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^{19}F NMR CHEMICAL SHIFTS OF n-*F*-ALKYL COMPOUNDS

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SUMMARY

The examination of ^{19}F chemical shifts for *ca.* 650 *F*-alkylated compounds of general formula $CF_3(CF_2)_nCF_2X$ led to the following conclusions: the CF_2 groups α to X are very sensitive to the nature of X, and are spread over a range of 85 ppm. The effect of the length of the *F*-alkyl chain decreases rapidly, so that $\delta CF_2(\alpha)$ can already be considered as characteristic of X for n = 1 or 2 for most practical purposes. Solvent effects (in 9 different solvents having $\varepsilon = 1.8$ to 52.1) were found to be rather small except for the *F*-alkyl iodides. A chart which indicates the domain in which the $CF_2(\alpha)$ resonance signal is to be expected is given for 42 different series of *F*-alkylated compounds; it is expected to provide the synthetic chemist with a useful tool for the identification and characterization of such compounds.

INTRODUCTION

As a consequence of the development of the chemistry of per and polyfluorinated compounds ("fluorocarbon" derivatives) and of the commercial availability of an increasing number of perfluorinated starting materials, one observes a considerable growth in the ^{19}F NMR data published on such compounds. Several compilations [1] and annual reviews [2] concerning ^{19}F NMR in general are available.

The aim of the present contribution is to find which general trends exist between the chemical shifts of compounds of type $CF_3(CF_2)_nCF_2X$, where X is an organic or inorganic moiety, and the nature of X and of the chain length. Solvent effects have also been studied. We expect in this way to provide synthetic chemists in the field with a convenient analytical tool for the identification and characterisation of compounds of this general type. For this purpose we collated data on more than 650 compounds, part of which are scattered in the literature, part of which result from synthetic work done in our Laboratory [3-11].

The scope of this contribution is restricted to perfluoroalkylated derivatives with linear chains having more than one carbon atom; CF_3 derivatives are excluded since most of the correlations found in the present study are based on the chemical shifts of the CF_2 groups located at the end of the chain. On the other hand the case of CF_3, which is unique, has already been reviewed [1b].

DISCUSSION

For *F*-alkyl derivatives the ^{19}F chemical shifts range from 55 to 140 ppm upfield from CCl_3F. When the *F*-alkyl chain has up to six carbon atoms, the resonances of the trifluoromethyl and of each of the difluoromethylene groups can be distinguished with routine NMR instruments working at 56.46 MHz in a 14,090 gauss field. For example :

$$\begin{array}{lcccccc} & CF_3 - & CF_2(\varepsilon) - & CF_2(\delta) - & CF_2(\gamma) - & CF_2(\beta) - & CF_2(\alpha) - I \quad [11] \\ \delta^{\dagger} = & 81.6 & 126.6 & 123.1 & 121.4 & 113.3 & 59.3 \quad (\text{in } CCl_4). \end{array}$$

Sometimes, the assignment of the central CF_2 groups (γ and δ) may be troublesome. This difficulty may be overcome by comparing compounds having the same chain but different X groups, in so far as one expects the effect of the substitution on the chemical shifts to be larger for $CF_2(\gamma)$ than for $CF_2(\delta)$. From seven carbon atoms upwards, the signals due to the central difluoromethylene groups are generally not resolved any more in routine conditions, and only five resonances can then be assigned :

$$\begin{array}{lcccccc} & CF_3 - & CF_2 - & (CF_2CF_2CF_2CF_2) - & CF_2 - & CF_2 - & CBr = CHBr \quad [10] \\ \delta^{\dagger} = & 81.2 & 126.6 & 121.5 - 122.5 & 120.4 & 105.9 & (\text{in } CCl_4). \end{array}$$

Due to the great number of fluorine atoms present, and consequently to the many fluorine-fluorine coupling constants, the individual CF_3 and CF_2 units consist of rather broad multiplets, so that the only useful parameters are generally the chemical shifts.

[†] All the chemical shifts are given in ppm positive upfield from CCl_3F. The errors on δ were evaluated at 0.25 ppm for routine experiments, and the incertitude relative to data from the literature having various origins was estimated at 0.5 ppm.

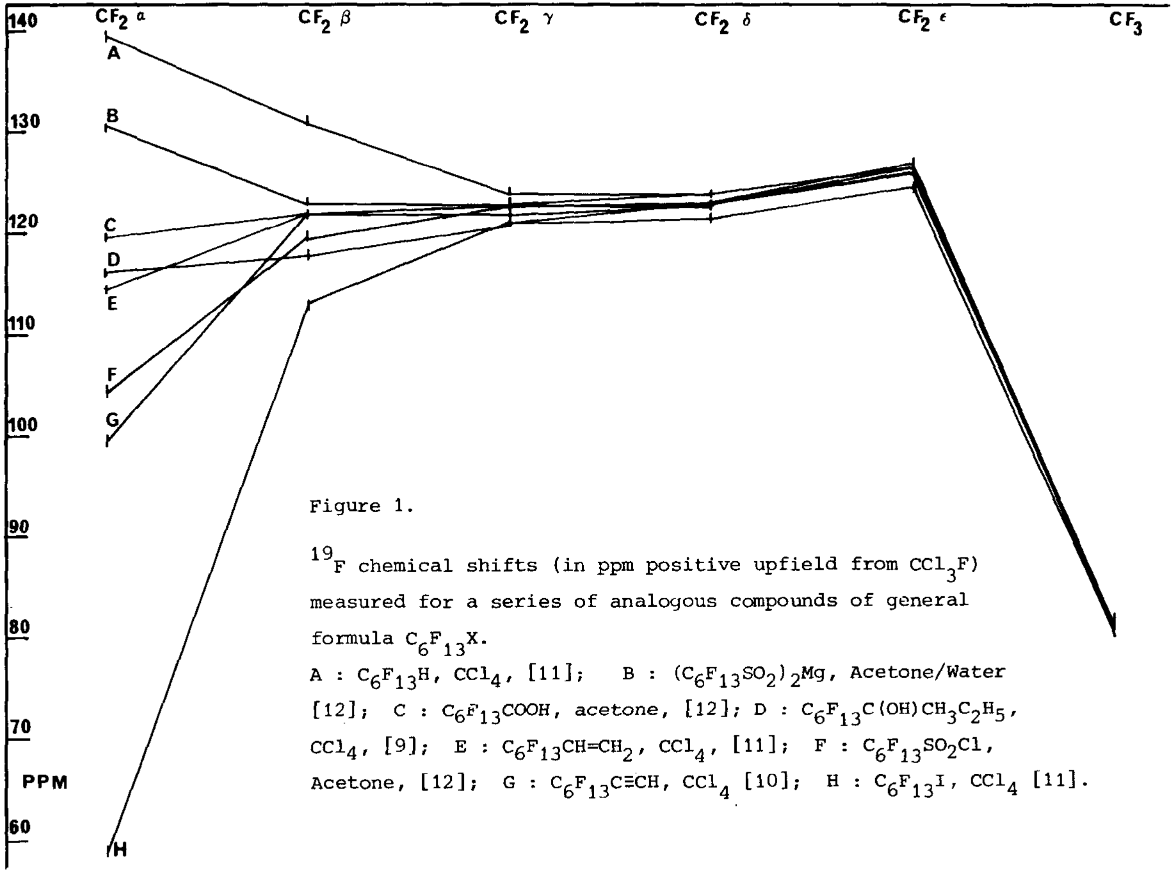

Figure 1.

^{19}F chemical shifts (in ppm positive upfield from CCl_3F) measured for a series of analogous compounds of general formula $C_6F_{13}X$.

A : $C_6F_{13}H$, CCl_4, [11]; B : $(C_6F_{13}SO_2)_2Mg$, Acetone/Water [12]; C : $C_6F_{13}COOH$, acetone, [12]; D : $C_6F_{13}C(OH)CH_3C_2H_5$, CCl_4, [9]; E : $C_6F_{13}CH=CH_2$, CCl_4, [11]; F : $C_6F_{13}SO_2Cl$, Acetone, [12]; G : $C_6F_{13}C\equiv CH$, CCl_4 [10]; H : $C_6F_{13}I$, CCl_4 [11].

If one considers *analogous* series of compounds in which the same *F*-alkyl chain is linked to various X moieties, as exemplified in Fig. 1 for C_6F_{13}- derivatives, it appears clearly that the main effect on the ^{19}F chemical shifts is observed for $CF_2(\alpha)$. The variations in chemical shifts as a function of X are still noticeable for $CF_2(\beta)$, become smaller for $CF_2(\gamma)$, and negligible for the following CF_2 groups. This analysis, based on the C_6F_{13} compounds, proved to be general, and shows that the chemical shift of the $CF_2(\alpha)$ is likely to provide the most interesting clue for the identification of X.

In order to evaluate the usefulness and reliability of this parameter as an analytical tool, we had to examine the influence on $\delta CF_2(\alpha)$ of the length of the *F*-alkyl chain, and of the nature of the solvent used for the measurement.

Fig. 2 shows the variation of $\delta CF_2(\alpha)$ versus the chain length in several *homologous* series of *F*-alkylated compounds : the highest value of $\delta CF_2(\alpha)$ is always found for n = 0; it then decreases rapidly and comes to an almost constant value (within 1 ppm) from n = 1 or 2 upwards. Hence for compounds where n > 1 the $CF_2(\alpha)$ is directly related to the nature of X. The interest of the ^{19}F NMR chemical shifts of the longer chain *F*-alkylated compounds is thus brought into evidence, since the measurement of $\delta CF_2(\alpha)$ is then independent of the chain length and thus permits the appreciation of the specific effect of substituent X. In practice this independence is already attained for C_3F_7, so that the $\delta CF_2(\alpha)$ data are valid for any higher homolog in the series. For C_2F_5 chains (n = 0) the $\delta CF_2(\alpha)$ are higher by *ca.* 3 to 6 ppm than their value for longer chains.

The solvent effects on the ^{19}F chemical shifts have often been reported to be important with respect to those observed on ^1H chemical shifts [1b]. They were first evidenced on fluorocarbons [20], and soon assigned to large Van der Waals interactions between solute and solvent as the major contribution [21-23]. In order to obtain a more precise estimation of these effects, we measured the spectra of nine series of widely different $CF_3(CF_2)_nCF_2X$ compounds as neat liquids, and in nine solvents having widely different dielectric constants (ε = 1.8 to 52.1) (Table I). It was found, first, that the sole significant variation in chemical shift exists for $CF_2(\alpha)$, the other signals being practically unaffected by changes in solvents; second, even for $\delta CF_2(\alpha)$, the range of variation is in most cases less than 2 ppm (see Table I). The effect of the concentration was also found to be small, since the measurements performed on neat liquids (Table I) gave very similar values. Thus the effects of solvents on the chemical shifts of the

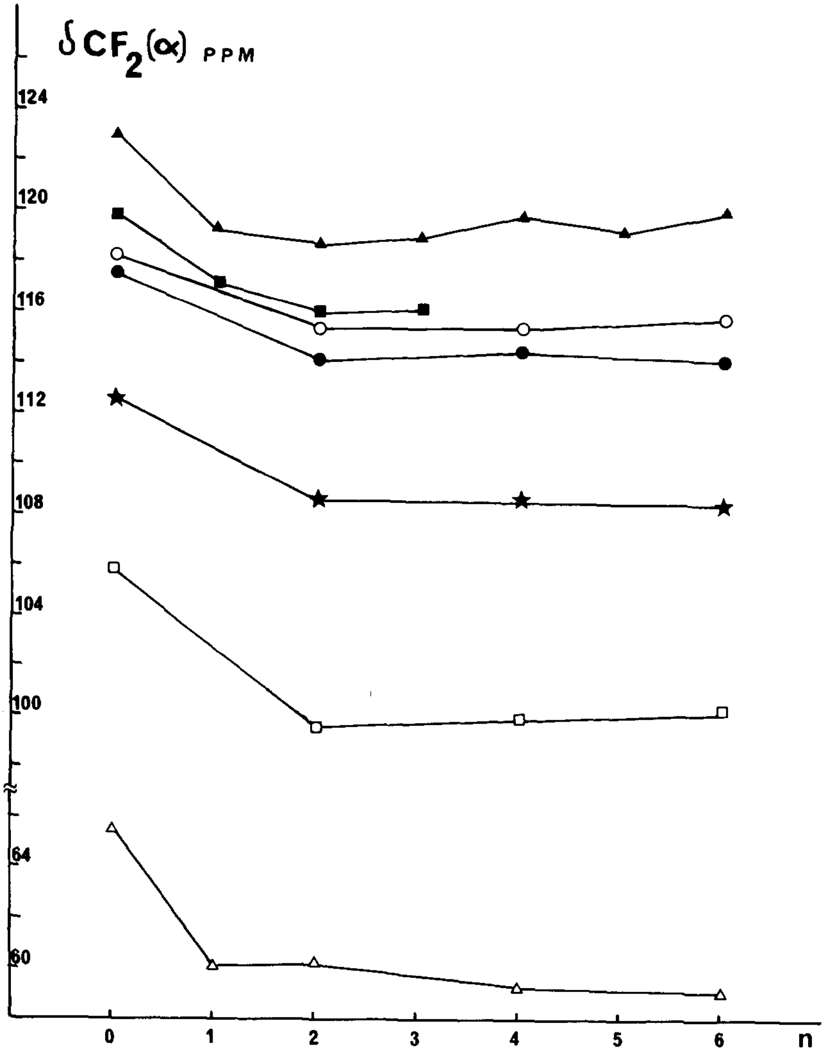

Figure 2. ^{19}F Chemical shifts (in ppm positive upfield from CCl_3F) of the $CF_2(\alpha)$ group in $CF_3(CF_2)_nCF_2X$ as a function of n.

▲ X = COOH [11-14]; ■ X = NF_2 [15-18]; ○ X = C_2H_4I [11];
● X = $CH{=}CH_2$ [11]; □ X = C≡CH [10]; △ X = I [11-10];
★ X = $CBr{=}CH_2$ [3,11].

TABLE I : ^{19}F Chemical shifts of CF_2(α) groups in various $R_F\underline{CF_2}X$ compounds in various solvents and as neat liquids at 20°C.

Values are given positively and upfield from CCl_3F, with ± 0.25 ppm.
a) 0.79M solutions; $R_F = C_6F_{13}$; b) $R_F = C_7F_{15}$, 0.79M solutions; c) $R_F = C_8F_{17}$, 0.79M solutions;
d) $R_F = C_7F_{15}$, 0.395M solutions; e) saturated solution; f) product not soluble; g) solid.

Solvent (ε[24])	X = H a)	$CH=CH_2$ a)	I	C≡CH a)	C_2H_4I a)	COOH b)	COOMe b)	C_2H_5 c)	C(O)CH=CH-N< d)
Pentane (1.84)	138.1	115	58.0	99.7	116	- f)	119.5	117.8	120.4 e)
CCl_4 (2.23)	138.2	115	59.3	99.8	116.1	- f)	119.7	117.8	120.8
Et_2O (4.33)	139.2	114.5	62.8	98.8	115.5	120.0	119.5	117.5	120.0
$CHCl_3$ (4.80)	138.5	114.9	59.6	99.7	116	- f)	119.7	117.8	120.3
THF (7.58)	139.3	114.4	64.5	98.5	115.8	119.8	119.6	117.6	120.1
Acetone (20.70)	139.5	114.4	64.1	98.5	115.8	120.0	119.6	117.3	120.0
EtOH (24.55)	139.5	114.7	65.2	98.9	116	120.0	119.5	- f)	120.5
CH_3CN (37.5)	139.5	- f)	62.8	98.5	115.6	120.1	119.6	- f)	120.3
DMF (52.1)	139.7	- f)	67.5	98.0	115.5	119.3	- f)	- f)	120.0
neat liquid	138.6	115	57.7	99.8	115.3	- g)	119.5	117.8	- g)
Δδ max. (ppm)	1.6	0.6	9.5	1.8	0.8	0.8	0.2	0.5	0.8

F-alkyl compounds generally appear not to be as drastic as those found in the case of fluoromethanes and fluoroethanes [22,23]. One should also keep in mind that the ^{19}F chemical shifts are spread over a much larger frequency range than the proton resonances so that the relative influence of the solvent on the shifts, when it exists, still remains small in proportions in most cases. An exception to this was found for the *F*-alkyl iodides, for which the $CF_2(\alpha)$ resonance varies over a range of nearly 10 ppm as the dielectric constant of the solvent changes; again, the chemical shifts of the other signals are much less affected by the nature of the solvent : for $C_6F_{13}I$ one finds :

$112.7 < \delta CF_2(\beta) < 113.8$; $121.1 < \delta CF_2(\gamma) < 121.7$; $122.6 < \delta CF_2(\delta) < 123.2$; $126.4 < CF_2(\varepsilon) < 126.6$; $81.3 < \delta CF_3 < 81.6$.

This particular behaviour of the *F*-alkyl iodides is in agreement with previous experiments made on fluorinated methanes and ethanes, which suggested that the more polarisable group X is, the greater the upfield solvent shift will be [23].

This study shows that in most cases the solvent effects are of the same order of magnitude as the experimental errors of standard routine measurements. Hence reliable data can easily be obtained, and most data available in the literature can safely be used for the purpose of comparison, even when obtained in different solvents and/or concentrations. Nevertheless, the recording of the spectra on CCl_4 solutions, in which most *F*-alkyl compounds are soluble, and in which their interactions with the solvent are small, is proposed for obtaining homogenous data [25].

Having thus established that for widely different series of $CF_3(CF_2)_nCF_2X$ compounds having $n \geqslant 1$, the value of $\delta CF_2(\alpha)$ is essentially related to the nature of X, we have built a chart (Fig. 3) which correlates these two parameters. The previous studies available in the literature on ^{19}F NMR chemical shifts are either very general [26a] or based upon few data and not very recent [26b]. Our chart gives the domain in which the $CF_2(\alpha)$ can be expected to be found for 42 series of $CF_3(CF_2)_nCF_2X$ compounds, where X is an organic or inorganic moiety. This correlation is based on nearly 300 compounds, on which the NMR data were considered reliable. The compounds prepared in our Laboratory - more than 80 - played an important part in the establishment of this chart, with regard to the variety of X moieties available, to the homogeneity of the series, and to the fact that the measurements were performed in comparable experimental conditions.

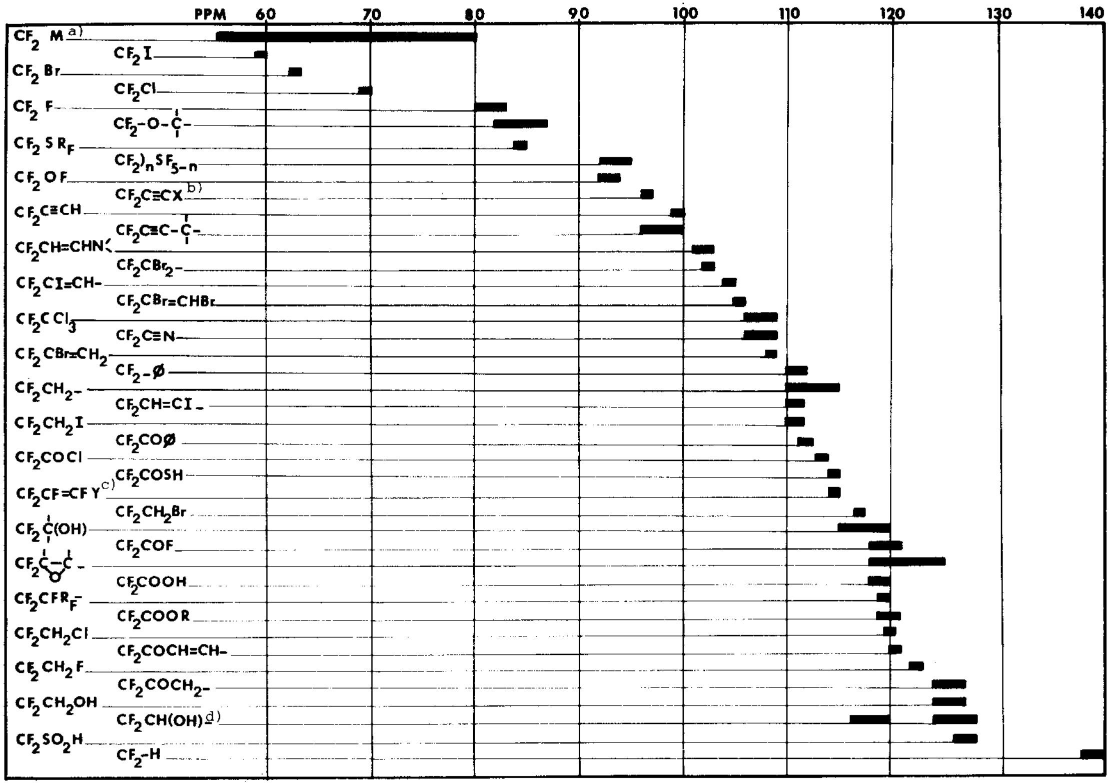

Fig. 3. A correlation chart of ^{19}F nmr chemical shifts of $CF_2(\alpha)$ groups in $CF_3(CF_2)_nCF_2X$ ($n > 0$) as a function of the nature of X. [a] M = transition metal; [b] X = Cl, Br, I; [c] Y = H, F, Cl, Br, I; [d] AB system, $\delta(F_A) - \delta(F_B) \simeq 8 - 10$ ppm. Chemical shifts are taken positively upfield from CCl_3F.

Fig. 3 shows the wide range of chemical shifts which can be expected to be found for the $CF_2(\alpha)$ group as a function of X (55-140 ppm/CCl_3F). This illustrates the high sensitivity of the fluorine nuclei to their environment, and shows the relevance of their study for the identification and characterisation of the *F*-alkyl compounds.

Correlations between ^{19}F NMR chemical shifts and structural parameters have met little success yet, as shown by the following examples :

- in the series of compounds $(CF_3)_2\underline{CF}X$ (X = F, Cl, Br, I, H) δCF is shifted towards higher fields as the electronegativity of X decreases [27], as would be expected for a simple inductive effect :

X	=	F	Cl	Br	I	H	
δ	=	131.4	139.4	142.2	147	214.7	ppm

- the opposite effect is observed in the series $R_FCF_2CH_2X$ and $R_FCF_2CF_2X$, where X = F, Cl, Br, I, H, for which a decrease in the electronegativity of X causes a deshielding of the fluorine nuclei :

	F	Cl	Br	I	H		
$\delta CF_2(\alpha)$ in $R_F\underline{CF_2}CH_2X$ =	122.5	120	117	111	115.2	ppm	[28,29]
$\delta CF_2(\alpha)$ in $R_FCF_2\underline{CF_2}X$ =	82	69	63	60	139	ppm	[11,28,30,31]

It has been postulated that "repulsive interactions may induce electron displacement away from fluorine", which would cause a deshielding of these nuclei [29]. Furthermore, the influence of the hydrogen atom (X = H) could never be clearly rationalised.

In the series of tertiary alcohols, $R_2C(OH)C_6F_{13}$, steric effects may also be invoked to explain the particular downfield shift of the $CF_2(\alpha)$ when R = iPr [9]:

R	CH_3	C_2H_5	C_4H_9	iC_3H_7
$\delta CF_2(\alpha)$	117.9	115.8	115.8	108

These puzzling data led some authors to attempt a calculation of the substituent effects on the ^{19}F chemical shifts. These concerned the influence of the Huggins electronegativity of geminal [32] and vicinal substituent [33] and were in satisfactory agreement with the experimental results. They were however performed on rather limited series of compounds, and a larger number of more homogenous data on new series of compounds would be of interest to check the reliability of this calculation procedure. The recognized difficulty of establishing quantitative correlation of chemical shifts with fundamental structural or electronic factors, enhanced by the limited amount of available data in the field, further increases the value of the empirical identification tool which is presented here.

REFERENCES

1 a) C.H. Dungan and J.R. Van Wazer, Compilation of reported ^{19}F nmr chemical shifts, Wiley Interscience, New York, 1970; b) J.W. Emsley, J. Feeney and L.H. Sutcliffe, Progress in nmr spectroscopy, vol. 7, Pergamon Press, Oxford, 1971.

2 E.F. Mooney, Annual reports on nmr spectroscopy, vol. 1, Acad. Press, London, 1968, p. 244; vol. 3, 1970, p. 261; vol. 4, 1971, p. 391; vol. 5A, 1972, p. 99.

3 G. Santini, M. Le Blanc and J.G. Riess, Tetrahedron, 29 (1973) 2411.

4 F. Jeanneaux, G. Santini, M. Le Blanc, A. Cambon and J.G. Riess, ibid, 30 (1974) 4197.

5 F. Jeanneaux, M. Le Blanc, A. Cambon and J. Guion, J. Fluorine Chem., 4 (1974) 261.

6 M. Le Blanc, G. Santini, J. Guion and J.G. Riess, Tetrahedron, 29 (1973) 3195.

7 G. Santini, M. Le Blanc and J.G. Riess, J. Organometal. Chem., 102 (1975) C21.

8 M. Le Blanc, G. Santini, J. Gallucci, J.G. Riess, Tetrahedron, in press.

9 G. Santini, M. Le Blanc and J.G. Riess, submitted for publication.

10 M. Le Blanc, G. Santini, F. Jeanneaux and J.G. Riess, J. Fluorine Chem., 7 (1976) 525.

11 G. Santini, M. Le Blanc and J.G. Riess, unpublished work.

12 G. Dalverny, Thèse de 3e Cycle, Montpellier, 1975.

13 D.P. Graham and V. Weinmayr, J. Org. Chem., 31 (1966) 958.

14 W.A. Sheppard and E.L. Muetterties, J. Org. Chem., 25 (1960) 180.

15 J.A. Ruff, J. Org. Chem. 32 (1967) 1675.

16 R.A. Mitsch and E.W. Neuvar, ibid, 33 (1968) 3675.

17 B.C. Bishop, J.D. Hynes and L.A. Bigelow, J. Amer. Chem. Soc., 85 (1963) 1606.

18 R.A. Mitsch, ibid, 87 (1965) 328.

19 C.S. Rondestvedt, J. Amer. Chem. Soc., 91 (1969) 415.

20 D.F. Evans, Proc. Chem. Soc., (1958) 115.

21 D.F. Evans, J. Chem. Soc., (1960) 877.

22 R.J. Abraham, G.R. Bedford and D.F. Wileman, J. Chem. Soc. Perkin Trans. II, (1973) 1027.

23 R.J. Abraham and D.F. Wileman, J. Chem. Soc. Perkin Trans. II, (1973) 1521.

24 J.A. Riddick and W.B. Burger, Organic Solvents, Wiley-Interscience, New York, 1970.

25 L. Phillips, Applications of ^{19}F nuclear magnetic resonance - Techniques of chemistry, vol. 4, 2nd Ed., Wiley-Interscience, New York, 1972, p. 33.

26 a) R.E. Banks, Fluorocarbons and their derivatives, Oldbourne, London, 1970, 2nd Ed., p. 231; b) E.G. Brame, Analyt. Chem., 34 (1962) 591.

27 L.H. Meyer and H.S. Gutowsky, J. Phys. Chem., 57 (1953) 481.

28 D.D. Elleman, L.C. Brown and D. Williams, J. Mol. Spectrosc., 7 (1961) 322.

29 G.V.D. Tiers, J. Amer. Chem. Soc., 78 (1956) 2914.

30 S. Brownstein, Chem. Rev., 59 (1959) 463.

31 R.D. Dresdner, E.N. Thimac et J.A. Young, J. Amer. Chem. Soc., 82 (1960) 5831.

32 L. Phillips and V. Wray, J. Chem. Soc. (B), (1971) 2068.

33 L. Phillips and V. Wray, J. Chem. Soc., Perkin Trans. II, (1972) 220.