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GAS-LIQUID CHROMATOGRAPHY OF NITROPHENOLS AND METHYL DERIVATIVES

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SUMMARY

The gas-liquid chromatographic behaviour of nitrophenols, nitrocresols and nitroxylenols has been studied on three stationary phases, Apiezon L and two silicone gum rubbers. The retention index of each compound is discussed from the viewpoint of electronic and steric effects arising upon substitution.

INTRODUCTION

The role of chromatography in structural analysis is based on the idea that the chromatographic behaviour of a molecule in a particular system is the result of a thermodynamically fundamental property of the molecule. Any changes in chromatographic behaviour, on modification, can be ascribed to changes in the structures of the molecules concerned[1]. It can be shown that if the free energy of the whole molecule is considered to be the sum of the partial free energies of the single functional groups constituting the molecule, the R_m value of the whole molecule is the sum of the R_m values for the constituent functional groups as defined by BATE-SMITH AND WESTALL[2]. The retention index (I) system proposed by KOVÁTS[3] serves as the basic system for the application of this additivity principle to gas chromatography (GC). This paper describes the chromatographic behaviour of the three isomeric nitrophenols on three stationary phases and the extension of the investigation to certain nitrocresols and nitroxylenols. Little work on the GC behaviour of nitrophenols has been published to date. Separations of the three isomers have however been described on some polyesters and on silicones[4-6].

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EXPERIMENTAL

The compounds were chromatographed on a Pye, Series 105, gas chromatograph with a flame-ionization detector. A column temperature of 204 ± 0.5° was used throughout.

The columns consisted of 155 cm × 0.6 cm O.D. copper tubing with the following stationary phases: column A, 10% of Apiezon L, on silylated Celite, 80–120 mesh; column B, 10% of silicone gum rubber SE-30, on silylated Celite, 80–120 mesh; and column C, 10% of silicone gum rubber SE-52, on silylated Celite, 80–120 mesh.

Nitrogen carrier gas flow-rates used for the determination of retention data for benzene, phenol and nitrobenzene were 60 ml/min with column A, 48 ml/min with column B and 45 ml/min with column C. The nitrogen flow-rates in the cases of nitrophenols, nitrocresols and nitroxylenols were 100 ml/min with column A, 55 ml/min with column B and 90 ml/min with column C.

All retention times were recorded directly with a stop-watch, and corrected values were calculated by the method of PETERSON AND HIRSCH[7] using *n*-paraffins and the calculated dead-times checked by measuring the retention time of coal gas. Samples were injected with two appropriate *n*-paraffins for the calculation of retention index data. The efficiency (benzene peak at 80°) for each column and the resolution between pairs of the isomeric nitrophenols on each stationary phase were also determined.

RESULTS

The results are given in Tables I–IV.

DISCUSSION

Nitrophenols

Using the additivity concept, the theoretical retention index for nitrophenol was calculated for each stationary phase from the increments for free hydroxyl and nitro groups substituted into a benzene ring. On comparison with the data obtained for actual nitrophenol isomers, it is not surprising to find that the retention index of 2-nitrophenol is lower than the calculated value, regardless of stationary phase. This can be explained in terms of intramolecular hydrogen bonding which will increase the volatility of the compound. On SE-30, the difference between actual and calculated values only amounts to 3 index units, which suggests a specific interaction of 2-nitrophenol with the phase counterbalancing the intramolecular hydrogen-bonding effect. In 3- and 4-nitrophenols, intermolecular hydrogen bonding will exist, causing the molecules to associate. This will lead to a decrease in volatility with a corresponding increase in retention index over the theoretical value. This effect can be seen from the ΔI values given in Table II. One would expect a larger increase in retention index, from the calculated value, for 4-nitrophenol as the electron-withdrawing nitro group is able to promote intermolecular hydrogen bonding to a greater extent when substituted *para* to the hydroxyl than when substituted in the *meta* position. This is found to be the case for all three stationary phases. Here again, the higher increment

TABLE I

RETENTION DATA (*I*) OBTAINED UNDER THE CONDITIONS DESCRIBED

Compound	*Apiezon L*	*SE-30*	*SE-52*
Benzene	696	895	756
Phenol	960	950	961
Nitrobenzene	1138	1114	1143
2-Nitrophenol	1229	1166	1216
3-Nitrophenol	1514	1439	1530
4-Nitrophenol	1634	1502	1607
3-Methyl-2-nitrophenol	1306	1267	1308
2-Methyl-6-nitrophenol	1318	1270	1305
2-Methyl-5-nitrophenol	1592	1537	1619
2-Methyl-4-nitrophenol	1644	1571	1665
4-Nitro-2,6-xylenol	1680	1617	1694
4-Nitro-2,5-xylenol	—	1622	1701

TABLE II

RETENTION INDICES (*I*) FOR THE THREE ISOMERIC NITROPHENOLS AND THEIR DIFFERENCES (ΔI) FROM THE THEORETICAL VALUE CALCULATED FROM RETENTION DATA OF BENZENE, PHENOL AND NITROBENZENE

Compound	*Apiezon L*		*SE-30*		*SE-52*	
	I	ΔI	*I*	ΔI	*I*	ΔI
Nitrophenol (theoretical)	1402		1169		1358	
2-Nitrophenol	1229	−173	1166	−3	1216	−132
3-Nitrophenol	1514	+112	1439	+270	1530	+182
4-Nitrophenol	1634	+232	1502	+333	1607	+259

for SE-30 over the other two phases suggests a specific solute–stationary phase interaction.

Nitrocresols and nitroxylenols

In these compounds, the hyperconjugative release of electrons by the methyl group will have the effect of reducing the polarity of the molecule. Therefore, the increase in retention index expected from the addition of –CH$_2$– will be offset by the increase in volatility of the substituted nitrophenol owing to this decrease in polarity and the consequent decrease in hydrogen bonding. In addition to electronic effects caused by substitution into the ring, the approach of the hydroxyl and nitro groups to the phase interface may be sterically hindered by the methyl group or groups when substituted in positions which are *ortho* to either of the functional groups.

3-Methyl-2-nitrophenol and 2-methyl-6-nitrophenol

From their structures, one would expect similar behaviour from these two compounds, and this similarity is seen in Table III. Both electronic and steric effects will be in evidence, the electronic outweighing the steric effect for Apiezon L and SE-52 where the increments are well below the theoretical increment of 100 units. For SE-30, this theoretical value is reached, which can only be explained on the basis of a specific interaction with this phase.

2-Methyl-5-nitrophenol

From its structure, one would expect the steric effect to be less pronounced with this compound than for the two previous compounds. No evidence for this is seen in the data in Table III unless the slight decrease of the ΔI increment on SE-30 is considered to be significant.

2-Methyl-4-nitrophenol

In this compound, the hyperconjugative release of electrons by the methyl group must result in a vast reduction of the intermolecular hydrogen bonding encountered in 4-nitrophenol. This reduction on substitution causes a large increase in volatility with corresponding decrease in retention index from that expected. The effect is seen on Apiezon L, where the addition of $-CH_2-$ gives an increment of only 10 units.

4-Nitro-2,6-xylenol

In this compound, a second methyl group has been substituted into the previously discussed 2-methyl-4-nitrophenol at the position *ortho* to the hydroxyl group. A large electronic effect would therefore be expected, but not as large as the effect caused by substitution of the first methyl group. This is clearly seen on Apiezon L, where interactions with the stationary phase are minimal. The first methyl group gave an increment of only 10 units whereas the increment for the two methyl groups is seen to be 46 units, implying that the increment for the second methyl group, on going from 2-methyl-4-nitrophenol to 4-nitro-2,6-xylenol, is 36 units. This reasoning, however, may be an oversimplification as the steric effect in this xylenol, with methyl substitutions at both positions *ortho* to the hydroxyl group, may play a significant role in the chromatographic behaviour of this compound. In fact, on the two silicone phases, increments for the second methyl group are seen to be 46 and 29 units, whereas for the first methyl group they were 69 and 58 units, which suggests that on these phases the steric hindrance is negligible, the important effect being hyperconjugative electron release.

4-Nitro-2,5-xylenol

This compound may again be compared with the parent 2-methyl-4-nitrophenol, but in this case the second methyl substitution is at a position *ortho* to the nitro group. It is clear from Table III that the increment for substitution at position 5 is greater than the increment for substitution at position 6 when position 2 is already occupied by a methyl group. Either electronic effects are less important or steric effects are more significant in this compound. Although it may seem unlikely that steric effects would be more important here than in 4-nitro-2,6-xylenol, it is quite feasible that the steric hindrance caused by substitution of methyl groups in positions 2 and 6 will produce a greater reduction in the intermolecular hydrogen bonding of 4-nitrophenol than will substitution of methyl groups at positions 2 and 5. On this basis, one would expect the retention index of 4-nitro-2,6-xylenol to be less than that of 4-nitro-2,5-xylenol, and on the silicone phases this is seen to be so.

In conclusion, it can be seen that the increase in retention index for the substitution of a methyl group into a nitrophenol is less than 100 units, as the dominant factors controlling the chromatographic behaviour of such compounds are the hy-

TABLE III

RETENTION INDICES (*I*) AND THEIR INCREMENTS (ΔI) FOR THE METHYL GROUPS ADDED TO THE NITROPHENOLS

Compound	*Apiezon L*		*SE-30*		*SE-52*	
	I	*ΔI*	*I*	*ΔI*	*I*	*ΔI*
2-Nitrophenol	1229		1166		1216	
3-Methyl-2-nitrophenol	1306	77	1267	101	1308	92
2-Methyl-6-nitrophenol	1318	89	1270	104	1305	89
3-Nitrophenol	1514		1439		1530	
2-Methyl-5-nitrophenol	1592	78	1537	98	1619	89
4-Nitrophenol	1634		1502		1607	
2-Methyl-4-nitrophenol	1644	10	1571	69	1665	58
4-Nitro-2,6-xylenol	1680	46	1617	115	1694	87
4-Nitro-2,5-xylenol	—	—	1622	120	1701	94

droxyl and nitro groups. Substituted 2- and 3-nitrophenols appear to prove an exception when using silicone gum rubber (SE-30) as the stationary phase, the change in retention index per methyl substituent then approximating to 100 units. The effect of further substitution of methyl groups into the aromatic nucleus is to further modify, electronically and sterically, the existing functional groups. The change in retention index depends, therefore, not only on the position of substitution relative to the functional groups but also on the number and positions of the methyl groups already in the ring. From Table IV, it can be seen that SE-30 gives the best resolution and would be the stationary phase of choice for nitrophenol isomer analysis.

TABLE IV

RESOLUTION (*R*) BETWEEN PAIRS OF 2-, 3- AND 4-NITROPHENOL ISOMERS AND COLUMN EFFICIENCIES (HETP)

Column	*Resolution*			*HETP (cm)*
	2-/3-	*2-/4-*	*3-/4-*	
Apiezon L	1.7	2.8	0.3	0.3
SE-30	7.1	7.9	1.8	0.15
SE-52	2.6	5.1	0.5	0.25

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