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PHOTO- AND THERMOCHROMIC SPIRANS 40*. SPIROPYRANS BASED ON 5-BENZOXAZOLYL-4-HYDROXYISOPHTHALIC ALDEHYDE

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Formylation of 2-(2-hydroxyphenyl)benzoxazole gave 5-benzoxazolyl-substituted 4-hydroxyisophthalic aldehyde, which served as a precursor to the synthesis of novel photochromic spiro[indoline-benzopyrans] containing a benzoxazole group at position 8 of the benzopyran moiety. The obtained compounds possess photochromic properties in solution.

Keywords: benzoxazole, hydroxyisophthalic aldehyde, merocyanines, spiropyrans, photochromism.

The synthesis and investigation of novel photochromic compounds for applications in polyfunctional molecular electronics materials and chemical sensors is a high priority task of modern chemical research [2-5].

Spiropyrans are a well-known type of photochromic compounds that offer the possibility of tuning the spectral-kinetic properties over a relatively broad range, depending on the molecular structure [4-8]. A wide variety of polyfunctional photochromic molecular systems can be prepared by decorating spiropyrans with suitable functional fragments, exhibiting optically switchable magnetic [9], fluorescent [10-14], and complexing [12, 15-18] properties.

The search for novel photochromic organic compounds with functional groups that effectively coordinate with metal ions is a task of high priority for the development of various fields in molecular electronics, chemical sensors, and environmental monitoring [2, 3, 6, 19].

Azolyl-substituted spiropyrans having luminescent properties in the spirocyclic form are an example of a photochromic system that can effectively chelate transition metal ions. Many publications have been devoted to the synthesis, as well as the spectral, photochromic, and complexing properties of azolyl-substituted spirooxazines [20-23] and spiropyrans [24-26] with bivalent heavy metal ions.

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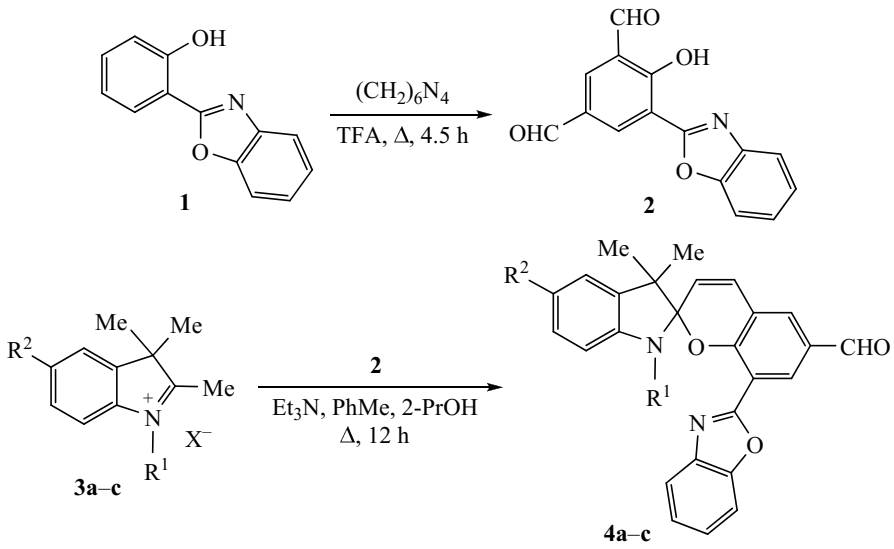
We continued the research towards the synthesis of photochromic spiropyrans as potential chemosensors for heavy metal cations by using 5-benzoxazolyl-4-hydroxyisophthalic aldehyde to prepare indoline spiropyrans containing 6-formyl group and 1,3-benzoxazole substituent at position 8 of the benzopyran system. The presence of a formyl group in the prepared spiropyrans offered possibilities for further structural modifications of these compounds.

The 8-benzoxazolyl-6-formyl-substituted spirobenzopyrans **4a-c** were obtained by reacting the 3*H*-indolium salts **3a-c** with the 5-benzoxazolyl-substituted 4-hydroxyisophthalic aldehyde **2** in the presence of triethylamine as a base. The synthesis of the hydroxyisophthalic aldehyde **2** by the Duff reaction in a toluene–acetic acid mixture has been described previously [27]. We have also obtained the aldehyde **2** by formylation of the hydroxyphenylbenzoxazole **1** by the Duff reaction using trifluoroacetic acid.



a $R^1 = CH_2Ph$, $R^2 = H$; **b** $R^1 = Me$, $R^2 = Br$; **c** $R^1 = Me$, $R^2 = Cl$; **3 a**,**b** X = I, **c** $X = ClO_4$

The structure of the obtained compounds **4a-c** was established by ^1H NMR spectroscopy and confirmed by elemental analysis. The ^1H NMR spectra of the spiropyrans **4a-c** contained two nonequivalent geminal methyl group signals, as well as upfield proton signals of the *N*-alkyl substituents in the indoline fragment and several groups of coupled proton signals in the downfield region, due to the indoline, pyran, and benzoxazole fragments. The prochiral nature of methylene protons in the *N*-benzyl substituent of the spiropyran **4a** resulted in a diastereotopic splitting of proton signals into two doublets at 4.17 and 4.52 ppm.

All these ^1H NMR data unequivocally confirmed the structures of the obtained spiropyrans. The lack of indoline and benzopyran signals in the spectral regions characteristic of the open merocyanine form **MC** [28-31] indicated that the obtained compounds existed in the spirocyclic form **SP** in $CDCl_3$ solutions.

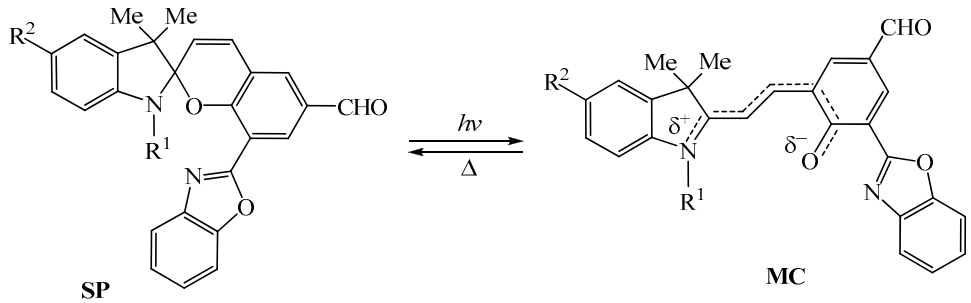


TABLE 1. The Spectral-kinetic Properties of the Spiropyrans **4a-c** in toluene*

Compound	λ_{max}^{abs}(**SP**), nm (ε, l·mol^{-1}·cm^{-1})	λ_{max}^{abs}(**MC**), nm	τ_{293}, s	E_a, kJ·mol^{-1}
4a	329 (8880), 340 (7650), 358 (5300)	627	15.4	63.8
4b	338 (9500), 357 (4740)	630	16.4	62.9
4c	339 (6820), 357 (4360)	629	15.8	63.4

*τ_{293} – the lifetime of the colored form at 293 K, E_a – the activation energy of the reverse thermal recyclization reaction.

The spirocyclic forms of the compounds **4a-c** have absorption spectra in toluene that feature two weak, diffuse bands without pronounced maxima, located at 339 and 357 nm with the molar extinction coefficients equal to 6820-9500 and 4360-5300 l·mol^{-1}·cm^{-1}, respectively (Table 1). The substituents in the indoline system had no effect on the absorption intensity, but caused a slight bathochromic shift of the longer wavelength side of the absorption band. In contract to the benzoxazolyl-substituted spironaphthopyrans [32], our investigated spirobenzopyrans had no luminescent properties in the spirocyclic form.

The colorless spiropyran solutions became colored upon UV irradiation at 365 nm wavelength and 293 K temperature due to a photochemical opening of the pyran ring and the formation of merocyanine type structures (Fig. 1). This was manifested as absorbtion bands in the solution phase spectra at 500-700 nm, with the maxima at 627-630 nm, which are known to be characteristic of merocyanines [2]. Substitution at position 5 of the indoline moiety caused a slight shift of the merocyanine absorption maximum to the longer wavelengths, compared to the unsubstituted analog (Table 1). The color of the solutions spontaneously faded after the irradiation was discontinued, because of the reverse thermal recyclization of the merocyanine species to the initial spirocyclic form. The kinetic data of thermal recyclization were satisfactorily described by a monoexponential function, which indicated a monomolecular character of the process.

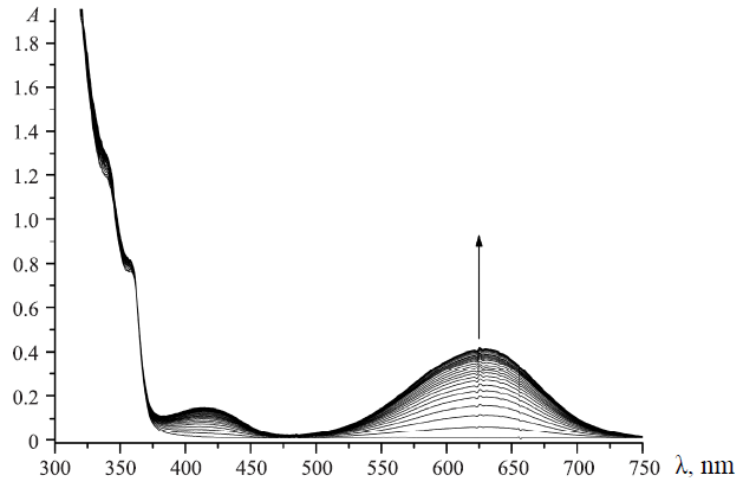


Fig. 1. The coloration of spiropyran **4c** solution upon irradiation with light at λ=365 nm, the solvent was toluene, *T* 293 K.

The calculated half-lives of merocyanine isomers are presented in the Table 1. The temperature dependence of rate constants was investigated in order to establish the activation parameters of the thermal recyclization reaction. For the examined compounds **4a-c**, the temperature dependence of the thermal fading rate constant k_{MC-SP} followed the Arrhenius equation, which enabled to assess the activation energy for this reaction as equal to 62.9-63.8 kJ·mol^{-1}.

Thus, we have obtained novel compounds that exhibit photochromic properties in solutions, spiro[benzopyranindolines] having a formyl group at position 6 and 1,3-benzoxazole substituent at position 8 of the benzopyran fragment.

EXPERIMENTAL

The electronic absorption spectra and the kinetic curves from the thermal recyclization reactions of the investigated compounds were recorded with an Agilent 8453 spectrophotometer equipped with a sample thermostat. The photolysis of the solutions ($2 \cdot 10^{-4}$ M) was performed with a Newport system based on a 200 W mercury lamp and a set of interference filters. ^{1}H NMR spectra were acquired on a Varian Unity 300 spectrometer (300 MHz) in $CDCl_3$, with residual solvent protons as internal standard (7.24 ppm). Elemental analysis was performed with a KOVO CHN analyzer. Melting points were determined on a Boetius hot stage. The solutions were prepared with spectral grade toluene (Sigma–Aldrich). The benzoxazole **1** was purchased from Sigma–Aldrich, and compounds **3a-c** were obtained according to previously described methods [32, 33].

5-(1,3-Benzoxazol-2-yl)-4-hydroxyisophthalic Aldehyde (2). A mixture of the phenol **1** (2.10 g, 10 mmol), hexamethylenetetramine (8.40 g, 60 mmol), and CF_3COOH (30 ml) was refluxed under inert atmosphere for 4.5 h, cooled, treated with a mixture of conc. HCl (14 ml) and H_2O (28 ml), then poured into water (130 ml). The precipitate was filtered off, washed with water, dried, and recrystallized from a 1:1 mixture of 2-PrOH and toluene. Yield 1.15 g (43%). Yellow crystals. Mp 214-216°C. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 7.42-7.51 (2H, m, H-5,6 oxazole); 7.66-7.70 (1H, m, H-7 oxazole); 7.77-7.81 (1H, m, H-4 oxazole); 8.48 (1H, d, *J* = 2.2, H-6); 8.82 (1H, d, *J* = 2.2, H-2); 10.01 (1H, s, 1-CHO); 10.63 (1H, s, 3-CHO); 13.05 (1H, s, OH). Found, %: C 67.53; H 3.31; N 5.18. $C_{15}H_9NO_4$. Calculated, %: C 67.42; H 3.39; N 5.24.

8-(1,3-Benzoxazol-2-yl)-3',3'-dimethylspiro[2*H*-1-benzopyran-2,2'-indoline]-6-carbaldehydes 4a-c (General Method). A mixture of the 3*H*-indolium salt **3a-c** (1 mmol), the aldehyde **2** (0.27 g, 1 mmol), and Et_3N (0.14 ml, 1 mmol) in toluene (10 ml) and 2-PrOH (4 ml) was refluxed for 12 h, the solvent was evaporated, the residue was purified by column chromatography on Al_2O_3 (the eluent was benzene), and recrystallized from a 1:1 mixture of heptane and toluene.

8-(1,3-Benzoxazol-2-yl)-1'-benzyl-3',3'-dimethylspiro[2*H*-1-benzopyran-2,2'-indoline]-6-carbaldehyde (4a). Yield 42%. Pale-pink crystals. Mp 187-189°C. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 1.36 (3H, s, 3'-CH_3); 1.39 (3H, s, 3'-CH_3); 4.17 (1H, d, *J* = 16.4) and 4.52 (1H, d, *J* = 16.4, 1'-C$\underline{H_2}$Ph); 6.02 (1H, d, *J* = 10.5, H-3); 6.35 (1H, d, *J* = 7.7, H-7'); 6.85-6.89 (1H, m, H-7 oxazole); 6.94 (1H, dt, *J* = 7.4, *J* = 1.0, H-5'); 6.97 (1H, d, *J* = 10.5, H-4); 7.08-7.23 (5H, m, H-4',6', H Ph); 7.25-7.30 (4H, m, H-5,6 oxazole, H Ph); 7.64-7.68 (1H, m, H-4 oxazole); 7.76 (1H, d, *J* = 2.1, H-5); 8.59 (1H, d, *J* = 2.1, H-7); 9.92 (1H, s, CHO). Found, %: C 79.62; H 5.31; N 5.56. $C_{33}H_{26}N_2O_3$. Calculated, %: C 79.50; H 5.26; N 5.62.

8-(1,3-Benzoxazol-2-yl)-5'-bromo-1',3',3'-trimethylspiro[2*H*-1-benzopyran-2,2'-indoline]-6-carbaldehyde (4b). Yield 45%. Pale-pink crystals. Mp 190-192°C. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 1.24 (3H, s, 3'-CH_3); 1.33 (3H, s, 3'-CH_3); 2.70 (3H, s, 1'-CH_3); 5.94 (1H, d, *J* = 10.5, H-3); 6.43 (1H, d, *J* = 8.2, H-7'); 6.93-6.97 (1H, m, H-7 oxazole); 7.03 (1H, d, *J* = 10.5, H-4); 7.22 (1H, d, *J* = 2.0, H-4'); 7.33 (1H, dd, *J* = 8.2, *J* = 2.0, H-6'); 7.26-7.30 (2H, m, H-5,6 oxazole); 7.64-7.67 (1H, m, H-4 oxazole); 7.78 (1H, d, *J* = 2.1, H-5); 8.58 (1H, d, *J* = 2.1, H-7); 9.92 (1H, s, CHO). Found, %: C 64.60; H 4.31; N 5.65. $C_{27}H_{21}BrN_2O_3$. Calculated, %: C 64.68; H 4.22; N 5.59.

8-(1,3-Benzoxazol-2-yl)-5'-chloro-1',3',3'-trimethylspiro[2*H*-1-benzopyran-2,2'-indoline]-6-carbaldehyde (4c). Yield 47%. Pale-pink crystals. Mp 175-177°C. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 1.24 (3H, s, 3'-CH_3); 1.33 (3H, s, 3'-CH_3); 2.70 (3H, s, 1'-CH_3); 5.94 (1H, d, *J* = 10.4, H-3); 6.47 (1H, d, *J* = 8.2, H-7'); 6.92-6.96 (1H, m, H-7 oxazole); 7.03 (1H, d, *J* = 10.4, H-4); 7.08 (1H, d, *J* = 2.1, H-4'); 7.18 (1H, dd, *J* = 8.2, *J* = 2.1, H-6'); 7.25-7.29 (2H, m, H-5,6 oxazole); 7.63-7.67 (1H, m, H-4 oxazole); 7.78 (1H, d, *J* = 2.1, H-5); 8.57 (1H,

d, J = 2.1, H-7); 9.92 (1H, s, CHO). Found, %: C 80.12; H 4.51; N 6.05. $C_{27}H_{21}ClN_2O_3$. Calculated, %: C 70.97; H 4.63; N 6.13.

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