Cent. Eur. J. Chem. • 9(5) • 2011 • 813-824
DOI: 10.2478/s11532-011-0060-4

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Central European Journal of **Chemistry**

Partition coefficients of ketones, phenols, aliphatic and aromatic acids, and esters in *n*-hexane/nitromethane

Research Article

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Received 20 January 2011; Accepted 30 April 2011

Abstract: Liquid-liquid partition is used in sample preparation and in countercurrent and liquid-liquid chromatographic separations. Partition coefficients are widely used in toxicology, environmental, and analytical chemistry. The K_{hn} determination procedure for the *n*-hexane/nitromethane system was optimized and partition coefficients for 99 ketones, esters and trimethylsilyl derivatives of phenols, aliphatic and aromatic acids were determined. For 130 compounds, K_{hn} values were predicted using mathematical relationships between K_{hn} and other physicochemical and structural parameters.

Keywords: *Partition coefficients • n-Hexane/nitromethane system • Structure-partitioning relationships*

1. Introduction

Partition between two “largely immiscible” solvents is widely used in sample preparation for matrix simplification and isolation of target analytes, as well as in countercurrent and liquid-liquid chromatographic separations. The equilibrium concentration ratio is called the partition (or distribution) coefficient; the concentration in the less polar phase is the numerator of $K_p = C_1/C_2$. It is a physicochemical constant of the compound, and is widely used in toxicology, environmental and analytical chemistry. The key parameter describing the partitioning behavior of organic toxicants in biological and environmental compartments is the *n*-octanol/water partition coefficient, K_{ow} [1,2].

Liquid-liquid distribution methods, commonly including the use of water as one component, determine descriptors in solvation models [3,4]. Employing systems of two organic solvents makes it possible to use gas chromatography to determine partition coefficients, while solute descriptors can be based on quantified retention factors [5].

Distribution coefficients may also be used as identifying parameters in the analysis of complex organic mixtures [6,7]. For example, partition coefficients were employed in the identification of compounds in plant essential oils [8-11], sodium-bituminous masses [12], communal wastewaters [13], pesticides, and in environmental samples containing compounds formed during treatment and disposal of chemical warfare agents [14,15]. This application allows us to increase the identification reliability simply and inexpensively [8-15]. This additional identification parameter is particularly helpful when analyzing complex unknown mixtures.

n-Hexane/acetonitrile has achieved the highest applicability of wholly organic biphasic systems, while the *n*-hexane/nitromethane system has been recognized as the most promising for identification in terms of complementarity or interchangeability [7]. The two solvents are commonly used as extractant or reaction medium. They are also used as mobile phases in countercurrent chromatography [16] and high performance liquid chromatography [17,18]. Nitromethane is also a solvent in capillary electrophoresis [19], so partition coefficients in this system could find diverse applications.

An aim of this study was the experimental determination of *n*-hexane/nitromethane partition coefficients for different types of organic compounds: ketones, esters, and TMS-derivatized aliphatic and aromatic acids, and phenols. A calculation method to determine K_{hn} values analogous to Quantitative Structure–Retention Relationships was examined.

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2. Experimental procedure

2.1. Materials

n-Hexane (Baker, HPLC grade), nitromethane (Aldrich, HPLC grade), and anhydrous pyridine (Fluka) were used without additional purification or drying. The derivatization reagent was bis(trimethylsilyl)trifluoroacetamide (BSTFA) containing 1% trimethylchlorosilane (Sigma). Series of $C_6 – C_{30}$ *n*-alkanes, toluene and *n*-butyl benzene (internal standards) were purchased from Sigma. Other chemicals were obtained from several sources.

2.2. Instrumentation

Gas chromatographic analyses were carried out on an HP 6890 GC with electronic pressure control, split/splitless injector, and flame ionization detector (FID) from Agilent Technologies, USA. It was equipped with a HP-5 column (30 m × 0.25 mm coated with 0.25 µm 5% phenylmethylsiloxane). Helium (99.999%, 1 mL min^{-1}) was the carrier gas. FID flow rates were: hydrogen 40 mL min^{-1}, air 400 mL min^{-1}, nitrogen (make-up gas) 40 mL min^{-1}. The injector and FID temperatures were 250 and 300°C, respectively. The oven temperature was programmed from 40°C to 300°C at 5°C min^{-1} and was maintained for 30 minutes. The split ratio was set to 50:1; septum purge was 1 mL min^{-1}.

2.3. Partition coefficients determination

Samples were prepared at 22°C. A 2 mL flask was charged by pipette with 0.5 mL of *n*-hexane solution of the compounds (at 100 µg mL^{-1}), 0.5 mL of nitromethane,

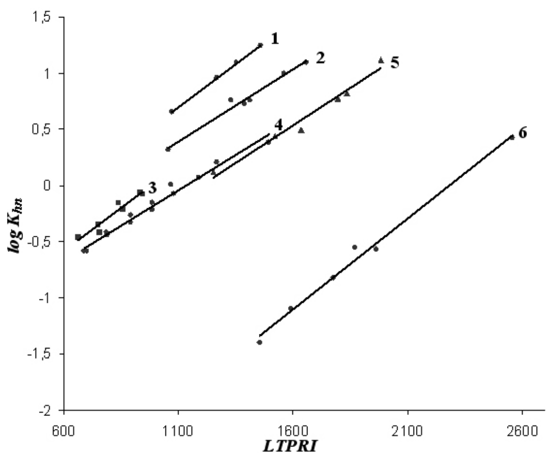

Figure 1. Log K_{hn} and chromatographic retention indices relationships: (1) aliphatic monocarboxylic acids, TMS ($y = 0.001390x – 0.8019$, $R^2 = 0.991$); (2) phenols, TMS ($y = 0.001297x- 1.0132$, $R^2 = 0.949$); (3) monosubstituted ketones ($y = 0.001530x – 1.4972$, $R^2 = 0.934$); (4) unbranched ketones ($y = 0.001284x-1.4212$, $R^2= 0.980$); (5) aromatic acids, TMS ($y = 0.001371x – 1.7174$ $R^2 = 0.951$); (6) phthalic acid esters ($y = 0.001519x – 3.4763$, $R^2 = 0.990$).

5 µL of *n*-alkanes mixture and 0.5 µL of *n*-butylbenzene. The flask was closed and intensely shaken for 5 minutes. After the phases were separated, the solution stood for half an hour. Each phase was then subjected to GC-FID analysis. Distribution coefficients were calculated from the ratio of the peak areas by Eq. 1:

$$K_{hn} = (S_h/S_n)\cdot(B_n /B_h)\cdot K_b, \qquad (1)$$

where S_h and S_n are the peak areas of the component *x* on the chromatograms of the hexane and nitromethane phases, respectively, and B_h and B_n are the peak areas of *n*-butylbenzene (internal standard). K_b is the butylbenzene partition coefficient (K_b=4.00±0.40). The retention times of the compounds and *n*-alkanes were used to calculate linear temperature programmed retention indices (LTPRI) [20].

Phenols and aliphatic and aromatic acids were analyzed as trimethylsilyl derivatives. 20 µL of pyridine and 50 µL of BSTFA were added to 1 mg of compound, the mixture was heated for one hour at 70ºC to form the TMS derivative and the resulting solution was used for partition coefficient determination.

3. Results and discussion

3.1. Experimental partition coefficient determinations

The volume of the gaseous phase and the resulting GC injector pressures after the evaporation 1 µL of *n*-hexane or nitromethane were different. This could affect K_{hn} precision since the higher injector pressure after nitromethane evaporation pushes out more of the sample during removal of the needle from the injector. To avoid this difficulty the needle was left in the injector for about a minute after injection to allow the sample to move onto the column.

The determination of a partition coefficient is possible only when the liquid-liquid system is in equilibrium. Thus, both shaking time and the phase separation time required for the distribution coefficient to reach a constant value were determined. Satisfactory results were achieved when the shaking time was 5 minutes and the phase separation time 30 minutes. Relative standard deviations (rsd) obtained for measurements carried out between 30 minutes and eight hours after phase separation did not exceed 3.5%. The difference between the rsd obtained 24 hours after the partition and the rsd obtained from earlier measurements was substantial, *i.e.*, as great as 80%. We conclude that correct distribution coefficient values can be determined from 30 minutes to 8 hours after partition.

Table 1. Influence of temperature on K_{hn} values

Compound	K_{hn}±SD		
	18°C	22°C	26°C
Ketones			
2-Pentanone	0.19±0.01	0.20±0.01	0.21±0.01
3-Pentanone	0.18±0.01	0.19±0.01	0.20±0.01
2,4-Dimethyl-3-pentanone	0.59±0.01	0.61±0.02	0.63±0.02
2-Methyl-3-hexanone	0.54±0.02	0.56±0.02	0.58±0.02
5-Methyl-2-hexanone	0.29±0.02	0.31±0.02	0.33±0.02
2-Heptanone	0.33±0.02	0.35±0.02	0.37±0.02
2-Methyl-3-heptanone	0.74±0.05	0.78±0.04	0.79±0.05
5-Methyl-3-heptanone	0.65±0.04	0.69±0.04	0.70±0.04
Phthalic acid esters			
Dimethyl phthalate	0.02±0.01	0.03±0.01	0.03±0.01
Diethyl phthalate	0.05±0.01	0.07±0.01	0.07±0.01
Diisopropyl phthalate	0.12±0.01	0.14±0.01	0.15±0.01
Di-n-butyl phthalate	0.25±0.01	0.28±0.01	0.28±0.01
Diisobutyl phthalate	0.23±0.02	0.26±0.01	0.27±0.01
Di-2-ethylhexyl phthalate	2.99±0.13	2.93±0.17	2.83±0.10

Two approaches were studied: (1) injection of each phase after separation and (2) injection of one layer prior to and after equilibration. The precision of K_{hn} values obtained by injecting a single phase was worse (rsd > 10%). When both phases were analyzed rsd did not normally exceed 5%. K_{hn} determinations based on the analysis of both phases is superior and this method was adopted.

The distribution coefficient depends both on temperature and pressure. However, atmospheric pressure changes do not significantly affect liquid-liquid equilibria. On the other hand, temperature changes around room temperature do affect the equilibrium, to an extent depending on the structure. Table 1 presents K_{hn} values for ketones and phthalic acid esters at 18, 22 and 26°C. For phthalates the change is the largest and is equal to 2-4% per °C. We conclude that the determination of K_{hn} values should be carried out at a constant temperature (± 1-2°C).

K_{hn} values in *n*-hexane/nitromethane were determined for 99 ketones, esters, and TMS-derivatized phenols and aliphatic and aromatic carboxylic acids. Linear temperature programmed retention indices were determined simultaneously with the distribution coefficients. K_{hn} and *LTPRI* values obtained in consecutive measurements (3-5 repetitions) were averaged and the standard deviation calculated (Tables 2-4). K_b for the internal standard was used as a check - it could not deviate more than 10% from the expected value.

3.2. Calculation of partition coefficients

The partition coefficient in a heterogeneous system is a physicochemical constant that characterizes a compound in the same way as, for instance, its boiling point. There are relationships among physicochemical and structural properties within a homologous series or other similarity. Fig. 1 plots log K_{hn} and the compounds' retention indices on the phenylmethylsiloxane phase (type DB-5). The slopes (k) are similar for the all compound classes; this value is a characteristic of the liquid/liquid system. This coefficient is proportional to the difference in free energies of solvation for the homologous difference ($k = 10^{-2}\ \Delta G^{CH2}/2.303RT$) in the two phases [6]. The value of k for the *n*-hexane/nitromethane system is $(1.4\pm0.2)\times10^{-3}$, while for octanol/water it is $(5.4\pm0.5)\times10^{-3}$ and for *n*-hexane/acetonitrile it is $(1.10\pm0.20)\times10^{-3}$. The y-intercept in the equation:

$$\log K_{hn} = k \cdot LTPRI - j,$$

is characteristic of a homologous series. Thus the group parameter j, a combination of K_{hn} and retention indices, can be used for compound identification [7].

The relationship between distribution coefficients and other physicochemical parameters can be used to predict unknown K_{hn} values. Mathematical models were constructed described by a general relationship:

$$\log K_{hn} = a \log X + b \log Y + c. \qquad (2)$$

Such parameters as molar mass, number of carbon atoms in a molecule, density, molar volume, octanol/water distribution coefficient, and chromatographic retention index were used as variables X and Y. Coefficients *a*, *b* and *c* of Eq. 2 were calculated by the method of least squares. The coefficient of determination (R^2) was the matching criterion. F-Snedecor values [21] characterized the significance of the correlation equations. These equations also served to test the experimental K_{hn} determinations. Predicted values and the parameters used are in Tables 2-4.

The predicted K_{hn} are in good agreement with the experimental values; the average difference was 5%. The F-test shows is that the equations are meaningful at a significance level of at least 95%. The majority of R^2 values are close to 0.99. A considerably lower R^2 was obtained for acetates of terpene alcohols because the compounds belonging to this group differ considerably

Table 2. Experimental and predicted K_{hn} values of ketones and the parameter values used in predicting K_{hn}

Compound	Bp (°C)	MW	LTPRI ± SD	K_{hn}^{exp} ± SD	K_{hn}^{calc}
		Unbranched			
2-Pentanone	102.2	86	688±1	0.26±0.01	0.25
3-Pentanone	102.0	86	700±1	0.26±0.01	0.25
3-Hexanone	123.5	100	786±2	0.38±0.02	0.37
2-Hexanone	127.6	100	790±1	0.36±0.02	0.37
4-Heptanone	144.0	114	891±2	0.54±0.02	0.52
2-Heptanone	151.5	114	892±2	0.47±0.01	0.52
4-Octanone	172.7	128	970±1	0.70±0.02	0.69
2- Octanone	172.5	128	987±2	0.61±0.01	0.69
5-Nonanone	188.4	142	1069±2	1.02±0.01	0.90
2-Nonanone	195.3	142	1089±2	0.85±0.01	0.91
2- Decanone	210.0	156	1190±2	1.18±0.02	1.16
6-Undecanone	226.0	170	1269±2	1.61±0.04	1.44
2-Tridecanone	-	212	1493±3	2.40±0.05	2.55
3-Heptanone	163.0	114	887	-	0.52
3- Octanone	172.7	128	986	-	0.69
4-Nonanone	187.5	142	1079	-	0.90
3-Nonanone	190.0	142	1080	-	0.90
3-Decanone	205.0	156	1174	-	1.15
4-Decanone	206.0	156	1174	-	1.15
3- Undecanone	227.0	170	1270	-	1.44
2- Undecanone	231.5	170	1272	-	1.44
5- Undecanone	227.0	170	1270	-	1.47
		Monosubstituted			
3-Methyl-2-butanone	94.25	86	661±2	0.35±0.02	0.19
4- Methyl-2-pentanone	116.8	100	750±1	0.45±0.02	0.41
3- Methyl-2-pentanone	118.0	100	755±2	0.38±0.01	0.39
2- Methyl-3-pentanone	114.8	100	749±1	0.45±0.02	0.43
2- Methyl-3-hexanone	135.0	114	838±1	0.70±0.01	0.69
5- Methyl-2-hexanone	144.0	114	859±1	0.62±0.01	0.59
2- Methyl-3-heptanone	158.0	128	930±2	0.88±0.04	0.98
5- Methyl-3-heptanone	167.5	128	943±2	0.85±0.04	0.88
4- Methyl-3-hexanone	134.5	114	877	-	0.65
3-Ethyl-2-pentanone	139.0	114	892	-	0.62
4- Methyl-2-hexanone	142.0	114	903	-	0.60
5- Methyl-3-hexanone	136.0	114	836	-	0.64

Continued **Table 2.** Experimental and predicted K_{hn} values of ketones and the parameter values used in predicting K_{hn}

Compound	Bp (°C)	MW	LTPRI ± SD	K_{hn}^{exp} ± SD	K_{hn}^{calc}
2- Methyl-4-heptanone	155.0	128	923	-	0.96
3- Methyl-4-heptanone	156.3	128	929	-	0.95
6- Methyl-2-heptanone	170.5	128	1024	-	0.82
5- Methyl-4-heptanone	160.4	128	991	-	0.91
6- Methyl-3-heptanone	163.5	128	1001	-	0.88
3- Methyl-2-heptanone	167.0	128	1012	-	0.85
3- Methyl-4-octanone	174.0	142	1064	-	1.48
7- Methyl-4-octanone	178.0	142	1077	-	1.43
5- Methyl-3-octanone	179.0	142	1080	-	1.41
7- Methyl-3-octanone	182.5	142	1091	-	1.37
2- Methyl-3-octanone	183.0	142	1093	-	1.36
4- Methyl-2-octanone	184.0	142	1096	-	1.35
2- Methyl-5-nonanone	203.0	156	1188	-	2.14
2- Methyl-4-nonanone	207.5	156	1202	-	2.06
	Disubstituted				
4,4-Dimethyl-2-pentanone	125.5	114	788±2	0.55±0.01	-
2,4-Dimethyl-3-pentanone	124.5	114	795±2	0.75±0.01	-
2,6-Dimethyl-4-heptanone	169.4	142	971±2	1.44±0.07	-

Experimentally determined K_{hn}^{exp} and predicted K_{hn}^{calc} n-hexane/nitromethane partition coefficients; linear temperature programmed retention index (LTPRI) values and standard deviation (SD) were determined experimentally; LTPRI values without SD are from the literature [22, 23]; K_{hn}^{calc} were calculated from the equations: unbranched ketones: $\log K_{hn} = 2.3462 \log MW + 0.0010\ LTPRI - 5.2042$, $R^2 = 0.9942$, $F_{cal} = 857.0$; $F_{x,2,\alpha=0.05} = 4.1$; monosubstituted ketones: $\log K_{hn} = -1.6578 \log Bp + 0.1935\ MW + 1.1373$, $R^2 = 0.9818$, $F_{cal} = 134.9$; $F_{x,2,\alpha=0.05} = 5.8$.
MW – molar weight; Bp – boiling point.

Table 3. Experimental and predicted K_{hn} values of esters and the parameter values used in predicting K_{hn}

Compound	MW	Log K_{ow}	LTPRI ± RSD	K_{hn}^{exp} ± SD	K_{hn}^{calc}
	Aliphatic esters				
***n*-Butyl formate**	102.07	-	737±2	0.30±0.03	-
***iso*-Pentyl formate**	116.09	-	792±2	0.33±0.03	-
***n*-Pentyl formate**	116.09	-	825±2	0.33±0.04	-
***n*-Hexyl formate**	130.11	-	927±3	0.44±0.04	-
***n*-Butyl acetate**	116.09	-	812±1	0.49±0.04	-
***n*-Hexyl acetate**	144.12	-	1008±2	0.62±0.04	-
***n*-Butyl propanoate**	130.11	-	908±3	0.57±0.03	-
***iso*-Pentyl propanoate**	144.12	-	969±3	0.71±0.03	-
Methyl butanoate	88.05	-	724±1	0.50±0.04	-
Ethyl butanoate	116.09	-	800±2	0.56±0.03	-
***n*-Pentyl butanoate**	158.14	-	1094±2	0.92±0.08	-

Continued **Table 3.** Experimental and predicted K_{hn} values of esters and the parameter values used in predicting K_{hn}

Compound	MW	Log K_{ow}	LTPRI ± RSD	K_{hn}^{exp} ± SD	K_{hn}^{calc}
***n*-Hexyl butanoate**	172.15	-	1190±3	1.24±0.21	-
Methyl pentanoate	116.09	-	825±3	0.68±0.04	-
Ethyl pentanoate	130.11	-	898±3	0.81±0.07	-
Ethyl hexanoate	144.12	-	998±2	1.29±0.08	-
Propyl hexanoate	158.14	-	1089±3	1.58±0.14	-
	Acetates of terpene alcohols				
Linalool	196.16	-	1257±2	1.05±0.05	1.10
***cis*-Chrysanthenyl**	194.14	-	1261±1	1.10±0.07	1.02
Isobornyl	196.16	-	1289±2	1.18±0.06	1.16
Bornyl	196.16	-	1291±2	1.23±0.06	1.16
***trans*-Sabinyl**	194.14	-	1291±2	1.21±0.07	1.25
***trans*-Verbenyl**	194.14	-	1294±3	1.27±0.06	1.25
α-Terpenyl	196.16	-	1351±1	1.29±0.07	1.31
Citronellyl	198.17	-	1355±1	1.24±0.05	1.24
Santolyl	196.16	-	1171	-	0.94
Artemisyl	196.16	-	1173	-	0.94
Dihydromyrcenol	198.17	-	1215	-	0.96
***cis*-Sabinene hydrate**	196.16	-	1219	-	1.03
endo-Fenchyl	196.16	-	1220	-	1.03
exo-Fenchyl	196.16	-	1234	-	1.05
Myrtenyl	194.14	-	1235	-	1.12
***trans*-Sabinene hydrate**	196.16	-	1253	-	1.10
Tetrahydrolavandulol	200.19	-	1270	-	1.00
***neo*-3-Thujyl**	196.16	-	1271	-	1.13
Isopulegol	196.16	-	1273	-	1.13
***neo*-Isopulegol**	196.16	-	1273	-	1.13
***neo*-Menthyl**	198.17	-	1275	-	1.17
***neo*-izo-3-Thujyl**	196.16	-	1278	-	1.15
***iso*-Isopulegol**	196.16	-	1281	-	1.15
***cis*-Verbenyl**	194.14	-	1282	-	1.13
Lavandulil	196.16	-	1289	-	1.23
***trans*-3-Thujyl**	196.16	-	1291	-	1.17
Menthyl	198.17	-	1294	-	1.17
***trans*-Pinocarvyl**	194.14	-	1297	-	1.11
***cis*-Dihydro-α-terpenyl**	198.17	-	1298	-	1.26

Continued **Table 3.** Experimental and predicted K_{hn} values of esters and the parameter values used in predicting K_{hn}

Compound	MW	Log K_{ow}	LTPRI ± RSD	K_{hn}^{exp} ± SD	K_{hn}^{calc}
***iso*-3-Thujyl**	196.16	-	1301	-	1.12
***neo*-Dihydrocarveol**	196.16	-	1303	-	1.20
Dihydrocarveol	196.16	-	1305	-	1.20
***iso*-Verbanol**	196.16	-	1306	-	1.21
Isomenthyl	198.17	-	1306	-	1.21
***neo*-*iso*-Isopulegol**	196.16	-	1308	-	1.14
***cis*-Pinocarvyl**	194.14	-	1309	-	1.21
***trans*-Dihydro-α-terpenyl**	198.17	-	1315	-	1.29
***neo*-Verbanol**	196.16	-	1318	-	1.16
Dihydrocitronellol	200.19	-	1320	-	1.23
***iso*-Dihydrocarveol**	196.16	-	1325	-	1.10
***neo*-*iso*-Verbanol**	196.16	-	1328	-	1.25
***cis*-Piperitol**	196.16	-	1330	-	1.26
***trans*-Carvyl**	194.14	-	1337	-	1.36
***trans*-Piperitol**	196.16	-	1340	-	1.29
Verbanol	196.16	-	1340	-	1.29
Terpi*n*-4-ol	196.16	-	1340	-	1.29
***neo*-Dihydrocarveol**	196.16	-	1356	-	1.33
Neryl	196.16	-	1365	-	1.35
***cis*-Carvyl**	194.14	-	1362	-	1.42
***trans*-Myrtanol**	196.16	-	1381	-	1.39
Geranyl	196.16	-	1383	-	1.39
1-Menthe*n*-9-yl	196.16	-	1420	-	1.40
	Phthalic acid esters				
Dimethyl phthalate	194.2	1.61	1455±2	0.03±0.01	0.03
Diethyl phthalate	222.2	2.54	1591±2	0.07±0.01	0.07
Diisopropyl phthalate	250.3	3.40	1773±1	0.15±0.01	0.14
Di-*n*-butyl phthalate	278.4	4.27	1961±2	0.27±0.02	0.28
Diisobutyl phthalate	278.4	4.27	1868±3	0.29±0.02	0.28
Di-2-ethylhexyl phthalate	390.6	7.73	2555±2	2.83±0.04	2.82
Diallyl phthalate	246.2	3.11	-	-	0.12
Di-*n*-propyl phthalate	250.3	5.12	-	-	0.20
Butylbenzyl phthalate	312.4	4.70	-	-	0.53
Di-*n*-hexyl phthalate	334.4	6.00	-	-	0.96
Di-*n*-heptyl phthalate	362.5	6.87	-	-	1.67

Continued **Table 3.** Experimental and predicted K_{hn} values of esters and the parameter values used in predicting K_{hn}

Compound	MW	Log K_{ow}	LTPRI ± RSD	K_{hn}^{exp} ± SD	K_{hn}^{calc}
Di-*n*-octyl phthalate	390.6	7.73	-	-	2.82
Butyl-2-ethylhexyl phthalate	334.4	5.64	-	-	0.89
Diisooctyl phthalate	390.6	7.73	-	-	2.82
Di-*n*-nonyl phthalate	418.6	8.60	-	-	4.66
Diisononyl phthalate	418.6	8.60	-	-	4.66
Di-*n*-decyl phthalate	446.7	9.46	-	-	7.53
Diisodecyl phthalate	446.7	9.46	-	-	7.53
Diundecyl phthalate	474.7	10.33	-	-	11.96
Ditridecyl phthalate	530.8	12.06	-	-	28.70
	Other esters				
Citronellyl formate	184.15	-	1271±1	0.76±0.02	-
Linalool propanoate	210.17	-	1340±1	0.87±0.18	-
Nopyl acetate	208.15	-	1427±1	1.12±0.01	-
Citryl acetate	208.15	-	1517±2	0.72±0.01	-
Geranyl butanoate	224.18	-	1564±3	1.19±0.40	-

Experimentally determined K_{hn}^{exp} and predicted K_{hn}^{calc} n-hexane/nitromethane partition coefficients; linear temperature programmed retention index (LTPRI) values and standard deviation (SD) were determined experimentally; LTPRI values without SD are from the literature [24]; K_{hn}^{calc} were calculated from the equations: acetates of terpene alcohols: $\log K_{hn} = -5.8349 \log MW + 0.0082\ LTPRI + 12.3922$, $R^2 = 0.8779$, $F_{cal} = 18.0$, $F_{x,2,\alpha=0.05} = 5.8$; phthalic acid esters: $\log K_{hn} = -4.7198 \log MW + 0.0874 \log K_{ow} - 12.4570$, $R^2 = 0.9996$, $F_{cal} = 1499$, $F_{x,2,\alpha=0.05} = 9.5$. MW – molar weight; K_{ow} – octanol/water partition coefficient.

Table 4. Experimental and predicted K_{hn} values of TMS derivatives of carboxylic acids and phenols and the parameter values used in predicting K_{hn}

Compound	MW	LTPRI±SD	K_{hn}^{exp} ± SD	K_{hn}^{calc}
Aliphatic monocarboxylic acids, mono-TMS				
2-Methylpropanoic	88.11	832±2	-	2.05
2.2-Dimethylpropanoic	102.13	851±2	-	2.70
Hexanoic	116.16	1074±1	4.51±0.10	4.51
Octanoic	144.22	1269±1	9.01±0.15	8.98
Nonanoic	158.24	1355±2	12.34±0.20	12.42
Isodecanoic	172.27	1458±2	17.40±0.60	17.33
Dodecanoic	200.32	1654±2	-	33.05
Hexadecanoic	256.43	2052±2	-	114.34
Heptadecanoic	270.46	2153±2	-	155.21
Octadecanoic	284.48	2255±2	-	208.29
Eicosanoic	312.54	2451±3	-	380.49
Butanoic	88.11	883	-	2.19
Pentanoic	102.13	977	-	3.15
Dipropylacetic	144.22	1151	-	8.04

Continued **Table 4.** Experimental and predicted K_{hn} values of TMS derivatives of carboxylic acids and phenols and the parameter values used in predicting K_{hn}

Compound	MW	LTPRI±SD	K_{hn}^{exp}± SD	K_{hn}^{calc}
Heptanoic	130.19	1165	-	6.35
Decanoic	172.27	1450	-	17.23
Undecanoic	188.30	1550	-	24.73
Tridecanoic	214.35	1755	-	45.30
Tetradecanoic	228.37	1850	-	61.73
Pentadecanoic	242.40	1951	-	84.19
Aliphatic dicarboxylic acids, di-TMS				
Propanedioic (malonic)	104.06	1216±1	1.06±0.09	1.05
Heptanedioic (pimelic)	160.17	1612±1	1.89±0.19	1.95
Nonanedioic (azelaic)	188.22	1806±2	3.10±0.31	3.03
Decanedioic (sebacic)	202.25	1904±2	4.02±0.32	3.99
Undecanedioic	216.28	2005±2	5.16±0.42	5.21
Butanedioic (succinic)	118.09	1321±1	-	1.13
Etanedioic	90.04	1139	-	0.88
Methylpropanedioic	118.09	1225	-	1.79
Ethylpropanedioic	132.12	1289	-	2.34
2.2-Dimethylbutanedioic	146.14	1320	-	3.61
Methylbutanedioic	132.12	1333	-	1.91
meso-2.3-Dimethylbutanedioic	146.14	1365	-	2.95
Pentanedioic (glutaric)	132.12	1410	-	1.37
2-Methylpentanedioic	146.14	1423	-	2.30
3-Methylpentanedioic	132.12	1431	-	1.25
3,3-Dimethylpentanedioic	160.17	1431	-	3.95
Hexanedioic (adipic)	146.14	1514	-	1.58
3-Methylhexanedioic	160.17	1544	-	2.50
Octanedioic (suberic)	174.20	1710	-	2.41
3-Methyloctanedioic	188.23	1743	-	3.82
Dodecanedioic	230.30	2102	-	6.98
Tetradecanedioic	258.36	2305	-	12.68
Aliphatic hydroxycarboxylic acids, TMS				
2-Hydroxypropionic (lactic)	90.08	1065±1	3.19±0.14	3.25
3-Hydroxybutyric	104.11	1167±1	4.52±0.14	4.52
2-Hydroxyhexanoic	132.16	1289±1	9.27±0.25	8.87
2-Hydroxyoctanoic	160.21	1464±1	16.89±0.46	17.34
3-Hydroxypropanoic	90.08	1151	-	3.21
2-Hydroxyisobutyric	104.11	1071	-	4.58

Continued **Table 4.** Experimental and predicted K_{hn} values of TMS derivatives of carboxylic acids and phenols and the parameter values used in predicting K_{hn}

Compound	MW	LTPRI±SD	K_{hn}^{exp}± SD	K_{hn}^{calc}
2- Hydroxybutyric	104.11	1136	-	4.54
3- Hydroxyisobutyric	104.11	1170	-	4.52
2-Hydroxyisopentanoic	118.13	1174	-	6.37
2-Hydroxypentanoic	118.13	1207	-	6.35
2-Methyl-3-hydroxybutyric	118.13	1214	-	6.34
3-Hydroxyisopentanoic	118.13	1216	-	6.34
3-Hydroxypentanoic	118.13	1245	-	6.32
2-Hydroxyisohexanoic	132.16	1252	-	8.91
3-Methyl-2-hydroxypentanoic	132.16	1253	-	8.91
4-Hydroxyisopentanoic	118.13	1260	-	6.31
4-Hydroxypentanoic	118.13	1265	-	6.30
2-Methyl-3-hydroxypentanoic	132.16	1275	-	8.89
3-Hydroxyhexanoic	132.13	1317	-	8.84
5-Hydroxyhexanoic	132.13	1366	-	8.79
2,2-Dimethyl-3-hydroxybutanoic	132.13	1395	-	8.76
2-Propyl-3-hydroxypentanoic	160.21	1402	-	17.46
7-Hydroxyoctanoic	160.21	1555	-	17.18
Phenols				
Phenol, mono-TMS	94.11	1055±2	2.09±0.10	-
Pyrocatechol (1,2-dihydroxybenzene), di-TMS	110.11	1330±2	5.70 ± 0.08	-
Resorcinol (1,3-dihydroxybenzene), di-TMS	110.11	1390±1	5.33 ± 0.02	-
Hydroquinone (1,4-dihydroxybenzene), di-TMS	110.11	1410±1	5.74 ± 0.02	-
Pyrogallol (1,2,3-trihydroxybenzene), tri-TMS	126.11	1559±2	9.91 ± 0.69	-
Phloroglucinol (1,3,5-trihydroxybenzene), tri-TMS	126.11	1659±2	12.43 ± 0.14	-
Aromatic acids				
Benzoic, mono-TMS	122.12	1250±1	1.30 ± 0.04	-
Salicylic (2-hydroxybenzoic), di-TMS	138.12	1522±1	2.76 ± 0.04	-
4-Hydroxybenzoic, di-TMS	138.12	1635±1	3.07 ± 0.06	-
Gentisic (2,5-dihydroxybenzoic), tri-TMS	154.12	1793±3	5.98 ± 0.16	-
Protocatechuic (3,4-dihydroxybenzoic), tri-TMS	154.12	1835±2	6.59 ± 0.12	-
Gallic (3,4,5-trihydroxybenzoic), tri-TMS	170.12	1981±2	14.13 ± 0.30	-
Alkilaromatic acids				
Benzeneacetic, mono-TMS	136.15	1298±2	0.66 ± 0.01	-
Mandelic (α-hydroxybenzeneacetic), di-TMS	152.14	1489±2	1.85 ± 0.03	-
4-Hydroxybenzeneacetic, di-TMS	152.14	1648±2	1.46 ± 0.03	-

Continued **Table 4.** Experimental and predicted K_{hn} values of TMS derivatives of carboxylic acids and phenols and the parameter values used in predicting K_{hn}

Compound	MW	LTPRI±SD	K_{hn}^{exp}± SD	K_{hn}^{calc}
Homogentisic (2,5-dihydroxybenzeneacetic), tri-TMS	168.14	1853±2	4.30 ± 0.07	-
Cinnamic acids				
o-Coumaric (2-hydroxycinnamic), di-TMS	164.15	1818±1	2.07 ± 0.07	-
m-Coumaric (3-hydroxycinnamic), di-TMS	164.15	1878±2	2.11 ± 0.07	-
p-Coumaric (4-hydroxycinnamic), di-TMS	164.15	1949±1	1.84 ± 0.07	-
Caffeic (3,4-dihydroxycinnamic), tri-TMS	180.16	2151±1	4.99 ± 0.22	-

Experimentally determined K_{hn}^{exp} and predicted K_{hn}^{calc} n-hexane/nitromethane partition coefficients; linear temperature programmed retention index (LTPRI) values and standard deviation (SD) were determined experimentally; LTPRI values without SD are from the literature [25-27]; K_{hn}^{calc} were calculated from the equations: aliphatic monocarboxylic acids: $\log K_{hn} = 1.1377 \log LTPRI + 0.0077 MW - 3.6924$, $R^2 = 0.9992$, $F_{cal} = 499.5$, $F_{x,2,\alpha=0.05} = 200$; aliphatic dicarboxylic acids: $\log K_{hn} = -5.9992 \log LTPRI + 0.0178 MW + 16.6760$, $R^2 = 0.9996$, $F_{cal} = 999.0$; $F_{x,2,\alpha=0.05} = 19$; aliphatic hydroxycarboxylic acids: $\log K_{hn} = -0.1522 \log LTPRI + 0.0107 MW + 0.0106$, $R^2 = 0.9995$, $F_{cal} = 499.5$, $F_{x,2,\alpha=0.05} = 200$.
MW – molar weight of non-silylated compound.

Table 5. Average j ± SD values

Group of compounds	j ± SD
Aliphatic ketones	1.40 ± 0.12
Aliphatic esters	1.12 ± 0.17
Acetates of terpene alcohols	1.65 ± 0.03
Phthalic acid esters	3.17 ± 0.16
Aliphatic monocarboxylic acids, mono-TMS	0.73 ± 0.03
Aliphatic dicarboxylic acids, di-TMS	1.85 ± 0.15
Aliphatic hydroxycarboxylic acids, TMS	0.82 ± 0.10
Phenols, TMS	1.01 ± 0.12
Aromatic acids, TMS	1.55 ± 0.11
Alkyl aromatic acids, TMS	1.87 ± 0.13
Cinnamic acids, TMS	2.19 ± 0.10

in structure, *i.e.*, the number of rings and number of double bonds in a molecule. These models can be called Quantitative Structure – Partition Relationship (QSPR) or Quantitative Property – Partition Relationship (QPPR), analogous to the Quantitative Structure – Retention Relationships (QSRR) used in the predictions of retention indices [21].

Table 5 gives the *j* values calculated using only the experimental K_{hn} values. As can be seen, the *j* values cover a narrow range, but overlap within experimental error for only a few representatives of different groups. Hence, *j* is characteristic of a homologous series and can be used as a group identification parameter.

4. Conclusions

Partition coefficients (K_{hn}) in the *n*-hexane/nitromethane partition system were determined for 99 ketones, esters and trimethylsilyl derivatives of phenols, aliphatic and aromatic acids. Seven tri-parameter correlation equations between K_{hn} and other physicochemical and structural parameters were developed. Using these models K_{hn} values were predicted for approximately 130 compounds. In almost all the equations, $R^2 > 0.98$ indicating good correlation between the experimental and calculated values. The F values indicate that the models are meaningful at a significance level of at least 95%. The average deviation of the predicted values from the experimental ones was 5%.

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