Journal of Fluorine Chemistry, 53 (1991) 369–377

Received: April 3, 1991; accepted: August 6, 1991

N-F 19-FLUORINE NUCLEAR MAGNETIC RESONANCE OF *N*-FLUOROPYRIDINIUM SALTS

Teruo UMEMOTO,* Kikuko HARASAWA, Ginjiro TOMIZAWA

Sagami Chemical Research Center, Nishi-Ohnuma 4-4-1, Sagamihara, Kanagawa 229 (Japan)

Kosuke KAWADA and Kyoichi TOMITA

Onoda Cement Company (Japan)

SUMMARY

N-F ^{19}F chemical shifts of *N*-fluoropyridinium salts are independent of the nature of counteranions clearly supported their completely ionic structure. The ^{19}F chemical shifts of β- and γ-substituted *N*-fluoropyridinium salts are both correlated to pKa values of the corresponding pyridines, but in different ways. However, the shifts of α-substituted *N*-fluoro salts except for those with alkyl substituents were abnormal upfield shifts due to nonbonded electronic interactions, regardless of the pKa's. The relationship between variable fluorinating power and ^{19}F chemical shifts of *N*-fluoropyridinium salts was also discussed.

INTRODUCTION

Since *N*-fluoropyridinium salts are the first stable 1:1 salts of the pyridine nucleus and halogen atom [1] and serve as power and structure-variable fluorinating agents [2], N-F bonding should be of particular interest. Fortunately, their ^{19}F-NMR spectra provided direct information in these regards.

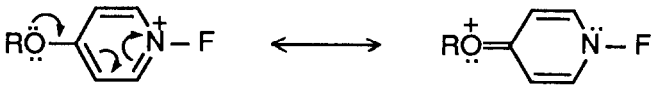
0022-1139/91/$3.50

RESULTS AND DISCUSSION

Table 1 shows N-F ^{19}F chemical shifts of *N*-fluoropyridinium salts **1-46** with a non- or weakly nucleophilic counteranion or with an electron-donating or -withdrawing substituent(s) on the pyridine ring. Since ^{19}F chemical shifts reflect the electron-density about the fluorine nucleus, N-F ^{19}F chemical shifts of the *N*-fluoropyridinium salts should vary according to the particular nature of the counteranions, assuming that they possess a two coordination structure, C_5H_5N-F···Y (C_5H_5N=pyridine nucleus; Y=counteranion part). However, the ^{19}F chemical shifts of *N*-fluoropyridinium salts are not changed significantly by different counteranions as observed among **1a-k**, **7a-d**, **29a-b** and **30a-b**. It is thus evident that they have a one-coordination form and consequently a completely ionic structure, $[C_5H_5N\text{-}F]^+ Y^-$.

Though not affected by different counteranions as discussed above, N-F ^{19}F chemical shifts are sensitive to electron-donating or withdrawing substituents on the pyridine rings. Variation in chemical shifts should perhaps give some indication of the nature of N-F bonding. The nature of N-F bonding should be determined to some degree by electron density of the corresponding pyridine nitrogens, as estimated from pKa values [3].

Figures 1 and 2 indicate the relation between the ^{19}F chemical shifts and pKa's of β- and γ-substituted pyridines, respectively. In Fig. 1, a linear relationship between them is shown, which thus means that the N-F chemical shifts are linearly related to the electron density of N-F bonding in this series. However, according to Fig. 2, with γ-substituents, ^{19}F chemical shifts do not have a linear relation with pKa's but show two lines, one for electron-donating substituents and one for electron-withdrawing substituents. The slope of the former line is quite steep. This great deviation is of interest in regard to a linear relationship between pKa's of γ-substituted pyridines and Hammett *para*-substituent constants σ_p [4]. The explanation for this is as follows; pKa's are associated with the *N*-protonated pyridinium salt system while ^{19}F chemical shifts are evaluated in the *N*-fluoropyridinium salt system. *N*-Fluoro quinonoid form (right in Scheme 1) as a resonance for electron-donating γ-substituents should contribute quite extensively to the *N*-fluoropyridinium salt system owing to the high electronegativity of



Scheme 1.

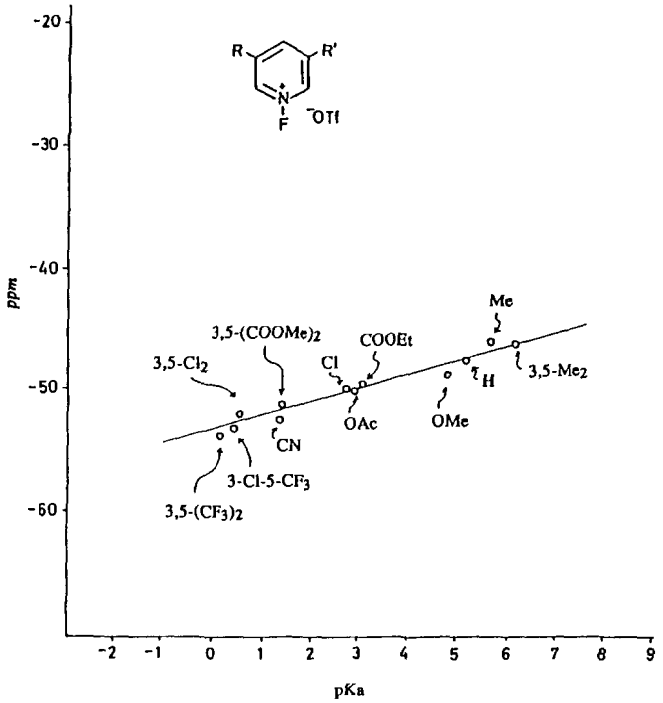


Fig. 1. A plot of N-F ^{19}F chemical shifts of β-substituted *N*-fluoropyridinium triflates versus pKa values of the corresponding pyridines. The pKa's were given from the literature [3] except for those of OAc, 3,5-$(CF_3)_2$, 3-Cl-5-CF_3, and 3,5-$(COOMe)_2$ which were calculated by using the Hammett constants [4].

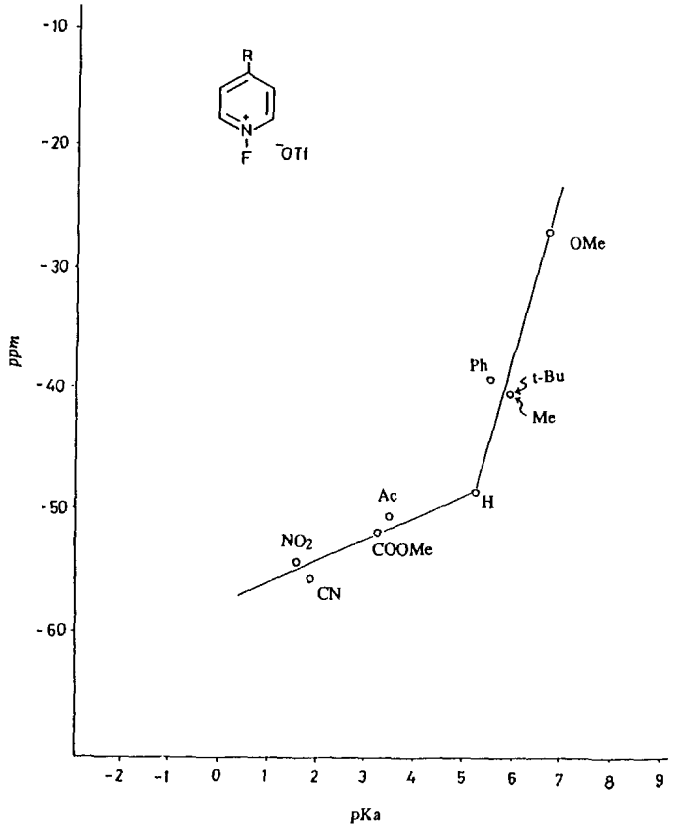


Fig. 2. A plot of N-F ^{19}F chemical shifts of γ-substituted *N*-fluoropyridinium triflates versus pKa values of the corresponding pyridines. All the pKa's were given from the literature [3].

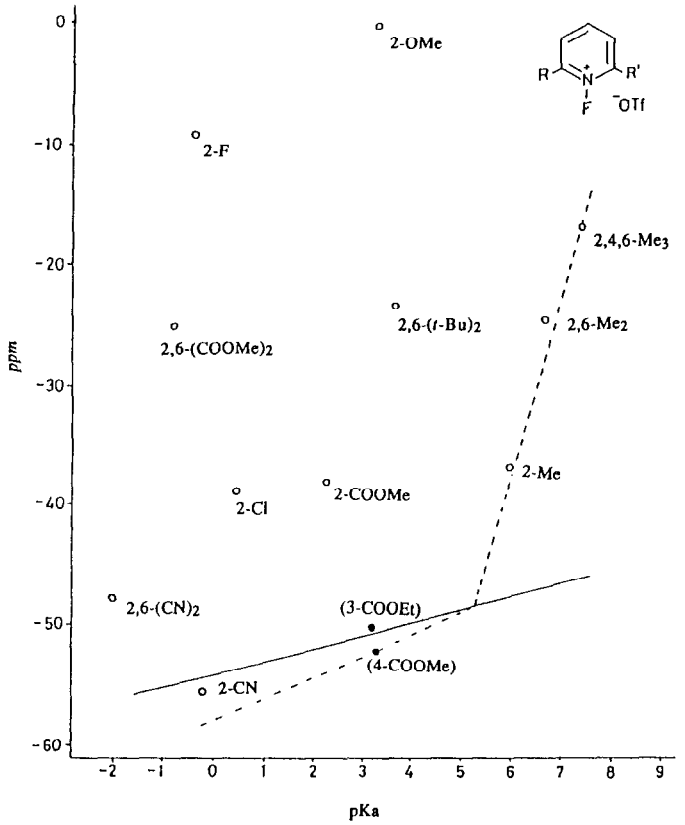


Fig. 3. A plot of N-F ^{19}F NMR chemical shifts of α-substituted *N*-fluoropyridinium triflates versus pKa values of the corresponding pyridines. The pKa's were given from the literature [3] except for that of 2,6-$(COOMe)_2$ which was roughly calculated by the assumption of additive rule of COOMe at the α-position. A line ———— is for β-substituted N-fluoropyridinium triflates and a dotted line -------- is for γ-substituted salts.

fluorine, but contribution of the *N*-hydro quinonoid form to the former proton system is negligibly small. The N-F ^{19}F chemical shifts was found to still deviate considerably from other Hammett *para*-substituent constants σ_p^+, which have been proposed for cases of predominant resonance effect, as in the electrophilic displacement reaction [4,5]. This may perhaps be indication that electron-donating γ-substituents exert a greater effect than expected from σ_p^+, due to the additional electron-withdrawing effect by the most electronegative fluorine atom.

Figure 3 shows that ^{19}F chemical shifts for α-substituents do not appear to depend on the electron density of the pyridine nitrogens. Thus, the ^{19}F chemical shift of *N*-fluoro-2-(methoxycarbonyl)pyridinium salt **34** appears at a higher field than that of its 3- or 4-(alkoxycarbonyl) isomer **35** or **36** though the α-isomer of three isomeric (alkoxycarbonyl)pyridines has the lowest pKa. 2,6-Bis(methoxycarbonyl) salt **37** shows a further upfield shift compared with mono(methoxycarbonyl) salt **34**. 2-Methoxy salt **20** appears at extremely high field, compared with 3- and 4-methoxy isomers **21** and **22**. Essentially the same was noted for the 2-fluoro, chloro, cyano, and substituted methyl substituents. In the last case, the upfield shift effect was small. In counteranion-bound *N*-fluoropyridinium salts, there was observed the same upfield shift by an α-chloro substituent as evident from the data of *N*-fluoropyridinium-2-sulfonate (-41.2) and its 6-chloro derivative (-30.6). An upfield shift of *N*-fluoroquinolinium salt (-23.7) compared with **1** may be regarded as due to the same α-substituent effect of the pyridinium salt system rather than the nature of quinolinium salt itself, since the pKa value of quinoline is virtually the same as that of pyridine.

Bulky 2-menthyloxy salt **23** showed an ^{19}F chemical shift the same as that of small 2-methoxy salt **20**. As seen in Fig. 3, 2-methyl salt **2**, 2,6-dimethyl salt **5** and 2,4,6-trimethyl salt **7** appear on a line of *N*-fluoro salts with electron-donating γ-substituents, indicating the steric or spacial effect of methyl or menthyl to be negligible. It should thus be reasonable to conclude that the above abnormal upfield shifts are due to through-space electronic interactions of the fluorine atom with neighbouring hetero atoms or unsaturated functional groups.

As shown in Fig. 3, the ^{19}F chemical shift of 2,6-di-*t*-butyl salt **11** greatly deviated from the expected position, in consideration of its low pKa (3.58). However, it was quite similar to that of 2,6-dimethyl salt **5**. According to Brown and Kanner, the abnormal low pKa of 2,6-di-*t*-butylpyridine is explained on the basis of steric interactions of two α-*t*-butyl groups with a N^+-H bond of protonated pyridine [6]. It does result, however, from steric hindrance in a dynamic protonation system. But since the *N*-fluoropyridinium salts belong to a static system, it follows that the ^{19}F chemical shift of **11** should appear in essentially the same proportion as **5**, in that the σ_p (-0.20) of *t*-butyl is virtually the same as -0.17 of methyl; that is, the electron-donating ability of *t*-butyl group is essentially the same as

that of methyl. As expected, γ-*t*-butyl salt **10** has the same ^{19}F chemical shift as γ-methyl salt **4**. It is thus evident that the statically steric interaction in **11** is negligible in the ^{19}F chemical shift.

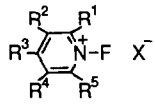
Variable fluorinating power [2] of β- and γ-substituted *N*-fluoropyridinium salts is correlated to their ^{19}F chemical shifts. Thus, the power increases as downfield shift of ^{19}F chemical shifts. This clearly indicates the power to depend on the degree of electron deficiency at the fluorine nucleus. With *N*-fluoro salts having α-substituents except for alkyl substituents, the power is not related to the ^{19}F chemical shifts at all. It is still correlated to the pKa's of the corresponding α-substituted pyridines. This means that the through-space effects of the α-substituents completely overcome ^{19}F chemical shifts due to electron density variation at the fluorine nucleus. On the other hand, the steric bulkiness toward N-F does not affect the N-F ^{19}F chemical shifts, as discussed above.

EXPERIMENTAL

N-Fluoropyridinium salts were synthesized according to the methods described in the previous paper [1]. ^{19}F NMR spectra were obtained on a Hitachi R-20B NMR spectrometer or a Varian XL-100 NMR spectrometer. The concentrations of the ^{19}F-NMR samples were about 0.2 - 0.8 mol/L. The chemical shifts were given in ppm upfield from $CFCl_3$ as an internal standard in CD_3CN solvent, unless otherwise noted. N-F ^{19}F chemical shifts of **1**-**46** are shown in Table 1 and other ^{19}F chemical shift data are shown in the following. **1a**; 77.6 (3F, s, Tf). **1b**; -38.2 (1F, s, SO_2F). **1e**; 80.3 (3F, tt, J=10.1, 3.0 Hz, CF_3), 114.2 (2F, m, CF_2), 120.9 (2F, m, CF_2), 125.2 (2F, m, CF_2S). **1f**; 149.6 (4F, s, BF_4). **1g**; 71.7 (6F, d, J=715 Hz, PF_6). **1h**; 64.1 (6F, q, J=931 Hz, AsF_6). **1i**; 69.0-175.0 (6F, m, SbF_6). **2**; 77.3 (3F, s, Tf). **3**; 78.0 (3F, s, Tf). **4**; 77.6 (3F, s, Tf). **5**; 77.8 (3F, s, Tf). **6**; 77.8 (3F, s, Tf). **7a**; 77.6 (3F, s, Tf). **7b**; -38.3 (1F, s, SO_2F). **7d**; 149.6 (4F, s, BF_4). **8**; 78.0 (3F, s, Tf). **9**; 77.8 (3F, s, Tf). **10**; 78.0 (3F, s, Tf). **11**; 78.0 (3F, s, Tf). **12**; 77.3 (3F, s, Tf). **13**; 77.7 (3F, s, Tf). **14**; 78.1 (3F, s, Tf). **15**; 77.3 (3F, s, Tf). **16**; ($CDCl_3$) 78.1 (3F, s, Tf). **17**; 77.4 (3F, s, Tf). **18**; 77.3 (3F, s, Tf). **19**; 78.1 (3F, s, Tf), 227.7 (1F, t, J_{F-H}=45.0 Hz, CH_2F). **20**; 77.6 (3F, s, Tf). **21**; 77.6 (3F, s, Tf). **22**; 77.3 (3F, s, Tf). **23**; 77.6 (3F, s, Tf). **24**; 77.9 (3F, s, Tf). **25** (1:1 salt with LiOTf); 78.1 (6F, s, 2xTf), 92.9 (1F, d, J_{F-F}=34 Hz, 2-F). **26**; 77.8 (3F, s, Tf). **27**; 77.7 (3F, s, Tf). **28**; 78.0 (3F, s, Tf). **29a**;

TABLE 1

N-F ^{19}F Chemical Shifts of *N*-Fluoropyridinium Salts **1 - 46**



No.[a]							^{19}F NMR[c]
	X[b]	R^1	R^2	R^3	R^4	R^5	(ppm)
1a	OTf[d]	H	H	H	H	H	-48.8
1b	OSO_2F	H	H	H	H	H	-48.2
1c	OSO_2CH_3	H	H	H	H	H	-48.4
1d	OSO_2CCl_3	H	H	H	H	H	-48.2
1e	$OSO_2C_4F_9$[n]	H	H	H	H	H	-48.4
1f	BF_4	H	H	H	H	H	-48.8
1g	PF_6	H	H	H	H	H	-48.6
1h	AsF_6	H	H	H	H	H	-48.2
1i	SbF_6	H	H	H	H	H	-48.8
1j	ClO_4	H	H	H	H	H	-48.8
1k[e]	F(HF)n	H	H	H	H	H	-48.2
2	OTf	Me	H	H	H	H	-37.1
3	OTf	H	Me	H	H	H	-46.9
4	OTf	H	H	Me	H	H	-40.1
5	OTf	Me	H	H	H	Me	-24.8
6	OTf	H	Me	H	Me	H	-46.9
7a	OTf	Me	H	Me	H	Me	-17.3
7b	OSO_2F	Me	H	Me	H	Me	-17.3
7c	OSO_2Camph[f]	Me	H	Me	H	Me	-17.3
7d	BF_4	Me	H	Me	H	Me	-17.3
8	OTf	Me	Me	H	Me	Me	-28.9
9	OTf	Me	Me	Me	Me	Me	-26.8
10	OTf	H	H	*t*-Bu	H	H	-40.1
11	OTf	*t*-Bu	H	H	H	*t*-Bu	-23.1
12	OTf	*t*-Bu	H	*t*-Bu	H	*t*-Bu	-17.3
13	OTf	*t*-Bu	H	Me	H	*t*-Bu	-15.8
14	OTf	$-(CH_2)_4-$		H	$-(CH_2)_4-$		-18.8
15	OTf	CH_2OMe	H	H	H	CH_2OMe	-20.0
16	OTf	CH_2OMe	H	CH_2OMe	H	CH_2OMe	-15.0[h]
17	OTf	CH_2OCOPh	H	H	H	H	-36.4

(continued)

TABLE 1 (cont.)

No.[a]	X[b]	R^1	R^2	R^3	R^4	R5	^{19}F NMR[c]
18	OTf	CH_2OAc	H	H	H	CH_2OAc	-23.3
19	OTf	CH_2F	H	Me	H	Me	-15.3
20	OTf	OMe	H	H	H	H	-0.8
21	OTf	H	OMe	H	H	H	-50.0
22	OTf	H	H	OMe	H	H	-27.4
23	OTf	OMenth[g]	H	H	H	H	-0.8
24	OTf	H	H	Ph	H	H	-39.2
25	OTf	F	H	H	H	H	-9.6
26	OTf	Cl	H	H	H	H	-39.1
27	OTf	H	Cl	H	H	H	-50.6
28	OTf	Cl	H	H	H	Cl	-31.7
29a	OTf	H	Cl	H	Cl	H	-52.1
29b	BF_4	H	Cl	H	Cl	H	-52.7
30a	OTf	Cl	Cl	Cl	Cl	Cl	-48.0
30b	BF_4	Cl	Cl	Cl	Cl	Cl	-47.6
31	OTf	H	Cl	H	CF_3	H	-54.1
32	OTf	H	CF_3	H	CF_3	H	-54.8
33	OTf	H	OAc	H	H	H	-51.0
34	OTf	COOMe	H	H	H	H	-38.4
35	OTf	H	COOEt	H	H	H	-50.0
36	OTf	H	H	COOMe	H	H	-51.5
37	OTf	COOMe	H	H	H	COOMe	-25.5
38	OTf	H	COOMe	H	COOMe	H	-51.9
39	OTf	COOMe	H	COOMe	H	COOMe	-29.3
40	OTf	$COCH_3$	H	H	H	H	-37.5
41	OTf	H	H	$COCH_3$	H	H	-50.4
42	BF_4	CN	H	H	H	H	-47.9
43	OTf	H	CN	H	H	H	-52.8
44	OTf	H	H	CN	H	H	-55.5
45	OTf	CN	H	H	H	CN	-48.2
46	OTf	H	H	NO_2	H	H	-54.2

a) Compound numbers. b) Counteranion part of N-fluoropyridinium salts. c) The ^{19}F signals appear as broad singlets. d) Tf=SO_2CF_3. e) Salt **1k** was described in the previous paper [1b]. f) (+)-10-Camphorsulfonate anion. g) (1*R*,3*R*,4*S*)-Menthyloxy group. h) $CDCl_3$ was used as a solvent.

77.6 (3F, s, Tf). **29b**; 150.5 (4F, s, BF_4). **30a**; 78.2 (3F, s, Tf). **30b**; 152.6 (4F, s, BF_4). **31**; 61.5 (3F, s, Tf), 78.1 (3F, s, Tf). **32**; 61.5 (6F, s, $2xCF_3$), 78.0 (3F, s, Tf). **33**; 77.6 (3F, s, Tf). **34**; 78.0 (3F, s, Tf). **35**; 77.7 (3F, s, Tf). **36**; 77.6 (3F, s, Tf). **37**; 77.6 (3F, s, Tf). **38**; 78.0 (3F, s, Tf). **39** (1:1 salt with LiOTf); 78.3 (6F, s. 2xTf). **40**; 77.3 (3F, s, Tf). **41**; 77.8 (3F, s, Tf). **42**; 151.1 (4F, s. BF_4). **43**; 78.1 (3F, s, Tf). **44**; 77.9 (3F, s, Tf). **45**; 77.9 (3F, s, Tf). **46**; 78.0 (3F, s, Tf). ^{19}F chemical shifts of other *N*-fluoro salts are shown in the following. ***N*-Fluoropyridinium-2-sulfonate**; -41.2 (bs, NF). ***N*-Fluoro-6-chloropyridinium-2-sulfonate**; -30.6 (bs, NF). ***N*-Fluoroquinolinium triflate**; -23.7 (1F, bs, NF), 78.2 (3F, s, Tf).

REFERENCES

1 a) T.Umemoto and K.Tomita, *Tetrahedron Lett.*, **27** (1986) 3271. b) T.Umemoto, K.Harasawa, G.Tomizawa, K.Kawada, and K.Tomita, *Bull. Chem. Soc. Jpn.*, **64** (1991) 1081.

2 a) T.Umemoto, K.Kawada, and K.Tomita, *Tetrahedron Lett.*, **27** (1986) 4465. b) T.Umemoto and G.Tomizawa, *Bull. Chem. Soc. Jpn.*, **59** (1986) 3625. c) T.Umemoto, S.Fukami, G.Tomizawa, K.Harasawa, K.Kawada, and K.Tomita, *J. Am. Chem. Soc.*, **112** (1990) 8563.

3 K.Schofield, 'Hetero-Aromatic Nitrogen Compounds, Pyrroles and Pyridines,' Butterworth & Co. Ltd., London, 1967, pp 146-149.

4 a) N.B.Chapman and J.Shorter, 'Advances in Linear Free Energy Relationship,' Plenum (1972). b) Y.Okamoto, 'San To Enki (Acid and Base),' Tokyo Kagaku Dojin, Tokyo, 1967, pp 71-80. c) N.Inamoto, 'Hametto Soku (Hammett Rule),' Maruzen, Tokyo, 1983, pp 74-80.

5 a) H.C.Brown and Y.Okamoto, *J. Am. Chem. Soc.*, **79** (1957) 1913. b) Y.Okamoto and H.C.Brown, *J. Org. Chem.*, **22** (1957) 485.

6 H.C.Brown and B.Kanner, *J. Am. Chem. Soc.*, **88** (1966) 986.