JOURNAL OF CHROMATOGRAPHY

CHROM. 4986

GAS-LIQUID CHROMATOGRAPHY OF DISUBSTITUTED BENZENE ISOMERS

II. SEPARATION AND STUDY OF THE HALONITROBENZENES, ANISOLES AND TOLUENES

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(Received June 10th, 1970)

SUMMARY

Quantitative separation of halonitrobenzenes, anisoles and toluenes was studied on polyethyleneglycol, polyethyleneglycol succinate, polyoxyethylenesorbitan monostearate, silicone oil and squalane as liquid phases. The interactions and forces that affected the separation of the isomers and their elution sequences were discussed. It was found that polyethyleneglycol succinate and polyoxyethylenesorbitan monostearate could selectively separate all the isomers studied.

INTRODUCTION

The separation and study of the dichlorobenzene isomers were presented in Part I (ref. 1). The present work concerns the study of fluoro-, chloro-, and bromonitrobenzenes, fluoro-, chloro-, bromo-, and nitroanisoles, and fluoro-, chloro-, bromo-, iodo-, cyano-, and nitrotoluenes. HABBOUSH AND NORMAN[2] recorded the retention data for nineteen sets of *o*-, *m*-, and *p*-isomers on Apiezon L, dinonyl phthalate, polyethyleneglycol-stearic acid, tritolyl phosphate, 2,4,7-trinitrofluorenone and silicone gum rubber. Nitrotoluenes were resolved by NORMAN[3] on 2,4,7-trinitrofluorenone, by COURTIER *et al.*[4] on cyanated silicone oil, and by PARSON *et al.*[5] using Apiezon L. BOMBAUGH[6] examined chloronitrobenzene on Carbowax (1000) and other liquid phases. RATUSKY AND BASTER[7] studied chloronitrobenzenes, nitroanisoles and other solutes on 1,2,3,4-tetrakis(2-cyanoethoxy)butane.

Most of the reported work did not discuss mechanisms for the separations and interactions involved, but few suggestions for the efficiencies of some systems were given. General quantitative separations and mechanisms of interactions for the isomers dealt with in this study are not available.

The selectivity of stationary liquid phases was studied by several workers[8-13], and others[14-26] discussed the role of stationary phases in gas-liquid chromatography (GLC), aiming to evaluate quantitatively the interactions of the solutes with liquid

TABLE I

SPECIFIC RETENTION VOLUMES, V_g^0 (ml/g), FOR DISUBSTITUTED BENZENE ISOMERS AT DIFFERENT COLUMN TEMPERATURES

Isomer	*PEGS*[a]		*PA*		*PEG*		*SO*		*SQ*	
Temperature (°C)	(140)		(120)	(140)	(120)	(140)	(120)	(140)	(140)	
o-Fluoronitrobenzene	931		1017	562	319	162	538	332	1174	
m-Fluoronitrobenzene	483		509	294	168	91	384	244	617	
p-Fluoronitrobenzene	615		644	367	213	111	423	266	760	
Temperature (°C)	(160)	(180)	(140)	(150)	(140)	(160)	(120)	(140)	(120)	(140)
o-Chloronitrobenzene	944	360	758	662	283	162	NR[b]	NR	NE[c]	NE
m-Chloronitrobenzene	673	266	538	474	210	124	NR	NR	NE	NE
p-Chloronitrobenzene	778	303	612	538	228	133	NR	NR	NE	NE
Temperature (°C)	(160)		(140)	(150)	(140)	(160)	(120)	(140)	(120)	(140)
o-Bromonitrobenzene	1564		1038	977	405	221	NR	NR	NE	NE
m-Bromonitrobenzene	1119		754	722	302	169	NR	NR	NE	NE
p-Bromonitrobenzene	1305		850	806	328	182	NR	NR	NE	NE
Temperature (°C)	(80)	(120)	(100)	(120)	(100)	(120)	(120)	(140)	(120)	(140)
o-Fluoroanisole	658	161	184	98	58	32	216	127	276	155
m-Fluoroanisole	462	124	135	75	46	27	201	120	215	123
p-Fluoroanisole	509	135	150	82	49	29	201	120	233	134
Temperature (°C)	(120)	(140)	(100)	(120)	(100)	(120)	(120)	(140)	(120)	(140)
o-Chloroanisole	516	277	682	326	157	73	632	345	1001	508
m-Chloroanisole	348	195	450	225	111	54	561	312	706	372
p-Chloroanisole	400	221	523	260	128	61	595	330	812	424
Temperature (°C)	(120)	(140)	(120)	(140)	(100)	(120)	(120)	(140)	(140)	
o-Bromoanisole	905	467	580	291	263	113	1017	540	881	
m-Bromoanisole	629	340	415	217	193	86	928	495	668	
p-Bromoanisole	727	387	482	250	226	99	928	495	767	
Temperature (°C)	(160)	(180)	(150)		(140)	(160)	(140)	(180)	(140)	
o-Nitroanisole	2622	1200	1328		456	237	1218	374	NE	
m-Nitroanisole	1438	690	703		214	119	1061	342	NE	
p-Nitroanisole	2859	1315	1473		502	260	1572	467	NE	

Temperature (°C)	(80)									
o-Fluorotoluene	72		NR		NR		NR		NR	
m-Fluorotoluene	79		NR		NR		NR		NR	
p-Fluorotoluene	79		NR		NR		NR		NR	
Temperature (°C)	(80)	(100)	(80)	(100)					(120)	(140)
o-Chlorotoluene	262	139	247	132	NR		NR		192	168
m-Chlorotoluene	292	153	275	144	NR		NR		208	183
p-Chlorotoluene	292	153	275	144	NR		NR		208	183
Temperature (°C)	(100)		(120)	(140)	(100)				(120)	(140)
o-Bromotoluene	262		132	87	90		NR		353	292
m-Bromotoluene	290		144	96	101		NR		378	318
p-Bromotoluene	290		144	96	112		NR		390	318
Temperature (C°)	(120)		(100)		(100)					
o-Iodotoluene	276		409		86		NR		NR	
m-Iodotoluene	290		442		95		NR		NR	
p-Iodotoluene	290		442		105		NR		NR	
Temperature (°C)	(140)		(120)	(140)	(120)	(140)	(140)	(180)	(140)	
o-Nitrotoluene	1051		876	457	279	141	458	178	1076	
m-Nitrotoluene	1343		1160	597	390	188	566	216	1427	
p-Nitrotoluene	1582		1369	706	455	218	620	234	1657	
Temperature (°C)	(140)	(180)	(120)	(140)	(100)	(120)	(120)	(140)	(140)	
o-Tolunitrile	465	131	708	415	345	186	458	284	906	
m-Tolunitrile	571	156	898	517	455	236	524	321	1111	
p-Tolunitrile	656	176	1041	593	526	271	565	344	1258	

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[a] Abbreviations used: PEGS = polyethyleneglycol succinate; PA = polyoxyethylenesorbitan monostearate; PEG = polyethyleneglycol; SO = silicone oil; SQ = squalane.

[b] NR = no resolution.

[c] NE = no elution.

TABLE II

COLUMN EFFICIENCIES FOR DISUBSTITUTED BENZENE ISOMERS AT DIFFERENT COLUMN TEMPERATURES

Where a set of isomers was examined at more than one temperature, values of n, α, and η are recorded for the temperature at which resolution was more satisfactory.

Isomer	*PEGS*			*PA*			*PEG*			*SO*			*SQ*		
	n	α	η	n	α	η	n	α	η	n	α	η	n	α	η
Temperature (°C)	(140)			(120)			(120)			(120)			(140)		
m-Fluoronitrobenzene	2560			2270			352			6050			1550		
		1.27	$1\cdot10^{-10}$		1.26	$1\cdot10^{-9}$		1.27	$2\cdot10^{-3}$		1.1	$5\cdot10^{-5}$		1.23	10^{-6}
p-Fluoronitrobenzene	2670			2800			600			6550			2050		
		1.51	$\ll10^{-14}$		1.58	$\ll10^{-14}$		1.5	$8\cdot10^{-8}$		1.27	$<10^{-14}$		1.55	$<10^{-14}$
o-Fluoronitrobenzene	3800			2500			380			5100			1710		
Temperature (°C)	(160)			(140)			(140)								
m-Chloronitrobenzene	1600			1950			175			NR[a]			NE[b]		
		1.15	$4\cdot10^{-4}$		1.14	$1\cdot10^{-3}$		1.09	$>10^{-1}$						
p-Chloronitrobenzene	2210			2200			270			NR			NE		
		1.22	$6\cdot10^{-6}$		1.24	$7\cdot10^{-7}$		1.24	$5\cdot10^{-2}$						
o-Chloronitrobenzene	2510			2530			600			NR			NE		
Temperature (°C)	(160)			(140)			(140)								
m-Bromonitrobenzene	2650			2240			435			NR			NE		
		1.16	$6\cdot10^{-5}$		1.13	$5\cdot10^{-4}$		1.08	$>10^{-1}$						
p-Bromonitrobenzene	2380			3000			890			NR			NE		
		1.2	$8\cdot10^{-6}$		1.22	$5\cdot10^{-8}$		1.24	$5\cdot10^{-4}$						
o-Bromonitrobenzene	4000			4100			970			NR			NE		
Temperature (°C)	(80)			(100)			(100)			(120)			(120)		
m-Fluoroanisole	1870			1520			1025			2150			1380		
		1.13	$1\cdot10^{-3}$		1.1	$3\cdot10^{-2}$		1.07	$>10^{-1}$		1.0			1.08	$>10^{-1}$
p-Fluoroanisole	2140			1580			700			2150			960		
		1.29	10^{-9}		1.23	$5\cdot10^{-5}$		1.16	$3\cdot10^{-2}$		1.07	10^{-2}		1.18	$5\cdot10^{-3}$
o-Fluoroanisole	3200			2070			1600			3840			1250		
Temperature (°C)	(120)			(100)			(100)			(120)			(120)		
m-Chloroanisole	2720			1970			455			3060			1210		
		1.15	$5\cdot10^{-5}$		1.16	$2\cdot10^{-3}$		1.16	10^{-2}		1.06	$2\cdot10^{-2}$		1.15	$1\cdot10^{-3}$

p-Chloroanisole	3040			1600			815			4670			1800		
		1.29	10^{-12}		1.3	$5 \cdot 10^{-8}$		1.22	$2 \cdot 10^{-3}$		1.06	$2 \cdot 10^{-2}$		1.23	$5 \cdot 10^{-6}$
o-Chloroanisole	3100			1700			1160			6070			1650		
Temperature (°C)	(120)			(120)			(100)			(120)			(140)		
m-Bromoanisole	2060			2000			364			1490			1530		
		1.15	$2 \cdot 10^{-4}$		1.16	$6 \cdot 10^{-4}$		1.17	$3 \cdot 10^{-2}$		1.0			1.15	$3 \cdot 10^{-3}$
p-Bromoanisole	2620			1820			675			1490			1760		
		1.25	10^{-8}		1.2	$5 \cdot 10^{-5}$		1.16	$4 \cdot 10^{-2}$		1.1	$3 \cdot 10^{-2}$		1.15	$5 \cdot 10^{-4}$
o-Bromoanisole	3900			1740			1120			1520			2340		
Temperature (°C)	(160)			(150)			(140)			(140)					
m-Nitroanisole	3470			2660			424			3170			NE		
		1.82	$\ll 10^{-14}$		1.89	$\ll 10^{-14}$		2.12	10^{-11}		1.15	$5 \cdot 10^{-7}$			
o-Nitroanisole	6750			2320			342			4900			NE		
		1.09	$2 \cdot 10^{-4}$		1.11	$7 \cdot 10^{-3}$		1.1	$> 10^{-1}$		1.29	$< 10^{-14}$			
p-Nitroanisole	9750			3600			468			4080			NE		
Temperature (°C)	(80)														
o-Fluorotoluene	1710			NR			NR			NR			NR		
		1.09	$7 \cdot 10^{-2}$												
m-Fluorotoluene	1025			NR			NR			NR			NR		
		1.0													
p-Fluorotoluene	1025			NR			NR			NR			NR		
Temperature (°C)	(80)			(80)			(100)						(120)		
o-Chlorotoluene	1370			2239			675			NR			2610		
		1.12	$8 \cdot 10^{-3}$		1.11	$6 \cdot 10^{-3}$		1.15	$3 \cdot 10^{-2}$					1.09	$7 \cdot 10^{-2}$
m-Chlorotoluene	1760			2250			710			NR			1300		
		1.0			1.0			1.0						1.0	
p-Chlorotoluene	1760			2250			710			NR			1300		
Temperature (°C)	(100)			(120)			(100)						(120)		
o-Bromotoluene	2045			1670			975			NR			3070		
		1.1	10^{-2}		1.1	10^{-2}		1.11	$> 10^{-1}$					1.07	$6 \cdot 10^{-3}$

(continued on p. 156)

TABLE II (*continued*)

Isomer	*PEGS*			*PA*			*PEG*			*SO*			*SQ*		
	n	α	η	n	α	η	n	α	η	n	α	η	n	α	η
m-Bromotoluene	2070	1.0		2070	1.0		304	1.11	$>10^{-1}$	NR			5250	1.03	$>10^{-1}$
p-Bromotoluene	2070			2070			375			NR			1110		
Temperature (°C)	(120)			(100)			(100)								
o-Iodotoluene	1870	1.05	$>10^{-1}$	1250	1.08	$>10^{-1}$	448	1.1	$>10^{-1}$	NR			NR		
m-Iodotoluene	1600	1.0		825	1.0		225	1.11	$>10^{-1}$	NR			NR		
p-Iodotoluene	1600			825			520			NR			NR		
Temperature (°C)	(140)			(120)			(120)			(140)			(140)		
o-Nitrotoluene	3450	1.28	$5\cdot10^{-14}$	3660	1.33	$<10^{-14}$	260	1.4	10^{-3}	4000	1.24	10^{-11}	1920	1.33	$<10^{-14}$
m-Nitrotoluene	3520	1.18	$5\cdot10^{-7}$	3300	1.18	10^{-6}	320	1.16	$8\cdot10^{-2}$	4250	1.09	10^{-3}	3200	1.16	10^{-5}
p-Nitrotoluene	6650			4550			640			6300			3270		
Temperature (°C)	(140)			(120)			(100)			(120)			(140)		
o-Tolunitrile	2100	1.23	$5\cdot10^{-8}$	1720	1.27	$5\cdot10^{-8}$	940	1.32	$5\cdot10^{-7}$	6250	1.14	10^{-10}	1200	1.22	10^{-6}
m-Tolunitrile	2700	1.15	$2\cdot10^{-4}$	1900	1.16	$4\cdot10^{-4}$	1220	1.15	$8\cdot10^{-3}$	7420	1.08	10^{-4}	2240	1.13	10^{-3}
p-Tolunitrile	3770			2300			1680			11750			1700		

[a] NR = not resolved.
[b] NE = not eluted.

TABLE III

SOME PHYSICAL CONSTANTS FOR DISUBSTITUTED BENZENES

Isomer	n_D^T	*T (°C)*	*E.P. (cm³ × 10²⁶)*	*B.p.*[c] *(°C)*	*D.M.*[d] *(Debye)*
o-Fluoronitrobenzene	1.5278[a]	31	12.196	214.6	4.86
m-Fluoronitrobenzene	1.5212[a]	31	12.068	205.0	3.49
p-Fluoronitrobenzene	1.5269[a]	31	12.179	205.0	2.53
o-Chloronitrobenzene	1.5330[a]	85	12.296	245.7	5.01
m-Chloronitrobenzene	1.5385[a]	85	12.402	235.6	3.47
p-Chloronitrobenzene	1.5501[a]	85	12.622	242.0	2.43
o-Bromonitrobenzene				261.0	4.97
m-Bromonitrobenzene				256.5	3.48
p-Bromonitrobenzene				256.0	2.45
o-Fluoroanisole	1.4940[a]	30.5	11.534	155.0	2.32
m-Fluoroanisole	1.4859[a]	30.5	11.373		1.35
p-Fluoroanisole	1.4830[a]	30.5	11.313	157.0	0.18
o-Chloroanisole	1.5478[b]	12.0	12.581	195.0	2.43
m-Chloroanisole	1.5378[b]	12.0	12.390	194.0	1.65
p-Chloroanisole	1.5401[b]	12.0	12.434	198.0	0.28
o-Bromoanisole	1.5691[a]	29.0	12.982	210.0	2.41
m-Bromoanisole	1.5591[a]	29.0	12.794	211.0	1.41
p-Bromoanisole	1.5596[a]	29.0	12.802	215.0	0.26
o-Nitroanisole	1.5428[a]	59	12.483	277.0	4.73
m-Nitroanisole	1.5410[a]	59	12.446	258.0	3.53
p-Nitroanisole	1.5698[a]	59	12.994	260.0	2.71
o-Fluorotoluene	1.4703[a]	20	11.062	114.0	1.28
m-Fluorotoluene	1.4691[a]	20	11.034	116.0	1.66
p-Fluorotoluene	1.4699[a]	20	11.054	117.0	1.85
o-Chlorotoluene	1.528[b]	20	12.200	159.4	1.34
m-Chlorotoluene	1.523[b]	20	12.106	162.4	1.74
p-Chlorotoluene	1.521[b]	20	12.064	162.5	1.96
o-Bromotoluene				181.8	1.31
m-Bromotoluene				183.7	1.71
p-Bromotoluene				183.6	1.93
o-Iodotoluene				211.0	1.15
m-Iodotoluene				204.0	1.54
p-Iodotoluene				211.5	1.77
o-Nitrotoluene	1.5488[b]	15	12.600	222.3	3.83
m-Nitrotoluene	1.5491[b]	15	12.606	231.0	4.18
p-Nitrotoluene	1.5384[b]	15	12.401	238.0	4.38
o-Tolunitrile				204.0	3.82
m-Tolunitrile				214.0	4.22
p-Tolunitrile				217.0	4.42

[a] Measured in this laboratory.
[b] Ref. 28 and 29.
[c] Ref. 30 and 31.
[d] Calculated as given by SMITH[32].

phases. However, separations of complex mixtures of various chemical compositions were given in the literature, but investigations of their mechanisms of separation were rather rare.

EXPERIMENTAL AND RESULTS

The apparatus, columns and experimental conditions were the same as given in Part I (ref. 1).

Materials

Pure *o*-, *m*- and *p*-fluorotoluenes, chloroanisoles and chlorotoluenes, iodotoluenes, fluoroanisoles and bromoanisoles were obtained from T. J. Sas and Son Ltd., Great Britain. Pure bromotoluenes, nitrotoluenes, tolunitriles, nitroanisoles, *p*-fluoronitrobenzene, chloronitrobenzenes and bromonitrobenzenes were from Hopkin and Williams Ltd., Great Britain. Pure *o*- and *m*-fluoronitrobenzenes were from L. Light and Co. Ltd., Great Britain.

Sampling for liquid isomers was the same as in the previous work, but for solid isomers a 10% (w/w) acetone or ether solution of the isomers was used. Sample sizes ranged from 1–3 μl.

Specific retention volumes, $v_g{}^0$, for all the isomers on the liquid phases studied were calculated as given by LITTLEWOOD *et al.*[27] and are listed in Table I. From the results obtained, the number of theoretical plates, n, relative peak separation, α, and the fractional band impurity, η, were calculated as in Part I. The values of n, α, and η are listed in Table II.

Refractive indices for some isomers were not available; therefore, they were determined in this laboratory in order to calculate the electron polarizabilities per unit volume, α_e^v, as in Part I. An Ape Refractometer fitted with a Colara K0930 ultrathermostat was used for this purpose. Table III gives some important physical constants (refractive indices, electron polarizabilities, boiling points and dipole moments) for the disubstituted benzene isomers to be utilized in the discussion.

DISCUSSION

The elution order of halonitrobenzenes and of anisoles was always *m*-, *p*- and *o*-. For nitroanisoles, it was *m*-, *o*- and *p*-. These orders are not the order of the increase of the calculated dipole moments of these isomers. The calculated electron polarizabilities per unit volume for these isomers show that the polarization of the *p*-isomers is higher than that of the corresponding *m*-isomer. In fact, *p*-isomers would exert higher polarity than the calculated polarity, this being due to the polarizing effect of the solvent (as shown in Table III).

Toluenes, namely fluoro-, chloro-, bromo-, iodo-, nitro- and cyanotoluenes were eluted in the order: *o*-, *m*- and *p*-. They seem to follow the same order of their calculated dipole moments (as seen in Table III and Fig. 1).

In general, the explanation of the orders can be simplified if one considers the large dipole moment of *p*-isomers, other than toluenes, and the steric effects of the *ortho*-derivatives. The consistently stronger retention of the *p*- *versus* *m*-isomers seems most likely to be due to an intramolecular electronic effect, as by resonance-

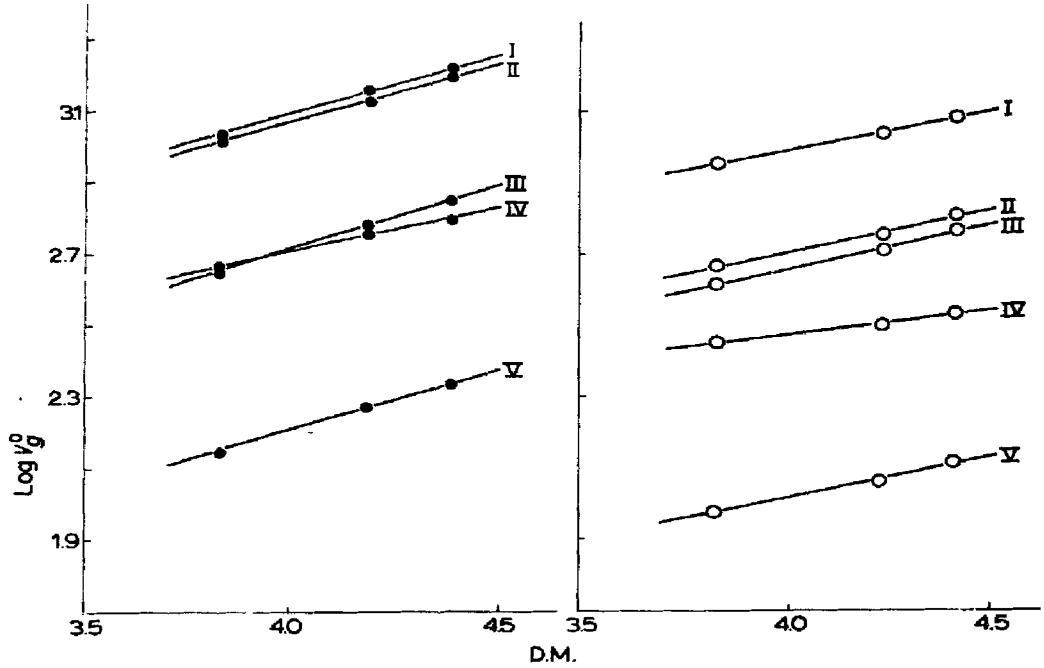

Fig. 1. Variation of log $V_g{}^0$ with dipole moment for nitrotoluenes (●) and tolunitriles (○) at 140° and on the following liquid phases: I, Squalane; II, polyethyleneglycol succinate; III, polyoxyethylenesorbitan monostearate; IV, silicone oil; and V, polyethyleneglycol.

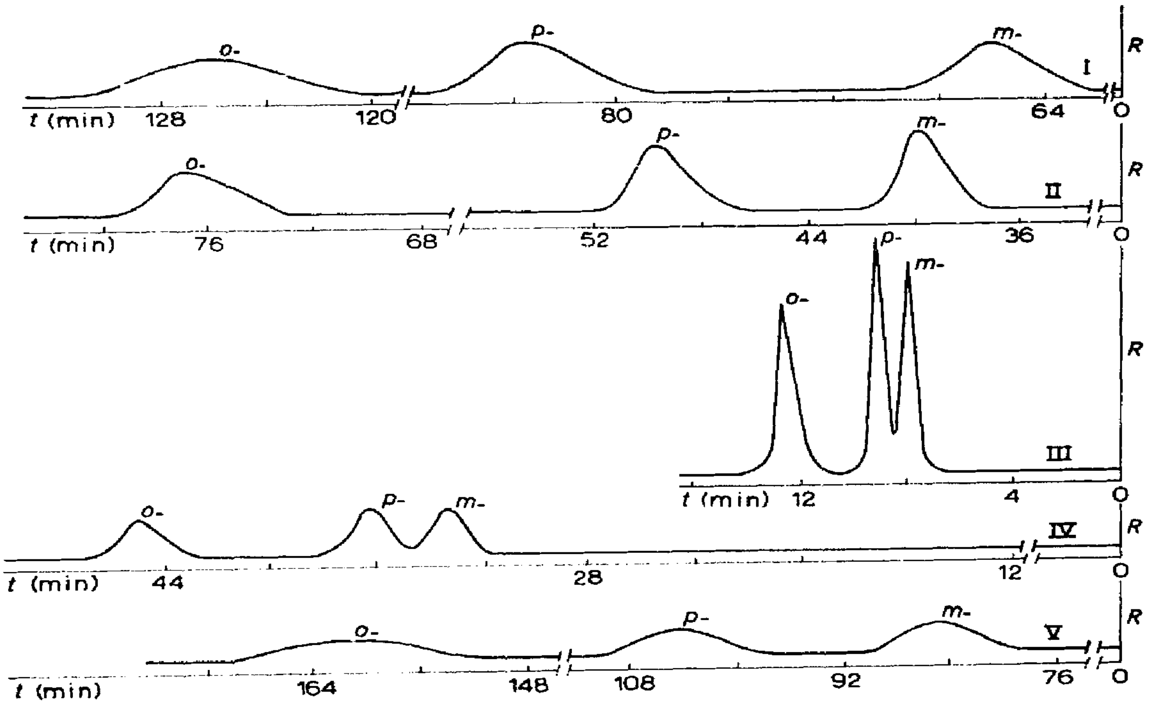

Fig. 2. Chromatograms showing the separation of fluoronitrobenzene isomers on I, polyethyleneglycol succinate at 140°; II, polyoxyethylenesorbitan monostearate at 140°; III, polyethyleneglycol at 160°; IV, silicone oil at 140°; and V, squalane at 140°. *R* is the recorder deflection and *t* is the retention time in min.

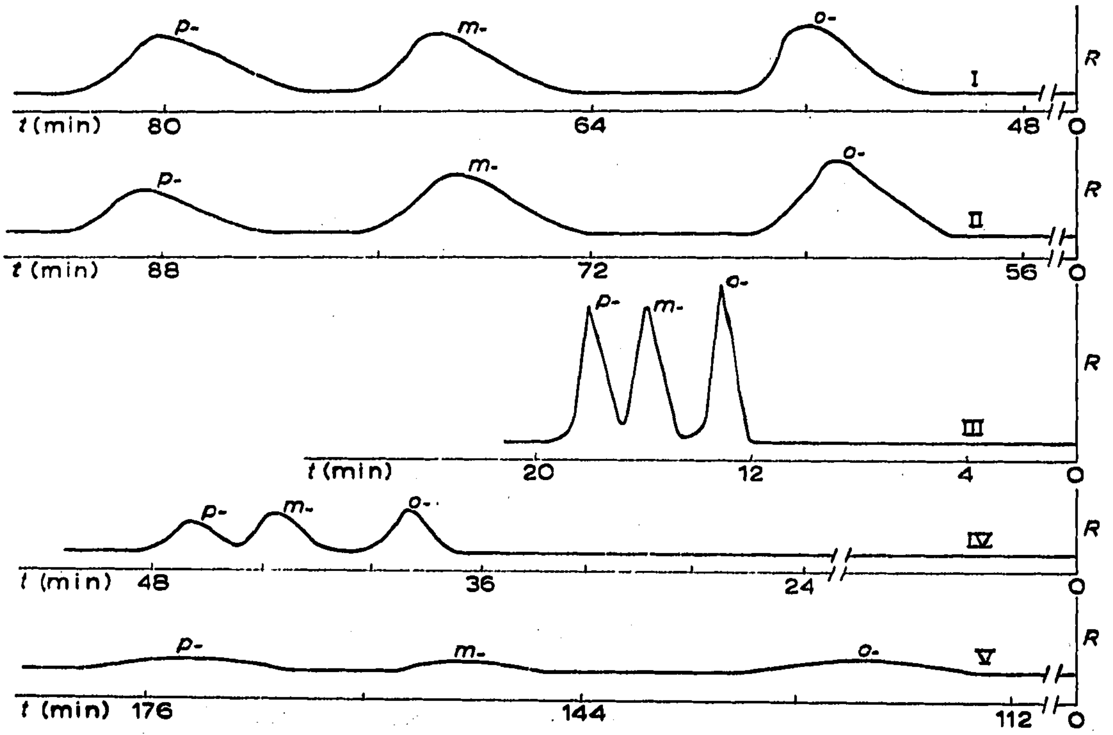

Fig. 3. Chromatograms showing the separation of tolunitriles at 140° on I, polyoxyethylene-sorbitan monostearate; II, polyethyleneglycol succinate; III, polyethyleneglycol; IV, silicone oil; V, squalane. *R* is the recorder deflection and *t* is the retention time in min.

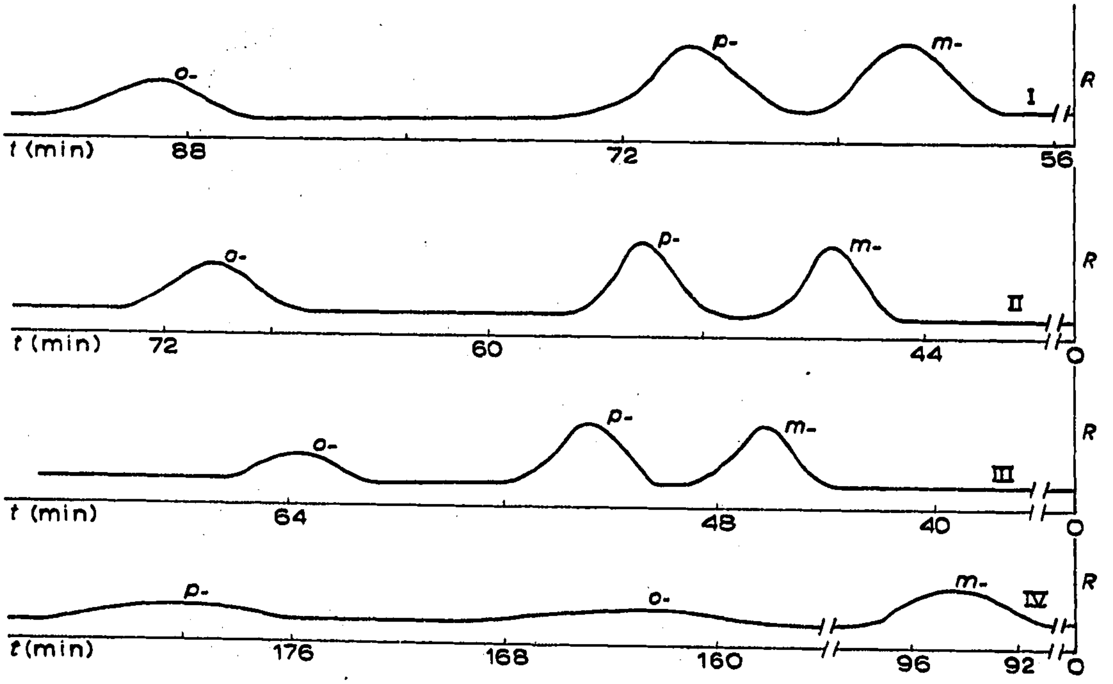

Fig. 4. Chromatograms showing the separation of anisoles on polyethyleneglycol succinate. The chromatograms are represented as follows: I, fluoroanisoles at 80°; II, chloroanisoles at 120°; III, bromoanisoles at 140°; IV, nitroanisoles at 180°. *R* is the recorder deflection and *t* is the retention time in min.

induced electron transfer to one of the ring substituents when it is under the influence of a solvent dipole. For toluenes, it seems fairly clear that the steric effects in the *ortho*-derivatives are the main differences. For other derivatives (chloromethoxy, bromonitrobenzene, etc.) the *ortho*-derivatives have an effectively larger dipole moment, leading to stronger interactions with the solvent. In the toluenes this effect is missing (alkyl group dipole moments are small) and steric hindrance to solvent interactions with the dipole by the methyl becomes dominant, leading to lesser interaction of the *o*-toluene isomers.

The most selective liquid phases for separation and quantitative determination in this work are the polyesters, *i.e.* PEGS and PA (as seen in Table II, and Figs. 2–4). The substitution of a hydrogen atom in a glycol-type liquid phase by an ester group (succinate or stearate) seems to enhance greatly the selectivity. Carbonyl groups of esters may act as a good polarizing group and would then yield a better resolution of polar solutes.

In SO and SQ, the selectivity was lower than in other liquid phases. They gave wide peaks but were accompanied with larger retention volumes. PEG gave sharp peaks but with a wide base; therefore, the number of theoretical plates was the lowest among the other solvents. In PEG, the specific retention volumes are the smallest among the other liquid phases. This may be caused by the thinner film of the liquid on the solid support due to the higher density of this liquid relative to the other liquids (as in Part I, Table I). In addition, the high molecular weight of PEG and the presence of intermolecular hydrogen bonds would also decrease the retentions of the isomers on this liquid phase.

ACKNOWLEDGEMENTS

The authors are thankful to the Head of the Chemistry Department, College of Science, and to the University of Baghdad for providing every facility to accomplish this work.

REFERENCES

1 A. E. Habboush and A. H. Tameesh, *J. Chromatog.*, 53 (1970) 143.
2 A. E. Habboush and R. O. C. Norman, *J. Chromatog.*, 7 (1962) 438.
3 R. O. C. Norman, *Proc. Chem. Soc.*, (1958) 151.
4 J. C. Courtier, L. Etienne, J. Tranchant and S. Vertalier, *Bull. Soc. Chim. France*, (1965) 3181.
5 J. S. Parsons, S. M. Tsang, M. P. DiGiaimo, R. Feinland and R. A. Paylor, *Anal. Chem.*, 33 (1961) 1858.
6 K. Bombaugh, *Anal. Chem.*, 33 (1961) 29.
7 J. Ratusky and L. Baster, *Chem. Ind. (London)*, (1964) 579.
8 T. Araki, *Bull. Chem. Soc. Japan*, 36 (1963) 879.
9 A. N. Korol, *Teoreticheskaya i Eksperimental'naya Khimiya*, 1, No. 6 (1965) 769.
10 A. N. Korol, *Teoreticheskaya i Eksperimental'naya Khimiya*, 2, No. 1 (1966) 79.
11 A. I. M. Keulemans, in C. G. Verver (Editor), *Gas Chromatography*, Reinhold, New York, 1959, p. 166.
12 L. Rohrschneider, *Z. Anal. Chem.*, 211 (1965) 18.
13 S. H. Langer, *Anal. Chem.*, 39 (1967) 524.
14 H. M. McNair and T. M. DeVries, *Anal. Chem.*, 33 (1961) 806.
15 I. Brown, *J. Chromatog.*, 10 (1963) 284.
16 S. H. Langer and J. H. Purnell, *J. Phys. Chem.*, 67 (1963) 263.
17 P. Chovin, *Bull. Soc. Chim. France*, (1964) 1800.
18 L. Rohrschneider, *J. Chromatog.*, 22 (1966) 6.
19 A. N. Korol, *Ukr. Khim. Zh.*, 32 (1966) 329.

20 A. R. Cooper, C. W. P. Crowne and P. G. Farrell, *J. Chromatog.*, 27 (1967) 362.
21 A. O. S. Maczek and C. S. G. Phillips, *J. Chromatog.*, 29 (1967) 15.
22 A. R. Cooper, C. W. P. Crowne and P. G. Farrell, *J. Chromatog.*, 29 (1967) 1.
23 C. Bighi, A. Betti and G. Saglietto, *Bull. Soc. Chim. France*, (1967) 4637.
24 S. H. Langer, C. Zahn and G. Pantazoplos, *J. Chromatog.*, 3 (1960) 154.
25 J. Janák and M. Hřivnáč, *J. Chromatog.*, 3 (1960) 297.
26 D. E. Martire, in A. B. Littlewood (Editor), *Gas Chromatography, 1966*, Inst. Petrol., London, 1967, p. 21.
27 A. B. Littlewood, C. S. G. Phillips and D. T. Price, *J. Chem. Soc.*, (1955) 1480.
28 E. H. Huntress, *Organic Chlorine Compounds*, J. Wiley & Sons, New York, 1948.
29 J. Timmermans, *Physico-Chemical Constants of Pure Organic Compounds*, Vol. 1, Elsevier, Amsterdam, London, New York, 1950.
30 E. W. Washburn, *International Critical Tables*, Vols. I and VII, McGraw-Hill Co., New York, 1926.
31 C. D. Hodgman (Editor), *Hand Book of Chemistry and Physics*, 42th Ed., 1960–1961, The Chemical Rubber Publishing Co., Ohio, 1960–1961.
32 J. W. Smith (Editor), *Electrical Dipole Moments*, Butterworths, London, 1955, p. 96.