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RETENTION PREDICTION OF ANALYTES IN REVERSED-PHASE HIGH-PERFORMANCE LIQUID CHROMATOGRAPHY BASED ON MOLECULAR STRUCTURE

IV. BRANCHED AND UNSATURATED ALKYLBENZENES

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SUMMARY

As part of a study to predict the retention of analytes in reversed-phase liquid chromatography the effects of isomerisation and unsaturation in alkyl chain substituents on an aromatic ring have been examined. The contributions of the presence of branching and of olefinic groups have been related to the eluent composition in methanol-buffer and acetonitrile–buffer eluents. These results have been applied to a comparison of the influence on retention of primary, secondary and tertiary hydroxyl groups in isomeric phenylpropanols.

INTRODUCTION

A method has been developed to predict the retention of analytes in reversed-phase liquid chromatography based on their molecular structure and the composition of the mobile phase[1]. The retention index (I) of a compound is calculated by the summation of the retention index of a parent structure (I_P, benzene) and substituent index contributions from alkyl groups ($I_{S,R}$), from substituents on the aromatic ring ($I_{S,Ar-X}$) and on aliphatic carbons ($I_{S,Al-X}$), and from interactions between the substituents ($I_{I,Z-Y}$). In previous reports the coefficients of the quadratic equations relating the eluent composition to the contributions for individual aromatic[1] and aliphatic[2] substituent groups have been reported and the steps taken to ensure reproducibility throughout the study have been described[3]. The retention coefficients are held in a database which can be interrogated by an expert system program CRIPES (Chromatographic Retention Index Prediction Expert System)[4]. Throughout the study the retention measurements have been based on retention indices using the alkyl aryl ketone scale to increase the reproducibility and to improve the interchangability of the predictions between columns[5].

Previous studies in a number of laboratories have examined the capacity factors of branched and normal chain alkylbenzenes[6–8], alkylphenols[9] and aliphatic al-

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kanes[10] in reversed-phase liquid chromatography. The presence of secondary and tertiary groups were found to cause a reduction in the retention compared to unbranched compounds and the effect increased with the degree of branching. This suggested that a prediction method could not be based on a simple summation of the number of aliphatic carbon atoms. In an attempt to quantify the changes in phenolic antioxidants Popl *et al.*[9] have calculated the contributions for the different alkyl groups as retention index increments using a scale based on the polycyclic aromatic hydrocarbons. They related the changes to the eluent composition using a linear function and found that the slope of the relationship for *n*- and branched alkyl groups differed and this could be predicted in an additive manner. In a more recent study Knox *et al.*[8] confirmed the relative retentions observed earlier by Smith[6] for the isomeric alkyl- and polymethylbenzenes. Both these studies suggested that although the molecular connectivity of the alkylbenzenes showed a reasonable correlation with retention this was largely a function of the number of carbon atoms and was a poor guide to the relative retentions of isomeric compounds such as iso- and *sec.*-butylbenzene.

In the present paper the effect of branching and unsaturation in alkyl groups substituted on an aromatic ring are examined. The results are then applied to the comparison of isomeric phenylpropanols to determine the contributions from primary, secondary and tertiary hydroxyl groups.

EXPERIMENTAL

The chemical, methods and equipment were as described in Part I[1].

RESULTS AND DISCUSSION

The first step in the prediction of the retention of a compound is to calculate a value for the unsubstituted carbon skeleton as a summation of contributions from the aromatic ring and from the aliphatic carbon side chains. The parent retention index values for benzene have been determined empirically[1] and as the method is based in retention indices each aliphatic carbon atom should by definition make a contribution of 100 units. However, when studying the retention increments for increases in the length of *n*-alkyl group substituted on an aromatic ring, it was found that going from toluene to ethylbenzene caused a smaller change than 100 units in the retention indices, which was ascribed to the effects of hyperconjugation. An interaction index term ($I_{\mathrm{I,PhCH_2R}}$ = -12 units; Ph = phenyl) for alkyl substitution on the benzylic carbon in both methanol–buffer and acetonitrile–buffer eluents was determined. In view of the earlier reports of the differences in the retention of branched alkylbenzenes, it appeared that a similar interaction term might also be needed if secondary and tertiary carbons are present in the analyte.

Isomeric alkylbenzenes

The capacity factors (Table I) of isopropylbenzene and iso-, *sec.*- and *tert.*-butylbenzene were determined over the eluent ranges methanol–buffer (50:50) to (80:20) and acetonitrile–buffer (30:70) to (80:20) and were compared with the capacity factors of ethyl-, *n*-propyl- and *n*-butylbenzene determined previously[2]. The ethyl-

TABLE I

CAPACITY FACTORS OF ISOMERIC ALKYLBENZENES

Compound	*Capacity factor*					
	Modifier (%)					
	30	*40*	*50*	*60*	*70*	*80*
Methanol–buffer						
Ethylbenzene[a]		65.28	27.28	13.73	5.02	2.35
Isopropylbenzene		130.97	51.64	19.16	7.41	3.08
n-Propylbenzene[a]		165.50	59.57	24.60	8.19	3.38
tert.-Butylbenzene		–	76.08	27.61	9.69	3.81
sec.-Butylbenzene		–	95.77	32.85	11.16	4.38
Isobutylbenzene		–	123.12	38.89	12.84	4.72
n-Butylbenzene[a]		–	130.97	41.20	13.37	4.95
Acetonitrile–buffer						
Ethylbenzene[a]	59.53	22.38	9.46	4.66	2.67	1.58
Isopropylbenzene	131.26	35.92	14.36	6.70	3.50	2.06
n-Propylbenzene[a]	137.23	42.42	15.83	7.17	3.88	2.15
tert.-Butylbenzene	216.36	53.09	19.57	8.77	4.07	2.50
sec.-Butylbenzene	290.89	65.43	23.39	10.28	4.69	2.82
Isobutylbenzene	334.41	73.41	25.71	11.01	5.38	3.02
n-Butylbenzene[a]	308.86	79.97	27.39	11.81	5.63	2.94

[a] included from ref. 2 for comparison.

TABLE II

RETENTION INDICES OF ISOMERIC ALKYLBENZENES

Compound	*Retention index*					
	Modifier (%)					
	30	*40*	*50*	*60*	*70*	*80*
Methanol–buffer						
Ethylbenzene[a]		1073	1101	1126	1149	1170
Isopropylbenzene		1154	1179	1202	1224	1246
n-Propylbenzene[a]		1173	1201	1226	1249	1270
tert.-Butylbenzene		–	1251	1269	1290	1313
sec.-Butylbenzene		–	1280	1298	1320	1341
Isobutylbenzene		–	1296	1317	1341	1362
n-Butylbenzene[a]		–	1301	1326	1349	1370
Acetonitrile–buffer						
Ethylbenzene[a]	1098	1115	1128	1139	1146	1151
Isopropylbenzene	1169	1186	1196	1203	1211	1215
n-Propylbenzene[a]	1198	1215	1228	1239	1246	1251
tert.-Butylbenzene	1230	1248	1256	1264	1272	1280
sec.-Butylbenzene	1266	1281	1291	1302	1312	1325
Isobutylbenzene	1283	1299	1310	1322	1333	1344
n-Butylbenzene[a]	1298	1315	1328	1339	1346	1351

[a] Predicted retention indices calculated as in ref. 2.

TABLE III

RETENTION INDEX INCREMENTS FOR METHYL SUBSTITUENTS ON ALKYL CHAINS

Alkylbenzene	*Carbon substituted*	*Retention index increment for each branched methyl*											
		Compared to n-alkylbenzene						*Corrected for $I_{I,PhCH_2-R}$*					
		Modifier (%)						*Modifier (%)*					
		30	*40*	*50*	*60*	*70*	*80*	*30*	*40*	*50*	*60*	*70*	*80*
Methanol–buffer													
Isopropylbenzene	1	–	81	78	76	75	76	–	93	90	88	87	88
sec.-Butylbenzene	1	–	–	79	72	71	71	–	–	91	84	83	83
tert.-Butylbenzene[a]	1	–	–	75	71	70	71	–	–	87	83	82	83
Isobutylbenzene	2	–	–	95	91	92	92	–	–	95	91	92	92
Acetonitrile–buffer													
Isopropylbenzene	1	71	71	68	64	65	64	83	83	80	76	77	76
sec.-Butylbenzene	1	68	66	63	63	66	74	80	78	75	75	78	86
tert.-Butylbenzene[a]	1	66	66	64	61	62	64	78	78	76	73	74	76
Isobutylbenzene	2	85	84	82	83	87	93	85	84	82	83	87	93

[a] Change in retention index divided by 2.

and propylbenzenes were also examined at methanol–buffer (40:60). These results were then used to calculate the retention indices (Table II). As expected from the earlier work, as the degree of branching increased from normal to iso or *sec.* to *tert.* groups the capacity factors and retention index values decreased. The elution order agreed with the earlier studies[6,8].

In order to determine the changes due to the addition of the secondary or tertiary methyl group to the alkyl chain, the retentions of the branched compounds were compared with those of the corresponding unsubstituted *n*-alkylbenzenes. Thus isopropylbenzene and *tert.*-butylbenzene were compared with ethylbenzene and isobutylbenzene and *sec.*-butylbenzene with *n*-propylbenzene. In each case the retention index increment for the addition of the branched methyl group (Table III) was calculated by subtracting the predicted retention index for the parent *n*-alkylbenzene derived from the earlier study[2] (given in Table II).

The increments for the secondary and tertiary methyl groups substituted on the benzylic carbon (isopropyl-, *sec.*-butyl- and *tert.*-butylbenzene) were very similar (71–81 units in methanol and 61–74 units in acetonitrile). However, the retention index increments of a methyl group substituted onto the second carbon (91–95 units in methanol and 82–93 units in acetonitrile) were always larger. Both groups therefore made a smaller contribution to retention than that for an increase in a linear alkyl chain by a methylene group (100 units).

It can be assumed that the interactions noted earlier in the *n*-alkylbenzenes for substitution on the benzylic carbon are also present in the branched chain compounds. The retention index increments for the methyl groups substituted on a benzylic carbon should therefore be corrected by adding 12 units to their value. These corrected values (Table III) show only small differences between the increments for secondary and tertiary methyl groups, irrespective of their position.

Thus the presence of a branched carbon reduces the effect of alkyl substitution compared to an unbranched group. This can be accounted for by an interaction index term ($I_{\mathrm{I,branch}}$) whose value can be determined from the difference between the expected increment of 100 units for a methylene group and the corrected retention index increments from Table III. The magnitude of the branching increments vary over only a small range with eluent composition (-7 to -18 units in methanol–buffer and -17 to -27 units in acetonitrile–buffer, Table IV). These changes in the values with eluent composition are within the experimental error margins of ± 10 retention index units estimated for the study[3]. The mean value for each eluent was therefore used as the interaction increment (methanol, $I_{\mathrm{I,branch}} = -12$ and acetonitrile, $I_{\mathrm{I,branch}} = -20$). With this proposal a *tert.*-butyl group would be considered to contain two branches.

The retention indices of the alkylbenzenes can be correlated with the corresponding Hansch π constants used in the determination of predicted octanol–water partition coefficients[11]. These contributions decrease from *n*-propyl (1.55) to isopropyl (1.53) and from *n*-butyl (2.13) to *sec.*-butyl (2.04) to *tert*-butyl (1.98). However, a value for isobutyl has not been reported[11]. Thus branching decreases the partition coefficients for *tert.*-butyl by nearly twice the value of a single branch.

It is also possible to calculate the molecular connectivity indices for the alkyl chains as described by Kier *et al.*[12]. The indices for the straight chain isomer, *n*-propyl (1.411) is higher than for the corresponding branched chain, isopropyl (1.354). How-

TABLE IV

INTERACTION INCREMENTS FOR A BRANCH IN AN ALKYL GROUP ON AN AROMATIC RING

Interaction increment for branching = corrected retention index increment for branched methyl (from Table III) − 100 (nominal value for methyl). The mean values are used to determine values for $I_{\mathrm{I,branch}}$ (see discussion).

Carbon chain	*Interaction increment branching*[a] *Modifier (%)*					
	30	*40*	*50*	*60*	*70*	*80*
Methanol–buffer						
$CH(CH_3)_2$	–	−7	−10	−12	−13	−12
$C(CH_3)_3$	–	–	−13	−17	−18	−17
$CH(CH_3)CH_2CH_3$	–	–	−9	−16	−17	−17
$CH_2CH(CH_3)_2$	–	–	−5	−9	−8	−8
Mean	–	−7	−9	−14	−14	−14
Acetonitrile–buffer						
$CH(CH_3)_2$	−17	−17	−20	−24	−23	−24
$C(CH_3)_3$	−22	−22	−24	−27	−26	−24
$CH(CH_3)CH_2CH_3$	−20	−22	−25	−25	−22	−14
$CH_2CH(CH_3)_2$	−15	−16	−18	−17	−13	−7
Mean	−19	−19	−22	−23	−21	−17

[a] A *tert.*-butyl group is considered to contain two branches.

ever, as found previously[6,8] although the indices for the butyl groups decrease as the branching increases, *n*-butyl (1.971), isobutyl (1.827), *sec.*-butyl (1.892) and *tert.*-butyl (1.661), they do not agree with the order of elution of the iso- and *sec.*-isomers.

Unsaturated alkyl chains

In early high-performance liquid chromatography studies Shabron *et al.*[13] suggested that the presence of an unsaturated group (–CH = CH–) had a similar effect on retention as a single methylene group and showed that this relationship was valid for a series of polycyclic hydrocarbons. In the present work, the unsaturated alkylbenzenes, 1-phenyl-1-propene ($PhCH=CHCH_3$) and 3-phenyl-1-propene ($PhCH_2CH=CH_2$) have been examined. The capacity factors of these compounds were used to calculate their retention indices (Table V). In both cases the retentions were shorter than for *n*-propylbenzene, the corresponding saturated alkylbenzene (Tables I and II). It was decided that, rather than regarding the olefinic group as part of an alkyl chain, it would be treated as a substituent placed either on the aromatic ring or on an aliphatic side chain. This approach has also been used for other π-bonded carbons such as ketones and esters. The contributions of the olefinic groups were therefore calculated as retention index increments (Table VI) by subtraction of the calculated retention index values for benzene and 100 units for the methylene or methyl group from the indices of the phenylpropenes.

In both eluents the effect of the aliphatic olefinic group [$Ph(CH_2)_nCH=CHR$] was larger than for the aryl conjugated group ($PhCH=CHR$). The range of values

TABLE V

CAPACITY FACTORS AND RETENTION INDICES OF PHENYLPROPENES

Compound	*Capacity factor*						*Retention index*					
	Modifier (%)						*Modifier (%)*					
	30	*40*	*50*	*60*	*70*	*80*	*30*	*40*	*50*	*60*	*70*	*80*
Methanol–buffer												
3-Phenyl-1-propene		91.64	31.68	12.03	5.41	2.39		1105	1133	1151	1166	1186
1-Phenyl-1-propene		112.43	38.39	14.85	6.17	2.80		1128	1156	1176	1194	1220
Acetonitrile–buffer												
3-Phenyl-1-propene	83.52	29.08	10.38	5.06	2.63	1.28	1119	1127	1132	1135	1135	1138
1-Phenyl-1-propene	96.47	32.77	13.13	5.56	2.90	1.43	1136	1144	1149	1157	1163	1175

TABLE VI

RETENTION INDEX INCREMENTS FOR OLEFINIC GROUP –CH = CH–

Retention index increments and coefficients for their relationship to eluent composition: $I_S = ax^2 + bx + c$; x = % modifier.

Compound	*Retention index increment*						*Coefficients of regression equation for I_S*			
	Modifier (%)									
	30	*40*	*50*	*60*	*70*	*80*	*Substituent group*	*a*	*b*	*c*
Methanol–buffer										
3-Phenyl-1-propene		122	118	114	108	83	Aliphatic CH = CH	−0.0314	2.891	74
1-Phenyl-1-propene		145	141	139	136	111	Aromatic CH = CH	−0.0307	2.956	55
Acetonitrile–buffer										
3-Phenyl-1-propene	109	100	92	84	75	78	Aliphatic CH = CH	0.0100	−1.780	154
1-Phenyl-1-propene	126	117	109	106	103	115	Aromatic CH = CH	0.0223	−2.741	189

from 99 to 142 units agreed with the observation[13] that the effect was much less than an ethyl group and was similar to an single methylene group. The coefficients for the substituent indices (I_S) relating the contributions of the substituents to the eluent composition were then calculated (Table VI).

Differences between the allyl and propenyl groups are also seen in the octanol–water partition coefficients (P) of the two alkenes: allylbenzene, log P = 3.23 and 1-phenyl-1-propene, 3.35[11]. Hansch and Leo[11] suggested that conjugation reduced the polarity of the latter alkene and hence it has a higher partition coefficient and longer retention.

Isomeric phenylpropanols

In a previous study[2], we examined the retention of a series of phenyl-*n*-alkanols and determined the contribution of the primary aliphatic hydroxyl group. The extent of the interaction between the phenyl and hydroxyl groups on the same ($I_{\mathrm{I},1\text{-OH}}$, 20–100 units) and adjacent carbon atoms ($I_{\mathrm{I},2\text{-OH}}$, 15–50 units) were also measured[2]. These values and the coefficients of the retention indices for the branched alkyl chains can be used to provide a baseline for the comparison of the effects of primary, secondary and tertiary hydroxyl groups.

The capacity factors and retention indices of five isomeric phenylpropanols were measured (Table VII) The compounds can be divided into those containing primary (3-phenyl-1-propanol and 2-phenyl-1-propanol), secondary (1-phenyl-1-propanol and 1-phenyl-2-propanol) and tertiary hydroxyl groups (2-phenyl-2-propanol). The retention of each isomer differed and the order differed in the two eluents.

The effect of the hydroxyl groups on the retention indices can be determined by subtracting the calculated retention index of the corresponding unsubstituted alkylbenzene and corrections for any interactions between the phenyl and hydroxyl groups

TABLE VII

CAPACITY FACTORS AND RETENTION INDICES OF ISOMERIC PHENYLPROPANOLS

Compound	*Capacity factor*						*Retention index*					
	Modifier (%)						*Modifier (%)*					
	30	*40*	*50*	*60*	*70*	*80*	*30*	*40*	*50*	*60*	*70*	*80*
Methanol–buffer												
2-Phenyl-2-propanol	–	7.83	3.31	1.70	1.01	0.54	–	825	823	819	809	789
2-Phenyl-1-propanol	–	8.15	3.48	1.72	1.02	0.55	–	830	827	821	812	792
1-Phenyl-2-propanol	–	8.18	3.52	1.75	1.02	0.57	–	830	829	824	812	797
3-Phenyl-1-propanol	–	9.12	3.75	1.78	1.03	0.56	–	840	835	828	813	793
1-Phenyl-1-propanol	–	9.81	4.04	1.95	1.11	0.60	–	851	847	842	830	812
Acetonitrile–buffer												
2-Phenyl-2-propanol	4.73	2.29	1.48	0.97	0.66	0.42	772	760	750	745	742	746
2-Phenyl-1-propanol	4.96	2.35	1.45	0.94	0.63	0.42	778	763	746	738	733	740
1-Phenyl-2-propanol	4.61	2.23	1.41	0.92	0.64	0.43	769	755	740	734	734	748
3-Phenyl-1-propanol	5.18	2.37	1.42	0.91	0.62	0.41	782	756	739	728	731	735
1-Phenyl-1-propanol	6.00	2.79	1.74	1.10	0.73	0.47	801	791	780	775	773	777

TABLE VIII

SUBSTITUENT INDEX INCREMENTS CALCULATED FOR HYDROXYL GROUPS

Compound	*Retention index increment*					
	Modifier (%)					
	30	*40*	*50*	*60*	*70*	*80*
Methanol–buffer						
3-Phenyl-1-propanol		−333	−366	−398	−436	−477
2-Phenyl-1-propanol		−339	−376	−411	−444	−486
1-Phenyl-1-propanol		−358	−399	−438	−485	−531
1-Phenyl-2-propanol		−363	−393	−432	−444	−505
2-Phenyl-2-propanol		−360	−399	−437	−482	−521
$\delta I_{sec.\text{-}OH}$ (mean)		−360	−393	−436	−470	−519
Acetonitrile–buffer						
3-Phenyl-1-propanol	−416	−459	−489	−511	−515	−516
2-Phenyl-1-propanol	−415	−452	−487	−509	−526	−527
1-Phenyl-1-propanol	−456	−495	−527	−550	−566	−585
1-Phenyl-2-propanol	−456	−492	−525	−545	−557	−551
2-Phenyl-2-propanol	−456	−494	−526	−549	−565	−584
$\delta I_{sec.\text{-}OH}$ (mean)	−456	−494	−526	−548	−563	−573

on the assumption that these are not dependent on the "type" of hydroxyl group but only on the distance between the groups. For the compounds containing a branched alkyl chain (2-phenyl-2-propanol and 2-phenyl-1-propanol), this calculation should also include the interaction index term for branched alkyl chains ($I_{I,\mathrm{branch}}$) as well as the interaction index for the substitution of methyl groups on the benzylic carbon ($I_{I,\mathrm{PhCH_2R}}$). Thus for 1-phenyl-2-propanol, which contains a straight alkyl chain with a secondary hydroxyl group substituted on C-2 of the side chain, the predicted retention for the skeleton and interactions can be calculated as ($I_P + 3I_{S,CH_2} + 2I_{I,PhCH_2R} + I_{I,2\text{-}OH}$) and for the more complex tertiary alcohol, 2-phenyl-2-propanol, which contains a branched chain and a tertiary hydroxyl group ($I_P + 3I_{S,CH_2} + 2I_{I,PhCH_2R} + I_{I,1\text{-}OH} + I_{I,\mathrm{branch}}$).

TABLE IX

SUBSTITUENT INDEX EQUATIONS FOR SECONDARY AND TERTIARY HYDROXYL GROUPS

The same substituent index value is used for both secondary and tertiary hydroxyl groups. Based on mean values in Table VIII. $I_{S,sec.\text{-}OH} = ax^2 + bx + c$; x = % modifier

Modifier	*Coefficients of regression equation*		
	a	*b*	*c*
Methanol	−0.0164	−1.979	−254
Acetonitrile	0.0371	−6.411	−297

The retention index increments (Table VIII) for the secondary hydroxyl groups in 1-phenyl-1-propanol and 1-phenyl-2-propanol and the tertiary hydroxyl group in 2-phenyl-2-propanol were very similar but all were significantly larger than those for the primary hydroxyl groups in 3-phenyl-1-propanol and 2-phenyl-1-propanol. At each eluent composition most of the values for the secondary and tertiary hydroxyl groups were within a range of ± 10 units and as they are based on the accumulation of multiple interaction terms, they can be considered to be well within the experimental error estimated for the accuracy of the determination of retention indices[3]. The coefficients of a single quadratic equation relating the change in substituent index ($I_{S,sec.\text{-}OH}$) with proportion of organic modifier for both the secondary and tertiary hydroxyl groups has therefore been calculated (Table IX) from the mean retention increments [$\delta I_{sec.\text{-}OH}$ (mean), Table VIII].

CONCLUSIONS

It has been possible to derive coefficients for expressions which represent the effect of branching of the alkyl chain in alkylbenzenes and for the presence of aliphatic and aromatic unsaturated groups. The validity of their use in prediction has been tested by examining isomeric phenylpropanols and the results suggest a distinction between primary hydroxyl and secondary and tertiary hydroxyl groups. Each of the terms has been included in the database for retention prediction.

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REFERENCES

1 R. M. Smith and C. M. Burr, *J. Chromatogr.*, 475 (1989) 57.
2 R. M. Smith and C. M. Burr, *J. Chromatogr.*, 481 (1989) 71.
3 R. M. Smith and C. M. Burr, *J. Chromatogr.*, 475 (1989) 75.
4 C. M. Burr and R. M. Smith, *Anal. Proc.*, 26 (1989) 24.
5 R. M. Smith, *Adv. Chromatogr.*, 26 (1987) 277.
6 R. M. Smith, *J. Chromatogr.*, 209 (1981) 1.
7 K. Jinno and K. Kawasaki, *Chromatographia*, 17 (1983) 337.
8 J. H. Knox, J. Kriz and E. Adamcova, *J. Chromatogr.*, 447 (1988) 13.
9 M. Popl, I. Vit and F. Smejkal, *J. Chromatogr.*, 213 (1981) 363.
10 J. Burda, M. Kuras, J. Kriz and L. Vodicka, *Fresenius' Z. Anal. Chem.*, 321 (1985) 549.
11 C. Hansch and A. Leo, *Substituent Constants for Correlation Analysis in Chemistry and Biology*, Wiley, New York, 1979.
12 L. B. Kier, L. H. Hall, W. J. Murray and M. Randic, *J. Pharm. Sci.*, 64 (1975) 1971.
13 J. F. Schrabon, R. J. Hurtubise and H. F. Silver, *Anal Chem.*, 49 (1977) 2253.