

# Effects of molecular structure on the $S$ index in the retention equation in reversed-phase high-performance liquid chromatography

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## ABSTRACT

The  $S$  index in the retention equation  $\log k' = \log k'_w - S\varphi$  in reversed-phase high-performance liquid chromatography was systematically investigated as the function of molecular structure parameters. The  $S$  index, which has been observed to be nearly constant for a specific solute even when column systems with different  $C_{18}$  packing materials are used, was quantitatively correlated with the solvatochromic parameters of the solutes. The coefficients in the correlation of the  $S$  index with the solvatochromic parameters of the solutes were investigated and were found to be consistent with the results of using a solvatochromic comparison method. For non-polar compounds, a simplified linear relationship between  $S$  and the Van der Waals volume of the solute was observed. For homologues, a linear relationship between  $S$  and carbon number was found. Therefore, when other factors remain the same, increasing the size of the solute results in an increase in  $S$  whereas increasing the dipolarity or hydrogen bonding ability of the solute will result in a decrease in  $S$ .

## INTRODUCTION

The selectivity of the chromatographic system in reversed-phase high-performance liquid chromatography (RP-HPLC) is generally manipulated by changing the composition of the mobile phase. The linear relationship between the logarithm of capacity factors and the composition of the mobile phase in RP-HPLC has found considerable application and has been shown to be fairly reliable in practice, as expressed by the equation [1-3]

$$\log k' = \log k'_w - S\varphi \quad (1)$$

where  $k'$  is the capacity factor,  $\varphi$  is the volume fraction of strong solvent in a binary mobile phase,  $\log k'_w$  is the extrapolated value for the capacity

factor in pure water and  $S$  is defined as the negative of the slope of the plot of  $\log k'$  versus volume fraction ( $\varphi$ ).

The  $S$  value in eqn. 1 plays an important role in understanding the interactions in binary mobile phases and in computer simulations of RP-HPLC [3,4]. It has been suggested that  $S$  should be a constant, characterizing the solvent strength [1,2]; however, it has been found that  $S$  is variable tending to increase with increasing solute retention, and there is a general trend of increasing  $S$  in RP-HPLC as the molecular size of the solute increases. It has been observed that  $S$  values can be approximately related to the molecular weight ( $M$ ) of the solute [3], and therefore it may be questioned whether  $S$  is a characteristic constant of the solvent. In several other studies, a linear relationship between  $S$  and  $\log k'_w$  has been found [5-11].

It has also been found that  $S$  depends on the structure of the eluents [4,12-14]. One study showed

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$S$  increasing for the following benzene derivatives [11,12]: aniline < alkylbenzene < chlorobenzene < ether < aldehydes, ketones < nitriles < unsubstituted polyaromatics < nitro compounds < phthalates < phenylalkanols.

It has been found when other factors remain the same, there is a tendency for more polar compounds to exhibit smaller values of  $S$ . All the above results show that  $S$  is a solute-related constant.

In a previous paper [4], the  $S$  index (the "hydrophilic index") was observed to be nearly constant for a specific solute even when column systems with different  $C_{18}$  packing materials are used. The  $S$  index quantitatively describes the difference between the free-energy change of the solute in a weak solvent and a strong solvent, and it is therefore a function of the molecular structural parameters of the solute. This paper describes the effect of molecular structure on  $S$  in RP-HPLC. The  $S$  index was quantitatively correlated with the solvatochromic parameters of the solutes. The coefficients in the correlation of  $S$  with the solvatochromic parameters of the solutes are discussed based on the solvatochromic comparison method.

## EXPERIMENTAL

Detailed chromatographic conditions have been described in a previous paper [4]. All data were processed with a BASIC program on an IBM-AST 286 microcomputer. Other experimental results utilized in this work were taken from papers by Hammers *et al.* [6], Hafkenscheid and Tomlinson [15], Harnisch *et al.* [16] and Hanai and Hubert [17], which gave exact descriptions of the chromatographic conditions employed.

## RESULTS AND DISCUSSION

The  $S$  index quantitatively describes the difference in free-energy change between solute-weak solvent and solute-strong solvent systems, as is shown by the following equation [4]:

$$S = (\Delta G_{A,C}^0 - \Delta G_{A,B}^0) / RT \quad (2)$$

where  $\Delta G_{A,C}^0$  and  $\Delta G_{A,B}^0$  are the free-energy change between solute-weak solvent and solute-strong solvent, respectively,  $R$  is the gas constant and  $T$  is the column absolute temperature.

The non-electrostatic free-energy change can be separated into Van der Waals interactions [ $\Delta G^0(\text{van})$ ] and hydrogen bonding interactions [ $\Delta G^0(\text{H})$ ]:

$$\Delta G^0 = \Delta G^0(\text{van}) + \Delta G^0(\text{H}) \quad (3)$$

Dispersion, dipole-dipole (dipolarity) and dipole-induced dipole (polarization) interactions are included in the Van der Waals interactions. These interactions can be characterized by using solvatochromic parameters which have been shown to be useful in evaluating and identifying the physicochemical properties governing aqueous solubilities [18-23]. As in linear solvation energy relationships (LSERs), solvent-dependent properties depend on three types of terms according to the following equation:

$$SP = SP_0 + \text{cavity term} + \text{dipolar term} + \text{hydrogen bonding terms} \quad (4)$$

The general LSER for solutes has taken the form

$$SP = SP_0 + mv_w/100 + d\pi^* + b\beta + a\alpha \quad (5)$$

where  $v_w$  measures the cavity term and is the Van der Waals molecular volume, and can be calculated by using Bondi's method [24],  $\pi^*$  is a measure of solute dipolarity/polarizability,  $\alpha$  is the hydrogen bond donor ability (HBD) or HBD acidity and  $\beta$  is the hydrogen bond acceptor ability (HBA) or HBA basicity.

The parameters  $v_w$ ,  $\pi^*$ ,  $\beta$  and  $\alpha$  characterize the solutes and the coefficients  $m$ ,  $d$ ,  $b$  and  $a$  characterize the solvents. The solvent property complementary to solute HBA basicity is solvent HBD acidity. According to the solvatochromic comparison method [20], solvent-dependent properties are given by the following equation:

$$SP = SP_0 + mv_w/100 + d\pi^* + b\beta + a\alpha \quad (6)$$

where

$$m = f(\delta_C^2 - \delta_B^2) \quad (7)$$

$$d = g(\pi_B^* - \pi_C^*) \quad (8)$$

$$b = h(\alpha_B - \alpha_C) \quad (9)$$

$$a = l(\beta_B - \beta_C) \quad (10)$$

where  $\delta_C$  and  $\delta_B$  the solubility parameters for weak solvent and strong solvent, respectively,  $\pi_B^*$ ,  $\alpha_B$  and  $\beta_B$  are solvatochromic parameters for the strong

TABLE I  
SOLUBILITY AND SOLVATOCHROMIC PARAMETERS  
FOR METHANOL AND WATER

Solubility and solvatochromic parameters taken from refs. 18 and 10, respectively.

Parameter	Methanol	Water
$\pi^*$	0.60	1.09
$\beta$	0.62	0.18
$\alpha$	0.93	1.17
$\delta(\text{cal/ml})^{1/2}$	14.5	23.4

solvent,  $\pi_c^*$ ,  $\alpha_c$  and  $\beta_B$  are solvatochromic parameters for the weak solvent and  $f$ ,  $g$ ,  $h$  and  $l$  are constants.

In RP-HPLC, the difference in free-energy change between solute–weak solvent and solute–strong solvent can be directly correlated with the solvatochromic parameters, hence  $SP$  in eqn. 6 refers to the  $S$  index. Therefore,  $S$  can be quantitatively correlated with the solvatochromic parameters.

In eqn. 6, the magnitude of  $m$  denotes the difference in the solubility parameters for the weak solvent and the strong solvent,  $d$  is determined mainly by the difference between the strong solvent and the weak solvent in the dipolarity/polarizability parameters,  $b$  shows the difference in hydrogen donor ability of the strong solvent and the weak solvent and  $a$  shows the difference in hydrogen acceptor ability of the strong solvent and the weak solvent. The solvatochromic and solubility parameters for methanol and water are given in Table I.

Table II gives the experimental  $S$  values and the  $S$  values calculated from the solvatochromic parameters; the resulting equation obtained by least-squares regression is

$$S = (1.09 \pm 0.14) + (4.55 \pm 0.15)v_w/100 - (0.252 \pm 0.13)\pi^* - (2.50 \pm 0.17)\beta + (0.0948 \pm 0.15)\alpha \quad (11)$$

$n = 49; R = 0.987; \text{S.D.} = 0.156$

In this and all the regression equations that follow,  $n$  is the number of data points in the regression,  $R$  is the coefficient of the regression and S.D. is the standard deviation.

The sign of the coefficients is determined by whether the term represents an exoergic or endoergic factor in the retention process. The coefficients of

the  $m$ ,  $d$ ,  $b$  and  $a$  terms have the expected signs. The value of solubility parameter for water is greater than that for methanol (see Table I), whereas the dipolarity of water ( $\pi_c^* = 1.09$ ) is higher than that of methanol ( $\pi_B^* = 0.60$ ), which leads to  $m$  having a positive sign and  $d$  a negative sign.

As methanol ( $\beta_B = 0.62$ ) is more basic than water ( $\beta_C = 0.18$ ), this leads to a value of  $a$  that is positive, whereas water is a stronger HB acid ( $\alpha_C = 1.17$ ) than methanol ( $\alpha_B = 0.93$ ), so  $b$  is negative.

The contribution of the  $\alpha$  term to  $S$  is not very significant compared with  $\beta$ . There is no deterioration in the statistical goodness of fit when the  $\alpha$  term is omitted, which is consistent with earlier conclusions for the acetonitrile–water system [23] and the methanol–water system [22], but we use a different approach. We believe that if the relationship between the logarithmic capacity factors and the mobile phase composition is linear (plots of  $\log k'$  vs.  $\varphi$  are less linear when acetonitrile is used instead of methanol as the organic modifier), the parameters  $\log k'_w$  and the  $S$  would be sufficiently unbiased to be useful as input data for solvatochromic comparison studies.  $\log k'_w$  or  $S$  is correlated well with the solvatochromic parameters (see Tables II–IV).  $\log k'_w$  and  $S$  do offer some advantages over  $\log k'$  at a particular eluent composition when correlated with the solvatochromic parameters.  $\log k'_w$  and  $S$  contain the retentions over a wide range of concentrations of the mobile phase for a particular solute. The slope of  $\log k'$  vs.  $\varphi$  is determined by the mobile phase effect, whereas the intercept of the plots is determined mainly by the properties of the stationary phases. Therefore, the mobile phase effects have been separated from the stationary phase effects by using this approach.

Eqn. 11 shows that increasing hydrogen bonding interaction results in a dramatic decrease in  $S$  when other conditions remain the same. This is consistent with the practical observations that when other factors remain the same, more polar compounds will have decreased  $S$  values, whereas increasing the size of the solute leads to an increase in  $S$ . Therefore, there is a general trend that as the solute becomes increasingly hydrophobic,  $S$  will become increasingly positive; in contrast, as the solute becomes more hydrophilic and more polar,  $S$  will decrease when other conditions remain the same.

Table III shows the results of another example.

TABLE II

VALUES OF SOLVATOCHROMIC PARAMETERS AND COMPARISON OF EXPERIMENTAL *S*-VALUES WITH CALCULATED VALUES FOR VARIOUS AROMATICSColumn, Lichrosorb RP-C<sub>18</sub>; eluent, methanol-water (methanol from 30 to 90%, v/v). *S* values from ref. 6; solvatochromic parameters from ref. 18.

Compound	$v_w/100$	$\pi^*$	$\beta$	$\alpha$	<i>S</i> (exp.)	<i>S</i> (calc.) <sup>a</sup>	$\Delta$
Benzene	0.491	0.59	0.10	0	2.71	2.92	0.21
Toluene	0.592	0.55	0.11	0	3.28	3.37	0.09
1,2-Dimethylbenzene	0.668	0.51	0.12	0	3.64	3.70	0.06
1,3-Dimethylbenzene	0.668	0.51	0.12	0	3.74	3.70	-0.04
1,4-Dimethylbenzene	0.668	0.51	0.12	0	3.69	3.70	0.01
1,3,5-Trimethylbenzene	0.769	0.47	0.13	0	4.23	4.16	-0.07
1,2,3,4-Tetramethylbenzene	0.867	0.43	0.15	0	4.45	4.55	0.10
1,2,3,5-Tetramethylbenzene	0.867	0.43	0.15	0	4.48	4.55	0.07
Pentamethylbenzene	0.965	0.39	0.17	0	4.90	4.96	0.06
Hexamethylbenzene	1.063	0.35	0.19	0	5.40	5.36	-0.04
Ethylbenzene	0.668	0.53	0.12	0	3.77	3.70	-0.07
<i>n</i> -Propylbenzene	0.769	0.51	0.12	0	4.43	4.16	-0.27
<i>n</i> -Butylbenzene	0.867	0.49	0.12	0	4.95	4.61	-0.34
Naphthalene	0.753	0.70	0.15	0	4.03	3.97	-0.06
Fluorene	0.960	1.18	0.22	0	4.53	4.61	0.08
Phenanthrene	1.015	0.80	0.20	0	4.80	5.01	0.21
Anthracene	1.015	0.80	0.20	0	4.95	5.01	0.06
Pyrene	1.156	0.90	0.25	0	5.18	5.50	0.32
Biphenyl	0.92	1.18	0.20	0	4.68	4.48	-0.20
Bibenzyl	1.116	1.10	0.22	0	5.33	5.34	0.01
Fluorobenzene	0.520	0.62	0.07	0	2.99	3.12	0.13
Chlorobenzene	0.581	0.71	0.07	0	3.36	3.38	0.02
Bromobenzene	0.624	0.79	0.06	0	3.42	3.58	0.16
1,2-Dichlorobenzene	0.671	0.80	0.03	0	3.88	3.87	-0.01
1,3-Dichlorobenzene	0.671	0.75	0.03	0	3.93	3.88	-0.05
1,4-Dichlorobenzene	0.671	0.70	0.03	0	3.90	3.89	-0.01
1,2,3-Trichlorobenzene	0.761	0.85	0	0	4.33	4.34	0.01
1,2,4-Trichlorobenzene	0.761	0.75	0	0	4.35	4.36	0.01
1,3,5-Trichlorobenzene	0.761	0.70	0	0	4.45	4.38	-0.07
1,2,3,4-Tetrachlorobenzene	0.851	0.80	0	0	4.75	4.76	0.01
1,2,3,5-Tetrachlorobenzene	0.851	0.80	0	0	4.80	4.76	-0.04
1,2,4,5-Tetrachlorobenzene	0.851	0.70	0	0	4.80	4.79	-0.01
Pentachlorobenzene	0.941	0.75	0	0	5.25	5.18	-0.07
Hexachlorobenzene	1.031	0.70	0	0	5.70	5.61	-0.09
2-Chloroaniline	0.652	0.83	0.40	0.25	2.84	2.87	0.03
3-Chloroaniline	0.652	0.78	0.40	0.31	2.91	2.89	-0.02
4-Chloroaniline	0.653	0.73	0.40	0.31	2.96	2.91	-0.05
3-Chlorophenol	0.626	0.77	0.23	0.69	3.34	3.23	-0.11
4-Chlorophenol	0.626	0.72	0.23	0.67	3.35	3.25	-0.10
Aniline	0.562	0.73	0.50	0.26	1.98	2.24	0.26
Phenol	0.536	0.72	0.33	0.61	2.35	2.58	0.23
Benzyl alcohol	0.634	0.99	0.52	0.39	2.55	2.46	-0.09

TABLE II (continued)

Compound	$v_w/100$	$\pi^*$	$\beta$	$\alpha$	$S(\text{exp.})$	$S(\text{calc.})^a$	$\Delta$
Benzaldehyde	0.606	0.92	0.44	0	2.80	2.52	-0.28
Benzonitrile	0.590	0.90	0.37	0	2.90	2.62	-0.28
Nitrobenzene	0.631	1.01	0.30	0	2.69	2.96	0.27
Acetophenone	0.690	0.90	0.49	0.04	3.10	2.78	-0.32
Anisole	0.639	0.73	0.32	0	2.88	3.01	0.13
Methyl benzoate	0.736	0.75	0.39	0	3.20	3.27	0.07
N,N-Dimethylaniline	0.752	0.90	0.43	0	3.09	3.21	0.12

<sup>a</sup>  $S = (1.09 \pm 0.14) + (4.55 \pm 0.15)v_w/100 - (0.252 \pm 0.13)\pi^* - (2.50 \pm 0.17)\beta + (0.0948 \pm 0.15)\alpha$ ;  $n = 49$ ;  $R = 0.987$ ; S.D. = 0.156.

TABLE III

VALUES OF SOLVATOCHROMIC PARAMETERS AND COMPARISON OF EXPERIMENTAL  $S$  VALUES WITH CALCULATED VALUES FOR VARIOUS COMPOUNDS

Column, Hypersil-ODS; eluent, methanol-water (methanol from 30 to 90%, v/v); phosphate buffer was used when applied to ionizable compounds. Data for  $S$  from ref. 15; solvatochromic parameters from ref. 18.

Compound	$v_w/100$	$\pi^*$	$\beta$	$\alpha$	$S(\text{exp.})$	$S(\text{calc.})^a$	$\Delta$
4-Nitrophenol	0.676	1.15	0.32	0.82	3.09	3.19	0.10
4-Nitroaniline	0.702	1.25	0.48	0.42	2.78	2.77	-0.01
Benzene	0.491	0.59	0.10	0	2.83	3.03	0.20
Toluene	0.592	0.55	0.11	0	3.27	3.45	0.18
Chlorobenzene	0.581	0.71	0.07	0	3.48	3.41	-0.07
Nitrobenzene	0.631	1.01	0.30	0	2.97	2.92	-0.05
Phenol	0.536	0.72	0.33	0.61	2.64	2.76	0.12
Aniline	0.562	0.73	0.50	0.26	2.28	2.37	0.09
Benzoic acid	0.650	0.74	0.40	0.59	3.13	3.05	-0.08
<i>p</i> -Xylene	0.668	0.51	0.12	0	3.76	3.76	0.0
4-Chlorotoluene	0.679	0.67	0.08	0	3.99	3.82	-0.17
4-Nitrotoluene	0.729	0.97	0.31	0	3.40	3.32	-0.08
<i>p</i> -Cresol	0.634	0.68	0.34	0.58	3.08	3.16	0.08
<i>p</i> -Toluidine	0.660	0.69	0.51	0	2.74	2.71	-0.03
<i>p</i> -Toluic acid	0.748	0.70	0.41	0.59	3.57	3.45	-0.12
1,4-Dichlorobenzene	0.671	0.70	0.03	0	4.04	3.89	-0.15
4-Nitrochlorobenzene	0.721	1.01	0.26	0	3.32	3.39	0.07
4-Chlorophenol	0.626	0.72	0.23	0.67	3.34	3.38	0.04
4-Chloroaniline	0.653	0.73	0.40	0.31	3.06	3.00	-0.06
4-Chlorobenzoic acid	0.740	0.74	0.36	0.63	3.71	3.53	-0.18
1,3,5-Trimethylbenzene	0.769	0.47	0.13	0	4.21	4.17	-0.04
1,2,4,5-Tetramethylbenzene	0.867	0.43	0.15	0	4.48	4.55	0.07
Naphthalene	0.753	0.70	0.15	0	3.98	3.94	-0.08
Phenanthrene	1.015	0.80	0.20	0	4.84	4.85	0.01
Anthracene	1.015	0.80	0.20	0	4.96	4.85	-0.11
Pyrene	1.156	0.90	0.25	0	5.10	5.26	0.16
Perylene	1.415	1.0	0.30	0	6.11	6.17	0.06

<sup>a</sup>  $S = (1.55 \pm 0.11) + (4.13 \pm 0.12)v_w/100 - (0.523 \pm 0.14)\pi^* - (2.357 \pm 0.21)\beta + (0.249 \pm 0.10)\alpha$ ;  $n = 27$ ;  $R = 0.993$ ; S.D. = 0.116.

TABLE IV

COEFFICIENTS OF  $SP_0$ ,  $m$ ,  $d$ ,  $b$  AND  $a$  ON DIFFERENT COLUMNS PACKED WITH VARIOUS  $C_{18}$  PACKING MATERIALS WITH SURFACE COVERAGE RANGING FROM 0.255 TO 0.690 mmol/g

$S$  values for regression taken from refs. 25 and 26. Compounds used for the regression: acetophenone, *p*-cresol, benzyl alcohol, phenol, aniline, benzene, toluene, ethylbenzene, *n*-propylbenzene, *n*-butylbenzene, pentane, hexane, heptane, octane, 1-butanol, 1-pentanol, 1-hexanol.

$C_{18}$ coverage (mmol/g)	$SP_0$	$m$	$d$	$b$	$a$	$R$	$n$	S.D.
0.255	0.21 ( $\pm 0.17$ )	6.25 ( $\pm 0.24$ )	-0.43 ( $\pm 0.11$ )	-2.87 ( $\pm 0.21$ )	-0.16 ( $\pm 0.16$ )	0.997	17	0.098
0.335	0.28 ( $\pm 0.17$ )	6.21 ( $\pm 0.24$ )	-0.53 ( $\pm 0.11$ )	-2.71 ( $\pm 0.22$ )	-0.10 ( $\pm 0.16$ )	0.997	17	0.099
0.499	0.24 ( $\pm 0.13$ )	6.15 ( $\pm 0.18$ )	-0.41 ( $\pm 0.08$ )	-2.63 ( $\pm 0.16$ )	-0.22 ( $\pm 0.12$ )	0.998	17	0.074
0.690	0.50 ( $\pm 0.15$ )	5.76 ( $\pm 0.21$ )	-0.44 ( $\pm 0.09$ )	-2.64 ( $\pm 0.19$ )	-0.25 ( $\pm 0.14$ )	0.998	17	0.087

listing the experimental  $S$  values and the values calculated on the basis of the relationship between  $S$  and the solvatochromic parameters for 27 aromatic compounds.

Table IV gives the coefficients  $SP_0$ ,  $m$ ,  $d$ ,  $b$  and  $a$  on four different  $C_{18}$  packings with surface coverages ranging from 0.255 to 0.699 mmol/g. The variation of  $S$  for a specific solute on the four different columns is within  $\pm 0.04$  [4], and the values of  $m$ ,  $d$ ,  $b$  and  $a$  on the four columns are approximately equal, showing the characteristic constants of the solvents used.

TABLE V

COMPARISON OF EXPERIMENTAL  $S$  VALUES [ $S(\text{exp.})$ ] WITH THOSE CALCULATED [ $S(\text{calc.})$ ] FROM THE SOLVATOCHROMIC PARAMETERS FOR SOME PAHs

Column, YWG- $C_{18}$ ; eluent, methanol-water (methanol from 60 to 90%, v/v).  $S$  values taken from ref. 4.

Compound	$v_w/100$	$S(\text{exp.})$	$S(\text{calc.})^a$	$\Delta$
Benzene	0.49	2.74	2.74	0.00
Naphthalene	0.75	3.60	3.62	0.02
Biphenyl	0.92	4.24	4.20	-0.04
Phenanthrene	1.01	4.44	4.50	0.06
Anthracene	1.01	4.54	4.50	-0.04
Chrysene	1.25	5.24	5.32	0.08
<i>p</i> -Terphenyl	1.38	5.73	5.66	-0.07

<sup>a</sup>  $S = (1.14 \pm 0.06) + (3.32 \pm 0.06)v_w/100$ ;  $n = 7$ ;  $R = 0.9996$ ; S.D. = 0.061.

For non-polar compounds such as polynuclear aromatic hydrocarbons (PAHs), from eqn. 6 we can see that there is a linear relationship between  $S$  and the Van der Waals volume of the solute. Table V shows the experimental  $S$  value and values calculated from the Van der Waals volume for some PAHs in methanol-water.

For homologous series, as  $v_w$  can be written as

$$v_w = n\Delta v_w(\text{CH}_2) + n_e\Delta v_w(\text{e}) \quad (12)$$

where  $n$  and  $n_e$  are the number of methylene groups and end-groups, respectively, and  $\Delta v_w(\text{CH}_2)$  and  $\Delta v_w(\text{e})$  are the Van der Waals volume contributed by the methylene groups and end-groups, respectively, then for homologues the insertion of a  $\text{CH}_2$  group into a compound should give a constant change in  $S$  values, as can be seen from Tables VI and VII. The average contribution of a methylene group to  $S$  approaches a constant value. The average contribution of a methylene group to  $S$  for alkylbenzenes is defined by

$$\Delta S(\text{CH}_2) = [S(n\text{-alkylbenzene}) - S(\text{benzene})]/n \quad (13)$$

where  $S(n\text{-alkylbenzene})$  is the experimental  $S$  value for  $n$ -alkylbenzenes and  $S(\text{benzene})$  is the experimental  $S$  value for benzene. The calculated  $S$  values for these alkylbenzenes based on the linear relationship between  $S$  and carbon number are also listed in Tables VI and VII.

In conclusion, the  $S$  index (the "hydrophilic

TABLE VI

EXPERIMENTAL  $S$  VALUES [ $S(\text{exp.})$ ],  $\Delta S(\text{CH}_2)$  AND CALCULATED VALUES [ $S(\text{calc.})$ ] FOR  $n$ -ALKYLBENZENES IN METHANOL-WATER SYSTEMColumn, SIL-X-5- $\text{C}_{18}$ ; eluent, methanol-water (methanol from 60 to 95%, v/v).  $S$  values from ref. 16.

Compound	$n$	$S(\text{exp.})$	$\Delta S(\text{CH}_2)$	$S(\text{calc.})^a$	$\Delta$
Benzene	0	2.95	—	2.96	0.01
Toluene	1	3.52	0.57	3.48	-0.04
Ethylbenzene	2	3.96	0.51	4.01	0.05
Propylbenzene	3	4.55	0.53	4.53	-0.02
Butylbenzene	4	5.06	0.53	5.05	-0.01
Hexylbenzene	6	6.10	0.53	6.10	0.00
Octylbenzene	8	7.14	0.52	7.15	0.01
Decylbenzene	10	8.20	0.53	8.20	0.00

<sup>a</sup>  $S = (2.96 \pm 0.02) + (0.524 \pm 0.03)n$ ;  $n = 8$ ;  $R = 0.9999$ ; S.D. = 0.03.

index") in the retention equation  $\log k' = \log k'_w - S\phi$  in RP-HPLC can be calculated by using the solvatochromic parameters. The coefficients in the correlation of the  $S$  index with the solvatochromic parameters of the solutes are determined mainly by the properties of the mobile phase. For non-polar compounds, a linear relationship between  $S$  and the Van der Waals volume can be used to calculate  $S$  values. For homologues, a linear correlation between  $S$  and carbon number is strictly observed.

Therefore, increasing the volume of the solute results in an increase in  $S$ , whereas increasing the dipolarity and hydrogen bonding ability of the solute lead to a dramatic decrease in  $S$  when other factors remain the same.

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TABLE VII

EXPERIMENTAL  $S$  VALUES [ $S(\text{exp.})$ ],  $\Delta S(\text{CH}_2)$  AND CALCULATED VALUES [ $S(\text{calc.})$ ] FOR  $n$ -ALKYLBENZENES IN ACETONITRILE-WATER SYSTEM

Column, YMC-phenyl; eluent, acetonitrile-water (acetonitrile from 50 to 80%, v/v). Data recalculated from ref. 17.

Compound	$S(\text{exp.})$	$n$	$\Delta S(\text{CH}_2)$	$S(\text{calc.})^a$	$\Delta$
Benzene	2.21	0	—	2.21	0.00
Toluene	2.41	1	0.20	2.44	0.03
Ethylbenzene	2.69	2	0.24	2.66	-0.03
Propylbenzene	2.88	3	0.22	2.89	0.01
Butylbenzene	3.12	4	0.23	3.11	-0.01
Hexylbenzene	3.57	6	0.23	3.56	-0.01
Heptylbenzene	3.80	7	0.23	3.79	-0.01
Octylbenzene	4.04	8	0.23	4.01	-0.03
Nonylbenzene	4.25	9	0.23	4.24	-0.01
Decylbenzene	4.43	10	0.22	4.47	0.04

<sup>a</sup>  $S = (2.21 \pm 0.01) + (0.226 \pm 0.002)n$ ;  $n = 10$ ,  $R = 0.9997$ ; S.D. = 0.03.

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