) ≥ 15,000 ($A = 0.194$).

(iv) It is already published that the BCB dye sensitizer shows three dominant absorption bands, i.e., the main peak between 619 and 630 nm (high intensity band, A = 0.99), a broad band at ~235–250 nm (A = 0.36), a shoulder band at about 281 nm (A = 0.2), and the absorbance beyond 680 nm (toward the lower energy side) is reported to be negligibly small (i.e., A = 0.02–0.03) [21]. These three bands are the characteristics inherent to the BCB dye.

With this background of published information, the spectra of the pre-illuminated electrolyte (consisting of the BCB dye, SLS, fructose, liquid water) obtained in the present study can be explained. Mainly, three prominent absorption bands (at wavelengths of 630, 340, and 240 nm) and negligible absorbance beyond 690 nm were observed in the spectra of the pre-illuminated electrolyte (Table 1, Fig. 1). A comparison with the published spectra [21] shows that these three bands at 630, 340, and 240 nm in the present study belong to the BCB dye, and the maximum absorbance takes place at $\lambda_{\max}$ = 630 nm. These three bands are not due to water, NaOH, SLS, or fructose. Evidence in favor of this observation is that the solution mixture of these four chemicals (water, NaOH, SLS, and fructose) was used as the blank solution (reference solution) to exclude their absorbance from that of the sample solution (the BCB dye with water, NaOH, SLS, and fructose).

In the present study, the position of the main band is at 630 nm (which is red-shifted with respect to the main band at 624.5 nm of the aqueous BCB dye [20]. Our focus will be on the band at 630 nm (A = 1.21) because it is the main band and also clearly noticeable within the visible range. This red-shifting of the main band (630 nm, A = 1.21) in the present study may be attributed to the effect caused by electrolytes on the absorption property of the BCB dye. The electrolyte solution (water, NaOH, SLS, and fructose) has anionic species such as the SLS surfactant anion and the OH^- anion (from NaOH). The surfactant has a solubilizing effect on the BCB dye facilitating de-aggregation of the dye. Further, the dipole–dipole interaction between the positively charged BCB dye molecule and the negatively charged SLS surfactant anionic molecule may also be responsible for the bathochromic shift with respect to the published data on the aqueous BCB dye [20].

Post-illumination spectra of the BCB dye in the electrolyte of the PG cell after the first time illuminating the electrolyte for 69 min. Both the blank solution and the sample solution (as used for determining the pre-illuminated spectra) were illuminated for 69 min identically with the sunlight intensity of 10.4 mWcm^{-2} emitted from an incandescent tungsten bulb of 200 wattage. These are the same blank solution and sample solution that were first used for determining the pre-illuminated spectra. Thereafter, these same solutions were illuminated for 69 min, and then the illuminated solutions were used for determining the post-illumination spectra. The illuminated sample and the blank solutions were scanned manually for the 205–830 nm wavelength range with the help of the Systronics UV-visible spectrophotometer. The post-illuminated spectra are characterized by two bands. These bands have position and intensity as the primary absorption band maxima at wavelength 610 nm (A = 0.455, $\varepsilon = 2.275\times10^3$ L/M · cm), and the absorption band at wavelength 365 nm (A = 0.349, $\varepsilon = 1.745\times10^3$ L/M · cm). Some special features in the post-illuminated spectra (after illuminating for 69 min) were also observed. The intensity of the main band at 610 nm in the post-illuminated spectra is also lower than that of the pre-illuminated electrolyte. Further, for the range 205–355 nm, there is no absorbance in the post-illuminated spectra (Fig. 1).

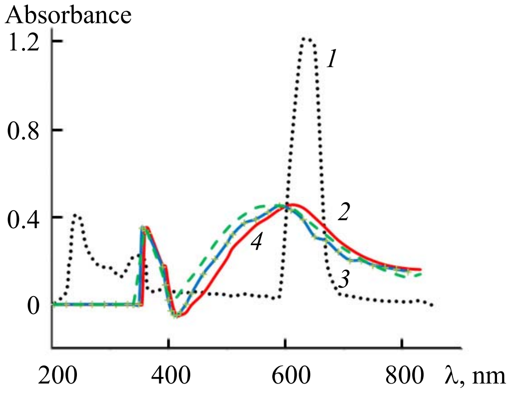


Fig. 1. UV-Visible spectra of the pre-illuminated spectra (*1*) and post-illuminated BCB dye sensitizer in the electrolytic solution (having NaOH, Fructose, SLS, and BCB dye) of the photo-galvanic cell: post 69 min illumination (*2*), after 24 h include illumination time of 129 min (*3*), and after 96 h include illumination time of 249 min (*4*).

TABLE 1. UV-Visible Spectra of the Pre-Illuminated and Post-Illuminated BCB Dye Sensitizer in the Electrolytic Solution (having NaOH, Fructose, SLS, and BCB dye) of the Photogalvanic Cell

Before the illumination		After the 1st time illumination for 69 min		After the 2nd time illumination for 60 min (after ~24 h including the 1st & the 2nd time total illumination for 129 min)		After the 3rd time illumination for 120 min (after ~96 h including the 1st & the 2nd & the 3rd time total illumination for 249 min)	
λ, nm	*A*	λ, nm	*A*	λ, nm	*A*	λ, nm	*A*
205	0.01	205	0	205	0	205	0
225	0.06	225	0	225	0	210	0
230	0.2	250	0	250	0	300	0
232	0.21	270	0	270	0	310	0
235	0.34	290	0	290	0	320	0
240	0.41	310	0	310	0	330	0
245	0.4	330	0	330	0	340	0
250	0.39	340	0	340	0	360	0.346
260	0.26	350	0	345	0.33	365	0.32
280	0.18	355	0	350	0	390	0.138
300	0.17	360	0.348	355	0.35	395	0.0798
320	0.13	365	0.349	360	0.34	405	0.0199
340	0.22	390	0.18	365	0.324	410	0.0249
360	0.2	395	0.176	390	0.17	415	0.036
365	0.07	400	0.09	395	0.089	420	0.055
390	0.07	405	0.0211	400	0.019	430	0.095
410	0.06	410	–0.0284	405	–0.028	440	0.126
430	0.055	415	–0.0521	410	–0.05	460	0.199
450	0.06	420	–0.049	415	–0.048	480	0.279
470	0.05	430	–0.0362	420	–0.036	500	0.344
490	0.05	440	0	430	0	510	0.37
510	0.04	460	0.053	440	0.051	530	0.41
530	0.05	480	0.131	460	0.14	550	0.441
550	0.04	500	0.21	480	0.206	570	0.449
570	0.04	510	0.259	500	0.278	590	0.450
590	0.04	530	0.312	510	0.319	611	0.438
610	0.72	550	0.363	530	0.37	630	0.4
630	1.21	570	0.396	550	0.389	650	0.355
650	1.18	590	0.434	570	0.42	670	0.314
670	0.214	610	0.455	590	0.45	690	0.272
690	0.058	630	0.441	610	0.431	710	0.236
710	0.042	650	0.396	630	0.387	730	0.205
730	0.03	670	0.345	650	0.31	750	0.178
750	0.023	690	0.293	670	0.29	770	0.155
762	0.0199	710	0.254	690	0.24	790	0.136
770	0.0172	730	0.222	710	0.202	810	0.124
790	0.0161	750	0.199	730	0.2	830	0.138
810	0.0131	770	0.181	750	0.179		
830	0.019	790	0.17	770	0.169		
850	0	810	0.163	790	0.16		
		830	0.16	810	0.15		

Note. The blank and the sample solutions were the same for all four spectral studies; blank solution (1 mL of 2.5 M NaOH+1 mL of fructose M/100+1 mL SLS of M/10+7 mL water = total solution 10 mL); sample cell (1 mL of 2.5 M NaOH+1 mL of fructose M/100+1 mL SLS of M/10+1 mL BCB dye of M/500+water 6 mL = total solution 10 mL); NA (no transmittance for the blank or for the sample solution).

The post-illuminated spectra (after 69 min of illumination) can be interpreted by focusing mainly on the primary band at a wavelength of 610 nm ($A = 0.455$, $\varepsilon = 2.275\times10^3$ L/M · cm). It is because the main aim of the present study is to make an exploratory insight into the photodecay aspect and the consequent electrical properties of the electrolyte having decayed the dye sensitizer. The intensity of the main band (610 nm, $\varepsilon = 2.275\times10^3$ L/M · cm) of the BCB dye in the post-69th minute illuminated spectra is lower than that of the intensity (630 nm, $\varepsilon = 6.05\times10^3$ L/M · cm) of the main band of the BCB dye in the pre-illuminated spectra. The hypochromic shift of the main band in the post-illuminated spectra may be explained by the photodecay of the BCB dye, which in turn decreases the dye concentration.

An analysis of the absorption data (after 69 min of illumination of the electrolyte) shows that the temperature and sunlight intensity affect the position of the spectral bands in both ways (bathochromic shifts and hypsochromic shifts), but only slightly. The aqueous solution of the BCB (in the presence of SLS, fructose, and NaOH) shows three spectral bands. These bands have a position as the primary main absorption band maxima at a wavelength of 630 nm ($A = 1.21$), the absorption band at a wavelength of 340 nm ($A = 0.22$), and the absorption band at a wavelength of 240 nm ($A = 0.41$) at room temperature (38°C). Upon photo-illumination of the reference and dye sample solutions with the sunlight intensity 10.4 mW/cm^2 for the 69-min duration, a temperature rise, of about 12°C is observed. The spectra after this temperature rise and the illumination at an intensity of 10.4 mW/cm^2 show two bands at a temperature of 50°C. These bands have positions as the primary main absorption band maxima at a wavelength of 610 nm ($A = 0.455$), and the absorption band at a wavelength of 365 nm ($A = 0.349$) at a temperature of 50°C. This observation shows that the primary band position at 630 nm (38°C) is blue-shifted by 20 to 610 nm (50°C), the absorption band at 340 nm (38°C) is red-shifted by 25 to 365 nm (50°C), and the absorption band at 240 nm (38°C) is completely lost at 50°C.

The change in the band position, especially of the blue-shifted primary band, may be attributed to the dye decay on illumination followed by the temperature rise resulting in the reduced dipole–dipole interaction between the anionic surfactant SLS and the cationic dye. The present observations of both red shifts and blue shifts of the bands are also supported by the published literature.

Holmes et al. described the heating of a dye solution resulting in the actual decomposition of the dye. In general, temperature exerts only very minor effects on the spectra, and radical alterations of the dye spectra are rarely observed in varying the temperature of dye solutions. The small displacements in the spectral location of bands, occurring in both directions over the extreme temperature range of 60°C, are reported [22].

The BCB dye forms a stable dye–surfactant complex with SLS that results in red shifts of the band position from 624.5 to 644.5 nm at the laboratory temperature [20]. It means that the lowering of the dye–SLS complex formation as a result of dye decay may be one reason for the blue shift in this primary band (band shifts from 630 to 610 nm in the present study), although it should be noted that the study of the effect of the temperature and illumination intensity on the spectral bands was not planned in this work.

Post-illumination spectra of the BCB dye in the electrolyte of the PG cell after illuminating the electrolyte for 60 min for the second time. Both the blank solution and the sample solution (as used for determining the pre-illuminated spectra as well as the spectra after the first illumination) were illuminated for 60 min identically with the sunlight intensity of 10.4 mW/cm^2 emitted from the incandescent tungsten bulb of 200 W. These are the same blank solution and the sample solution that were first used for determining the pre-illuminated spectra and the post-illuminated spectra (after the first illumination for 69 min). Thereafter, these solutions were illuminated for the second time for 60 min, and then the illuminated solutions were used for determining the post-illumination spectra. The illuminated sample and blank solutions (after ~24 h including the first and the second illumination for a total of 129 min) were scanned manually for the 205–810 nm wavelength range with the help of a Systronics UV-visible spectrophotometer.

The post-illuminated spectra are characterized by two bands. These bands have position and intensity as the primary main absorption band maxima at the 590 nm wavelength ($A = 0.45$, $\varepsilon = 2.25\times10^3$ L/M · cm), and the absorption band at the 355 nm wavelength ($A = 0.35$, $\varepsilon = 1.75\times10^3$ L/M · cm). Some special features in the post-illuminated spectra (after ~24 h including the first and the second illumination for a total of 129 min) are also observed. The intensity of the main band at 590 nm in the post-illuminated spectra is lower than that of the pre-illuminated electrolyte. Throughout the scan range from 205 to 810 nm, the absorbance of the post-second illuminated spectra (after 24 h) resembles that of the post-first illuminated electrolyte. Further, for the range from 205 to 350 nm, there is no absorbance in the post-illuminated spectra (Fig. 1).

The post-illuminated spectra (after ~24 h including the 129-min illumination) can be interpreted by focusing mainly on the primary band at the 590 nm wavelength ($A = 0.45$, $\varepsilon = 2.25\times10^3$ L/M · cm). It is because the main aim of the present study is to make an exploratory insight into the photodecay aspect and consequent electrical properties of the electrolyte having decayed the dye sensitizer. The intensity of the main band (590 nm, $\varepsilon = 2.25\times10^3$ L/M · cm) of the BCB dye in the post-129th minute illuminated spectra is lower than the intensity (630 nm, $\varepsilon = 6.05\times10^3$ L/M · cm) of the main band of the BCB dye in the pre-illuminated spectra. The hypochromic shift of the main band in the post-illuminated spectra may be explained by the photodecay of the BCB dye, which in turn decreases the dye concentration.

Post-illumination spectra of the BCB dye in the electrolyte of the PG cell after ~96 h including the first, the second, and the third illumination for a total of 229 min. Both the blank solution and the sample solution (as used for determining the pre-illuminated spectra as well as the spectra after the first and the second illumination) were illuminated for the third time for 120 min identically with the sunlight intensity of 10.4 mW/cm^2 emitted from an incandescent tungsten bulb of 200 wattage. Thereafter, both the blank solution and the sample solutions were left for a period of up to ~96 h (including the first, the second, and the third illumination for a total of 229 min). The illuminated sample and blank solutions (after ~96 h including the first, the second, and the third illumination for a total of 229 min) were scanned manually for the 205–830 nm wavelength range with the help of a Systronics UV-visible spectrophotometer. The post-illuminated spectra (after ~96 h including the first, the second, and the third illumination for a total of 229 min) are characterized by two bands.

The post-illuminated spectra are characterized by two bands. These bands have position and intensity as the primary main absorption band maxima at the 590 nm wavelength ($A = 0.450$, $\varepsilon = 2.25\times10^3$ l/M · cm), and the absorption band at the 360 nm wavelength ($A = 0.346$, $\varepsilon = 1.73\times10^3$ l/M · cm). Some special features in the post-illuminated spectra (after ~96 h including illumination for a total of 229 min) are also observed. The absorbance pattern of the post-229th minute's illuminated spectra resembles that of the previously illuminated electrolyte. For the range from 205 to 340 nm, no transmittance for the blank or for the sample solution is observed in the post-illuminated spectra (Fig. 1).

The post-illuminated spectra (after ~96 h including the 229-min illumination) can be interpreted by focusing mainly on the primary band at the 590 nm wavelength ($A = 0.45$, $\varepsilon = 2.25\times10^3$ L/M · m. It is because the main aim of the present study is to make an exploratory insight into the photodecay aspect and the consequent electrical properties of the electrolyte having decayed the dye sensitizer. The main band (590 nm, $\varepsilon = 2.25\times10^3$ L/M · cm) of the BCB dye in the post-229th minute's illuminated spectra witnesses a hypsochromic and bathochromic shift with respect to the main band of the BCB dye in the pre-illuminated spectra. The shift of the main band in the post-illuminated spectra may be explained by the photodecay of the BCB dye, which in turn decreases the dye concentration.

Exploratory insight into the likely products of the photodegradation of the BCB dye in the electrolyte of the PG cell. The photodecay of the BCB dye in the alkaline medium may be attributed to the irradiation-induced degradation of the BCB dye molecules through the destruction of the aromatic ring via the organic intermediates into lower molecular weight organic fragments. The authors estimate that there is no complete degradation of the BCB dye molecule via mineralization as indicated by the presence of the peaks in the UV-visible region indicating the presence of the organic moiety in the post-degradation electrolyte [23]. The photocatalytic breakdown of the BCB dye is estimated to obey the pseudo-first-order reaction kinetics [24].

The photodegraded amount of the BCB dye may be approximately estimated by considering the absorbance 1.21 of the band at 630 nm (main band) in the pre-illuminated spectra and the absorbance $A = 0.441$ of the band at 630 nm in the post-69-min spectra. About 63.55% of the BCB dye in the electrolyte is estimated to have photodegraded at a rate ($-dA/dt$) of 0.0111 min^{-1} in 69 min. About 68.01% of the BCB dye in the electrolyte is estimated to have photodegraded at a rate ($-dA/dt$) of 0.000571 min^{-1} in 24 h. About 68% of the BCB dye in the electrolyte is estimated to have photodegraded at a rate ($-dA/dt$) of 0.00014 min^{-1} in 96 h. It is an interesting fact that most of the dye has degraded during the early period of 69 min. After that, the amount of the dye that has degraded has remained more or less the same during the next period of 96 h.

Exploratory insight into the photocurrent generated post-degradation of the BCB dye in the electrolyte of the PG cell. In this spectroscopic study, the sample solution (10 mL) is made of a mixture of 1 mL of 2.5 M NaOH (resultant pH 13.39), 1 mL of M/100 fructose (resultant concentration 1.0×10^{-3} M), 1 mL of M/10 SLS (resultant concentration 1.0×10^{-2} M), 1 mL of the M/500 BCB dye (resultant concentration 0.2×10^{-3} M), and 6 mL of singly distilled water. The same sample solution was used as an electrolyte to fabricate the PG cell for harnessing the solar energy using the Pt electrode (0.3×0.2 cm) as the working electrode and the saturated calomel electrode terminal of the combination electrode as the counter electrode.

The observed photocurrent was 120 μA after the first illumination for 69 min with a 200 W incandescent bulb. The observed photocurrent was again 80 μA from the ~24-h-old electrolyte (24 h includes the 69-min illumination with a 200-W bulb plus ~62 min taken in the post-illumination UV-vis study plus the rest time for which the electrolyte was left unattended and un-illuminated). The observed photocurrent was again 90 μA from the ~96-h-old electrolyte (~96 h includes two illuminations, the first illumination for 69 min and the second illumination for 60 min), for the rest of the time the electrolyte was left unattended and un-illuminated. The observed fact indicates that the BCB dye in the electrolyte of the PG cell undergoes photodegradation, but despite this degradation, the PG cell, having the photodegraded BCB dye-based electrolyte, also generates almost the same current as that generated by the electrolyte initially. The cell, as in this case having 68% of the Rhodamine B dye degraded during the early period of 96 h, is capable of producing the same level of current. The current generation from the degraded electrolyte can be explained on the basis of the fact that the PG cells use only very dilute concentrations of the dye. In the present spectroscopic study, the initial concentration of the BCB dye is 0.2×10^{-3} M. Therefore, even after ~68% of the BCB dye degradation during the early period of 96 h, the left-out BCB dye is 32% of the initial value, and the left-out concentration of the BCB dye after 96 h is $\sim0.064\times10^{-3}$ M. Therefore, the cell is capable of giving a current even with the left-out concentration ($\sim0.064\times10^{-3}$ M) of the BCB dye. Further, the photodegradation products of the BCB dye and SLS are also potential candidates for current generation. Thus, it can be concluded that even after photodegradation of the sensitizer in the electrolyte, the PG cells are potential candidates for the generation of solar electricity in the long term. Further, the observation of current generation from the electrolyte even after cutting off the illumination is indicative of the power storage capacity of the PG cell.

The stability of the PG cell's characteristics over a month can be estimated on the basis of the available spectral data (Fig. 1) and the electrical data. The spectral curves of the PG cell's photo-illuminated electrolyte after 1 h and 9 min, 24 h, and 96 h practically do not differ from each other in shape, absorbance, and wavelength maxima throughout the UV as well as the visible spectral region. This observation is indicative of the cells' chemical stability over the 96-h period, and the same may be estimated and extrapolated over a month's duration. Similarly, the electrical properties of the cell after 1 h and 9 min, 24 h, and 96 h of illumination practically do not differ from each other in magnitude. This observation is indicative of the cells' electrical stability over the 96-h period, and the same may be estimated and extrapolated to be over a month's duration.

Conclusions. In the present spectroscopic study of the long-term photostability of the Brilliant Cresyl Blue dye sensitizer fructose reductant SLS surfactant NaOH alkali electrolyte solution of the photogalvanic cells cell, the initial concentration of the Brilliant Cresyl Blue dye is 0.2×10^{-3} M. During the early period of 68 h, about 68% of the Brilliant Cresyl Blue dye degradation is observed. The cell is able to give a current even with the left-out concentration $\sim0.064\times10^{-3}$ M (i.e., 32% of the initial concentration). Further, the photodegradation products (organic intermediates, lower molecular weight organic fragments) of the Brilliant Cresyl Blue dye and SLS are also potential candidates for current generation. Thus, it can be concluded that even after the photodegradation of the Brilliant Cresyl Blue dye sensitizer in the electrolyte, Brilliant Cresyl Blue dye photogalvanic cells cells are potential candidates for the generation of solar electricity in the long term. Further, the observation of current generation from the electrolyte even after cutting off the illumination is indicative of the power storage capacity of the photogalvanic cells cell. The observed spectral data and electrical data are quite indicative of the stability of the photogalvanic cells cell's characteristics.

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