Fluorination of Nitriles over Cobalt Trifluoride and Potassium Tetrafluorocobaltate

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Fluorinations of acetonitrile and propiononitrile by cobalt trifluoride and potassium tetrafluorocobaltate leave the nitrile groups mainly intact, as expected from their high ionization potentials. Major products from acetonitrile are CH₂F·CN (main) and CHF₂·CN, and from propiononitrile, CH₃·CHF·CN (main), CH₃·CF₂·CN, CH₂F·CHF·CN, and CH₂F·CF₂·CN, with α -fluorination strongly predominating. Succinonitrile and fumaronitrile both give a mixture of difluoro-fumaro- and -maleo-nitriles.

THERE are only a few reports on the fluorination of nitriles; these describe the further fluorination of ¹ G. E. Coates, J. Harris, and T. Sutcliffe, J. Chem. Soc., 1951, 2762.

 R_FCN compounds (R_F = perfluoroalkyl) with cobalt trifluoride ¹ or silver difluoride,² and the fluorination of ² J. A. Young, W. S. Durrell, and R. S. Dresdner, *J. Amer. Chem. Soc.*, 1960, **82**, 4553.

nitriles generally with elemental fluorine.³ In every case the nitrile group was destroyed. We now report the first examples * of the partial fluorination of nonfluorine-containing nitriles over high-valency transition metal fluorides.

There were two reasons for carrying out the present work: first, to see whether the fluorination could provide useful synthetic routes to polyfluoro-nitriles; and secondly, to examine the stability of the nitrile group under fluorination conditions. This second point arises from our recently published theory 5 of the mechanism of fluorination with transition metal fluorides; we suggested that the major pathway involves electron removal from a substrate to give a radical cation. Nitriles have very high ionization potentials (e.g. MeCN, 12.2 eV) and so it seemed probable that they would not undergo oxidative electron removal and would have to react, if they did react, by some other mechanism. In fact, this theoretical prediction has been fulfillednitriles are relatively inert to fluorination by cobalt trifluoride and potassium tetrafluorocobaltate, and the CN group does remain largely intact-but the reactions are of no great synthetic value, mixtures of partially fluorinated materials being formed in each case.

The major product from the fluorination of acetonitrile with either potassium tetrafluorocobaltate or cobalt trifluoride was monofluoroacetonitrile; small amounts of difluoroacetonitrile and 1,1,1,2-tetrafluoroethane were also identified. There were no detectable amounts of N-F compounds or of trifluoroacetonitrile. As usual,^{6,7} cobalt trifluoride was more reactive than potassium tetrafluorocobaltate, but with both reagents there was much more starting material unchanged than is usually the case when hydrogen-containing substrates are fluorinated.

Both fluorinating agents reacted with propiononitrile to give a range of partially fluorinated propiononitriles (see Table 2). The structures of all except one of these followed from elemental analysis and n.m.r. spectroscopy (see Table 4). The exception was 2,3-difluoropropiononitrile; this showed complex second-order ¹H and ¹⁹F spectra, which were, however, similar in general appearance to the spectra⁸ from the analogous ethyl 2,3-difluoropropionate. In fact, elemental analysis and the ¹⁹F chemical shifts alone were sufficient for identification.

Fluorination was not random, as are, for example, the fluorinations of ethane and ethene,⁷ and replacement of

⁴ F. Nerdel, Naturwiss., 1952, 39, 209.

⁵ J. Burdon, I. W. Parsons, and J. C. Tatlow, Tetrahedron, 1972, 28, 43.

⁶ P. L. Coe, R. G. Plevey, and J. C. Tatlow, J. Chem. Soc. (C), 1969, 1060; J. Burdon, G. E. Chivers, and J. C. Tatlow, ibid., p. 2585.

a-hydrogen atoms by fluorine predominated clearly over replacement of β -hydrogen atoms. This behaviour is similar to the fluorination of ketones,⁹ esters,¹⁰ and acid fluorides,¹⁰ where α -fluorination is again strongly favoured. Two other products were isolated from the propiononitrile-potassium tetrafluorocobaltate reaction: bistrifluoromethylamine and a-fluoroacrylonitrile, the n.m.r. spectrum of which clearly differentiates it from either of its β -fluoro-isomers.

As discussed earlier, these reactions probably do not proceed via a simple oxidation to a radical cation, [RCN]⁺, because the ionization potentials of nitriles are too high.

Hydrogen atom abstraction is also unlikely, e.g. $MeCH_2 \cdot CN + CoF_3 \longrightarrow MeCH \cdot CN + CoF_2 + HF$, because nitriles are known¹¹ to react with radicals mainly by abstraction of β -, not α -hydrogen atoms as the products of our reactions demand.

It has been suggested that ketones,⁹ acid fluorides,¹⁰ and esters 10 react via their enols and so give α -fluoroproducts in the initial stage of their fluorinations. Indeed, it is known¹² that carboxylic acids undergo α -chlorination in the presence of any one of a range of known enolizing agents.

It seems likely that nitriles are fluorinated mainly via a similar route, with the fluorinating agent acting as the eneiminating agent (Scheme 1). Again, nitriles are

$$\begin{array}{ccc} \operatorname{MeCH}_2 \cdot \operatorname{CN} & \xrightarrow{\operatorname{CoF}_3} & \operatorname{MeCH} \colon \operatorname{CoF}_2 + \operatorname{HF} \\ & & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ &$$

known¹³ to undergo halogenation (by Cl₂ or Br₂) in the α -position under electrophilic conditions.

The aa-difluoropropiononitrile thus formed can then undergo fluorination to a small extent in the β -position in the usual way.

We are at a loss to rationalize the formation of bistrifluoromethylamine.

The fluorination of succinonitrile with potassium tetrafluorocobaltate gave a surprising result: difluorofumaro- and -maleo-nitrile were formed in quite high yields. No other products with four, or even three, carbon atoms were detected. (The product nitriles have been obtained previously by an exchange reaction

⁷ J. Burdon, J. R. Knights, I. W. Parsons, and J. C. Tatlow, *Tetrahedron*, 1976, **32**, 1041. ⁸ G. Hägele, R. K. Harris, and P. Sartori, *Org. Magnetic*

Resonance, 1971, 3, 463. ⁹ R. D. Bagnall, P. L. Coe, and J. C. Tatlow, J.C.S. Perkin I,

1972, 2277.

10 R. D. Bagnall, P. L. Coe, and J. C. Tatlow, J. Fluorine Chem., 1973, 3, 329.

¹¹ A. Bruylants, M. Tits, C. Dieu, and R. Gauthier, Bull. Soc. chim. belges, 1952, **61**, 366; C. Walling and B. B. Jacknow, J. Amer. Chem. Soc., 1960, **82**, 6113.

¹² Y. Ogata and K. Matsuyama, *Tetrahedron*, 1970, **26**, 5929.

¹³ C. L. Stevens, J. Amer. Chem. Soc., 1948, 70, 165; C. L. Stevens and T. H. Coffield, *ibid.*, 1951, 73, 103; C. L. Stevens and W. Holland, J. Org. Chem., 1953, 18, 1112.

^{*} There is a claim ⁴ that MeCN and HgF₂ give MeCF:NF, $MeCF_2$ ·NF₂, CH₂:C:NF, and CH₂:CF·NF₂, but little evidence was offered for any of these structures.

³ J. A. Cuculo and L. A. Bigelow, J. Amer. Chem. Soc., 1952, 74, 710; F. P. Avonda, J. A. Gervasi, and L. A. Bigelow, *ibid.*, 1956, 78, 2798; J. A. Attaway, R. H. Groth and L. A. Bigelow, *ibid.*, 1959, 81, 3559; B. C. Bishop, J. B. Hynes, and L. A. Bige-low, *ibid.*, 1963, 85, 1606; 1964, 86, 1827.

from the corresponding dichloro-compounds¹⁴ and by pyrolysis ¹⁵ of chlorofluoroacetonitrile at 700-900 °C.) This result is surprising for two reasons: first, dimethyl succinate ¹⁰ gives only polyfluoropropionyl fluorides as products, with apparently no trace of any dicarboxylic acid fluoride; and secondly, it is unusual, in a fluorination reaction, to obtain products with two fluorine atoms on a double bond; products of the types •CF:CH• and •CH:CH• are much commoner.6,16

It is *possible* that fumaro- and perhaps maleo-nitrile are intermediates in the fluorination, since fluorination of the former gave the same products as does succinonitrile.

We have also fluorinated malononitrile and benzonitrile; in both cases complex mixtures were obtained $\gg 35$ products in the former case and $\gg 25$ in the latter, according to g.l.c.) and so these experiments were abandoned.

There is one further puzzling feature of our fluorinations. The following reactions have been reported (major products only):

$$CF_{3} \cdot CN \xrightarrow[CoF_{3}]{100 \circ C} C_{2}F_{5}N \cdot NC_{2}F_{5} \text{ (ref. 2)}$$

$$CF_{3} \cdot CN \xrightarrow[CoF_{3}]{200 \circ C} C_{2}F_{6} + C_{2}F_{5}NF_{2} \text{ (ref. 1)}$$

$$C_{3}F_{7} \cdot CN \xrightarrow[AgF_{3}]{200 \circ C} C_{4}F_{9}N \cdot NC_{4}F_{9} \text{ (ref. 2)}$$

However, we have found no trace of any azo- or >N-F compounds in our fluorinations. We conclude that either we have missed such compounds (conceivable in the case of the azo-compounds, because, being partially fluorinated, they could be much higher boiling, or retained longer on g.l.c. than the nitriles actually identified), or that their formation does not begin until replacement of hydrogen by fluorine is virtually complete. If we have missed them, then their amounts must be small, since the yields of the identified products were high. (Note that the azo-compound-producing reactions mentioned above 1,2 proceed in quite high yields under relatively moderate conditions.)

EXPERIMENTAL

Fluorination of Acetonitrile.—The nitrile (1.5 g) was added dropwise to a stirred reactor containing potassium tetrafluorocobaltate (150 g) and heated to 80-400 °C. Nitrogen (6 dm³ h⁻¹) was then passed through the reactor for a further 1 h. The effluent gases were scrubbed free of hydrogen fluoride by passage over sodium fluoride pellets, and collected in a trap cooled with liquid air. Trap-to-trap distillation yielded fractions (a), b.p. <-15 °C, and (b), b.p. >-15 °C. Fraction (a) contained (i.r.¹⁷) CF_4 , CHF_3 , C_2F_6 , and a trace of C_2HF_5 , but no CF_3CN ; no liberation of ¹⁴ H. Cenci, Fr.P. 1325307/1963 (Chem. Abs., 1963, 59, 13830h);

B.P. 978241/1964. ¹⁵ S. Proskow, U.S.P. 3121734/1964 (Chem. Abs., 1964, 60,

10557b). ¹⁶ I. W. Parsons, P. M. Smith, and J. C. Tatlow, *J. Fluorine Chem.*, 1971, **1**, 141; R. G. Plevey, R. W. Rendell, and M. P. Steward, *ibid.*, 1973, **3**, 267. ¹⁶ Melevelar Spectroscopy.' Butterworths.

¹⁷ ' Documentation of Molecular Spectroscopy,' Butterworths, London.

iodine occurred when the fraction was passed through aqueous potassium iodide (absence of >N-F compounds). Fraction (b) was analysed by g.l.c. (Table 1), and a sample (1.0 cm³) from a fluorination at 200 °C was separated [1:2 dinonyl phthalate on Celite, column (column A) 9.5 m imes8 mm, temperature 70 °C, N₂ carrier gas] to give (i) a mixture of six components (ca. 0.05 g); (ii) acetonitrile (0.29 g) (i.r.); and (iii) monofluoroacetonitrile (0.34 g) (i.r.¹⁸), b.p. 81-82 °C (lit.,¹⁹ 81.8–82.0°) [$\delta_{\rm H}$ 4.59 (d, J 44.4 Hz); $\delta_{\rm F}$ 232.3 p.p.m. upfield from CFCl₃ (d, J 45.0 Hz)]. Separation of a larger sample (9.0 g) yielded 1,1,1,2-tetrafluoroethane (trace; i.r.²⁰) and difluoroacetonitrile (0.65 g), b.p. 22-23 °C (lit.,¹⁹ 22.8–23.4°) [$\delta_{\rm H}$ 5.92 (t, J 52.2 Hz); $\delta_{\rm F}$ 119.8 p.p.m. upfield from $CFCl_3$ (d, J 52.0 Hz)] as components of the mixture (i).

Similar fluorinations were carried out over cobalt trifluoride; the results are summarised in Table 1.

Fluorination of Propiononitrile.—The nitrile (30.0 g) was fluorinated over potassium tetrafluorocobaltate (2 kg) at 100-335 °C and the products were treated in a similar way to those from acetonitrile. The more volatile fraction (b.p. $< -15^{\circ}$) containing (i.r.¹⁷) CF₄, CHF₃, and C₂F₆. The less volatile products were analysed by g.l.c. and the results are summarised in Table 2. A sample (20.0 g) of these less volatile materials from a fluorination at 220 °C was separated [1:5 dinonyl phthalate on Chromosorb P, column (column B) 4.88 m \times 7.5 cm, temp. 96°, N₂ carrier gas] into five fractions [there were eight major peaks].

Analytical g.l.c. of fraction 1 showed three major and at least seven minor components. Separation (column A, 60 °C) gave (i) an unidentified mixture (0.12 g); (ii) a mixture (0.22 g) (analysed by n.m.r.; see Table 4 for parameters) of 2,2,3,3-tetrafluoropropiononitrile (60%) and 2,2-difluoropropiononitrile (40%); (iii) a mixture (0.15 g)(15:85) of the components of (ii); (iv) a mixture (0.13 g) (analysed by n.m.r.) of 2,2,3-trifluoropropiononitrile (60%) and 2-fluoroacrylonitrile [the n.m.r. spectra of the latter showed an ABX pattern with δ_{A} 6.51, δ_{B} 6.45 (1H nuclei), $\delta_{\mathbf{X}}$ 111.6 p.p.m. upfield from CFCl₃; J_{AB} 5.0, J_{AX} 43.9, $J_{\rm BX}$ 13.2 Hz].

Fraction 2 (3.3 g) was the mixture obtained in Fraction 1 (iv). Fraction 3 (7.2 g) was 2-fluoropropiononitrile, b.p. 83-84 °C (lit., 21 83-83.5°) (Found: C, 49.1; H, 5.4; F, 25.9; N, 19.5. Calc. for C₃H₄FN: C, 49.3; H, 5.5; F, 26.0; N, 19.2%). Fraction 4 (3.3 g) was a mixture of fractions 3 and 5 (i).

Separation of fraction 5 [1:9 Ucon fluid 50-HB-2000 on Chromosorb P, column (column C) $9.5~\text{m}\times8~\text{mm},$ temp. 100 °C, N₂ carrier gas] gave (i) propiononitrile (0.31 g, i.r.) and (ii) 2,3-difluoropropiononitrile (0.29 g), b.p. 135-136 °C (Found: C, 39.4; H, 3.3; F, 41.9; N, 15.3. C₃H₃F₂N requires C, 39.6; H, 3.3; F, 41.7; N, 15.4%).

The product mixture with b.p. ≥ -15 °C (29.9 g) from the 335 °C fluorination was distilled up a column packed with glass helices, and the still residues (1.32 g) were separated (column C, 100 °C) to give (i) bistrifluoromethylamine (0.05 g) $(i.r.^{17})$; (ii) 2-fluoropropiononitrile (0.34 g)(i.r.); (iii) propiononitrile (0.40 g) (i.r.); (iv) 2,3,3-trifluoro-

¹⁸ R. G. Jones and W. J. Orville-Thomas, AD-612166 (Chem. Abs., 1965, 63, 9781c).
 ¹⁹ F. Swarts, Bull. Soc. chim. belges, 1922, 31, 364.
 ²⁰ J. R. Nielson and C. J. Halley, J. Mol. Spectroscopy, 1965, 17 241

17, 341. ²¹ E. Gryskiewicz-Trochimowski and O. Gryskiewicz-Trochi-

mowski, Bull. Soc. chim. France, 1949, 928.

Reagent

KCoF₄

CoF₃

				Yield of	Product	(fraction b.p.)	> −15 °C) co	omposition •
		Tomo	Total	volatiles		(mole	%)	
agent		(°C)	vield (g) a	$< -15 ^{\circ}C$	MeCN	CH ₂ F·CN	CHF ₂ ·CN	CF ₃ ·CH ₂ F
0	ſ	`80	1.45 0	Trace	90	8	Trace	
CoF₄		140	1.25	0.15	61	34	4	
•	l	400	1.50	0.60	34	45	8	1
F	Š	90	1.17	Trace	81	15	1	
эг ₃	l	145	1.58	0.67	22	40	9	21
^a From	1.5 g.	^b From 2.0 g.	• By g.l.c.	Difference of to	tal from 100	represents un	identified pro	oducts.
				TABLE 2				
			Fluor	in at ion of propi	ononitrile			
	-	Yield of		Proc	duct (b.p. >	15 °C) composi	tion ^b (mole 9	%)
1	fotal	(b.p.		MeCF, CN	CH,F•CF,•	CN		
emp 1	rield a	<`_15 ℃)		-+				

	Temp.	yield	< -15 °	C)		+	+			
Reagent	(°C)	(g) a	(g)	EtCN	MeCHF·CN	CHF ₂ ·CF ₂ ·CN ^o	CH2:CF•CN d	CH₂F•CHF•CN	CHF ₂ •CHF·CI	N (CF ₃) ₂ NH
KCoF.	100	28.1	<1	83	12	1	1			
KCoF	335	72.9	42.9	20	26	16	9	6	3	4
CoF ₃	125	12.9	1.1	53	45	1				
CoF_3	205	15.4	6.1	45	31	11	5	Trace	Trace	
		• Fro	m 30.0 g.	ه Foot	note c, Table	1. ° Ca. 50 : 50	mixture. ^d C	a. 60 : 40 mixture		

TABLE 3										
Fluorination	of succino- and	fumaro-nitriles over	potassium	tetrafluorocobaltate						

	-		Total	Yield of volatiles	Product (fraction b.p. >0 °C) composition b (mole %)						
Nitrile		Temp. (°C)	yield (g) ^a	(b.p. <0 °C) (g)	(CH ₂ CN) ₂	cis- CNFC:CFCN	trans- CNFC : CFCN	(CF ₃) ₂ NH			
Succinonitrile	{	160 250 400	13.2 23.0 37.0	Trace Trace 8.9	16 Trace	41 45 32	28 30 28	$2 \\ 3 \\ 10$			

Fumaronitrile

^a From 30.0 g. ^b Footnote c, Table 1. ^c From 2.0 g.

0.4

1.6 °

TABLE 4

N.m.r.	data	\mathbf{for}	fluorinated	propiononitriles,	CHmBF3-	^{<i>m</i>} ^β ·CH _n ^α F _{2-n} ^α ·CN	ſ
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		Chemical s	shift ^a	Coupling constants (Hz)						
Compound	Fa	Fβ	Ha	Hβ	$\overline{J_{\mathrm{H}}}^{a_{\mathrm{H}}\beta}$	JHara	$\int_{\mathbf{H}} a_{\mathbf{F}} \boldsymbol{\beta}$	$\int F^{a}F^{\beta}$	$\int \mathbf{F}^{\mathbf{a}}_{\mathbf{H}}^{\mathbf{\beta}}$	$J_{\mathbf{H}}{}^{\boldsymbol{\beta}}{}_{\mathbf{F}}{}^{\boldsymbol{\beta}}$
MeCHF·CN	182.2		5.22	1.72	6.9	46.8			23.4	
CH.F.CHF.CN	196.6	244.7	ь	ь	ь	b	ь	ь	ь	ь
CHF, CHF CN	208.4	131.5	6.10	6.62	2.7 °	43.5 °	ء 10.8	7.9 °	6.0 °	52.5 °
MeCF₄∙CN	85.4			1.97					18.1	
CH.F.CF.CN	102.9	236.5		5.00				18.9	11.7	45.4
CHF₂∙CF₂∙CN	109.6	135.1		5.89				5.6	1.9	53.6

^a ¹H Shifts in p.p.m. downfield from Me₄Si; ¹⁹F shifts in p.p.m. upfield from CFCl₃. ^b Complex second-order spectrum, coupling not analysed (see text). • This spectrum was analysed as the first-order spectrum it appeared to be; this could be misleading as the compound has the same spin system as the one above it in the Table, which did show a second-order pattern.

propiononitrile [0.06 g; identified by n.m.r. (see Table 4)];and (v) 2,3-difluoropropiononitrile (0.11 g) (i.r.).

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Fluorinations over cobalt trifluoride were carried out in a similar way and the results are summarised in Table 2.

Fluorination of Succinonitrile.-The nitrile (30.0 g) was fluorinated at 160-400 °C over potassium tetrafluorocobaltate (2 kg) as described before; results are summarised in Table 3. The volatile components consisted (i.r.) of CF_4 , CHF_3 , and C_2F_6 . Separation (column A, 70 °C) of a sample (1.00 g) from a 400 °C fluorination gave: (i) a mixture (ca. 0.02 g) of at least 13 components; (ii) bistrifluoromethylamine (0.09 g) (i.r.); (iii) difluorofumaronitrile [0.21 g; identified by i.r. and ¹⁹F n.m.r.¹⁵ (sharp singlet at 147.9 p.p.m. upfield from CFCl₃; lit.,¹⁵ 148.3)], b.p. 80-81.5 °C; and (iv) difluoromaleonitrile [0.18 g;

identified by i.r. and ¹⁹F n.m.r.¹⁵ (s, § 126.7; lit.,¹⁵ 127.1)], b.p. 79-81 °C [lit., 15 79-81 °C for a mixture of (iii) and (iv)]. Analytical figures for a mixture of (iii) and (iv), isolated in another experiment, were as follows (Found: C, 42.1; F, 33.3; N, 24.5. Calc. for $C_4N_2F_2$: C, 42.1; F, 33.3; N, 24.6%).

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Fluorination over cobalt trifluoride at 200-250° gave products (ca. 8 g from 4 g of succinonitrile) of which 75-95% had b.p. <0 °C, and experiments were not pursued.

Fluorination of Fumaronitrile.--Results are summarised in Table 3.

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