Benzothiazole compounds
XXIX. Conductometric determination of dissociation constants and limiting molar conductivities for 2-styryl-3-R-benzothiazolium salts

[a]P. CHABREČEK, [a]V. SUTORIS, and [b]A. GÁPLOVSKÝ

[a]*Department of Organic Chemistry, Faculty of Natural Sciences,*
Comenius University, CS-842 15 Bratislava

[b]*Institute of Chemistry, Comenius University, CS-842 15 Bratislava*

Received 29 May 1986

Dissociation constants and limiting molar conductivities of 2-styryl-3-R-benzothiazolium salts were determined in anhydrous ethanol. The values showed dependence on the character of substituent at the position 3 and on the nature of counter-ion. There was found a relationship between the magnitudes of dissociation constants and stimulation/inhibition activity on plant-growth.

Определены константы диссоциации и граничные значения мольной электропроводности солей 2-стирил-3-замещенного бензотиазолия в безводном этаноле. Определенные значения зависели от типа заместителя в положении 3 бензотиазола и от типа противоиона. Установлена зависимость между величинами констант диссоциации и стимуляцией или ингибицией роста растений.

Among physical parameters that characterize organic ammonium salts belong dissociation constants, the values of which depend on solvent, temperature, and structural patterns of salts. Our present work is aimed at finding a dependence of dissociation constants (K) and limiting molar conductivities (Λ_0) of 2-styryl-3-R-benzothiazolium salts on the nature of both the counter-ion and the substituent R, and to examination of the relationship between K and biological activity in the area of plant-growth regulation. A study of influence of substituents on dissociation process requires utilization of solvents with low solvating ability and therefore, with just a partial dissociation of a solute in it [1]. The solvents most frequently used are 1,2-dichloroethane [2, 3], ethanol (96 %) [1], anhydrous ethanol [4], methanol [5], acetonitrile [6] or their mixtures [6, 7]. Conductometric measurements in our hands were performed in anhydrous ethanol; K and Λ_0 values were calculated from the data obtained by *Fuoss* and *Kraus*' method [8, 9]. The values of concentrations c, molar conductivities Λ, values of F/Λ and $cf^2\Lambda/F$ were obtained from 6—7 measurements of each compound (Table 1) and served for calculation of K and Λ_0 values (Table 2).

Table 1

Experimentally determined conductivities and values calculated for the dependence
F/Λ vs. $cf^2\Lambda/F$ for given concentrations of synthesized compounds

$\{c\}\cdot 10^{-4}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$
		I			*II*			*III*			*IV*	
10.00		*		34.5	0.02592	0.0255	40.6	0.02252	0.0301	35.1	0.02534	0.0259
7.50	27.3	0.03245	0.0160	35.4	0.02565	0.0204	42.4	0.02180	0.0226	35.8	0.02526	0.0206
5.00	28.0	0.03238	0.0114	36.5	0.02532	0.0147	44.5	0.02111	0.0179	36.7	0.02511	0.0147
3.75	28.4	0.03236	0.0089	37.2	0.02511	0.0116	45.7	0.02072	0.0141	37.2	0.02505	0.0115
2.50	28.9	0.03232	0.00625	38.0	0.02489	0.0081	47.2	0.02019	0.0101	37.8	0.02498	0.0081
1.25	29.6	0.03222	0.00333	39.1	0.02460	0.0044	49.2	0.01967	0.0055	38.6	0.02495	0.0043
1.00	29.75	0.03220	0.00271				49.7	0.01954	0.0045	38.8	0.02486	0.0035
		V			*VI*			*VII*			*VIII*	
10.00	31.4	0.02809	0.0233	35.1	0.02541	0.0259		*		31.3	0.02816	0.0233
7.50	32.1	0.02796	0.0186	35.9	0.02524	0.0207	34.1	0.02639	0.0190	32.0	0.02804	0.0188
5.00	33.05	0.02771	0.0133	36.9	0.02501	0.0148	34.8	0.02639	0.0140	32.8	0.02793	0.0133
3.75	33.6	0.02759	0.0105	37.5	0.02488	0.0116	35.3	0.02633	0.0110	33.3	0.02784	0.0104
2.50	34.2	0.02749	0.0073	38.2	0.02474	0.0082	35.9	0.02625	0.0077	33.8	0.02782	0.0073
1.25	35.0	0.02736	0.0039	39.05	0.02461	0.0044	36.6	0.02621	0.0041	34.6	0.02768	0.0039
1.00	35.25	0.02730	0.0032	39.3	0.02456	0.0036	36.8	0.02618	0.0033	34.8	0.02765	0.0032
		IX			*X*			*XI*			*XII*	
10.00		*		20.00	0.04239	0.0155	32.2	0.02778	0.0240	21.0	0.04053	0.0162
7.50	25.9	0.03410	0.0152	20.7	0.04191	0.0129	33.3	0.02726	0.0193	21.6	0.04031	0.0129
5.00	26.7	0.03392	0.0109	21.4	0.04166	0.0089	34.6	0.02670	0.0140	22.4	0.03990	0.0093
3.75	27.1	0.03385	0.0085	21.9	0.04136	0.0070	35.4	0.02637	0.0110	22.8	0.03983	0.0073
2.50	27.6	0.03378	0.0060	22.4	0.04120	0.0049	36.3	0.02605	0.0078	23.3	0.03969	0.0051
1.25	28.3	0.03364	0.0032	23.1	0.04092	0.0026	37.5	0.02563	0.0042	24.05	0.03936	0.0027
1.00	28.5	0.03358	0.0026	23.3	0.04081	0.0021	37.9	0.02546	0.0034	24.2	0.03935	0.0022

Table 1 (Continued)

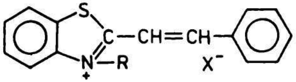
$\{c\}\cdot 10^{-4}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$	$\{\Lambda\}$	$\{F/\Lambda\}$	$\{cf^2\Lambda/F\}$
		XIII			*XIV*			*XV*			*XVI*	
10.00	30.2	0.02931	0.0262	30.3	0.02913	0.0226		*		28.9	0.03044	0.0216
7.50	31.0	0.02900	0.0180	31.1	0.02887	0.0181	28.25	0.03143	0.0165	29.6	0.03017	0.0172
5.00	32.0	0.02867	0.0130	32.0	0.02863	0.0130	29.0	0.03132	0.0118	30.4	0.03001	0.0123
3.75	32.6	0.02850	0.0102	32.5	0.02853	0.0101	29.4	0.03131	0.0092	30.9	0.02990	0.0097
2.50	33.4	0.02820	0.0072	33.2	0.02833	0.0071	29.9	0.03127	0.0064	31.4	0.02987	0.0068
1.25	34.3	0.02791	0.0038	34.1	0.02809	0.0038	30.55	0.03124	0.0034	32.2	0.02969	0.0036
1.00	34.5	0.02782	0.0031	34.3	0.02805	0.0031	30.7	0.03123	0.0028	32.4	0.02965	0.0029
		XVII			*XVIII*			*XIX*			*XX*	
10.00	29.8	0.02953	0.0222	29.8	0.02950	0.0222		*		28.9	0.03037	0.0216
7.50	30.55	0.02933	0.0177	30.4	0.02945	0.0177	29.1	0.03063	0.0170	29.6	0.03019	0.0172
5.00	31.4	0.02913	0.0127	31.3	0.02920	0.0127	29.9	0.03048	0.0122	30.4	0.03003	0.0123
3.75	31.9	0.02902	0.0100	31.8	0.02910	0.0099	30.4	0.03036	0.0095	30.95	0.02987	0.0097
2.50	32.5	0.02890	0.0070	32.4	0.02898	0.0068	30.9	0.03033	0.0067	31.55	0.02974	0.0068
1.25	33.3	0.02874	0.0037	33.1	0.02891	0.0037	31.7	0.03014	0.0036	32.3	0.02960	0.0036
1.00	33.5	0.02870	0.0030	33.3	0.02887	0.0030	31.85	0.03013	0.0030	32.5	0.02956	0.0029
		XXI										
10.00	31.1	0.02854	0.0232									
7.50	31.9	0.02828	0.0185									
5.00	33.0	0.02860	0.0134									
3.75	33.7	0.02760	0.0105									
2.50	34.15	0.02754	0.0073									
1.25	35.2	0.02725	0.0039									
1.00	35.65	0.02702	0.0032									

* — limited solubility.

Symbols F and cf^2 have the same meaning as in Ref. [8, 9].

Table 2

Dissociation constants, limiting molar conductivities, and growth effect of benzothiazolium salts



Compound	R	X^-	$\{K\}$	$\{\lambda_0\}$	Growth effect			
					Stimulatory		Inhibitory	
					$+\Delta/\%$	$c/(\text{mol dm}^{-3})$	$-\Delta/\%$	$c/(\text{mol dm}^{-3})$
I	CH_3	CH_3SO_4	0.06379	31.06	7.95	10^{-7}	21.52	10^{-3}
II	CH_3	I	0.00903	41.08	2.45	10^{-9}	44.64	10^{-3}
III	CH_3	ClO_4	0.00301	52.60			12.05	10^{-3}
IV	CH_3	BF_4	0.03206	40.27			37.28	10^{-3}
V	$CH_2C_6H_5$	Br	0.01848	36.78	1.02	10^{-7}	42.14	10^{-3}
VI	$CH_2C_6H_5$	ClO_4	0.01562	40.92			5.97	10^{-3}
VII	$CH_2C_6H_5$	BF_4	0.03478	38.29			49.56	10^{-3}
VIII	$CH_2C_6H_5$	NO_3	0.02890	36.26			49.28	10^{-3}
IX	$CH_2CH{=}CH_2$	Br	0.02873	29.85			33.36	10^{-3}
X	$CH_2CH{\equiv}CH$	Br	0.01474	24.61			30.23	10^{-3}
XI	CH_2COOH	Br	0.00579	39.80	4.34	10^{-13}	1.77	10^{-3}
XII	CH_2COOCH_3	Br	0.01770	25.49			42.36	10^{-3}
XIII	$CH_2COOC_2H_5$	Br	0.00990	36.23			32.14	10^{-3}
XIV	$CH_2COOC_3H_7$-i	Br	0.01363	35.90	5.05	10^{-13}	52.27	10^{-3}
XV	$CH_2COOC_3H_7$	Br	0.07532	32.06	16.51	10^{-11}	53.03	10^{-3}
XVI	$CH_2COOCH{=}CH_2$	Br	0.02445	33.84	4.11	10^{-11}	14.71	10^{-3}
XVII	$CH_2COOCH_2CH{\equiv}CH_2$	Br	0.01906	34.99			53.76	10^{-3}
XVIII	$CH_2COOC_4H_9$	Br	0.02345	34.76				
XIX	$CH_2COOC_5H_{11}$	Br	0.02450	33.31				
XX	$CH_2COOC_7H_{15}$	Br	0.01918	33.98	7.48	10^{-9}	17.04	10^{-3}
XXI	$CH_2COOCH_2C_6H_5$	Br	0.01022	37.17	7.24	10^{-5}	16.54	10^{-3}

Table 2 (Continued)

Compound	R	X^-	$\{K\}$	$\{\lambda_0\}$	Growth effect			
					Stimulatory		Inhibitory	
					$+\Delta/\%$	$c/(\mathrm{mol\,dm^{-3}})$	$-\Delta/\%$	$c/(\mathrm{mol\,dm^{-3}})$
IAA					10.20	10^{-12}	39.69	10^{-6}
2,4-D					8.74	10^{-9}	45.53	10^{-5}
CCC							4.38	10^{-3}

IAA — Indolylacetic acid; 2,4-D — 2,4-dichlorophenoxyacetic acid; CCC — (2-chloroethyl)trimethylammonium chloride.

In general, the dissociation of a salt is influenced by both ions. On dissociation, the compounds *I—IV* give the same cations but different anions. It means that variations of their K values are caused by anions. The same is the situation with the compounds *V—VIII.* If anions are arranged in increased order of K values of electrolytes, the sequence is ClO_4^-, I^-, BF_4^-, $CH_3SO_4^-$, *i.e.* the more powerful base is an anion, the higher is dissociation constant. Perchlorates exhibit the lowest values of K but the highest limiting molar conductivities. That implies stronger cation—anion interactions in these salts than in the rest of derivatives and furthermore, weak interactions of ions with solvent molecules. Also low K value of the compound *II* is accountable to strong interactions of large iodide anion with benzothiazolium cation. These values indicate that the salts do not exist in solutions in a form of free solvated ions (or if, so only in very low concentrations) but rather in the form of associates or unsolvated intimate ion pairs. Similar conclusions have been drawn also by *Kay* [5] who having studied tetraalkylammonium salts in methanol, declared that association of ions with large radius is generally attributed to their diminished solvation. He demonstrated that iodides, in contrast to chlorides and to some extent also to bromides, are almost completely associated in methanol. Even more marked association was found in ethanol [10]. The K and Λ_0 values of compounds *V—VIII* differ from each other to a less extent than those found for compounds *I—IV*. It suggests more important influence of anions on ion interactions in compounds *I—IV* than it is in the case of compounds *V—VIII.*

It is of interest to compare dissociation constants of compounds the anions of which are the same and cations are different (compounds *III* and *VI*). Stronger interactions of ions exist in compound *III* (K value is lower and Λ_0 is higher than the same values of *VI*). Also this conclusion is in agreement with the literature data. *Tucker* and *Kraus* [11] as well as *Kay* [5] found out that on passing from a cation with larger radius to a smaller one, the K value decreases and Λ_0 increases because smaller cations are more mobile. Moreover, benzyl group at the position 3 of the benzothiazole skeleton (compound *VI*) stabilizes cation by a space $N^+—\pi$ interaction which causes delocalization and dispersion of the charge to the greater extent than methyl group (compound *III*) can do. The consequence is weakened interaction between ions and therefore, facilitated dissociation of the compound *VI.* Interpretation of K and Λ_0 values of compounds *V—VIII* fits the conclusions made for compounds *I—IV*. Somewhat higher value of Λ_0 found for the compound *VII*, in comparison with compounds *V* and *VIII*, can be explained by the formation of small charged associates which are fairly mobile in a solution. Nonetheless, Λ_0 of the compound *VII* is lower than that of *IV*, which is in accord with the size of cations. The order of K values for bromides and nitrates is in agreement with *D'Aprano*'s sequence [6,7] found for tetraalkylammonium salts in solvents the relative permittivity of which is close to that of ethanol.

Compounds *IX*—*XXI* are of a different kind. The anion is the same (Br^-) but cations are differing. Though variation of the substituent at the nitrogen atom of benzothiazolium cation has an effect on dissociation process, the actual changes in both series of values are unimportant (the compound *XV* is an exception). It is a result of too a narrow range of substituents and their effects. Higher K value of the compound *IX* than the K value of the compound *X* is plausibly associated with different electron densities of the allyl and the propargyl groups. The former group is more polarizable and hence, in its case the feasibility of interaction with the anion is greater. The same reason applies also for compounds *XVI* and *XVII*, in favour of the compound *XVI*.

Compounds *XII*—*XXI* differ from each other by alkyl groups in the ester moiety of benzothiazolium cation. Steric effects of alkyl groups seem to play an inferior role in dissociation of our salts as, for instance, methyl ester has higher value of K than ethyl or isopropyl esters, but lower than propyl or heptyl esters. Resonance effect of the carbonyl group cannot operate due to the presence of the methylene group which insulates this group from the unsaturated bonds in benzothiazole skeleton. Inductive effects of alkyl groups [12] do not correlate with the K values, either. The overall effect of groups — as a sum of the all mentioned factors — does not operate through bonds but rather through space or solvent molecules. Hence, stereochemistry of species created as a result of nonbonding interactions plays an important role in the dissociation process. Apart from this, the dissociation is affected by association of ions. Such an association is preferred in solvents with low relative permittivity. In these solutions, K and Λ_0 values can as well reflect the presence of various polyionic, either charged or neutral species. For example, tetraisoamylammonium nitrate solution in dioxan ($c = 3 \times 10^{-5}\,\text{mol dm}^{-3}$) contains free nitrate ions with $c = 8 \times 10^{-12}\,\text{mol dm}^{-3}$; *i.e.* the salt appears to be almost completely in the form of associates [13].

Our previous paper [14] describes stimulatory/inhibitory effects of these compounds on the growth of vetch roots (*Vicia sativa* L.). Now we attempted to find a dependence of the activity of a particular compound on its value of dissociation constant. The synthesized compounds were divided into three groups. Each group contains the salts with either the same cation or anion. Trying to evaluate these relationships, we bear in mind the fact that overall activity is the result of operation of many factors, and moreover, no necessarily the same factor is crucial in all cases. Relatively high values of dissociation constants do not provide any information about the quality of the action (stimulation or inhibition). The compounds of the first group (*I*—*IV*) possess the same substituent at the position 3 ($R=CH_3$) and anions vary. As already mentioned, we assume the presence of strong ionic interactions and formation of associates in compounds *II* and *III*. Consequently, their activity in inhibition (*III*) or stimulation (*II*) areas is negligible. In this sense, it is quite interesting to compare the values of dissociation constants of compounds *III* and *VI* with their biological activities. Higher values of dissociation constants of compounds *I* and *IV* express their better activity in stimulation and inhibition areas, respectively. The second group of compounds is characterized by bulkiness (in comparison with the former group) of the cation and therefore, the influence of the anion is lessened and the differences between the K values are small. The third group (compounds *XII*—*XXI*) has the same anion ($X=Br^-$) and the alkoxy group of esters at the position 3 is altered. Comparison of the stimulation activity and the dissociation constants (compounds *XI*, *XIV*—*XVI*, *XX*, and *XXI*) revealed their parallelism. The only "anomaly" was observed: The activity of the compound *XVI* is lower than that of the compound *XX* (the difference being 3.3 %) while the values of dissociation constants are in the reverse order. Such an anomaly can as well account for an error in the biological testing. The activities of the rest of compounds follow the same trend as the values of dissociation constants in the whole concentration scale tested (10^{-13}—10^{-3} mol dm^{-3}).

Our first study of such relationships on benzothiazolium salts indicates the possibility to utilize dissociation constants as a method for the preliminary screening of growth-regulation activity. Compounds with very low K values can be immediately excluded as potential growth regulators and therefore, they do not have to pass any biological tests. In our case, just growth effect of compounds *I*, *IV*, *VII*—*IX*, *XV*, and *XVI* should have been tested. Dissociation constants can only be compared in one series of compounds, *e.g.* when either the substituent at position 3 or an anion is changed. The outlined relationship will be studied on larger series of compounds prepared in our laboratory.

Experimental

Benzothiazolium salts were synthesized according to [14]. Ethanol was dried by the method described by *Riddick* and *Bunger* [15]. Conductometric measurements were carried out with a Radelkis OK-102/1 instrument. Resistance capacity of a conductometric vessel was determined by means of known value of the molar conductivity of KCl solution ($c = 1 \times 10^{-3}$ mol dm^{-3}) in anhydrous ethanol at 25 °C. The relative permittivity of the solvent was 24.53 and its viscosity 0.001078 Pa s. All measurements were performed at 25 °C. The conductivity of anhydrous ethanol (0.13 μS cm^{-1}) is negligible in comparison with the conductivity established for a solution with the lowest concentration of the salt. The effect on growth regulation of vetch roots was determined according to [16].

References

1. Kraus, Ch. A. and Gleysteen, L. F., *J. Amer. Chem. Soc. 69,* 451 (1947).
2. Ramsey, J. B. and Colichman, E. L., *J. Amer. Chem. Soc. 69,* 3041 (1947).
3. Colichman, E. L., Varderzarden, W. R., and Gordon, A. R., *J. Amer. Chem. Soc. 74,* 1953 (1952).
4. Graham, J. R., Kell, G. S., and Gordon, A. R., *J. Amer. Chem. Soc. 79,* 2352 (1957).
5. Kay, R. L., Zawoyski, C., and Evans, D. F., *J. Phys. Chem. 69,* 4208 (1965).
6. D'Aprano, A., Donato, D. I., and Caponetti, E., *Ann. Chim.* (Rome) *66,* 186 (1976).
7. D'Aprano, A. and Fuoss, R. M., *J. Solution Chem. 4,* 175 (1975).
8. Fuoss, R. M. and Kraus, Ch. A., *J. Amer. Chem. Soc. 55,* 476 (1933).
9. Fuoss, R. M., *J. Amer. Chem. Soc. 57,* 488 (1935).
10. Kay, R. L. and Evans, D. F., *J. Phys. Chem. 68,* 1177 (1964).
11. Tucker, L. M. and Kraus, Ch. A., *J. Amer. Chem. Soc. 69,* 454 (1947).
12. Perjéssy, A. and Sutoris, V., *Acta Fac. Rerum Natur. Univ. Comenianae (Chimia) 20,* 71 (1974).
13. Dvořák, J. and Koryta, J., *Elektrochemie.* (Electrochemistry.) Academia, Prague, 1983.
14. Chabreček, P. and Sutoris, V., *Chem. Papers 40,* 631 (1986).
15. Riddick, J. A. and Bunger, W. B., *Techniques of Chemistry,* Vol. *II. Organic Solvents,* 3rd Edition. (Weissberger, A., Editor.) P. 645. Wiley—Interscience, New York, 1970.
16. Sutoris, V., Sekerka, V., and Halgaš, J., *Czechoslov. Appl.* 231212 (1986).

Translated by J. Šraga