SYNTHESIS AND OPTICAL PROPERTIES OF 5-SUBSTITUTED 2-(2-TOSYLAMINOPHENYL)BENZOXAZOLES

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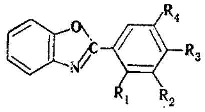
Various 5-substituted 2-(2-tosylaminophenyl)benzoxazoles were synthesized. The presence of intramolecular hydrogen bonding, the strength of which depends on the nature of the substituent, was shown by means of the IR spectra of the investigated series of compounds. A correlation between ν_{NH} and the Taft substituent constants was found. The investigated benzoxazoles have fluorescence in the yellow-green region of the spectrum; an anomalously large Stokes shift is characteristic for them. The position of the fluorescence spectrum depends on the strength of the hydrogen bond: when it becomes weaker, the spectrum is shifted bathochromically.

An anomalously large Stokes shift is characteristic for many fluorescing compounds that have an intramolecular hydrogen bond; since this characteristic is peculiar to substituted 2-tosylaminobenzylideneanilines and 2-tosylaminobenzylidenebenzylamines [1], we synthesized a number of benzoxazoles that contain a tosylamino group and investigated the optical properties of this system.



I a-h

In using the method in [2] for the synthesis of I, a method which is recommended for the preparation of 2-(2-hydroxyphenyl)benzoxazoles and consists of the reaction of the appropriate aldehydes with o-aminophenol in nitrobenzene, we obtained only azomethines. Bromination at the methyl group of the tosyl group occurs when these azomethines are treated with N-bromosuccinimide via the method in [3]. Oxidation of the azomethines with benzoyl peroxide under the conditions of the method in [3] led to resinification of the reaction products. Satisfactory results were obtained in the oxidation of the azomethines with potassium permanganate in acetone. When this procedure was used, in a number of cases the 2-(2-tosylaminophenyl)benzoxazoles were isolated in the form of their potassium salts, and the ease of salt formation increased in the order $OCH_3 < H < NO_2$; i.e., it increases as the electron-acceptor properties of the substituent, which increases the lability of the hydrogen of the tosylamino group, increase. This synthetic method proved to be applicable for all of the compounds of the series under consideration except Ia and Ib. These two compounds (as well as Ic and Ie) were obtained by dehydration [4] of the corresponding tosylamino-2'-hydroxybenzanilides.

The presence of and the strength of the intramolecular hydrogen bond in compounds that contain a tosylamino group in the ortho position of the phenyl ring (Ic-h) were determined from the shift in the band of the stretching vibrations of the NH group relative to ν_{NH}^{free}. Narrow ν_{NH}^{free} bands centered at 3393 and 3386 cm^{-1}, respectively, are characteristic for 2-phenylbenzoxazoles that contain a tosylamino group in the p and m positions (Ia and Ib). Absorption is absent in the IR spectrum of Ic in this region, but a broad

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TABLE 1. ν_{NH} and λ_{max} Values of the Long-Wave Absorption Band and Fluorescence Band of 5-Substituted 2-(2-Tosylaminophenyl)benzoxazoles

Compound	R	ν_{NH}, cm^{-1}	Long wave λ_{max}, nm	Fluorescence λ_{max}, nm
Ig	OCH_3	3116	338	544
Id	CH_3	3113	326	525
Ie	Cl	3112	330	525
If	Br	3110	330	522
Ic	H	3109	319	508
Ih	NO_2	3097	324 335 S	—

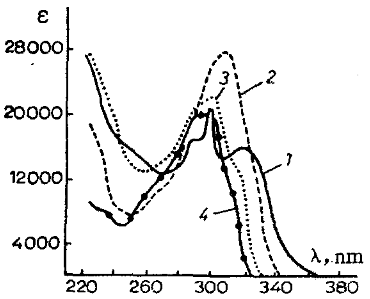


Fig. 1

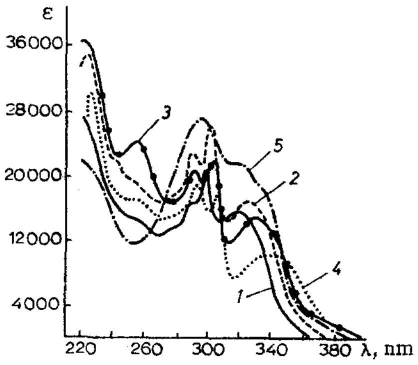


Fig. 2

Fig. 1. Absorption spectra in dichloroethane: 1) Ic; 2) Ia; 3) Ib; 4) 2-phenylbenzoxazole.

Fig. 2. Absorption spectra in dichloroethane: 1) Ia; 2) Id; 3) If; 4) Ig; 5) Ih.

diffuse band centered at 3109 cm^{-1}, which does not undergo changes when the concentration of the solution is lowered to $4 \cdot 10^{-3}$ M, appears. This low-frequency shift, the considerable width of the band, and the absence of a concentration dependence for it attest to the presence in the Ic molecule of an intramolecular hydrogen bond.

From the data presented in Table 1 it is seen that the introduction of electron-donor substituents into the p position relative to the tosylamino group causes an increase in ν_{NH}, i.e., it weakens the intramolecular hydrogen bond of the benzoxazoles under consideration; an electron-acceptor substituent (a nitro group), on the other hand, increases the strength of the hydrogen bond. A correlation analysis [5] of the dependence of ν_{NH} on the effect of the substituent has been made. A satisfactory correlation coefficient is observed when the inductive and resonance effects of the substituents are taken into account separately:

$$\nu_{NH} = \nu_0 + \rho_i\,\sigma_i + \rho_c\sigma_c,$$

where ν_{NH} and ν_0 are the frequencies in the substituted and unsubstituted compounds, σ_i and σ_c are the Taft substituent constants [6], which characterize the inductive and resonance effects of the substituents, and ρ_i and ρ_c are the efficiencies of transmission of the corresponding substituent effects. The correlation equation has the form

$$\nu_{NH} = 3107.9 - 6.909\sigma_i - 26.42\sigma_c \ (r\ 0.9703;\ S\ 2.8\,\text{cm}^{-1}).$$

From a comparison of this equation with the correlation equation obtained previously for 5-substituted 2-tosylaminobenzylidenebenzylamines [1],

$$\nu_{NH} = 2911.7 - 22.848\sigma_i - 94.274\sigma_c \ (r\ 0.9954;\ S\ 2.77\,\text{cm}^{-1}),$$

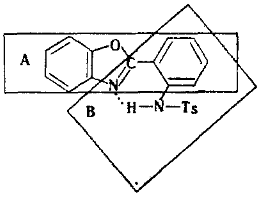
it follows that the effect of direct conjugation in the benzoxazole series is smaller than in the 2-tosylaminobenzylidenebenzylamine series (the ρ_c/ρ_i values are 3.82 and 4.13, respectively). A comparison of $\Delta\nu_{NH}$ between methoxy- and nitro-substituted compounds in systems of 2-(2-tosylaminophenyl)benzoxa-

TABLE 2. Effect of Substituents on the Position of the Maxima of the Long-Wave Absorption Bands with Respect to the Unsubstituted Compound ($\Delta\lambda_{max}$, nm)

5-R	5-Substituted 2-tosylaminobenzal-benzylamines	5-Substituted 2-(2-tosylaminophenyl)benzoxazoles
CH_3	11	7
Cl	10	11
Br	14	11
OCH_3	22	19

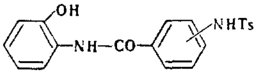
zoles and 2-tosylaminobenzylidenebenzylamines (19 cm^{-1} for the former and 67 cm^{-1} for the latter) indicates the weaker effect of substituents in the benzoxazole series. The observed fact can be explained by the lower strength of the hydrogen bond in benzoxazoles than in benzylidenebenzylamines; this is attested to by the fact that $\Delta\nu_{NH}$ between o and p isomers in the former is 284 cm^{-1} compared with 487 cm^{-1} in the latter. The decrease in the strength of the intramolecular hydrogen bond of benzoxazoles may be due to two factors: an increase in the distance between the nitrogen atoms in the $-N\ldots H-N$ system because of the inclusion of nitrogen – a proton acceptor – in the five-membered ring, and by a less favorable orientation of the axis of the orbital of the heteroring-nitrogen electrons with respect to the s orbital of the hydrogen atom of the tosylamino group.

Two intense bands – the first, which has a rough vibrational structure, at λ_{max} 298 nm (log ε 4.322) and the second at λ_{max} 319 nm (log ε 4.204) – can be isolated in the absorption spectrum of Ic at 270-360 nm (Fig. 1). These bands can be assigned to transitions localized on definite chromophores. The absorption band at λ_{max} 298 nm coincides in position, structure, and intensity with the absorption band of 2-phenylbenzoxazoles and can be assigned to an electronic transition localized on chromophore A, which is π-isoelectronic with respect to stilbene [7].



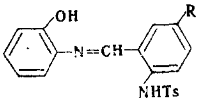
The introduction of a tosylamino group into the 3 position of the phenyl ring (Ib) does not lead to substantial changes in the absorption spectrum of 2-phenylbenzoxazole. The certain bathochromic shift and the

TABLE 3. Tosylamino-2'-hydroxybenzanilides



Position of tosyl-amino group	mp, °C	Empirical formula	Found, %				Calc., %				Yield, %
			C	H	N	S	C	H	N	S	
2	165—166	$C_{20}H_{18}N_2O_4S$	62,9	4,8	7,3	8,4	62,8	4,7	7,3	8,4	79
3	184—185	$C_{20}H_{18}N_2O_4S$	63,0	4,8	7,3	8,5	62,8	4,7	7,3	8,4	69
4	195—196	$C_{20}H_{18}N_2O_4S$	63,0	4,9	7,4	8,5	62,8	4,7	7,3	8,4	56

TABLE 4. 5-Substituted 2-Tosylaminobenzylidene-o-aminophenols



R	mp, °C	Empirical formula	Found, %			Calc., %			Yield, %
			C	H	N	C	H	N	
H	142—143	$C_{20}H_{18}N_2O_3S$	65,6	5,0	7,6	65,6	5,0	7,6	75
CH_3	149—150	$C_{21}H_{20}N_2O_3S$	66,5	5,3	7,3	66,3	5,3	7,4	76
Cl	161—162	$C_{20}H_{17}ClN_2O_3S$*	60,0	4,2	6,9	59,9	4,3	7,0	60
Br	150—151	$C_{20}H_{17}BrN_2O_3S$†	54,1	4,0	6,2	53,9	3,9	6,3	79
OCH_3	190—191	$C_{21}H_{20}N_2O_4S$	63,5	5,1	7,1	63,6	5,1	7,1	77
NO_2	213—214	$C_{20}H_{17}N_3O_5S$	58,2	4,1	10,1	58,4	4,2	10,2	60

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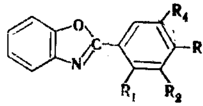
*Found: Cl 8.8%. Calculated: Cl 8.9%.

†Found: Br 17.9%. Calculated: Br 17.8%.

TABLE 5. 2-(Tosylaminophenyl)benzoxazoles



Compound	R1	R2	R3	R4	mp, °C	Empirical formula	Found, %				Calculated, %			
							C	H	N	S	C	H	N	S
Ia	H	H	$NH-SO_2-C_6H_4-CH_3$	H	217—218	$C_{20}H_{16}N_2O_3S$	65,8	4,3	7,8	8,6	65,9	4,4	7,7	8,8
Ib	H	$NH-SO_2-C_6H_4-CH_3$	H	H	199—200	$C_{20}H_{16}N_2O_3S$	65,9	4,6	7,9	8,7	65,9	4,4	7,7	8,8
Ic	$NH-SO_2-C_6H_4-CH_3$	H	H	H	165—166	$C_{20}H_{16}N_2O_3S$	66,1	4,5	7,5	8,7	65,9	4,4	7,7	8,8
Id	$NH-SO_2-C_6H_4-CH_3$	H	H	CH_3	189—190	$C_{21}H_{18}N_2O_3S$	66,6	4,7	7,4	8,4	66,7	4,8	7,4	8,5
Ie	$NH-SO_2-C_6H_4-CH_3$	H	H	Cl	188—190	$C_{20}H_{15}ClN_2O_3S$*	60,2	3,9	7,0	7,9	60,2	3,8	7,0	8,0
If	$NH-SO_2-C_6H_4-CH_3$	H	H	Br	202—203	$C_{20}H_{15}BrN_2O_3S$†	54,0	3,5	6,3	7,4	54,2	3,4	6,3	7,2
Ig	$NH-SO_2-C_6H_4-CH_3$	H	H	OCH_3	163—164	$C_{21}H_{18}N_2O_4S$	63,8	4,6	7,0	8,2	64,0	4,6	7,1	8,1
Ih	$NH-SO_2-C_6H_4-CH_3$	H	H	NO_2	223—224	$C_{20}H_{15}N_3O_5S$	58,6	3,7	10,1	8,0	58,7	3,7	10,3	7,8

*Found: Cl 8.9%. Calculated: Cl 8.9%.

†Found: Br 18.2%. Calculated: Br 18.0%.

increase in the intensity of the absorption band that are induced by a 4-tosylamino group at the end of the conjugation chain of chromophore A are analogous to the effect of the introduction into this position of an OCH_3 group [8]. The presence of a tosylamino group in the 2 position of the phenyl ring leads to the development of a new absorption band (λ_{max} 319 nm). A similar effect is observed when a tosylamino group is introduced into the o position of benzaldehyde [9] and benzylidenebenzylamine [1], so that, just as in the absorption spectra of these compounds, the long-wave band of 2-(2-tosylaminophenyl)benzoxazoles can therefore be assigned to an electronic transition localized on chromophore B, which includes a six-membered ring with an intramolecular hydrogen bond. Substituents of differing electronic nature in the 5 position of the phenyl ring of Ic have very little effect on the position of the absorption band that corresponds to transition to the "stilbene" chromophore (Fig. 2). However, the long-wave absorption band is sensitive to the nature of the substituent. Electron-donor substituents cause a bathochromic shift of this band, and the shift increases in the order $H < CH_3 < Cl < Br < OCH_3$. Above, on the basis of the IR spectra, it was shown that the system of 2-tosylaminobenzylidenebenzylamines is a better conductor of the conjugation effect than the system of 2-(2-tosylaminophenyl)-benzoxazoles. A comparison of the effect of substituents in series of these compounds on the position of the maximum of the long-wave absorption band of chromophore B also leads to the same conclusion. In this case, it is seen that the substituent effect in the series under discussion is identical in direction but differs in magnitude (Table 2). In comparing the frequencies of the stretching vibrations of the NH group, which characterize the strength of the hydrogen bond, and the shifts of the absorption bands of chromophore B under the influence of a substituent, it is seen that the weaker the hydrogen bond in the ground state the stronger the shift of the long-wave band in the absorption spectrum. The large bathochromic shift of the bands for compounds with a weaker hydrogen bond can be explained by the relatively greater strengthening in them of this bond at the instant of absorption.

Compounds Ia and Ib, which do not contain an intramolecular hydrogen bond, have, like 2-phenylbenzoxazole, blue fluorescence ($\tau \sim 10^{-9}$ sec) in crystals and frozen solutions at 77°K (λ_{max} 403 and 408 nm), respectively. The presence of chromophore B in Ic leads to considerable changes in the fluorescence properties: an anomalously high Stokes shift (200 nm) appears, and the maximum of the fluorescence band is shifted to the green region of the spectrum; the luminescence intensity increases by a factor of more than 30. The reason for this large Stokes shift may be a consequence of the consumption of energy in transfer of a proton during additional strengthening of the intramolecular hydrogen bond in the excited state. When electron-donor substituents are introduced into the p position relative to the tosylamino group (Id-g), the fluorescence band, just like the long-wave absorption band, experiences a bathochromic shift. In this case, the Stokes shift increases somewhat with an increase in the electron-donor properties of the substituent (Table 1). A nitro group (Ih) has a more complex effect on the absorption spectrum: the long-wave band is the result of the superimposition of the band of chromophore B and a band of the $l \rightarrow a_{\pi}$ type, which is due to conjugation between the tosylamino and nitro groups, and this makes it impossible to estimate the position of the band of chromophore B. The nitro derivative does not luminesce in the crystalline state, but phosphorescence (λ_{max} 475 and 516 nm) appears in frozen solutions at 77°K. The quenching of the fluorescence and the appearance of phosphorescence in Ih can be explained by intercombination conversion due to the presence of a nitro group [10].

EXPERIMENTAL

The IR spectra of the benzoxazoles in tetrachloroethylene were recorded with a UR-10 spectrophotometer with an LiF prism at 2500-3600 cm^{-1}. The solution concentrations and the cuvette thickness were, respectively, $8 \cdot 10^{-3}$ and $4 \cdot 10^{-3}$ M and 1 cm. Saturated solutions were used in the case of Ia and Ih. The UV spectra of dichloroethane solutions (c $2.5 \cdot 10^{-3}$ M) were recorded with an SF-4A spectrometer at 20°. The luminescence spectra of dichloroethane solutions were obtained with an ISP-51 apparatus at 77°K (c $2.5 \cdot 10^{-3}$ M); excitation was achieved with 313-nm light. The fluorescence lifetime was measured with a phase tautometer by the method in [13] with dichloroethane solutions ($2.5 \cdot 10^{-3}$ M) at 77°K.

Synthesis of 2-(Tosylaminophenyl)benzoxazoles. A 0.1-mole sample of the acid chloride of the appropriate tosylaminobenzoic acid [11, 12] was added in several portions with stirring at 50° to a solution of 0.1 mole of o-aminophenol in 250 ml of dioxane, after which the mixture was held at 60-65° for 1.5 h. It was then cooled to room temperature and poured into 750 ml of ice water. The resulting oil was converted to a crystalline precipitate after 30 min; this material was removed by filtration, washed with 200 ml of hot water, and crystallized from methanol (Table 3). Analysis of the IR spectra of the compounds provided evidence that acylation proceeds at the amino group of o-aminophenol. The acylated o-aminophenols were heated at 180-200° for 30 min, and the dark mass that formed on cooling was crystallized successively from methanol and benzene (Table 5).

Synthesis of 2-(2-Tosylaminophenyl)benzoxazoles by Oxidation of the Schiff Bases. A mixture of equimolecular amounts of the appropriate aldehydes [9] and o-aminophenol was refluxed for 1 h in a suitable solvent and crystallized from methanol (Table 4). A solution of 5 mmole of the appropriate 2-tosylaminobenzylidene-o-aminophenol in 30 ml of acetone was added in the course of 15-20 min to a boiling solution of 8 g of $KMnO_4$ in 600 ml of acetone. At the end of the addition, the mixture was refluxed and stirred for another 5 h, after which it was cooled. The precipitated MnO_2 was removed by filtration and washed with several portions of 300 ml of boiling acetone. The wash solutions were added to the initial filtrate. The acetone was then removed by vacuum distillation, and the residue was treated with 100 ml of boiling dilute (1 : 2) hydrochloric acid. The mixture was cooled, and the precipitate was removed by filtration, washed with water until the wash liquid was neutral, and recrystallized from a suitable solvent (Table 5).

2-Phenylbenzoxazole was obtained by the method in [4].

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