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Regioselective [2+2] photocycloaddition reaction of 2-(3,4-dimethoxystyryl)quinoxaline in solution

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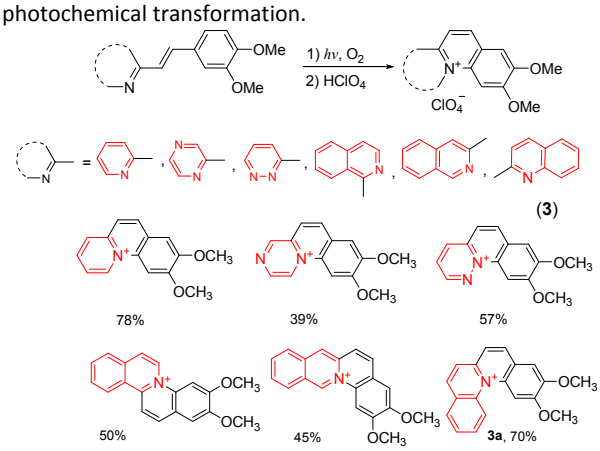
The [2+2] photocycloaddition between two molecules of (*E*)-2-(3,4-dimethoxystyryl)-quinoxaline (**1**) in acetonitrile solution to form only one cyclobutane isomer out of eleven possible was described. The observed photocycloaddition reaction is reversible, thus, the studied photocycloaddition reaction could be considered as photoreversible photochromic process. The removing of two methoxy group in (*E*)-2-(3,4-dimethoxystyryl)quinoxaline (**1**) structure produces compound **2** which is able to participate in photoisomerization reaction only. The change of quinoxaline residue in **1** to quinoline one results in the compound (**3**) demonstrated the regioselective oxidized electrocyclic transformation through the formation of novel C-N bond.

Introduction

While the photochemistry of stilbenes and its derivatives has been well studied,[1] there have been relatively less reports on the photolysis of stilbene derivatives with nitrogen-bearing rings. Nonetheless, it has been found that hetarylphenylethenes (heterostilbenes) like stilbenes exhibit a diverse photochemical behavior in solution such as reversible *trans-cis* isomerization,[2-4] cyclization of *cis*-heterostilbene to dihydrophenanthrene derivarive and further oxidation to the phenanthrene heteroanalogue,[5-7] and dimerization of *trans*-heterostilbene to yield cyclobutane products.[8-10]

Recently we have demonstrated that *ortho*-styryl-substituted N-heterocycles comprising one and two nitrogen atoms generally undergo the regioselective C–N bond formation during photocyclization, resulting in formation of the family of (aza)benzo[c]quinolizinium derivatives.[11-13] The photocyclization reactions of styryl derivatives (Scheme 1) were carried out in air-saturated solutions in acetonitrile or water upon irradiation with unfiltered or filtered light of a high-pressure Hg vapor lamp. The observation showed that under photolysis conditions the compounds also demonstrated *trans-cis* isomerization, but did not undergo a [2+2] photocycloaddition reaction resulting in the formation of the intermolecular dimers.

At the same time, the study of the photolysis of (*E*)-2-(3,4-dimethoxystyryl)quinoxaline (compound **1** in Scheme 1) showed that photocyclization reaction has not been observed in this case. Compound **1** differs from compound **3** which effectively participates in photoelectrocyclic transformation by presence of additional N-atom in heterocyclic part (Scheme 1). This small structural change causes the remarkable difference in photochemical behavior. In this paper we present the results of the investigation of the photochemical behavior of quinoxaline derivatives **1** and **2** aimed to understand the influence of the heterostilbene structure on its photochemical transformation.



Scheme 1 Photocyclization reaction of the series of hetarylphenylethenes and structures of the compounds **1** and **2** studied in the present paper.

Results and discussion

Synthesis of the compounds 1 and 2

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Synthesis of the compound **1** has been described earlier in [14]. Compound **2** has been prepared by using the similar method (see Experimental part).

Optical properties

The absorbance and fluorescence of both studied compounds **1** and **2** were measured. The absorption shift in acetonitrile caused by the presence of MeO substitutions can be seen in Fig. 1. The λ_{max} varies from 365 nm to 380 nm when going from **2** to **1**. Optical properties of the dyes are presented in Table 1. The stilbenes **1** and **2** show intensive fluorescence (Figs. S1, S2 in ESI). Fluorescence quantum yields of the compounds are 50% and 30% accordingly. Compound **1** demonstrates the large Stock's shift (128 nm), dye **2** in opposite has got closed position of absorption and fluorescence spectra.

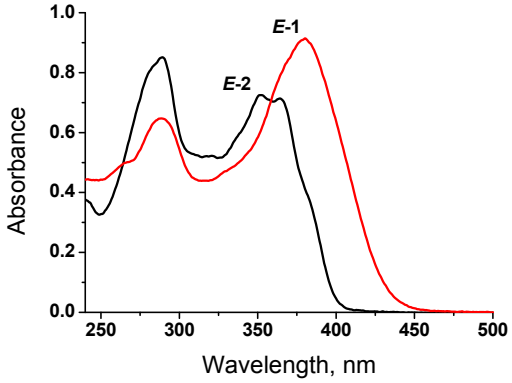


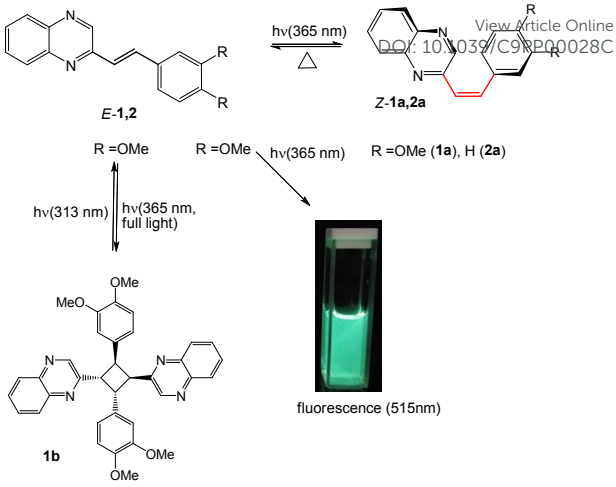
Fig. 1 Absorption spectra of ***E*-1** and ***E*-2**, MeCN, 20°C, $C_{E-1} = C_{E-2} = 4 \cdot 10^{-5}$ M.

Table 1 Optical and photochemical characteristics of compounds 1 and 2, MeCN, 20°C

Compound	λ^{abs}_{max}	λ^{fl}_{max} (Φ), λ^{ex}=365nm	$\phi_{(E-Z)} / \phi_{(Z-E)}$	$\Phi^{365}_{styryl-cyclobutane} / \Phi^{313}_{cyclobutane-styryl}$
1	380	508(0.5)	0.1/0.45	0.03/ 0.013
2	365	423 (0.3)	0.26/0.33	-

Photochemical study of the compounds 1 and 2

Irradiation of the acetonitrile solutions of stilbene derivatives **1** and **2** with filtered light (λ = 365 nm, 405nm or 313nm) of high pressure mercury lamp resulted in the decrease of the absorption intensities along with a slight blue shift of the absorption maxima that is indicative for the formation of photostationary mixtures of *E*- and *Z*-isomers of **1** and **2** (Scheme 2, Figures S3 and S4, ESI). More effective formation of Z-isomer has been found upon irradiation by 365 nm light. For compound **2**, the NMR observation indicates that photostationary mixture contains *E*-isomer with coupling constant of C=C double bond equal ^3J = 16.53 Hz and *Z*-isomers whose coupling constant of C=C double bond is ^3J = 12.08 Hz (Figs. S5,S6 in ESI). In case of dye **1** even short irradiation with light at 365nm shows the formation of two photoproducts, namely *Z*-isomer **1a** and cyclobutane **1b** (Scheme 2, Figs. S7, S8 in ESI). The isolation of *Z*-isomer was done by using HPLC (Fig. 2) what allows the obtaining of the absorption spectrum of pure *Z*-**1a** isomer (Fig. 3). The quantum yields of photoisomerization reactions were determined by analyzing the kinetics of changes in the absorption of solutions of dyes **1** and **2** upon irradiation with 365 nm light (see Experimental part), their magnitudes are listed in Table 1.



Scheme 2 Photochemical transformations of compounds **1** and **2**

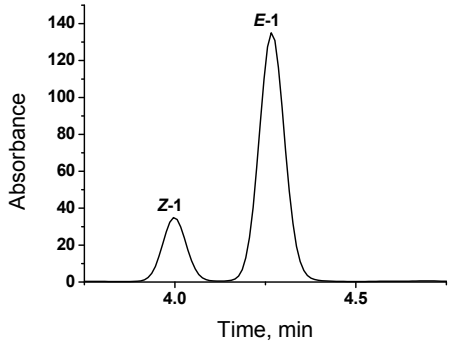


Fig. 2 HPLC of **1** solution after irradiation with light 365 nm, separation on HPLC, isolated ***E*-1** and ***Z*-1a**; acetonitrile: water, 85:15

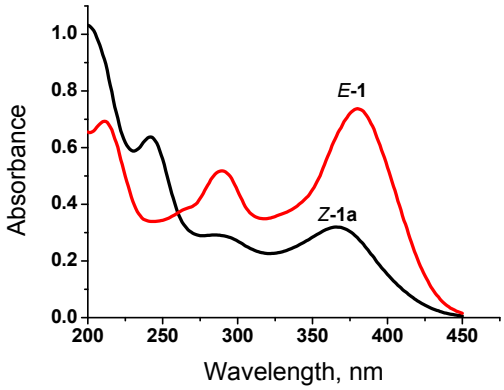


Fig. 3 Absorption spectra of ***E*-1** and ***Z*-1a**, obtained by HPLC, MeCN, 20°C, $C_1 = 4 \cdot 10^{-5}$ M

More prolonged photolysis of *E*-**1** under the unfiltered light or light at 365nm led to more pronounced and more complicated spectral changes. At first, a fast decrease of the absorption intensities of the long wavelength absorption bands and a slight blue shift of the absorption maxima were observed as it was found for *E*-*Z*-photoisomerization (Fig. 4). In case of *E*-**2** the irradiation by unfiltered light causes only *E*-*Z*-photoisomerization, no other photoprocesses were found (Fig.

S5 in ESI). Prolonged irradiation of *E*-**1** resulted in substantial decrease of the long wavelength absorption band in the spectral region at 380 nm indicating destruction of the conjugated chromophoric system (Fig. 4). At the same time, new significantly blue-shifted band appeared at 320 nm that is the characteristic absorption region of non-conjugated aromatic and heteroaromatic fragments (Fig. 4). The photolyt was analyzed by HPLC and it was shown that the process was completed in 7 min (Fig. S10 in ESI). To explain this observation, we assumed that *E*-**1** undergoes the [2+2] photocycloaddition reaction of the ethylene double bonds resulting in the formation of cyclobutane derivatives **1b**, in which conjugation between aromatic rings is disrupted by the cyclobutane ring closure (Scheme 2). The photolysis product was purified by HPLC, its absorption spectrum is presented in Fig. S11 in ESI, NMR spectrum in Fig. 6b in comparison with those of initial *E*-**1** (Fig. 6a). The quantum yield of direct cycloaddition reaction was determined upon irradiation of solution containing 10^{-3}M of *E*-**1** by 365nm light. The cycloreversion proceeds at irradiation with 313nm light. Kinetic studies allowed us to determine the value of the quantum yield of reverse photocycloaddition reactions (Table 1). The kinetic curve of reversible reaction is shown in Fig. 5. HPLC confirming that the main products formed during photolysis of **1b** are *E*-**1** and *Z*-**1a** is presented in Fig. S12 in ESI.

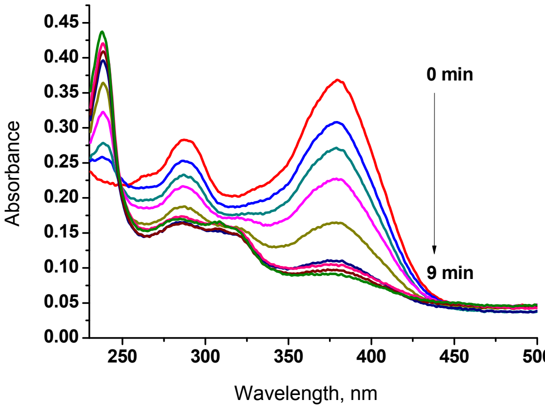


Fig. 4 Spectral changes during photolysis of ***E*-1** in acetonitrile under irradiation with 365nm light during 9 min, $C_1 = 4\cdot10^{-5}$ M

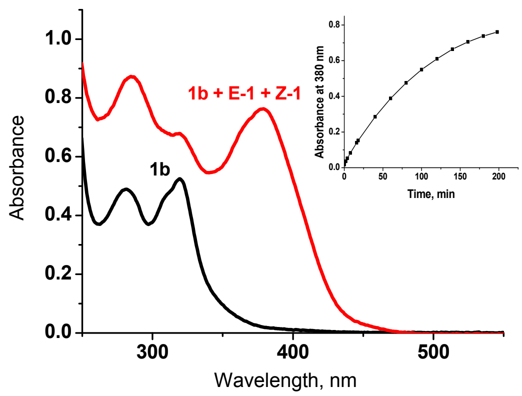


Fig. 5 Spectra of **1b** and photostationary mixture (**1b+*E*-1+*Z*-1a**) formed after photolysis of **1b** during 200 min; inserted picture shows spectral changes during photolysis of **1b** in acetonitrile at λ=313 nm, $C_1 = 4*10^{-5}$ M

According to the NMR observation, the main photochemical process was the formation of the only one cyclobutane derivative **1b**, as revealed by the presence of two doublets in a characteristic region of the cyclobutane ring protons (5.0-5.3 ppm) (^{13}C, COSY spectra of **1b** are presented in ESI, Figs. S13 and S14). Only side process detected was the *E-Z*-isomerization of the initial compounds that is in agreement with the steady-state optical spectroscopy data (Fig. 6).

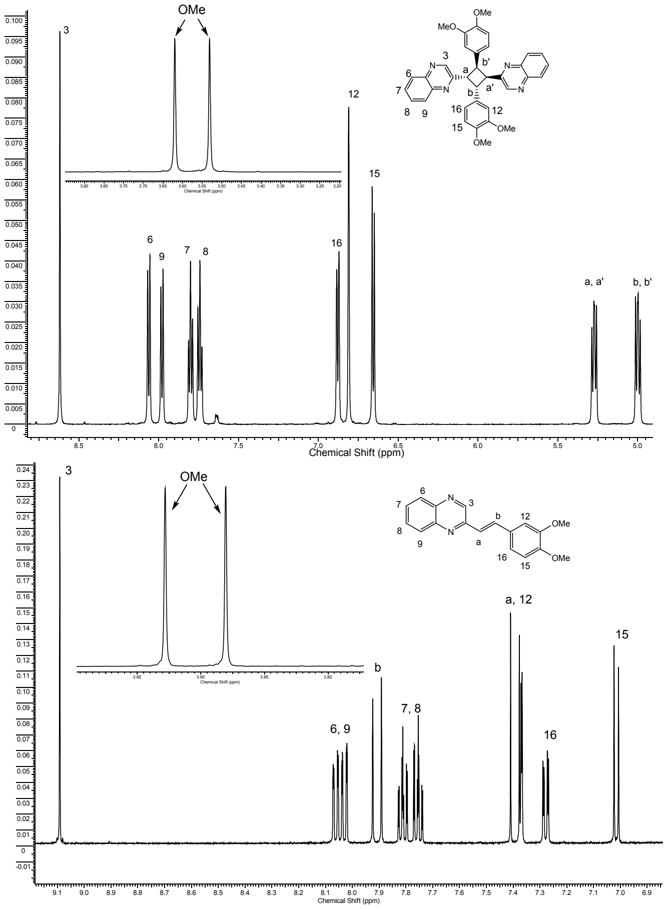


Fig. 6 1H NMR of ***E*-1** (a) and cyclobutane **1b** (b) in CD3CN, Bruker, 400MHz

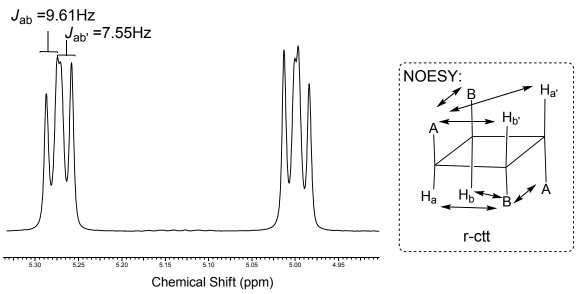


Fig. 7 ^{1}H NMR spectra (aliphatic part) of cyclobutane **1b** in CD_3CN, Bruker, 600MHz (a) and interactions of nucleus observed in NOESY spectrum are shown in the square

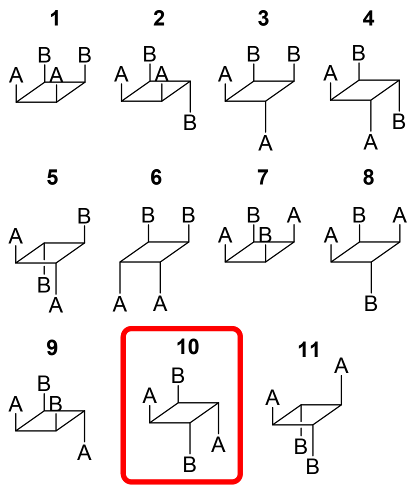
The relative positions of the protons in the cyclobutane structure can be identified with the aid of the two-dimensional NMR NOESY spectroscopy, in which the cross-peaks in 2D spectra depends on the distance between the corresponding nuclei (Fig. 7 and Fig. S15 in ESI).[15] In the obtained structure cyclobutane isomer has strong through-space interactions between protons H-12, H-15 and H-3 with protons of cyclobutane what means that these

protons are close to each other, as they are located on the same side of the cyclobutane ring (Fig. 7). Moreover, the signals for the protons of the cyclobutane fragment of the resulting photoadduct appear as a symmetric AA'BB' spin system with the vicinal coupling constants $^3J_{ab}$ = $^3J_{a'b'}$ = 9.61 and $^3J_{ab'}$ = $^3J_{a'b}$ = 7.55 Hz (Fig. 7). It is also indicative of a transoid geometry of H_a and H_b protons in **1b**.[16] Thus, we can conclude about formation of *r-ctt* cyclobutane dimer (Scheme 3). Similar structure of cyclobutane derivative with head-to-tail arrangement of heterocyclic and phenyl fragments formed upon photolysis of crown-ether styryl dye was found to demonstrate closed values of vicinal coupling constants.[17]

For a better understanding of the remarkable regioselectivity of the studied reaction, quantum chemical calculations were carried out. Thus, geometry optimization (PM6, MOPAC) of cyclobutane and electrocyclic poducts showed that electrocyclic product is 55 kJ/mol less stable in comparison with cyclobutane which completely matches with the experimental regioselectivity of this reaction (see Fig. S17 in ESI).

Intermolecular PCA reactions in solution are usually inefficient, due to short excited state lifetimes, and afford mixtures of cyclobutane isomers.[18] For the hetarylphenylethene derivaives it has been demonstrated that the regioselectivity and stereospecificity of [2+2] photocycloaddition can be controlled in solution and in solid state in the different ways.[19] Thus, the [2+2] photocycloaddition of the crown-derivatized styrylheterocycles takes place only in their supramolecular dimeric complexes, in which a favorable arrangement of the reactive C=C double bonds is provided.[20] A catalytic amount of HCl plays a key role in enhancing the [2+2] photocyclization reactions between (*Z*)- and (*E*)-4-styrylpyridines to give *r-cct* and *r-ctc* cyclobutane dimers through a cation–π interaction.[21] Similar approach has been applied for dimerization of (*E*)-styrylthiazoles.[8] The combination of HCl and cucurbituril template was used to decrease the amount of cyclobutane products in photocyclization of styrylpyridine derivatives.[22] Another templates for photocycloaddition reaction have been described in[23]. Chemists from Japan explored the viability of a new method for the synthesis of silicon-containing macrocyclic compounds, which utilizes intramolecular photocycloaddition reactions of substrates containing styrene and stilbene reaction centers tethered by bis (dimethylsilylmethyl)benzene chains.[24] The [2+2] cycloaddition-cycloreversion has been realized in solid state[25], for instance, by using of 1-(*N*,*N*-dimethyl-4-benzenamino)-2-(2-benzoxazolyl)ethane.[26] Also in solid state the quantitative [2+2] photocycloaddition of crystalline *trans*-2,4-dichloro-6-styrylpyrimidine to produce the corresponding *r-ctt* cyclobutane dimer has been described in [27]. In two last cases photocycloaddition produces selectively the regio- and stereoisomer of cyclobutane dictated by the molecular packing of the alkenes in the crystal. At the same time, authors mentioned that in solution, styrylpyridines, both as free bases and as various pyridinium salts, produce low yields of mixture dimers upon irradiation.

Earlier it was shown that the irradiation of hetarylphenylethenes containing two substituents in 3rd and 4th positions of aromatic ring can lead to the formation of 11 possible isomers of cyclobutanes.[20,28] The similar situation is possible in our case (Scheme 3). But the photolysis experiments demonstrated the formation of only one cyclobutane isomer out of eleven possible. This fact points on the stereospecific formation of cyclobutane derivative. To explain this fact, we can propose the head-to tail dimer organization of 2-styrylquinoxaline **1** in solution by dipole interaction between the donor phenyl ring with methoxy groups of one molecule with acceptor quinoxaline residue of the other one. Such structure could play important role in the proper arrangement of molecules in dimer assembly allowing the occurrence of photocycloaddition reaction. Aimed to find the dimerization in solution we analyzed the influence of molecular concentration on fluorescence spectra. In case of the formation of styryl eximers, shoulder in long-wavelength region of fluorescence should be observed. Unfortunately, there were no remarkable changes in fluorescence spectra upon increasing of concentration of styryl **1** (Fig. S1 in ESI). Also no cross-peaks between aromatic and heteroaromatic parts of molecules in NOESY spectrum of **1** confirming the preorganization of **1** in dimers were found (Fig. S9 in ESI).



Scheme 3 Possible isomeric cyclobutane derivatives that can be formed from 1,2-disubstituted ethenes upon [2+2] cycloaddition; in a frame the isolated isomer is presented

The analysis of the photolysis showed that the observed photocycloaddition reaction depends on the concentration of *E*-**1** in acetonitrile solution. Thus, at concentration of *E*-**1** lower then 10^{-5}M the photocyloaddition did not observe after 13 min of irradiation, whereas, upon the irradiation of solution with concentration of *E*-**1** 10^{-3}M or higher, the photocycloaddition was fully completed in 7 min. The high concentration of ethylene components can provide easer their interaction or formation of dimers with appropriate to photocycloaddition mutual arrangement of stilbene molecules.

Photolysis reaction of *E*-**1** in the solid state did not produce any cyclobutane derivatives. While X-ray crystal structure of *E*-**1** has been obtained earlier (Fig. S16 in ESI)[14], the reason of the failed photodimerization in solid state is clear. According to well-known "topochemical postulate",[28] the double bonds of crystalline reactants must be parallel to each other, and the center-to-center distance of the reacting alkenes must be less than 4.2 Å apart. These two essential criteria have not been realized in crystal structure of *E*-**1** (Fig. S16 in ESI).

Experimental

Materials and methods

All reagents and solvents were obtained from commercial sources and used as received. For the spectroscopic (UV/Vis and fluorescence) studies, HPLC-grade MeCN and water from a Milli-Q ultrapure water system were used.

Physical measurements

^{1}H-NMR spectra were recorded in CD_3CN and CD_3COCD_3 on a Bruker 400, 500 or 600 MHz, and ^{13}C NMR spectra were recorded at 101 or 151 MHz at ambient temperature using 5 mm tubes. Chemical shifts were determined with accuracy of 0.01 and 0.1 ppm for ^{1}H and ^{13}C spectra, respectively, and are given relative to the residual signal of the solvent that was used as internal reference. Spin−spin coupling constants for the proton spectra were determined with accuracy of 0.1 Hz. The ^{1}H NMR signal assignments were performed using COSY and NOESY 2D NMR techniques. The ^{13}C NMR signal assignments were performed by means of HSQC and HMBC 2D NMR techniques.

The reaction course and purity of the final products was followed by TLC on silica gel (DC-Fertigfolien ALUGRAM Xtra SIL60 G/UV254, MACHEREY-NAGEL). TLC was performed on silica gel on DC-Fertigfolien, eluent: EtOAc, Hexane. Column chromatography was conducted over silica gel (Kieselgel, particle size 40-60 µm, 60 Å, Acros Organics) on a flash chromatograph Biotage Isolera Prime and HPLC UltiMate 3000.

Preparation and handling of the solutions were carried out under red light. Photochemical reactions were carried out with a high-pressure Hg vapor lamp (120 W) and an immersed Hg photoreactor (125 W) with a borosilicate glass filter.

Elemental analyses were carried out in the Microanalysis Laboratory of the A.N. Nesmeyanov Institute of Organoelement Compounds.

Melting points were measured on Melt-temp melting point electrothermal apparatus and were uncorrected.

Steady-state optical measurements

The absorption spectra were obtained on a fiber-optic AvaSpec-2048-USB2, Avantes BV spectrophotometer or Varian-Cary 300 spectrophotometer. Fluorescence spectra were measured on a FluoroLog-3-221 spectrofluorometer. Spectral measurements were carried out in air-saturated acetonitrile solutions (acetonitrile of spectrophotometric grade, water content 0.005%, Aldrich) at 20 ± 1 C°; the concentrations of the studied compounds were about from $4.0{\cdot}10^{-6}$ M to $1{\cdot}10^{-3}$ M. All measured fluorescence spectra were corrected for the nonuniformity of detector spectral sensitivity. Coumarin 481 in ethanol (ϕ_{fl} = 0.78) was used as a reference for the fluorescence quantum yield measurements. The fluorescence quantum yields were calculated by eqn (1),

$$\varphi^{fl} = \varphi_R^{fl} \frac{S \cdot \left(1 - 10^{-A_R}\right) \cdot n^2}{S_R \cdot \left(1 - 10^{-A}\right) \cdot n_R^2} \quad , \qquad (1)$$

wherein ϕ^{fl} and $\phi^{fl}{}_R$ are the fluorescence quantum yields of the studied solution and the standard compound, respectively; A and A_R are the absorption of the studied solution and the standard respectively; S and S_R are the areas underneath the curves of the fluorescence spectra of the studied solution and the standard respectively; and n and n_R are the refraction indices of the solvents for the substance under study and the standard compound. The quantum yields were calculated using corrected fluorescence spectra.

The light intensity was measured by a Nova P/N 7Z01500 power meter equipped with 3A-FS P/N 7Z02628 thermal power/energy measurement sensor. The photochemical transformations were induced by irradiation of acetonitrile solutions of compounds **1** and **2** with a high pressure mercury lamp (DRK-120, 120 W). Particular lines of the mercury lamp spectrum with λ = 313, 365 and 405 nm were isolated by glass filters from the standard set of color optical glasses. The photoprocesses were studied in a 10 mm quartz cell with stirring or in a 1 mm and 0.1 mm quartz cells without stirring. The radiation intensities were 4.66 10^{-6} Einstein s^{-1} L^{-1} for λ = 365 nm and 9.38 10^{-7} Einstein s^{-1} L^{-1} for λ = 313 nm. For calculation of the spectra of the *Z*-isomers of dyes **1** and **2** by Fischer's method the solutions were irradiated at λ = 313, 365 and 405 nm until the photostationary states were attained.[29]

To determine the quantum yields of the forward and backward reactions of E—Z photoisomerization of dyes **1** and **2** the kinetics of changes in the absorption of $4.0{\cdot}10^{-5}$ M solutions of dyes upon irradiation with 365 nm light were analyzed. For this purpose, the program Sa3.3 (Simulation–adjustment) allowing the numerical simulation of the concentration of the various species versus time and the optimization of the parameter values until a good fit is obtained was used[36,37]. The absorption spectra of the corresponding Z-isomers were preliminarily obtained using the Fisher's method. The quantum yield of the forward photocycloaddition reaction of dye **1** was determined by analyzing the kinetics of spectral changes upon irradiation of $1.0{\cdot}10^{-3}$ M solution of dye **1** with 365 nm light. The quantum yield of the backward photocycloaddition reaction was determined by analyzing the kinetics of spectral changes upon irradiation of $1.0{\cdot}10^{-5}$ M solution of cyclobutane **1b** with 313 nm light. In both cases, during the fitting procedure using the program Sa3.3, the quantum yields of the forward and backward reaction of E—Z photoisomerization of dye **1** were fixed as known.

Synthesis of compounds

Synthesis of (*E*)-2-(3,4-dimethoxystyryl)quinoxaline (**1**) has beens described in[14].

Synthesis of 2,2'-((1R,2R,3S,4S)-2,4-bis(3,4-dimethoxyphenyl)cyclobutane-1,3-diyl)diquinoxaline (**1b**). Solution of **1** in acetonitrile (10^{-3}M) was irradiated with unfiltered light of high pressure mercury lamp for 4 minutes. The product was isolated by HPLC, eluent: H_2O:CH_3CN, 35:65, m.p. 79-81°C, ^{1}H NMR (MeCN-d_3, 500.13 MHz, 25 °C) d: 3.53 (s, 6H, OCH3), 3.62 (s, 6H, OCH3), 4.99 (m, 2H, H-a, H-d), 5.28 (m, 2H, H-b, H-c), 6.65-6.67 (d, 2H, H-15, H-15', ^{4}J = 8.0), 6.81 (s, 2H, H-12, H-12'), 6.87-6.89 (d, 2H, H-16, H-16', ^{3}J = 8.0), 7.74 (m, 2H, H-7, H-7'), 7.80 (m, 2H, H-7, H-7'), 7.97-7.99 (d, 2H, H-6, H-6', ^{3}J = 8.0), 8.05-8.07 (d, 2H, H-9, H-9', ^{3}J = 8.0), 8.62 (s, 2H, H-3, H-3'); ^{13}C NMR (MeCN-d3, 500.13 MHz, 25 °C) δ: 43.8 (2C, C-a, C-d), 46.9 (2C, C-b, C-c), 55.1 (4C, OCH3), 111.1 (2C, C-15, C-15'), 112.0 (2C, C-12, C-12'), 120.3 (2C, C-16, C-16'), 128.8 (2C, C-9, C-9'), 129.1 (2C, C-6, C-6'), 129.3 (2C, C-7, C-7'), 129.9 (2C, C-8, C-8'), 132.4 (2C, C-2, C-2'), 140.8 (2C, C-10, C-10'), 141.8 (2C, C-5, C-5'), 146.7 (2C, C-3, C-3'), 147.6 (2C, C-13, C-13'), 148.6 (2C, C-14, C-14'), 156.2 (2C, C-11, C-11'). Elemental analysis: calculated (%) for $C_{36}H_{32}N_4O_4$ (MW 568.44): C, 73.20; H, 5.63; N, 9.30; found C, 73.95; H, 5.52; N, 9.58.

Synthesis of (*E*)-2-styrylquinoxaline (**2**). A solution of 2.8 mmol of 2-methylquinoxaline, 2.10 mmol of benzaldehyde, 1.03 mmol of piperidine, and 1.50 mmol of acetic acid in toluene was kept in an inert atmosphere at 115°C for 48 h, and then the reaction mixture was evaporated in a vacuum. The residue was purified with column chromatography (SiO_2, eluent hexane–ethyl acetate, 2:1). The product was recrystallized from methanol to yield 0.10 g (20%), m.p. 102-105°C, lit. 106-107.5ºC.[30] ^{1}H NMR (acetone-d_6, 400.13 MHz, 25 °C): 7.39 (t, 1H, H-4`), 7.47 (t, 2H, H-3`, H-5`), 7.55-7.59 (d, 1H, H-a, J=16.0), 7.78 (t, 1H, H-8), 7.78-7.80 (d, 2H, H-2`, H-6`, J=8.0), 7.84 (t, 1H, H-7), 8.03-8.05 (d, 1H, H-6, J=8.0), 8.04-8.08 (d, 1H, H-b, J=16.0), 8.05-8.07 (d, 1H, H-9, J=8.0), 9.19 (s, 1H, H-3); ^{13}C NMR (acetone-d_6, 400.13 MHz, 25 °C) δ: 125.4 (C-a), 127.4 (3C, C-

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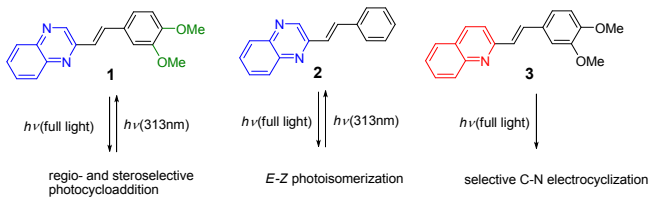
2', C-6', C-8), 127.9 (C-10), 128.9 (2C, C-3', C-5'), 129.1 (C-4'), 129.2 (2C, C-6, C-9), 130.2 (C-7'), 136.1 (C-b), 136.3 (C-1'), 145.1 (C-3), 150.8 (2C, C-2, C-5). Elemental analysis: calculated (%) for $C_{16}H_{12}N_2$ (MW 232.29): C, 82.73; H, 5.21; N, 12.06; found C, 82.85; H, 5.30; N, 12.03.

Conclusions

Here, we reported the [2 + 2] photocycloaddition between two molecules of (*E*)-2-(3,4-dimethoxystyryl)quinoxaline (**1**) to form the associated *r-ctt* cyclobutane dimer which was isolated and identified. The observed photocycloaddition reaction is reversible. The direct photodimerization occurs upon irradiation with 365nm light, the reversible phototransformation into the initial styryl derivative proceeds upon the irradiation with 313 nm light. From our knowledge the described reaction of the photolysis of *E*-**1** is the first example of the regioselective and stereospecific formation of cyclobutane derivative without applying of any methods of preorganization of molecules in dilute solution (metal ions, linker for binding of two styryl derivatives, crystal or molecular container preorganization).

The analysis of the photochemistry of compounds **1**-**3** (Scheme 3) showed the effect of structural changes on the way of phototransformation. Thus, removing of two methoxy group in (*E*)-2-(3,4-dimethoxystyryl)quinoxaline (**1**) structure produces compound **2** which is able to participate in photoisomerization reaction only. The change of quixoline residue in **1** to quinoline one results in the compound **3** demonstrated the regioselective oxidized electocyclic transformation through the formation of novel C-N bond.



Scheme 3 The illustration of dependence of photochemical way of transformation on heterostilbene structure.

The observed photocycloaddition reaction of *E*-**1** could be considered as photoreversible photochromic process.[31] Also it provides the easy way for obtaining of cyclobutane derivative. Cyclobutanes are important synthetic intermediates providing atom-economic one-step transitions from simple to complex structures that is especially important in the total synthesis of natural products and other intricate molecules.[32,33] The majority of naturally occurring cyclobutane derivatives demonstrates remarkable biological activity making them promising lead structures for the creation of novel anticancer, antibacterial and fungicidal drugs.[34, 35]

Conflicts of interest

There are no conflicts to declare.

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Regioselective [2+2] photocycloaddition reaction of 2-(3,4-dimethoxystyryl)quinoxaline in solution

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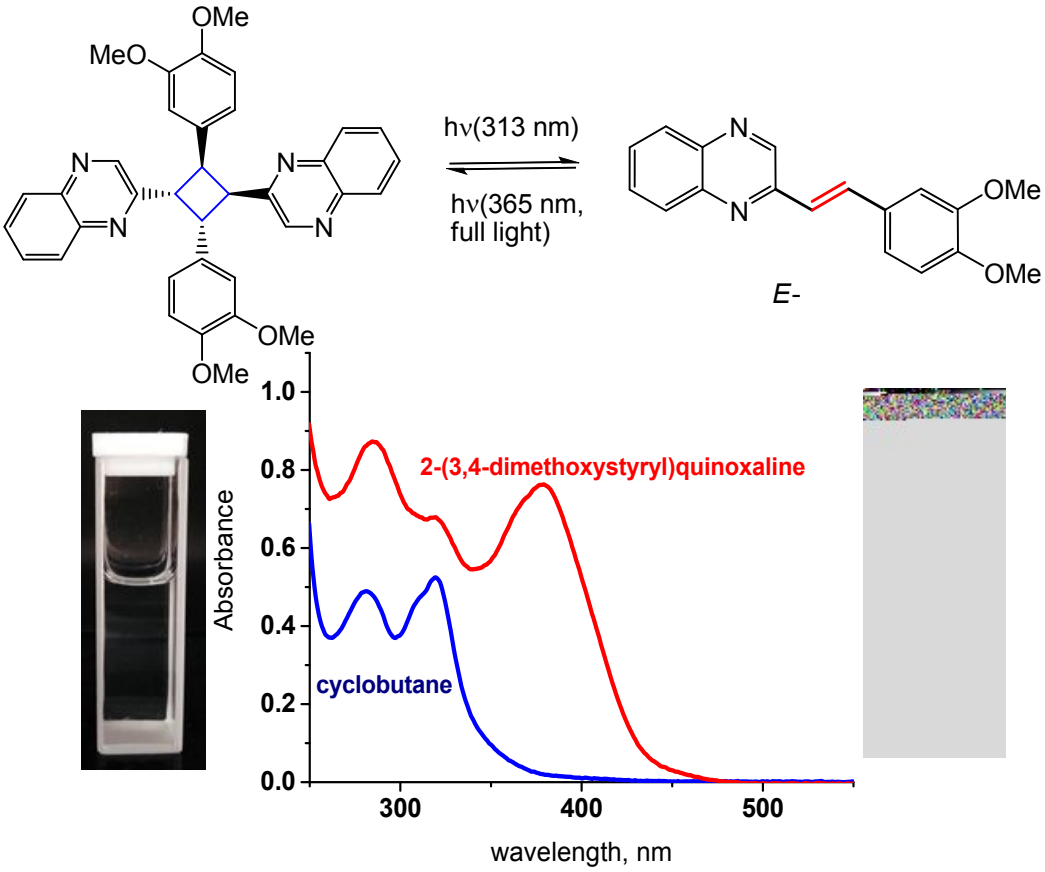

The [2+2] photocycloaddition between two molecules of (*E*)-2-(3,4-dimethoxystyryl)-quinoxaline (**1**) in acetonitrile solution is the first example of the regioselective and stereospecific formation of cyclobutane derivative without applying of any methods of preorganization of molecules in dilute solution.