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THE STERIC FACTOR IN THE GAS–LIQUID CHROMATOGRAPHIC RETENTION OF TOLUIC AND METHOXYBENZOIC ESTERS

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SUMMARY

The gas–liquid chromatographic retention parameters of the isomeric methyl methoxybenzoates have been studied by retention index determinations on Apiezon L and three isomeric *p*-dodecylphenyl methoxybenzoates. A similar study of methyl toluates on *p*-dodecylphenyl toluates has been carried out. A steric effect, causing enhanced retention of a solute on its isomeric stationary phase, has been measured for the methoxybenzoate system and its magnitude is in accordance with predictions. No steric effect was found in the toluate system studied.

INTRODUCTION

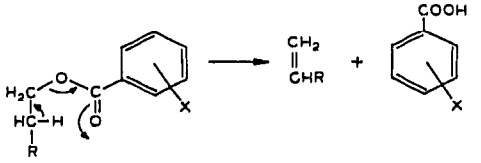
In recent years, many investigations into the correlation of retention data with structural parameters have been carried out, the intention of many investigators being to test the validity of the simple additivity principle of retention index (*I*).

Many systems have been studied where the additivity principle breaks down, examples being the chain-branching effect in esters[1,2] and the positional effect of the carboxylic group in nonane carboxylic acids[3]. Positional effects on *I* have been studied for polysubstituted benzenes[4,5] and the retention increments explained in terms of steric and dipole effects. Published work on the separation of isomeric disubstituted benzenes includes a xylenes separation on 7,8-benzoquinoline[6] and a separation of the chloronitrobenzenes on Carbowax[7]. Norman[8] separated the nitrotoluenes on 2,4,7-trinitrofluorenone and in this case there is the significant choice of a stationary phase structurally similar to the solutes (*i.e.* a nitro compound). Fitzgerald[9,10] has studied the retention of 3-methylphenol (b.p. 202°) and 2,6-dimethylphenol (b.p. 203°) on the donor phase diaminodiphenylsulphone and finds a difference which is not consistent with the boiling point variation of 1° and requires the postulation of a steric factor in retention. A similar effect is also noted with 3-methyl pyridine and 2,6-dimethyl pyridine on the acceptor phase tris-(2-cyanoethyl)-nitromethane.

Vernon[11] postulated a steric factor in retention where the isomeric solutes and stationary phases were structurally similar and determined the steric contribution to retention for the methyl nitrobenzoates on the isomeric dodecyl nitrobenzoate

stationary phases. This steric contribution to the retention index was quite small and ranged from an 18.5 unit enhancement for methyl σ-nitrobenzoate on the σ-nitro ester stationary phase, to an enhancement of 8 units for the *meta* isomer on the *meta* stationary phase. It was suggested that a study of the methoxybenzoate isomers should demonstrate a larger steric effect for the methoxy substituent than for the nitro group. This system, the three methyl methoxybenzoates together with benzene, anisole and methylbenzoate, has been studied on isomeric methoxybenzoate stationary phases and is the subject of this paper. As in the previous work, Apiezon L was used as the standard non-polar stationary phase. The work was then extended to a study of the isomeric toluate ester system and, in an attempt to reproduce the performance of a squalane stationary phase at high temperature, polyethylene was used as the non-polar reference thereby removing solute–stationary phase interactions which were due to the delocalized π-electron systems in the aromatic ingredients of Apiezon grease.

As temperatures in the region of 200° were required, the stability of the dodecyl benzoate derivatives was a problem which arose in the original work. Decomposition of stationary phase at high temperature will occur, irrespective of substituent, by rearrangement of the dodecyl benzoate to dodecane.



The reaction may be prevented by ensuring that the β-carbon is not hydrogen-donating, and consequently the dodecylphenyl esters of the toluates and methoxybenzoates were chosen as more stable stationary phases.

EXPERIMENTAL

Stationary phase and solute sample preparation

o-Methoxybenzoic acid was refluxed with purified thionyl chloride to produce the acid chloride, the excess thionyl chloride being removed by distillation under vacuum. One portion of the acid chloride was reacted with an equal amount of *p*-dodecylphenol at 100° overnight, and the product was dissolved in ether and washed with sodium carbonate solution to remove excess acid chloride. After water-washing, the etherial solution was dried with anhydrous sodium sulphate, filtered, and the ether removed by distillation to give the product as a pale yellow viscous liquid. The remaining acid chloride was reacted with an excess of anhydrous methanol under reflux and the excess methanol removed by evaporation. The *m*- and *p*-methoxybenzoates and the isomeric toluate esters were prepared by the same procedure. The methyl esters were checked for purity by determination of boiling points and comparison with the literature values[12,13]. The boiling points of the six esters are given in Tables I and II. All methyl and *p*-dodecylphenyl esters were also checked by infrared spectroscopy.

Columns

1 m × 6 mm O.D. glass columns were packed with 10% (w/w) of stationary

TABLE I

RETENTION INDICES (I) ON ISOMERIC METHOXYBENZOATE STATIONARY PHASES AT 195°

Solute	I				*B.p.* (°C)
	Apiezon L	*p-Dodecylphenyl o-methoxybenzoate*	*p-Dodecylphenyl m-methoxybenzoate*	*p-Dodecylphenyl p-methoxybenzoate*	
Benzene	685	773	715	732	
Anisole	957	1067	989	1006	
Methylbenzoate	1093	1349	1282	1296	
Methyl *o*-methoxybenzoate	1451	1686	1577	1581	246
Methyl *m*-methoxybenzoate	1419	1622	1555	1545	238
Methyl *p*-methoxybenzoate	1482	1687	1606	1650	256
Calculated value* of methyl methoxybenzoate	1365	1643	1556	1570	

* $I_{(calculated)} = I_{methylbenzoate} + I_{anisole} - I_{benzene}$.

phase on silylated Celite, 80–100 mesh. The methyl esters were chromatographed with the two appropriate *n*-paraffins as 10% solutions in ether (sample size 2 μl). Chromatographic retention data were obtained using a Pye 104 Series gas chromatograph with flame ionization detector. Retention times were measured directly by stopwatch, the dead times of the systems were determined by injection of coal-gas and measurement of peak elution time. Methoxybenzoate retention data were obtained at a column temperature of 195°. This temperature was used initially for the toluate series but slight loss of stationary phase was noted and the working temperature was reduced to 174°. As the boiling points of the methyl toluates are approximately 30° lower than the methoxybenzoates, no difficulty in elution of samples was experienced at this lower temperature. Nitrogen was used as the carrier gas at a flow-rate of 30 ml·min^{-1}.

TABLE II

RETENTION INDICES (I) ON ISOMERIC TOLUATE STATIONARY PHASES AT 174°

Solute	I					*B.p.* (°C)
	Polyethylene	*p-Dodecylphenyl benzoate*	*p-Dodecylphenyl o-toluate*	*p-Dodecylphenyl m-toluate*	*p-Dodecylphenyl p-toluate*	
Benzene	703	750	748	746	746	
Toluene	820	858	856	855	855	
Methylbenzoate	1119	1223	1214	1219	1220	
Methyl *o*-toluate	1203	1299	1294	1293	1298	213
Methyl *m*-toluate	1230	1336	1331	1330	1331	215
Methyl *p*-toluate	1238	1343	1342	1340	1343	217
Calculated value* of methyl toluate	1236	1331	1322	1328	1329	

* $I_{(calculated)} = I_{methylbenzoate} + I_{toluene} - I_{benzene}$.

RESULTS AND DISCUSSION

The retention indices of methyl methoxybenzoates together with benzene, anisole and methylbenzoate on Apiezon L and on the three isomeric ester phases are given in Table I. The corresponding methyl toluates together with benzene, toluene and methylbenzoate were chromatographed on a polyethylene standard column and also on a standard *p*-dodecylphenyl benzoate column in addition to the three isomeric toluate phases and these retention indices are given in Table II. Comparisons between Tables I and II can only be approximate as there was a 21° difference in operating temperatures. Accepting this, it is apparent that the polarities of the benzoate and toluate phases are virtually identical, whereas comparison of results on the various phases for methylbenzoate show that the methoxybenzoate ester phases are considerably more polar, the *o*-methoxy- by some 120 units and the *m*- and *p*-isomers by some 70 units. The *o*-methoxy polarity difference is so great as to be apparent in the retention indices of benzene which has its highest value on this phase. The fact that the benzene values are lower on the other two methoxy phases than on the benzoate and toluate phases must, therefore, be a temperature effect.

That the steric effect on retention is small was apparent from the nitrobenzoate studies[11] when emergence of the isomers was seen to be in order of increasing boiling points irrespective of the isomeric stationary phase, this order being *ortho*, *para*, *meta*. On the methoxy ester and toluic ester columns it is again found that the samples are eluted from all columns in order of boiling point. The significance of this however, depends upon the magnitude of boiling point variation. Thus the methyl toluates are separated by only 4° but this is sufficient to ensure their elution in the order *ortho*, *para*, *meta* from all columns. The implication is that any steric effect exerted by the $-CH_3$ is negligible, a fact not in dispute as the relatively small methyl group is not expected to be responsible for any steric effect. On the other hand, the boiling range of the methoxybenzoate esters covers 18° and elution in order of boiling point would be *meta*, *ortho*, *para*. Any steric effect capable of selectively retarding the elution of one of these isomers over the other two would have to be relatively large. This does not happen but a large *ortho* steric effect is apparent from the fact that *ortho* isomer retention is equal to *para* retention (although there is a 10° difference in b.p.) on the *ortho* stationary phase.

Functional group interactions

The functional retention index (F.R.I.) as defined by Swoboda[14] is the difference between retention indices of a substituted compound and its hydrocarbon skeleton and is a useful concept for measuring the extent of functional group–stationary phase interaction. Wehrli and Kováts[15] have stated that if a substance contains more than one "adhering zone", then the ΔI value is the sum of individual increments for each adhering zone. If one interprets "adhering zone" as functional group in the widest sense of the term then the additivity principle can be used to evaluate contributions to retention index of aromaticity, and the methyl-, methoxy-, and carboxymethoxy- functional groups studied in the systems described here. Furthermore, a "theoretical" methyl toluate and methyl methoxybenzoate can be constructed in terms of retention indices from the data available on benzene, toluene, anisole and methylbenzoate. Functional group interactions (ΔI) are listed in Table III, being derived

TABLE III

FUNCTIONAL RETENTION INDICES (ΔI) FOR METHYL, METHOXY AND CARBOXYMETHOXY GROUPS ON THE ESTER STATIONARY PHASES

Functional group	*Functional group interaction (ΔI) on stationary phase*			
	Apiezon L	*o-Methoxybenzoate*	*m-Methoxybenzoate*	*p-Methoxybenzoate*
$-OCH_3$	272	294	274	274
$-COOCH_3$	408	576	567	564
	Polyethylene	*o-Toluate*	*m-Toluate*	*p-Toluate*
$-CH_3$	117	108	109	109
$-COOCH_3$	416	466	473	474

from retention indices of methylbenzoate, anisole and toluene on the various phases less the appropriate value for benzene. The contribution of the methoxy group to retention is approaching 300 units, whereas the corresponding value for the methyl group is only slightly in excess of the theoretical 100 units per methylene added. The effects on carboxymethoxy- are predictable, both CH_3- and CH_3O- give rise to hyperconjugation with electron release to the ring affecting the other substituent. This effect on the carboxymethoxy group would appear to be in the region of 50 units for the toluate series but predictably, with its far greater activating effect, the methoxy group causes an enhancement of the carboxymethoxy F.R.I. by some 160 units for *meta* and *para* isomers and 170 units when in an adjacent position in the ring (the *ortho* effect).

Overall increments due to solute–stationary phase interactions are shown in

TABLE IV

SOLUTE–STATIONARY PHASE INTERACTIONS

Solute	ΔI^*		
	Dodecylphenyl o-methoxybenzoate	*Dodecylphenyl m-methoxybenzoate*	*Dodecylphenyl p-methoxybenzoate*
Benzene	88	30	47
Anisole	110	32	49
Methylbenzoate	256	189	203
o-Methoxy ester	235	126	130
m-Methoxy ester	203	136	126
p-Methoxy ester	205	124	168
	Dodecylphenyl o-toluate	*Dodecylphenyl m-toluate*	*Dodecylphenyl p-toluate*
Benzene	45	43	43
Toluene	36	35	35
Methylbenzoate	95	100	101
o-Methyl ester	91	90	95
m-Methyl ester	101	100	101
p-Methyl ester	104	102	105

* Retention increment (ΔI) = $I_{\text{ester stationary phase}} - I_{\text{hydrocarbon phase}}$

Table IV where preferential retention of a methoxybenzoate stationary phase for its own isomeric solute by enhanced interaction is apparent. Here it is clearly seen that the *ortho* interaction with the *ortho* phase is numerically the highest value of the series, the preferential *ortho* effect plus steric effect giving a ΔI of 235 units. Also in each case, the other two isomeric solutes have virtually the same degree of interaction, thus *m/p* on *ortho* phase is 204 ± 1, *o/p* on *meta* phase is 125 ± 1, and *o/m* on *para* phase is 128 ± 2.

TABLE V

MEASURED RETENTION INCREMENTS OF SOLUTES OVER CALCULATED VALUES AND THE CONTRIBUTION OF THE STERIC FACTOR ($\delta\Delta I$) TO RETENTION

Solute	$\Delta I = I_{found} - I_{theory}$			*Selective increment* ($\delta\Delta I$)
	Dodecylphenyl o-methoxybenzoate	*Dodecylphenyl m-methoxybenzoate*	*Dodecylphenyl p-methoxybenzoate*	
o-Methoxy ester	43	21	11	27 ± 5
m-Methoxy ester	−21	−1	−25	22 ± 2
p-Methoxy ester	44	50	80	33 ± 3
	Dodecylphenyl o-toluate	*Dodecylphenyl m-toluate*	*Dodecylphenyl p-toluate*	
o-Methyl ester	−28	−35	−31	5 ± 2
m-Methyl ester	9	2	2	−3 ± 5
p-Methyl ester	20	12	14	−2 ± 4

A completely different picture emerges on examination of solute–stationary phase interactions in the toluates. All three esters on the three phases have increments in order of boiling points, that is all have the lowest interaction for the *ortho* solute and the highest for the *para*. There is no sign of selective retention by any means (steric or electronic) in the toluates. Table V gives the differences between the retention indices of the various isomers as measured and as calculated in Tables I and II from the appropriate monosubstituted benzene figures. The steric effect has been isolated in Table V as a selective increment ($\delta\Delta I$) with the rather surprising result that it is not the *ortho* effect which predominates in solute retention of methoxybenzoates but the largest positive retention discrepancy between calculated and experimental values is given by the *para* isomer with an enhancement of 80 units. The enhancement of the CH_3O– group in the *ortho* position is 43 units, whilst the *meta* isomer shows a reduced retention increment compared to theory. Nevertheless, this reduction is just counterbalanced by the steric effect of the *meta* isomer on the *meta* stationary phase. The steric effect is seen to be considerably larger in the methoxy series than in the nitro series investigated earlier; this was predicted in the first paper[11]. For the toluates, there is no evidence for the existence of a steric effect. The *meta* and *para* isomers actually show a reduced selective increment which is, however, insignificant by comparison with performance on their other isomer stationary phases.

In conclusion, the earlier work on the nitrobenzoate system has been verified and predictions on the magnitude of the steric effect found to be accurate. An *ortho* substituent effect enhances the steric effect in retention of nitrobenzoate solutes but

the *para* isomer is found to demonstrate the largest steric effect ($\Delta I = 33$ units) in the methoxybenzoate series. No steric effect is caused by the presence of a methyl group as evidenced by the work carried out on the toluates.

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