STRUCTURAL CORRELATIONS TO SOLUTE ELUTION AND MOLECULAR SENSITIVITY DATA IN THE ELECTRON CAPTURE ANALYSIS OF ISOMERIC CHLOROPHENYL *m*-FLUOROSULFONYLBENZOATES

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An earlier study reported the gas chromatography of *m*-fluorosulfonylphenyl carbamates[1] in which it was noted that the solutes underwent thermal lysis to *m*-fluorosulfonylaniline and respective phenols during analysis. The thermal instability of the aryl carbamoyl grouping has been experienced in several other investigations[2–5]. It was of interest to compare the analytical stability of this moiety to the aryl ester linkage *via* chromatography of *m*-fluorosulfonylbenzoate esters and to investigate the gas chromatographic behavior of this related class of derivatives.

EXPERIMENTAL

The *m*-fluorosulfonylbenzoates were synthesized by reaction of *m*-fluorosulfonylbenzoyl chloride with various phenols in pyridine medium. Melting points were determined on a Fisher-Johns melting point apparatus. Gas chromatography was performed on a 3 ft. by 0.125 in. coiled Pyrex glass column packed with 4% Dow-11 silicone on 40–60 mesh HMDS-pretreated Chromosorb W, and housed in an Aerograph Hy-FI Model 600-B (Varian Aerograph, Walnut Creek, Calif., U.S.A.) containing a Model 600-D electrometer and an electron capture detector (250 mC titanium tritide). Experimental conditions are given in the footnotes to Table I.

RESULTS AND DISCUSSION

The analytical results obtained in this study are discussed in two parts, *viz.*: (A) chromatographic behavior and (B) delineation of electron capture sensitivity. Relationships between molecular structure of solutes and their chromatographic behavior have been reported for paper[6,7], alumina impregnated paper[8], thin-layer[9–12] and alumina column[13] chromatography; and in detailed studies by KOVATS[14,15] and other investigators[16–18] for gas chromatography.

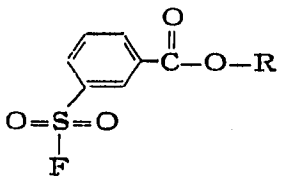
A. Chromatographic behavior

In view of the thermal lability of *m*-fluorosulfonylphenyl carbamates reported earlier[1], it was of interest to observe that the structurally-related aryl *m*-fluorosulfonylbenzoates did not degrade during gas chromatographic assay. This would appear consistent with the greater bonding energy associated with a C–O bond (*ca.* 81 kcal/mole) in contrast to that of a C–N bond (*ca.* 62 kcal/mole)[19].

The analytical results are presented in Table I. The elution data may be utilized to obtain linear relative contributions of moieties in the manner reported previously for carbamate chromatographic interpretations[20]. This was achieved in the present study by determining logarithmic differences of the relative elution values of the isomeric chlorophenyl derivatives with phenyl *m*-fluorosulfonylbenzoate (standard; relative elution of 1.00). The linear contributions of the isomeric aryl chloro substituents thus obtained, are shown in Table II. The relative importance of the various substitutions to the chromatographic data is indicated in the last column of the table.

TABLE I

GAS CHROMATOGRAPHY OF *m*-FLUOROSULFONYLBENZOATES



Compound No.	*R*	*Mol. wt.*	*M.p.*	*Relative elution*[a]	*N/ft.*[b]	*Relative sensitivity*[a]
6	ϕ	280	43– 44	1.00	34.7	1.00
10	*o*-Clϕ	314	68– 69	1.63	55.4	0.751
7	*m*-Clϕ	314	47– 48	2.14	53.6	0.964
9	*p*-Clϕ	314	78– 79	2.15	59.0	0.809
2	2,3-diClϕ	349	101–102	3.36	58.0	1.39
5	2,5-diClϕ	349	85– 86	2.86	52.4	1.22
1	2,6-diClϕ	349	129–130	2.34	42.4	1.60
8	3,4-diClϕ	349	74– 75	4.44	49.4	0.927
3	3,5-diClϕ	349	110–111	3.59	42.6	1.36
11	2,4,5-triClϕ	383	79– 81	5.06	50.4	0.505
4	2,4,6-triClϕ	383	118–119	3.38	46.6	1.33

[a] Relative to phenyl *m*-fluorosulfonylbenzoate. Typical sensitivity: 49.4 mm² (peak area)/ng.
[b] Theoretical plates calculated by: $N = 16[t_r^0/b]^2$, where t_r^0 = corrected retention time of the peak maximum in mm of chart and b = peak base calculated from $b = 2$ peak area (mm²)/peak height (mm) following calculation of peak area *via* triangulation (height and width at height/2).

TABLE II

RELATIVE LINEAR RETENTION CONTRIBUTIONS OF ISOMERIC ARYL CHLORO SUBSTITUENTS

Substituents	*Linear contribution*	*Relative contribution*
2-Chloro (*ortho*)	0.212	1.00
3-Chloro (*meta*)	0.330	1.56
4-Chloro (*para*)	0.332	1.57
2,6-Dichloro	0.369	1.78
2,5-Dichloro	0.456	2.15
2,3-Dichloro	0.526	2.48
2,4,6-Trichloro	0.529	2.50
3,5-Dichloro	0.555	2.62
3,4-Dichloro	0.647	3.05
2,4,5-Dichloro	0.704	3.32

It is of interest to note that, while the linear contributions should contain an additive feature, they obviously do not (*e.g.* the 3-chloro substituent value [0.330] and the 4-chloro value [0.332] do not add to the value for the 3,4-dichloro substituent value [0.647]). Hence, one must not only consider values for the presence or absence of groups, but the group interactions which must occur in di- and tri-substituted rings and which might influence the molecular chromatographic retention.

TABLE III

RETENTION EQUATIONS FOR INTERACTION ESTIMATION

Compound No.	*Equation*[a]
10	$a = 0.212$
7	$b = 0.330$
9	$c = 0.332$
1	$(2a)e = 0.369$
5	$(a + b)f = 0.456$
2	$(a + b)d = 0.526$
4	$(2a + c)h = 0.529$
3	$(2b)e = 0.555$
8	$(b + c)d = 0.647$
11	$(a + b + c)g = 0.704$

[a] Presence of chlorine atoms: a = positions 2 or 6; b = positions 3 or 5; c = position 4. Interactions: (1) Di-substituted compounds: d = attached to adjacent ring carbons; e = 1 ring carbon between points of attachment; f = 2 ring carbons between points of attachment. (2) Tri-substituted compounds: g = 0 and 1 ring carbons between points of attachment; h = 1 and 1 ring carbons between points of attachment.

Utilizing the linear contribution values of Table II, retention equations were written in an attempt to discern an estimation of the contribution of group interaction towards chromatography for the di- and trichloro substituted derivatives. These may be seen in Table III. The designations of *a–c* represent the physical presence of the chloro substituents; while those of *d–h* indicate the various interactions between chlorine atoms on the same ring, and are singularly identified in the footnote to Table III. The interaction product values obtained by solution of the equations are as follows:

$d = 0.971$ (Compound 2)
$d = 0.978$ (Compound 8)
$e = 0.871$ (Compound 1)
$e = 0.841$ (Compound 3)
$f = 0.842$ (Compound 5)
$g = 0.806$ (Compound 11)
$h = 0.699$ (Compound 4)

The agreement for the *d* and *e* replicates is quite remarkable when one considers the crudeness of this interpretative approach. Further, a rather interesting and reasonable generalization may be made concerning the spatial spread between ring chlorine atoms for both di- and trichloro derivatives: the interaction towards retention effects increases as the chlorine atom substitution sites get further apart. It should be readily apparent from the approach utilized, that an interaction product value of 1.000 would imply that no interaction was present. The graphic trend of the interaction product values may be seen in Fig. 1.

B. Delineation of electron capture sensitivity

An approach towards a delineation of relative quantitative contributions of molecular moieties to the electron capturing capacity of the molecule has been reported recently in an interpretation of the electron capture analysis of pesticides[21]. This technique has been employed in the present study for the aryl *m*-fluorosulfonylbenzoate derivatives.

A total of 6 moieties and 3 interaction designations were coded *A* through *H* and are given in Table IV. Linear equations for the coded moieties and interactions

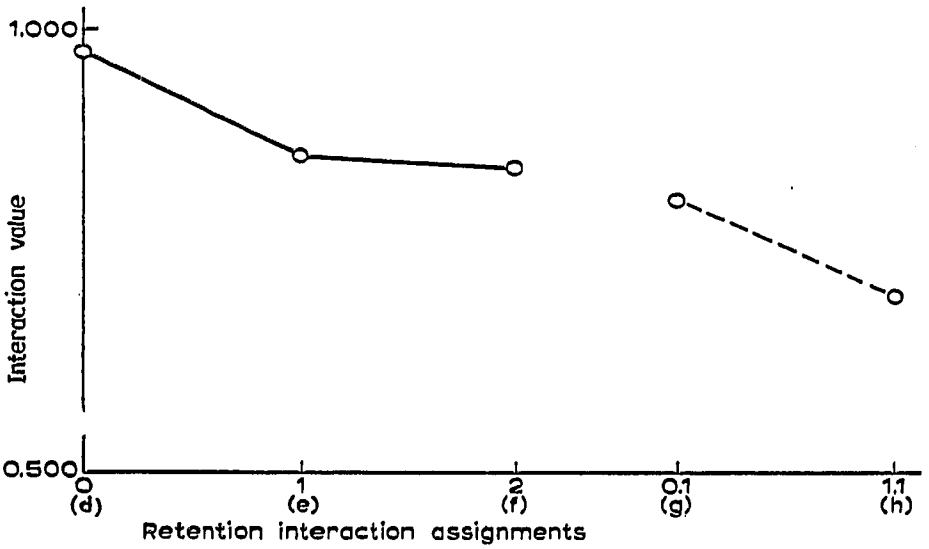
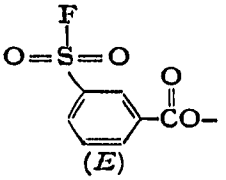


Fig. 1. Interaction factors in di- and tri-substituted phenyl *m*-fluorosulfonylbenzoates.

TABLE IV

CODE DESIGNATIONS FOR MOLECULAR MOIETIES AND INTERACTIONS

Compound No.	*Aryl chlorine*			*Phenyl ring* (*D*)		*Interactions*[a]			*Relative sensitivity*
	o (*A*)	*m* (*B*)	*p* (*C*)			(*F*)	(*G*)	(*H*)	
1	2	0	0	1	1	0	0	1	1.60
2	1	1	0	1	1	0	0	0	1.39
3	0	2	0	1	1	1	0	0	1.36
4	2	0	1	1	1	2	0	1	1.33
5	1	1	0	1	1	0	1	0	1.22
6	0	0	0	1	1	0	0	0	1.00
7	0	1	0	1	1	0	0	0	0.964
8	0	1	1	1	1	0	0	0	0.927
9	0	0	1	1	1	0	0	0	0.809
10	1	0	0	1	1	0	0	0	0.751
11	1	1	1	1	1	1	1	0	0.505

[a] Interactions are designated according to the number of ring carbon atoms located between the points of ring attachment for the chlorine atoms, as determined from position 2 to position 6, as: one ring carbon atom between two attached chlorine atoms (*F*); two ring carbons (*G*); three ring carbons (*H*).

are given in Table V. Regression weights (coded moieties and interactions) were calculated which minimized the difference between the observed and predicted relative sensitivities (as in the earlier study[21]) by means of a multiple linear regression program using a Control Data Corporation Model 3600 computer. It should be pointed out that the use of such a program as a model for interpretative purposes involves the degree of validity in the assumptions that (1) the overall electron capturing capacity of the molecule is a linear function of electron capturing groups in the molecule; and (2) that the contribution of a given type of moiety is roughly the same in one compound as it is in other compounds containing it. The computed regression weights may be inspected in Table VI. The implications are inconsistent with those obtained in the earlier study in which it was found that the *para* substitution site for an aryl chloro substituent afforded the greatest sensitivity. In addition, in the light of the acknowledged potential of aryl chlorine atoms for electron capture analysis, it was surprising to obtain less sensitivity for several chlorophenyl derivatives than for the phenyl derivative itself (Table I). It might be suggested that the presence of an electron-withdrawing group such as the fluorosulfonyl substituent, *meta* to a carbonyl grouping, could result in sufficient electronic inductive distortion away from the phenyl ring, thereby enhancing the electron capturing ability of that portion of the benzoate molecule to a degree which is not overcome by the addition of one chloro substituent.

TABLE V

LINEAR EQUATIONS OF MOIETY AND INTERACTION CONTRIBUTIONS TO MOLECULAR SENSITIVITY ON ELECTRON CAPTURE

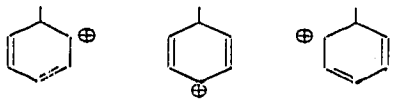
Compound No.	*Equation*	
1	$2A + D + E + H$	= 1.60
2	$A + B + D + E$	= 1.39
3	$2B + D + E + F$	= 1.36
4	$2A + C + D + E + 2F + H$	= 1.33
5	$A + B + D + E + G$	= 1.22
6	$D + E$	= 1.00
7	$B + D + E$	= 0.964
8	$B + C + D + E$	= 0.927
9	$C + D + E$	= 0.809
10	$A + D + E$	= 0.751
11	$A + B + C + D + E + F + G$	= 0.505

TABLE VI

MOLECULAR VALUES

Code	*Moiety/interaction*	*Value*	*Standard error*
A	*ortho* aryl Cl	+ 0.0241	0.219
B	*meta* aryl Cl	+ 0.263	0.156
C	*para* aryl Cl	— 0.231	0.195
D	phenyl ring	0.000	0.000
E	*m*-FSO_2-benzoxylate radical	0.000	0.000
F	1 interstitial ring C atom	— 0.103	0.167
G	2 interstitial ring C atoms	— 0.172	0.266
H	3 interstitial ring C atoms	+ 0.720	0.434

The relative sensitivity values for the *ortho*, *meta* and *para* monochloro derivatives conceivably then indicate a slight decline in molecular sensitivity by counteracting to some degree the electronic distortion of the phenyl ring, rendering it less positive (and less electron capturing) than the unsubstituted phenyl derivative. This counteraction is least for the *meta* chloro derivative, as might be explained by the hybrid unsubstituted phenyl structures:



Further interpretation of the data becomes increasingly difficult and necessarily cautious in view of the limited data on hand, excepting the expected trend of general enhancement of molecular sensitivity for the dichloro derivatives. Substitution of the values given in Table VI back into the equations (Table V) afforded a check on the validity of the procedure adopted for delineation of molecular sensitivity. The results are given in Table VII.

TABLE VII

RELATIVE SENSITIVITY DATA: PREDICTED *vs.* EXPERIMENTAL

Compound No.	*Predicted*	*Experimental*
1	1.68	1.60
2	1.20	1.39
3	1.34	1.36
4	1.25	1.33
5	1.03	1.22
6	0.92	1.00
7	1.18	0.96
8	0.95	0.93
9	0.68	0.81
10	0.94	0.75
11	0.70	0.51

Several qualifying remarks should be mentioned. The relative sensitivities of the moieties depend upon the frequency with which they appear in the compounds employed in their computation. The relative sensitivity for a moiety appearing in every compound in the calculations would be zero (as may be seen for two moieties in Table VI).

Caution should be exercised in excessive interpretation of the data because of the small number of compounds employed. Further experiments are presently in progress which will involve a large number of diverse compound classes to more fully evaluate the efficacy of this analytical approach towards a quantitative delineation of molecular sensitivity values. Fortified with properly qualified moiety values, it might be then possible to estimate the sensitivity of compounds possessing electron capturing ability *a priori* from structural considerations alone.

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SUMMARY

This study describes the chromatographic behavior and relative electron capturing ability of a number of *m*-fluorosulfonylbenzoate aryl esters. The discussion attempts to relate various portions of the ester molecules to the analytical results which were obtained. This was done by logarithmic differences for chromatographic interpretations, and by multiple linear regression analysis of the electron capture sensitivity data.

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