

# Benzoid–Quinoid Tautomerism of Schiff Bases and Their Structural Analogs: LII.\* Schiff Bases Derived from 6-*tert*-Butyl-5-hydroxy- and 5-Hydroxy-6-iodo-2,3-tetramethylenebenzo[*b*]furan-4-carbaldehydes\*\*

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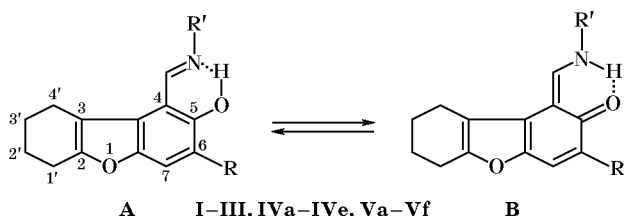
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**Abstract**—Two series of Schiff bases, 4-aryl(alkyl)iminomethyl-6-*tert*-butyl-5-hydroxy- and 4-aryl(alkyl)iminomethyl-5-hydroxy-6-iodo-2,3-tetramethylenebenzo[*b*]furans were synthesized. These compounds in solution give rise to tautomeric benzoid–quinoid equilibrium; the fraction of the quinoid form in the equilibrium mixture increases with rise in solvent polarity and in going from *N*-aryl to *N*-alkyl derivatives. The benzoid tautomer shows fluorescence with an anomalous Stokes shift. The absorption and luminescence spectral properties of the examined Schiff bases make them promising as signal fragments of chemosensors for metal cations.

Introduction of a crown ether moiety into the molecule of 5-hydroxy-6-nitro-4-phenyliminomethyl-2,3-tetramethylenebenzo[*b*]furan induces specific changes in the luminescence spectral properties on complex formation with alkali metal cations. This system can be regarded as the first fluorescent tautomeric benzoid–quinoid sensor for metal cations [2]. The benzo-15-crown-5 fragment therein is a receptor [2–4], and the role of the signal fragment is played by the 5-hydroxybenzo[*b*]furan moiety which can contain various substituents in the *ortho* position with respect to the hydroxy group. With the goal of establishing an optimal structure of the signal part of chemosensor molecule, in the present work we synthesized *N*-aryl- and *N*-alkyl-substituted Schiff bases **IV** and **V** on the basis of 6-*tert*-butyl-5-hydroxy- and 5-hydroxy-6-iodo-2,3-tetramethylenebenzo[*b*]furan-4-carbaldehydes (Scheme 1) and examined their absorption and luminescence spectral properties in comparison with the

corresponding properties of compounds **I–III** [5, 6] studied previously. Compounds **IV** and **V** were obtained by condensation of the corresponding amines with 6-*tert*-butyl-5-hydroxy- and 5-hydroxy-6-iodo-2,3-tetramethylenebenzo[*b*]furan-4-carbaldehydes **VI** and **VII**. The yields, melting points, and elemental analyses of products **IV** and **V** are given in Table 1. Their structure was studied by IR and <sup>1</sup>H NMR spectroscopy (Table 2), and the position of tautomeric equilibrium was established by electron absorption spectroscopy (Table 3).

Scheme 1.



**I**, R = H; **II**, R = Br; **III**, R = NO<sub>2</sub>; R' = Ar, Alk; **IV**, R = *t*-Bu; R' = Ph (**a**), C<sub>6</sub>H<sub>4</sub>OMe-*p* (**b**), C<sub>6</sub>H<sub>4</sub>OMe-*o* (**c**), CH<sub>2</sub>Ph (**d**), *i*-Pr (**e**); **V**, R = I; R' = Ph (**a**), C<sub>6</sub>H<sub>4</sub>OMe-*p* (**b**), C<sub>6</sub>H<sub>4</sub>COMe-*p* (**c**), 4-pyridylmethyl (**d**), cyclo-C<sub>7</sub>H<sub>13</sub> (**e**), *i*-Pr (**f**).

\* For communication LI, see [1].

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**Table 1.** Yields, melting points, and elemental analyses of Schiff bases **IVa–IVe** and **Va–Vf**

Comp. no.	Yield, %	mp, °C	Found, %			Formula	Calculated, %		
			C	H	N		C	H	N
<b>IVa</b>	61	160–161	79.40	7.22	4.10	C <sub>23</sub> H <sub>25</sub> NO <sub>2</sub>	79.51	7.25	4.03
<b>IVb</b>	65	198–199	76.48	7.32	3.78	C <sub>24</sub> H <sub>27</sub> NO <sub>3</sub>	76.36	7.21	3.71
<b>IVc</b>	50	178–179	76.18	7.33	3.74	C <sub>24</sub> H <sub>27</sub> NO <sub>3</sub>	76.36	7.21	3.71
<b>IVd</b>	72	148–149	79.71	7.48	3.93	C <sub>24</sub> H <sub>27</sub> NO <sub>2</sub>	79.74	7.53	3.88
<b>IVe</b>	67	135–136	76.79	8.66	4.51	C <sub>24</sub> H <sub>27</sub> NO <sub>2</sub>	76.64	8.68	4.47
<b>Va</b>	66	193–194	54.80	4.00	3.42	C <sub>19</sub> H <sub>16</sub> INO <sub>2</sub>	54.69	3.87	3.36
<b>Vb</b>	71	191–192	53.92	4.11	3.18	C <sub>20</sub> H <sub>18</sub> INO <sub>3</sub>	53.71	4.06	3.13
<b>Vc</b>	60	221–222	54.84	3.91	3.25	C <sub>21</sub> H <sub>18</sub> INO <sub>3</sub>	54.92	3.95	3.05
<b>Vd</b>	54	164–165	52.79	4.04	6.56	C <sub>19</sub> H <sub>17</sub> IN <sub>2</sub> O <sub>2</sub>	52.80	3.96	6.48
<b>Ve</b>	56	195–196	54.75	5.65	3.18	C <sub>20</sub> H <sub>24</sub> INO <sub>2</sub>	54.93	5.53	3.20
<b>Vf</b>	73	190–191	50.26	4.79	3.56	C <sub>16</sub> H <sub>18</sub> INO <sub>2</sub>	50.15	4.73	3.66

**Table 2.** IR and <sup>1</sup>H NMR spectra of Schiff bases **IVa**, **IVe**, **Va**, **Ve**, and **Vf**

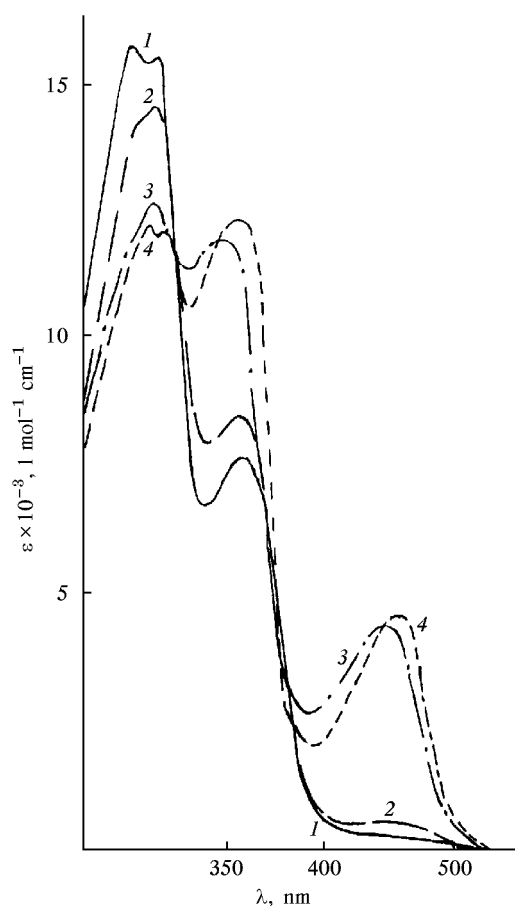
Comp. no.	IR spectrum, ν <sub>C=N</sub> , cm <sup>-1</sup>	<sup>1</sup> H NMR spectrum, δ, ppm						
		OH	=CH	7-H, s	1'-H, 4'-H, m	2'-H, 3'-H, m	R, s	R'
<b>IVa</b>	1600, 1575	14.20–14.38 br.s	9.15 s	see R'	2.68–2.87	1.83–1.98	1.44	7.27–7.49 m (Ph, 7-H)
<b>IVe<sup>a</sup></b>	1620, 1600	14.82 s	8.84 s	7.35	2.65–2.80	1.68–1.79	1.38	3.69 m (CH), 1.24 d (CH <sub>3</sub> )
<b>Va</b>	1600, 1580	15.08 s	8.98 s	7.87	2.68–2.90	1.83–1.95	–	7.22–7.47 m (Ph)
<b>Ve<sup>a</sup></b>	1610, 1585	15.32 s	8.61 d	8.01	2.64–2.78	see R'	–	3.79 m (CH), 1.44–1.96 (2'-H, 3'-H, CH <sub>2</sub> )
<b>Vf</b>	1625, 1610	15.29 s	8.54 s	7.86	2.65–2.76	1.81–1.95	–	1.34 d (CH <sub>3</sub> )

<sup>a</sup> The <sup>1</sup>H NMR spectra were recorded in DMSO-*d*<sub>6</sub>.

The electron absorption spectra of Schiff bases **IV** and **V** in nonpolar solvents contain absorption bands at λ 350–374 nm, which indicate almost complete displacement of the equilibrium toward the benzoid tautomer **A** [5, 6]. In polar solvents, a new absorption band appears in the region λ 440–490 nm, which corresponds to quinoid tautomer **B**. Thus a benzoid–quinoid equilibrium establishes, and the fraction of tautomer **B** in the equilibrium mixture increases with rise in solvent polarity and in going from *N*-aryl- to *N*-alkyl-substituted compounds, as well as from R = *t*-Bu to R = I (Table 3, see figure).

The existence of tautomeric equilibrium in polar media is also confirmed by the data of <sup>1</sup>H NMR

spectroscopy for *N*-cycloheptyl derivative (**Ve**) in DMSO-*d*<sub>6</sub> (Table 2). A characteristic spin–spin coupling between the NH and CH protons in the quinoid form ( $J_{\text{H,H}} = 5.5$  Hz) corresponds to a 42% fraction of tautomer **B**, taking into account that the value 13 Hz [7] corresponds to its 100% fraction. Using these data and those obtained by electron absorption spectroscopy for compound **Ve** in DMSO, we calculated the molar absorption factor of the quinoid form ( $\epsilon = 12.1 \times 10^3$  l mol<sup>-1</sup> cm<sup>-1</sup>) for 6-iodo derivatives **V**. In doing so, we assumed that this quantity weakly depends on the solvent polarity and the nature of the R' substituent. The fraction of quinoid tautomer **B** in the series of 6-*tert*-butyl



Electron absorption spectra of 4-cycloheptyliminomethyl-5-hydroxy-6-iodo-2,3-tetramethylenebenzo[*b*]furan (**Ve**) in (1) heptane, (2) toluene, (3) acetonitrile, and (4) isopropyl alcohol.

compounds **IV** was taken into account using an  $\epsilon_B$  value of  $10.4 \times 10^3 \text{ l mol}^{-1} \text{ cm}^{-1}$  [5]. According to the data of [8], the acidity of benzoid tautomer **A** (and hence its fraction in the equilibrium mixture) changes only slightly in going from  $R = \text{H}$  to  $R = t\text{-Bu}$  (Table 3).

The luminescence spectral properties were studied with *N*-phenyl derivatives **IVa** and **Va**. Excitation of their solutions in toluene at the wavelength corresponding to absorption of benzoid tautomer **A** ( $\lambda_{\text{exc}} = 385$  and  $383 \text{ nm}$ , respectively) induces fluorescence with an anomalous Stokes shift (ASS),  $\lambda_{\text{fl}} 565 \text{ nm}$  ( $\Delta\nu 8275 \text{ cm}^{-1}$ ) (**IVa**) and  $570 \text{ nm}$  ( $\Delta\nu 8566 \text{ cm}^{-1}$ ) (**Va**), which arises from intramolecular proton transfer in the excited state [9]. The fluorescence quantum yield  $\phi$  for compound **Va** relative to **IVa** is 4.1.

The results of our present and previous [5, 6] studies on Schiff bases **I–V** lead us to conclude that rise in the electron-acceptor power of substituents *R*

in the series  $\text{H} < t\text{-Bu} < \text{I} < \text{Br} < \text{NO}_2$  is accompanied by (1) enhancement of the stability of the quinoid tautomer whose fraction in the equilibrium mixture attains 50% and (2) increase of the anomalous Stokes shift in fluorescence of the benzoid tautomer. The systems under study meet the requirements imposed upon signal part of chemosensors [3, 4]; therefore, after introduction into their molecules of a receptor fragment (crown ether moiety), they can be examined as dynamic fluorescence sensors for metal cations [2].

## EXPERIMENTAL

The electron absorption spectra were recorded on a Specord M-40 spectrophotometer. The fluorescence spectra were measured on an Elyumin instrument. The IR spectra were obtained on a Specord 75IR spectrometer from samples dispersed in mineral oil. The  $^1\text{H}$  NMR spectra were recorded on a Varian Unity-300 instrument (300 MHz) in  $\text{CDCl}_3$  using tetramethylsilane as internal reference.

**6-*tert*-Butyl-5-hydroxy-2,3-tetramethylenebenzo[*b*]furan-4-carbaldehyde (VI)** was synthesized by a procedure similar to that described in [5]. The product was recrystallized from toluene. Yield 68%. mp  $150\text{--}151^\circ\text{C}$ .  $^1\text{H}$  NMR spectrum,  $\delta$ , ppm: 12.74 s (1H, OH), 10.38 s (1H, CHO), 7.63 s (1H, 7-H), 2.75–2.90 m (4H, 1'-H, 4'-H), 1.85–1.99 m (4H, 2'-H, 3'-H), 1.47 s (9H,  $\text{CH}_3$ ). Found, %: C 74.86; H 7.41.  $\text{C}_{17}\text{H}_{20}\text{O}_3$ . Calculated, %: C 74.97; H 7.40.

**5-Hydroxy-6-iodo-2,3-tetramethylenebenzo[*b*]furan-4-carbaldehyde (VII)**. Freshly distilled morpholine, 30 ml, was added dropwise to a solution of 23 g of iodine in 25 ml of anhydrous methanol. The resulting suspension of a 1:3 iodine–morpholine complex was stirred for 1.5 h, 13 g of 5-hydroxy-2,3-tetramethylenebenzo[*b*]furan-4-carbaldehyde [5] in 40 ml of anhydrous methanol was added, and the mixture was stirred for 1 h. It was slowly heated to  $60^\circ\text{C}$ , kept for 1 h at that temperature, and left overnight. The precipitate was filtered off, washed with methanol and a 10:1 methanol–acetic acid mixture, and recrystallized from butyl alcohol. Yield 30%, mp  $158\text{--}159^\circ\text{C}$ .  $^1\text{H}$  NMR spectrum,  $\delta$ , ppm: 12.23 s (1H, OH), 10.21 s (1H, CHO), 7.98 s (1H, 7-H), 2.66–2.80 m (4H, 1'-H, 4'-H), 1.82–1.88 m (4H, 2'-H, 3'-H). Found, %: C 45.78; H 3.29.  $\text{C}_{13}\text{H}_{11}\text{O}_3\text{I}$ . Calculated, %: C 45.64; H 3.24.

**Schiff bases IVa–IVe and Va–Vf** were obtained from aldehydes **VI** and **VII** and the corresponding amines, following the procedure reported in [6].

**Table 3.** Electron absorption spectra of Schiff bases **IVa–IVe** and **Va–Vf** and parameters of the equilibrium  $A \rightleftharpoons B$ 

Comp. no.	Solvent	$\lambda_{\max}$ , nm ( $\epsilon \times 10^{-3}$ , $1 \text{ mol}^{-1} \text{ cm}^{-1}$ )	Fraction of tautomer <b>B</b> , %	$K^0 = [B]/[A]$	$\Delta G_{293}^{\circ}$ , kJ/mol
<b>IVa</b>	Toluene	357 (22.5)	0	—	—
	CH <sub>3</sub> CN	350 (25.4), 475 (0.3)	3	0.03	8.5
	2-Propanol	350 (21.9)	0	—	—
	DMSO	355 (21.0), 475 (0.3)	3	0.03	8.5
<b>IVb</b>	Toluene	365 (27.2)	0	—	—
	CH <sub>3</sub> CN	360 (27.4)	0	—	—
	2-Propanol	360 (28.1)	0	—	—
	DMSO	365 (26.0), 480 (0.4)	4	0.04	7.8
<b>IVc</b>	Toluene	365 (21.2), 480 (0.3)	3	0.03	8.5
	CH <sub>3</sub> CN	363 (21.0), 480 (0.6)	6	0.06	6.8
	2-Propanol	360 (21.8), 480 (0.6)	6	0.06	6.8
	DMSO	369 (21.8), 480 (0.7)	7	0.08	6.1
<b>IVd</b>	Toluene	320 (16.8), 350 (7.6)	0	—	—
	CH <sub>3</sub> CN	310 (15.9), 347 (7.2), 450 (0.3)	3	0.03	8.5
	2-Propanol	310 (16.4), 350 (7.2), 450 (0.5)	5	0.05	7.3
	DMSO	313 (14.6), 345 (7.3), 450 (0.7)	7	0.08	6.1
<b>IVe</b>	Toluene	315 (13.4), 350 (6.5), 440 (0.2)	2	0.02	9.5
	CH <sub>3</sub> CN	307 (13.2), 340 (6.8), 440 (0.6)	4	0.06	6.8
	2-Propanol	312 (13.4), 350 (6.5), 440 (0.4)	6	0.04	7.8
	DMSO	312 (12.8), 345 (7.2), 440 (0.8)	8	0.09	5.9
<b>Va</b>	Toluene	360 (22.7), 490 (0.3)	2.5	0.03	8.5
	CH <sub>3</sub> CN	357 (23.0), 490 (0.8)	6.5	0.07	6.5
	2-Propanol	357 (21.2), 490 (0.7)	6	0.06	6.8
	DMSO	360 (20.1), 490 (0.8)	6.5	0.07	6.5
<b>Vb</b>	Heptane	370 (32.4)	0	—	—
	Toluene	374 (27.1), 490 (0.3)	2.5	0.03	8.5
	CH <sub>3</sub> CN	370 (29.0), 476 (0.8)	6.5	0.07	6.5
	2-Propanol	374 (28.0), 476 (0.9)	7.5	0.08	6.1
	DMSO	374 (22.4), 476 (0.7)	6	0.06	6.8
<b>Vc</b>	Heptane	366 (25.4)	0	—	—
	Toluene	372 (26.4)	0	—	—
	CH <sub>3</sub> CN	366 (29.6), 490 (0.8)	6.5	0.07	6.5
	2-Propanol	370 (32.8), 490 (0.7)	6	0.06	6.8
	DMSO	372 (27.4), 490 (1.0)	8	0.09	5.9
<b>Vd</b>	Heptane	320 (23.0), 363 (11.4)	0	—	—
	Toluene	324 (15.8), 360 (8.6)	0	—	—
	CH <sub>3</sub> CN	321 (21.2), 353 (14.0), 455 (2.1)	17.5	0.21	3.8
	2-Propanol	322 (16.3), 360 (10.2), 460 (1.5)	12.5	0.14	4.8
	DMSO	325 (13.5), 357 (9.8), 455 (2.4)	20	0.25	3.4
<b>Ve</b>	Heptane	315 (15.5), 356 (7.6), 450 (0.4)	3.5	0.04	7.8
	Toluene	320 (14.7), 355 (8.5), 455 (0.6)	5	0.05	7.3
	CH <sub>3</sub> CN	318 (12.4), 346 (11.7), 443 (4.2)	35	0.54	1.5
	2-Propanol	320 (12.3), 355 (12.2), 450 (4.4)	36.5	0.57	1.4
	DMSO	323 (11.3), 350 (11.5), 445 (5.1)	42	0.72	0.8
<b>Vf</b>	Toluene	321 (12.6), 357 (7.8), 455 (0.5)	4	0.04	7.8
	CH <sub>3</sub> CN	318 (11.6), 350 (10.7), 445 (3.9)	32	0.47	1.8
	2-Propanol	320 (10.7), 355 (10.4), 455 (3.8)	31.5	0.46	1.9
	DMSO	321 (9.3), 350 (9.3), 445 (4.1)	34	0.52	1.6

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