

On the Solute–Stationary Phase Interaction in Gas-Liquid Chromatography. Evaluation on the Relative Retention Values for Mono- and Polyalkyl-Substituted Benzene Derivatives

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The values of $\log \gamma$ for monosubstituted benzene derivatives can be expressed after regression analyses by a linear combination of the quantitative structure–activity relationship (QSAR) descriptors σ_s , μ^2/α , and σ_π^\pm . The inclusion of aniline series derivatives demands an additional descriptor pK_a , ascribed to the CH/N interaction between the stationary liquid and the nitrogen lone pair. Furthermore, for all cases of polyalkylbenzene derivatives, the descriptor σ_s is effective, and the number of vicinal type CH_3 -pairs represented at first by the descriptor ortho number N_o can be transformed to the corrected σ_π^+ , representing the CH/ π type charge-transfer interaction between the substrate and the stationary liquid.

Keywords gas-liquid chromatography; relative retention value; regression analysis; substituent entropy constant σ_s ; descriptor μ^2/α ; substituent constant σ_π^\pm ; monosubstituted benzene derivative; polyalkylbenzene derivative; CH/ π interaction; ortho number N_o .

In our previous reports^{1,2)} on the study of the gas liquid chromatography (GLC) relative retention value $\log \gamma$, regression analyses using our novel quantitative structure–activity relationship (QSAR) descriptors σ_s and μ^2/α afforded successful results. In this work, in view of the above results, we have tried to extend our approach to the monosubstituted benzene series, together with polyalkylbenzene derivatives, and examined the usefulness of these descriptors, as well as the role of the descriptor $\Sigma\sigma_\pi^\pm$ representing the charge-transfer interaction in a variety of CH/ π interactions.³⁾

Experimental

Conditions of GLC The conditions were the same as in our previous reports.^{1,2)} All materials used in the measurements were of JIS grade, purchased from commercial sources.

Substituent Entropy Constant σ_s . a) Monosubstituted Benzene Derivatives: All values were taken from our previous report.⁴⁾

b) Alkylbenzene Derivatives: For the monoalkylbenzene series, the data were taken from our previous report,⁴⁾ and those of polyalkylbenzenes were obtained from reported S_{298}° (g) values.⁵⁾

Descriptor μ^2/α a) Dipole Moment: All data were observed ones, cited from the literature.⁶⁾

b) Polarizability α [$\times 10^{-24} \text{ cm}^3$] was calculated by use of the Clausius–Mosotti equation, using the refractive indices⁷⁾ observed with the Na_D line at 20 °C.

c) Substituent Constant σ_π^\pm : Data were cited from the literature.⁸⁾

d) Regression Analyses: Regression analyses were carried out on NEC PC-9801/M/VX and EPSON PC-286V personal computers using a program package for multivariate analyses MVA (version 1.21) developed by Takagi *et al.*⁹⁾

Results and Discussion

Monosubstituted Benzene Derivatives In the first step of this work, the authors divided monosubstituted benzene derivatives into four groups—namely, monoalkylbenzene, alkoxybenzene, and aniline derivatives, and those having electron-attracting substituents—and regression analyses have been carried out separately. The following results were obtained.

A. Monoalkylbenzene Derivatives The data in Table I afforded Eq. 1 after regression analysis:

$$\log \gamma = 4.510(\pm 0.550)\sigma_s - 0.044(\pm 0.089) \quad (1)$$

$$n=9, r=0.991, s=0.046, F=375.6, AIC=-26.210$$

$$R=\text{H, Me, Et, Pr, iso-Pr, Bu, iso-Bu, sec-Bu, tert-Bu}$$

B. Alkoxybenzene Derivatives The data in Table II afforded Eq. 2 after regression analysis:

$$\log \gamma = 5.324(\pm 0.723)\sigma_s - 0.033(\pm 0.127) \quad (2)$$

$$n=6, r=0.995, s=0.050, F=418.4, AIC=-15.376$$

$$R=\text{H, OMe, O-Pr, O-iso-Pr, O-Bu}$$

C. Aniline Derivatives The data in Table III afforded Eq. 3 after regression analysis:

$$\log \gamma = 8.416(\pm 1.740)\sigma_s + 0.032(\pm 0.191) \quad (3)$$

$$n=6, r=0.989, s=0.078, F=180.4, AIC=-10.093$$

$$R=\text{H, NH}_2, \text{NHMe, NMe}_2, \text{NHEt, NEt}_2$$

D. Benzene Derivatives Having Electron-Attracting Substituents The data in Table IV afforded Eq. 4 after regression analysis:

$$\log \gamma = 5.351(\pm 0.832)\sigma_s + 0.337(\pm 0.140)\mu^2/\alpha - 0.006(\pm 0.153) \quad (4)$$

$$n=7, r=0.994, s=0.056, F=173.5, AIC=-16.308$$

$$R=\text{H, CN, COMe, COEt, COOMe, COOEt, NO}_2$$

TABLE I. Values of $\log \gamma$ for Monoalkylbenzene Derivatives and Their Descriptors σ_s .

		$\log \gamma$	σ_s
1	H	0.000	0.000
2	Me	0.258	0.076
3	Et	0.488	0.127
4	Pr	0.709	0.173
5	iso-Pr	0.637	0.159
6	Bu	0.950	0.213
7	iso-Bu	0.875	0.200
8	sec-Bu	0.845	0.202
9	tert-Bu	0.815	0.174

TABLE II. Values of $\log \gamma$ for Alkoxybenzene Derivatives and Their Descriptors σ_s .

		$\log \gamma$	σ_s
1	H	0.000	0.000
2	OMe	0.601	0.127
3	OEt	0.838	0.170
4	OPr	1.062	0.210
5	O-iso-Pr	1.025	0.200
6	OBu	1.302	0.237

TABLE III. Values of $\log \gamma$ for Monosubstituted Benzene Derivatives and Their Descriptors

		$\log \gamma$	σ_s	μ^2/α	σ_π^+	σ_π^-	pK_a
1	H	0.000	0.000	0.000	0.000		
2	Me	0.301	0.076	0.011	-0.078		
3	Et	0.538	0.127	0.024	-0.069		
4	Pr	0.760	0.173	0.021	-0.069		
5	iso-Pr	0.684	0.159	0.026	-0.051		
6	Bu	1.007	0.213	0.019	-0.069		
7	iso-Bu	0.895	0.200	0.019	-0.069		
8	sec-Bu	0.896	0.202	0.024	-0.051		
9	tert-Bu	0.853	0.173	0.027	-0.034		
10	COMe	0.940	0.142	0.602		0.266	
11	COEt	1.169	0.187	0.556		0.266	
12	COOMe	1.003	0.200	0.225		0.220	
13	COOEt	1.179	0.225	0.203		0.220	
14	CN	0.684	0.077	1.185		0.226	
15	NO ₂	0.977	0.115	1.134		0.332	
16	OMe	0.595	0.127	0.125	-0.281		
17	OEt	0.781	0.170	0.110	-0.281		4.58
18	NH ₂	0.670	0.074	0.196	-0.460		4.85
19	NHMe	0.939	0.103	0.203	-0.480		5.06
20	NMe ₂	1.051	0.134	0.150	-0.540		5.11
21	NHEt	1.104	0.116	0.180	-0.400		6.56
22	NEt ₂	1.340	0.157	0.159	-0.540		

TABLE IV. Values of $\log \gamma$ for Benzene Derivatives with Electron-Attracting Substituents, and Their Descriptors σ_s and μ^2/α

		$\log \gamma$	σ_s	μ^2/α
1	H	0.000	0.000	0.000
2	CN	0.743	0.077	1.134
3	COMe	0.999	0.142	0.621
4	COEt	1.245	0.187	0.512
5	COOMe	1.055	0.190	0.228
6	COOEt	1.227	0.225	0.225
7	NO ₂	1.048	0.121	1.185

E. Monosubstituted Benzene Derivatives All of the observed data and their descriptors are summarized in Table III, and the plots of $\log \gamma$ against σ_s are shown in Fig. 1. The regression analyses for 17 congeners, except the aniline series, afforded Eq. 5:

$$\log \gamma = 4.645(\pm 0.434)\sigma_s + 0.229(\pm 0.119)\mu^2/\alpha + 0.569(\pm 0.351)\sigma_\pi^- - 0.030(\pm 0.072) \quad (5)$$

$$n = 17, r = 0.992, s = 0.041, F = 280.7, AIC = -54.683$$

Inclusion of the aniline series requires an additional descriptor $pK_a^{(10)}$ as shown by Eq. 6:

$$\log \gamma = 4.736(\pm 0.490)\sigma_s - 0.238(\pm 0.140)\mu^2/\alpha + 0.549(\pm 0.412)\sigma_\pi^- + 0.090(\pm 0.011)pK_a - 0.045(\pm 0.081) \quad (6)$$

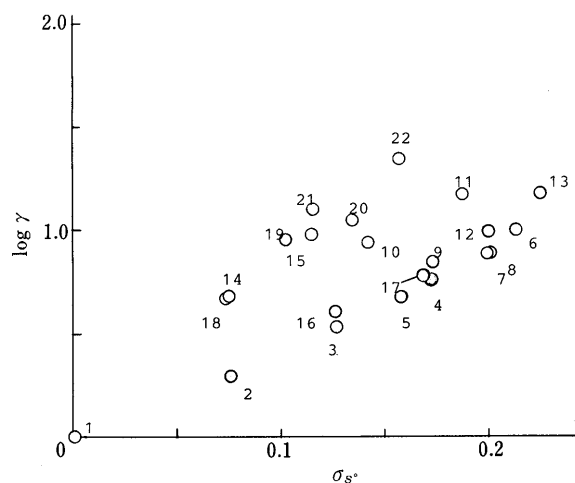
$$n = 22, r = 0.989, s = 0.050, F = 190.3, AIC = -63.326$$

The entry of pK_a for the aniline series could be ascribed to the participation of CH/N interaction between the hydrocarbon C-H on the stationary liquid and the nitrogen lone pair.

Alkylbenzene Derivatives All of the observed data and descriptors are summarized in Table V, and $\log \gamma$ is plotted against σ_s in Fig. 2, where the plots for the monoalkyl series are revealed to be linear against σ_s , but the accumulation of Me groups affords a marked increase of $\log \gamma$. The regression analyses for 27 congeners by use of the de-

TABLE V. Values of $\log \gamma$ for Mono- and Polyalkylbenzene Derivatives and Their Descriptors

		$\log \gamma$	σ_s	μ^2/α	$-\Sigma\sigma_\pi^+$	$\log K/K_0^{(1a)}$
1	H	0.000	0.000	0.000	0.000	0.000
2	Me	0.258	0.076	0.011	0.078	0.127
3	Et	0.488	0.127	0.024	0.069	
4	Pr	0.709	0.173	0.021	0.069	
5	iso-Pr	0.637	0.153	0.026	0.051	
6	Bu	0.950	0.213	0.019	0.069	
7	iso-Bu	0.875	0.200	0.019	0.069	
8	sec-Bu	0.845	0.202	0.024	0.051	
9	tert-Bu	0.813	0.173	0.027	0.034	
10	m-Me ₂	0.572	0.123	0.011	0.156	
11	p-Me ₂	0.536	0.117	0	0.156	0.265
12	m-Et ₂	0.920	0.213	0.019	0.136	
13	p-Et ₂	0.951	0.207	0	0.136	
14	m-Me,Et	0.734	0.176	0.019	0.147	
15	p-Me,Et	0.740	0.171	0	0.147	
16	1,3,5,-Me ₃	0.814	0.156	0	0.234	0.405
17	1,3,5,-Et ₃	1.275	0.276	0	0.207	
18	o-Me ₂	0.579	0.117	0.021	0.141	
19	o-Et ₂	0.971	0.208	0.019	0.126	
20	m-Me,Et	0.774	0.171	0.020	0.134	
21	1,2,4-Me ₃	0.846	0.167	0.006	0.219	
22	1,2,3-Me ₃	0.954	0.155	0.047	0.282	
23	1,2,3,4-Me ₄	1.233	0.190	0.018	0.423	
24	1,2,3,5-Me ₄	1.160	0.196	0.002	0.360	
25	1,2,4,5-Me ₄	1.142	0.192	0	0.282	0.625
26	Me ₅	1.522	0.217	0.014	0.564	0.791
27	Me ₆	1.870	0.225	0	0.846	1.010

Fig. 1. Plot of $\log \gamma$ versus σ_s for Monosubstituted Benzene Derivatives with Squalane Stationary Phase at 160 °C

scriptor σ_s afforded Eq. 7:

$$\log \gamma = 5.787(\pm 1.583)\sigma_s - 0.127(\pm 0.282) \quad (7)$$

$$n = 27, r = 0.833, s = 0.210, F = 56.70, AIC = -37.314$$

From the plots of Fig. 2, we have intuitively introduced an additional descriptor, ortho number N_o , representing the number of vicinal type CH_3 pairs. The result is given by Eq. 8:

$$\log \gamma = 4.615(\pm 0.388)\sigma_s - 0.141(\pm 0.014)N_o - 0.042(\pm 0.066) \quad (8)$$

$$n = 27, r = 0.992, F = 739.7, s = 0.049, AIC = -81.470$$

Furthermore, in this work, the authors have found for the first time a linear relation between $\log K/K_0$ of the charge-transfer associate formation for 1,3,5-trinitrobenzene plus

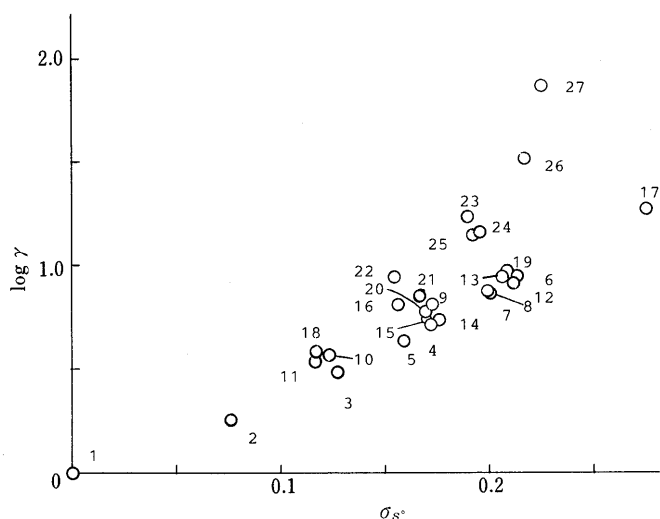


Fig. 2. Plot of $\log \gamma$ versus σ_s° for Polyalkylbenzene Derivatives with Squalane Stationary Phase at 160 °C

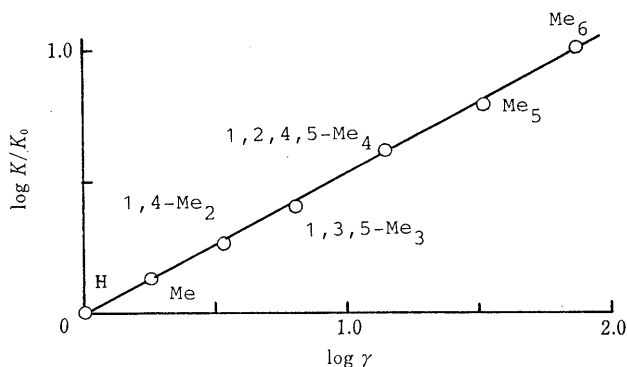


Fig. 3. Linear Relation between $\log K/K_0$ of Charge-Transfer Complex Formation and $\log \gamma$

K_0 , K : association constants for 1,3,5-trinitrobenzene plus polymethylbenzenes.^{11a)}

polymethylbenzene^{11a)} in solution and $\log \gamma$ of the same hydrocarbons (cf. Fig. 3). Similar trends were also observed when fluoroaniline^{11b)} and tetracyanoquinodimethane^{11c)} were used as acceptors.

From above results, the descriptor N_0 could be taken as

reflecting the charge-transfer contribution, and could be transformed to the term $-\Sigma\sigma_\pi^+$ given for congeners 18–27. The result of regression analysis using the descriptors σ_s° and $-\Sigma\sigma_\pi^+$ gave Eq. 9:

$$\log \gamma = 4.206(\pm 0.459)\sigma_s^\circ - 1.185(\pm 0.135)\Sigma\sigma_\pi^+ - 0.085(\pm 0.075) \quad (9)$$

$$n=27, r=0.990, s=0.058, F=565.4, AIC=-74.349$$

where the entry of the second term $-\Sigma\sigma_\pi^+$ reflects the participation of the CH/ π interaction³⁾ between polyalkylbenzene and stationary liquid.

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