Journal of Fluorine Chemistry, 21 (1982) 171–189

Received: February 18, 1982

FLUORINATIONS WITH POTASSIUM TETRAFLUOROCOBALTATE(III)
PART VII. FURTHER INVESTIGATIONS ON THE FLUORINATION OF PYRIDINE

PAUL L. COE, ANDREW G. HOLTON and JOHN COLIN TATLOW

Chemistry Department, The University of Birmingham,
P.O. Box 363, Birmingham B15 2TT (U.K.)

SUMMARY

The product from the fluorination of pyridine by $KCoF_4$ at ca. 220° contains eleven fluoropyridines, two fluoro-2-azahex-enes, three azahexadienes, and two fluoro-N-methylpyrrolidines, besides an azacyclohexa-1,3-diene. Four products were isolated from a fluorination of pyridine by CoF_3 at ca. 150°, a 2-azahexene, two N-methylpyrrolidines, and 4H-nonafluoropiperidine.

INTRODUCTION

This paper describes the investigation of the higher-boiling fraction from the reaction of pyridine with $KCoF_4$ at ca. 220°, referred to in part VI of this series [1]. Some possible fluorinated reaction intermediates were also passed over $KCoF_4$. For comparison, the major products from the reaction of pyridine with CoF_3 at ca. 150° were identified in a brief study. The work was done at about the same time (1972-4) as that described in the preceding paper [2] on the pyridine/$CsCoF_4$ reaction.

RESULTS

Fluorination of pyridine was done as before [1]. Weight recoveries were only moderate, being but little more than input.

The crude product was fractionally distilled to give 8 fractions. The first 4 of these (A-D) corresponded almost exactly with fractions of the previous study (A ≡ 1; B ≡ 2; C ≡ 3; D ≡ 4 + 5). The major

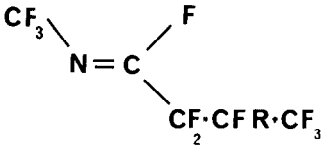
0022-1139/82/0000-0000/$02.75

compounds present (I; IV; V; and VI) were isolated by glc and each was shown to be identical with that of the same Roman numeral isolated then [1]. Products which are not pyridines are represented in Scheme 1, and pyridines in Table 2; those with Roman numerals were obtained before [1], those with Arabic numbers were found only in this work.

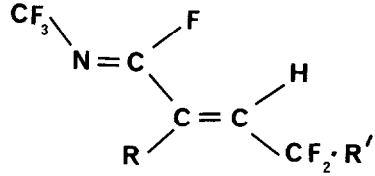
Fraction E corresponded to the previous fraction 6, and compounds VI and IX were present as before, but there were differences in the other components. Firstly, no compounds VII and VIII were found this time [cf. 1]; it was thought previously that these arose from a secondary reaction involving insertion of a $(CF_3)_2N$ unit into VI, or a compound with the same basic skeleton. Further however, four new compounds (1-4) were now present. The first (1) was trans-4,4,4-trifluorocrotononitrile as shown by analysis and mass, ir, and nmr spectroscopy. The trans arrangement of the H substituents on the double bond was shown by the ^1H nmr coupling constants for CH=CH of 16.5 Hz, and the CF_3C=CH coupling of 2.0 (see Table 1 for detailed nmr data on all new compounds made). This product (1) corresponded to the crystalline N-trifluoromethylamide of 4,4,4-trifluorocrotonic acid obtained before [1], and both probably arise by some sort of attack by HF or by partial hydrolysis on compound V (all have trans CH=CH units).

Compounds 2 and 3 were fluoropyridines (see later), but 4 was 4H-hexafluoroazacyclohexa-1,3-diene, as shown by its spectroscopic parameters (conjugated; no N-F bond; 2 vinylic F; 1 vinylic H). Final proof of structure was given by aqueous hydrolysis, and by the isolation of 4 from the fluorination of 4H-tetrafluoropyridine (12). Crystals appeared in fraction E if moisture was present, and they were identical with a compound (22) made by shaking compound 4 with water. Spectroscopy showed 22 to be 3,5,5,6,6-pentafluoropiperid-3-ene-2-one and, on low pressure hydrogenation, the 3(4)-double bond was saturated, to give 3,5,5,6,6-pentafluoropiperid-2-one (23). These reactions removed any doubts about the position of the H in compound 4. The boiling points of some of the components of fraction E indicated that some co-distillation must have occurred at this stage during the distillation.

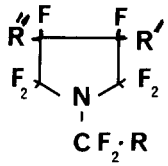
Fraction F had not been looked at previously, and had many components. A complicated series of glc separations was necessary to isolate pure compounds. Most were fluoropyridines (2; 6; 7; 9-14), but also found were more IX and 1, and two new compounds (5 and 8). One was an open chain compound, similar to VI, which was identified as 5H,6H-



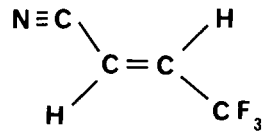
I R = F
IV R = H



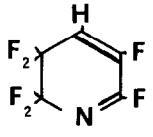
V R = H, R′ = F
VI R = R′ = F
5 R = F R′ = H



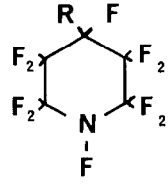
IX R = R′ = H R″ = F
8 R = R′ = R″ = H
16 R = R′ = R″ = F
17 R′ = H R = R″ = F



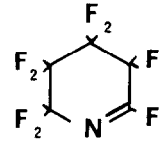
1



4



18 R = H
21 R = F



20

22

23

SCHEME 1

TABLE 1

Detailed ^{19}F and ^{1}H Nmr Data for all New Compounds
(and those incompletely recorded previously)

Compound No		Chemical Shifts	Relative Intensity	Position in Formula	Couplings
1	F	67.3	-	4	dd; J_{43}=6.0, J_{42}=2.0[1]
	H	3.64	-	2 & 3	cAB; J_{AB}=16.5[2] $\Delta\nu$=31.4, J_{24}=1.8, J_{34}=6.0
4	F	52.3	1	2	bs
		102.2	2	6	bs (collapsed AB)
		112.8	2	5	ddt; J_{53}=16.0, J_{56}=5.7, J_{54}=5.7
		122.5	1	3	ddt; J_{32}=23.5, J_{35}=16.0, J_{34}=6.3
	H	3.77	-	4	m
5	F	33.6	1	3	cdq; J_{31}=14.0, J_{34}=21.0
		57.1	3	1	d; J_{13}=14.0[3]
		116.0	2	6	cd; J_{6F6H}=53.5
		121.9	1	4	cdd; J_{43}=21.0, J_{45}=27.0[4]
	H	3.43	1	6	dt; J_{6H6F}=52.0; J_{6H5}=6.2
		3.71	1	5	dddt; J_{54}=26.0[3], J_{56H}=6.2, J_{56F}=6.2, J_{53}=1.5

7	F	69.5	-	2,6	bs
	H	2.20	1	4	p; $J_{42}=J_{46}=8.0, J_{43}=J_{45}=8.0$
		3.27	2	3,5	d; $J_{34}=J_{54}=8.0$
8	F	81.0	2	2,5	AB; J=198, Δν=295
		100.6	1	1 (CF_2H)	dAB; $J_{1F1H}=56.0$, JAB=252, Δν=203
		211.2	1	3,4	cd; $J_{3F3H(4F4H)}=47.0$
	H	3.44	1	1 (CHF_2)	t; $J_{1H1F}=54.0$
		4.93	2	3,4	cd; $J_{3H3F(4H4F)}=45.0$
10	F	68.9	1	6	b
		84.3	1	2	bd; $J_{23}=24.0$
		115.8	1	4	ddt; $J_{43}=18.0, J_{45}=8.0$
		169.5	1	3	dddd; $J_{32}=23.0, J_{34}=18.0, J_{35}=3.8, J_{36}=24.0$
	H	3.27	-	5	dddd; $J_{53}=3.5, J_{54}=8.0$
13	F	91.4	1	2	bt; $J_{23}=J_{25}=27.0$
		129.2	1	5	ddd; $J_{52}=29.0, J_{53}=3.1, J_{54}=7.1$
		135.9	1	3	ddd; $J_{32}=26.0, J_{34}=8.7, J_{35}=3.1$

(continued on next page)

TABLE 1 (Contd.)

Compound No		Chemical Shifts	Relative Intensity	Position in Formula	Couplings
	H	2.08	1	6	bt; $J_{62}=J_{64}=2.4$
		2.40	1	4	cd; $J_{46}=2.6$
14	F	62.6	1	2	bd; $J_{24}=24.0$
		98.6	1	4	dddd; $J_{42}=23.0, J_{43}=J_{45}=J_{46}=9.0$
	H	1.80	1	6	bdd; $J_{64}=9.0, J_{65}=6.0$
		3.05	1	5	ddd; $J_{53}=2.0, J_{54}=8.0$
		3.34	1	3	cdd; $J_{34}=9.0, J_{35}=2.5$
17	F	56.3	3	1 (CF_3)	p; $J_{13}=J_{15}=9.0$
		87.0	2	2	AB; J=192, $\Delta\nu$=582
		93.1	2	5	AB; J=186, $\Delta\nu$=219
		127.5	2	4	AB; J=270, $\Delta\nu$=474
		211.1	1	3	dp; $J_{3F3H}=48.0, J_{32}=J_{34}=9.0$
	H	5.06	-	3	cd; $J_{3H3F}=48.0$
18	F	109.3	4	2,6	CAB
		113.4	1	1 (NF)	bs
		125.4	4	3,5	AB; J=282, $\Delta\nu$=269
		225.9	1	4	cd; $J_{4F4H}=48.0$

	H	5.07	-	4	cd; J_{4H4F}=47.0
22	F	93.7	2	6	bdt; J_{64}=5.0,J_{65}=5.5
		109.9	2	5	ddt; J_{53}=16.5,J_{54}=J_{56}=6.0
		118.2	1	3	dt; J_{34}=10.5,J_{35}=17.0
	H	1.32	1	4	ddt; J_{43}=11.5,J_{45}=7.0,J_{46}=5.0
		-2.15	1	1 (NH)	bs; variable
23	F	90.4	2	6	AB; J=215, $\Delta\nu$=395
		116.8	2	5	cm
		190.2	1	3	dtdd; J_{3F3H}=47.0,J_{35}=15.0,J_{34}=7.0 and 8.0
	H	0.47	1	1 (NH)	bs
		4.78	1	3	dt; J_{3H3F}=45.0,J_{34}=7.0
		7.04	2	4	cm

Footnotes:

1 This CF_3-C=H (cis) coupling agrees with that of 2.3 reported in 1-[bis(trifluoromethyl)amino]-3,3,3-trifluoropropene [14].

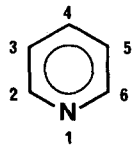
2 This value is in the normally accepted range (12-19 Hz) for trans CH=CH coupling in ^{1}H nmr (cf. range for cis coupling, 4-12 Hz) [15].

3 Indicates Z-stereochemistry [cf. 1].

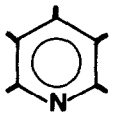
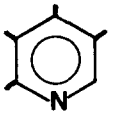
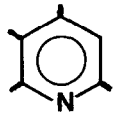
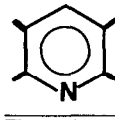
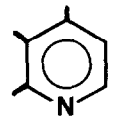
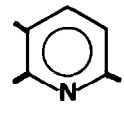
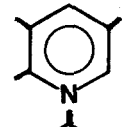
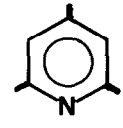
4 This value compares with normal trans CF=CH couplings (12-50 Hz) and contrasts with the cis (usually 0-15, occasionally 15-20) [15].

TABLE 2

CALCULATIONS OF ^{19}F NMR CHEMICAL SHIFTS FOR FLUOROPYRIDINES

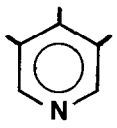
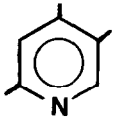
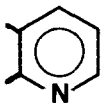
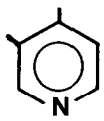
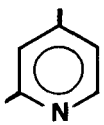
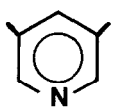
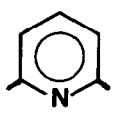
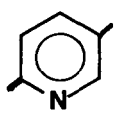


All marked bonds are to Fluorine

Compound & Number	( )$^+$	Value for Fluorine in Position:- 2	3	4	5	6
	(2)	87.7	162.4	134.3	162.4	87.7
	(9)	83.1 (-4.6)	158.3 (-4.1)	141.3 (+7.0)	149.7 (-12.7)	-
	(10)	84.3 (-3.4)	169.5* (+7.1)	115.8* (-18.5)	-	68.9 (-18.8)
	(12)	92.6 (+4.9)	141.3 (-21.1)	-	141.3 (-21.1)	92.6 (+4.9)
	[2]	83.3 (79.7)	165.4 (165.4)	123.1 (122.8)	-	-
	(3)	86.2 (89.2)	146.9 (148.4)	-	-	72.7 (73.8)
	(13)	91.4 (88.0)	135.9 (137.2)	-	129.2 (128.6)	-
	(11)	64.5 (65.5)	-	94.5 (97.3)	-	64.5 (65.5)

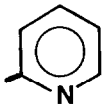
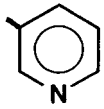
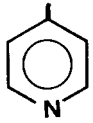
(continued on facing page)

TABLE 2 (Contd.)

Compound & Number	( )$^+$	Value for Fluorine in Position:- 2	3	4	5	6
	u	-	(145.6)	(148.3)	(145.6)	-
	u	(64.3)	-	(122.8)	(156.8)	-
	(6) [2]	87.2 (84.6)	140.4 (144.3)	-	-	-
	u	-	(152.7)	(129.8)	-	-
	(14)	62.6 (60.9)	-	98.6 (104.3)	-	-
	u	-	(124.5)	-	(124.5)	-
	(7)	69.5 (70.4)	-	-	-	69.5 (70.4)
	(15) [2]	72.8 (69.2)	-	-	133.8 (135.7)	-

(continued on next page)

TABLE 2 (Contd.)

Compound & Number	( )+	Value for Fluorine in Position:- 2	3	4	5	6
	[16]	70.4 (65.8)	-	-	-	-
	[16]	-	125.6 (131.6)	-	-	-
	[17]	-	-	104.2 (111.3)	-	-

Footnotes:

+ Numbers in square brackets are Literature References where the measurements did not come from this work.

* These values are our measurements and differ substantially from those cited earlier for positions 3 and 4 [4]: Professor R.D. Chambers informs us (personal communication) that his later measurements agree with ours (68.4; 84.1; 114.0; 168.6).

u unreported.

For all compounds, the figures with no brackets are the ^{19}F chemical shifts (δvalues) measured in this work. For known compounds, published values are acceptably close, except where stated. Figures in brackets below the chemical shift values for the tetrafluoropyridines (9, 10, 12) are the change in the ^{19}F chemical shift, relative to compound 2, at each ring position, arising when hydrogen is present in the 6, 5, and 4 positions (compounds 9, 10 and 12 respectively).

Figures in brackets below the chemical shifts for the other fluoropyridines are the expected values calculated from the upper part of the Table.

heptafluoro-2-azahex-2(Z), 4(Z)-diene (5), with a typical CH=CF coupling for a trans arrangement (Table 1). The other was 1-difluoromethyl-3H,-4H-hexafluoropyrrolidine (8).

Fraction G had four major components all fluoropyridines (3; 6; 7; 15).

Fraction H was viscous, and contained dimeric material, probably formed by loss of HF from some less stable and higher-boiling products during the distillation.

In all, eleven fluoropyridines were isolated. They were characterised by analysis, ir, and mass spectrometry. They were orientated by a simplistic but convincing calculation of expected ^{19}F nmr parameters, based on the differences between those for pentafluoropyridine [3] and the three known [4] tetrafluoropyridines (see Table 2 for details). ^{1}H nmr values are summarised in Table 3. A similar calculation could be done on these, relative to pyridine, and the same pattern emerged, with no discrepancies, though the results were not so clear cut, the values being closer.

Two of the fluoropyridines isolated were new compounds, the 2,3,5-tri- (13), and the 2,5-di (15)-fluoropyridine (15 is described in Ref.[2]).

Because of the involved glc separations required, it was difficult to calculate precise total yields of the various compounds isolated. Approximate figures (% ages present in the crude yield) were estimated as follows: I, IV, V, VI, IX, roughly as before: 8, 3%; 2, 2%; 1,4,5,11, 12,13,14, 1%; 3,6,7,9,10,15, 0.5%. Around 55% was open-chain, 5% pyrrolidines, and 10% pyridines.

Two apparently key intermediates were fluorinated under similar conditions. Pentafluoropyridine (2) afforded, besides aza-hexene I, the known [5] nonafluoroazacyclohex-1-ene (20), together with unchanged 2; further fluorination of the mixed product increased the proportion of I somewhat. Compound 20 had not been found in the product from pyridine, and could have been present there only in very small amounts.

2,3,5,6-Tetrafluoropyridine (12) also gave a mixture of two products, but no unchanged starting material, on fluorination. The acyclic diene VI and the cyclic diene 4 were obtained, and refluorination of the mixture gave more VI at the expense of 4. 2,6-Difluoropyridine (11) was not thought to be on a mainline fluorination pathway, and further fluorination of it gave no isolatable products, only degradation fragments and polymer.

TABLE 3

^{1}H nmr chemical shift values for fluoropyridines isolated in the present work

(Ring positions numbered as in Table 1)

Fluoropyridine Compound No ( )	Value for Hydrogen in Position:-				
	2	3	4	5	6
2,3-di F (6)	-	-	2.45	2.84	2.09
2,4-di F (14)	-	3.34	-	3.05	1.80
2,6-di F (7)	-	3.27	2.20	3.27	-
2,5-di F (15)	-	3.14	2.52	-	2.02
2,3,6-tri F (3)	-	-	2.37	3.25	-
2,3,5-tri F (13)	-	-	2.40	-	2.08
2,4,6-tri F (11)	-	3.46	-	3.46	-
2,3,4,5-tetra F (9)	-	-	-	-	2.05
2,3,4,6-tetra F (10)	-	-	-	3.27	-
2,3,5,6-tetra F (12)	-	-	2.21	-	-

For compounds 6 and 15 the values came from Ref. [2].

It was not thought that undecafluoropiperidine (21) played any part in this fluorination, and it was recovered unchanged after passage through the reactor under the usual conditions.

A preliminary investigation was done into the fluorination of pyridine over cobaltic fluoride at low temperatures (ca. 150°), which had not been done before. Recoveries were poor (ca. $^1/_3$ by weight of input): after a preliminary distillation, separation of the 5 major components was done by glc. The compound present in greatest quantity was the known [5] perfluoro(1-methylpyrrolidine) (16) and a new pyrrolidine, the 3H-hepta-fluoro-1-trifluoromethyl derivative (17) was also found. Also isolated was the open chain aza-ene IV. An interesting new product was 4H-deca-

fluoropiperidine (18), the only compound with an N-F bond isolated in the entire study. The fifth product could not be identified and could have been a mixture: it was however a C_8 material and must have been a rearrangement product. Clearly the CoF_3 product mixture was different from that produced by $KCoF_4$.

DISCUSSION

The results of this pyridine - $KCoF_4$ fluorination study are in accord with the cation-radical pathway [6,7] as far as the early stages are concerned, where "reversion to type" occurs, giving fluoropyridines. The 2,5-difluoro-derivative (15) is a key intermediate [cf. 8] from which the trifluoro-derivatives 13 and 3 can be derived. Isolation of difluorides 6,7, and 14, and trifluoride 11 show that directional effects are not completely specific however. Ultimately it appears that the fluoropyridines must rearrange by preferential rupture of the C_2-C_3 bond, giving either azahexadienes V, VI, and 5 (which can be further fluorinated to I and IV), or the N-methylpyrrolidines, IX, and 8. 2,3,5,6-Tetrafluoropyridine (12) is another key intermediate: it can give rise to the major open-chain products VI and IV, and to the N-methylpyrrolidine 17; it can fluorinate further, "aromatically" to pentafluoropyridine (2), or by addition to give the diene 4. Fluorination of 12 gave only VI and 4, but this was probably a milder reaction than in the fluorination of pyridine itself, when hot zones [8] develop in the reactor with the greater heat of reaction (17 was not isolated from pyridine/$KCoF_4$, only from pyridene/CoF_3). Likewise pentafluoropyridine (2) could give I and 16, as well as products of addition to the ring, such as 20, but 16 was not found (nor in fact from pyridine/$KCoF_4$). Aza-alkenes V and 5 must arise from 2,3,6-trifluoropyridine (3). The N-methylpyrrolidine IX presumably comes from 2,3,5-trifluoropyridine (13), and its analogue 8 from 2,5-difluoropyridine (15).

It seems that a major driving force in this reaction route is the inability of $KCoF_4$ to generate >N-F bonds, the C_2-C_3 bond breaking preferentially.

For the pyridine - CoF_3 reaction the same general sort of route seems to apply, though the poorer recoveries indicate much greater degradation, and only 4 products were identified, all with high degrees of fluorination. Here, expected N-methylpyrrolidines (16 and 17) were found, as well as the

azahexene IV. In fact CoF_3 is a more drastic fluorinating agent and saturates double bonds more readily than does $KCoF_4$, and it gave rise to the only >N-F compound isolated, the 4-H compound, 18. Presumably, 4H-tetrafluoropyridine is again a key intermediate, since 17 and 18 are derived from it. Ideas on why the heterocyclic ring breaks between C_2 and C_3 will be presented in a later paper [9] on the fluorination of methylpyridines by $CsCoF_4$.

EXPERIMENTAL

Techniques - Fluorinations Reactors used were standard stirred nickel tubes [8]: Reactor a was 1080 mm x 150 mm int. d., packed with ca. 6 Kg of reagent; b, 1300 mm x 180 mm, packed with ca. 10 Kg; c, 0.45 m x 45 mm containing ca. 100 g.

Gas-liquid chromatography Analytical and semi-preparative work was done on a Pye Series 104 instrument with a flame ionisation detector. Semi-preparative columns (9.2 m x 8 mm) were packed as follows : column a, UCON 550X on Chromasorb P30-60 (1:5); b, dinonyl phthalate on Celite (1:3); c, Kel F oil on Chromasorb P (1:10). The column (p) used for large scale separations (4.8 m x 75 mm) was packed with dinonyl phthalate on Chromasorb P30-60 (1:4) (fitted with a katharometer detector). Quoted for each run are the column used, temperature, and nitrogen flow rate (for p; ℓh^{-1})or over pressure (for a,b,c; p.s.i).

Spectroscopy As for the previous paper [2].

Fluorination of Pyridine over Potassium Tetrafluorocobaltate Pyridine (100 g) was passed during $3^1/2$ - 4 h into Reactor a which was at 215-225°, by dropping a slow stream into a horizontal glass inlet tube (0.3 m x 20 mm int. d.; temperature 120°) through which was being passed nitrogen (10 ℓh^{-1}). Products were passed through a copper tube at 100° containing sodium fluoride pellets, and condensed in a glass trap at -180°. After the addition, nitrogen was passed at 20 ℓh^{-1} for 2 h further.

The products from 5 runs (550 g) were dried ($MgSO_4$) filtered and distilled quickly (60 g h^{-1}) through a vacuum-jacketed column (0.75 m) packed with Dixon gauzes. There was some decomposition with etching of the apparatus, and the still residue was viscous. Fractions collected

were A, b.p. $<46^{o}$, 77.7 g; B, 46-52°, 29.3 g; C, 52-64°, 43.9 g; D, 64-70°, 28.1 g; E, 70-74°, 86.2 g; F, 74-107°, 73.2 g; G, 107-119°, 21.4 g; H, 119-140°, 20.2 g; still residue, ca 50 g. Further separations were carried out as follows:-

Fraction A had one major component, and was purified by glc (p, 60°, 60) to give undecafluoro-2-azahex-2(Z)-ene (I) [5;1].

Fraction B and C had a common major component. They were combined and purified by glc (p, 70°, 60) to give 5H-decafluoro-2-azahex-2(Z)-ene (IV) [1].

Fraction D by glc (p, 80°, 65) gave the two major components together, and further glc (b, 80°, 15) gave D(i), 4H,5H-heptafluoro-2-azahex-2(Z), 4(E)-diene (V) [1], and D(ii), 5H-octafluoro-2-azahex-2(Z), 4(Z)-diene (VI) [1].

Fraction E by glc (p, 90°, 60) gave 3 sub-fractions, E(i), E(ii), E(iii). Sub-fraction E(i) was VI.

Sub-fraction E(ii) by further glc (a, 120°, 15) gave E(ii)a, 1-difluoromethyl-3H-heptafluoropyrrolidine (IX) [1]: and E(ii)b, trans-4,4,4-trifluorocrotononitrile (1) nc, b.p. 87-88° (Found: C, 40.1; H, 1.8; F, 46.2; N, 11.6. $C_4H_2F_3N$ requires C, 39.7; H, 1.7; F, 47.1; N, 11.6%) (m/e 121 [M]; 102 [M-F]; 94 [M-HCN]): ir 3090 (m) (C-H), 2240 (w) (C≡N), 1655 (m) (C=C).

Sub-fraction E(iii), on further glc (a, 120°, 15) gave E(iii)a, pentafluoropyridine (2) [3]: E(iii)b, 2,3,6-trifluoropyridine (3) [4]. b.p. 118-119° (m/e 133 [M]; 106 [M-HCN]): E(iii)c, 4H-hexafluoroazacyclohexa-1,3-diene (4), nc b.p. 90-91° (Found: C, 31.9; H, 0.8; F, 60.3; N, 7.4. $C_5H F_6N$ requires C, 31.8; H, 0.5; F, 60.3; N, 7.4%) (m/e 189 [M]; 170 [M-F]; 169 [M-HF]; 162 [M-HCN]; 151 [$M-F_2$]; 120 [$M-CF_3$]): ir 1680(s),1710(s), 3100(w): there was a broad peak in the UV with maxima at 209 and 237 (shoulder) nm (hexane). See later for the identification of crystals sometimes present in sub-fraction E(iii) by hydrolysis of 4.

Fraction F was separated further by glc (p, 90°, 60) into 5 sub-fractions F(i)-F(v).

Sub-fraction F(i) was further separated (a, 115°, 15) into F(i)a, 1-difluoromethyl-3H-heptafluoropyrrolidine (IX) identical with sub-fraction E(ii)a: F(i)b, 5H,6H-heptafluoro-2-azahexa-2(Z),4(Z)-diene (5), nc, b.p. 93-94° (Found: C, 28.6; H, 1.2; F, 63.8; N, 6.4. $C_5H_2F_7N$ requires C, 28.7; H, 1.0; F, 63.6; N, 6.7%) (m/e 209 [M]; 190 [M-F]; 140 [$M-CF_3$]: ir 1690(s),

1720(s), 3000(w), 3100(w); UV peak at 211 nm (hexane): F(i)c, trans-4,4-4-trifluorocrotononitrile (1) identical with sub-fraction E(ii)b.

Sub-fraction F(ii) on further glc (a, 120°, 15) gave F(ii)a, pentafluoropyridine (2; fraction E(iii)a): F(ii)b, 2,3-difluoropyridine (6) [10], b.p. 125-126° (m/e 115 [M]): F(ii)c, 2,6-difluoropyridine (7) [10; 11], b.p. 127-128° (Found: m/e 115 [M]; 96 [M-F]).

Sub-fraction F(iii) was almost pure and by further glc (a, 120°, 15) gave 1-difluoromethyl-3H,4H-hexafluoropyrrolidine (8), nc, b.p. 97-98° (Found: C, 25.9; H, 1.3; F, 66.6. $C_5H_3F_8N$ requires C, 26.2; H, 1.3; F, 66.35%) (m/e 229 [M]; 210 [M-F]); ir 3000(w).

Sub-fraction F(iv) was separated by glc (a, 125°, 15) into F(iv)a, 2,3,4,5-tetrafluoropyridine (9) [4], b.p. 88-89° (m/e 151 [M]): F(iv)b, 2,3,4,6-tetrafluoropyridine (10) [4], b.p. 91-92° (m/e 151 [M]): F(iv)c, 2,4,6-trifluoropyridine (11) [4], b.p. 95-96° (m/e 133 [M]).

Sub-fraction F(v) was separated by glc (a, 130°, 15) into its 3 major components; F(v)a, 2,3,5,6-tetrafluoropyridine (12) [12; 4], b.p. 100-101° (m/e 151 [M]): F(v)b, 2,3,5-trifluoropyridine (13), nc, b.p. 101-102° (Found: C, 44.8; H, 1.7; F, 42.7. $C_5H_2F_3N$ requires C, 45.1; H, 1.5; F, 42.8%); ir 1440(m), 1485(s), 1605(m), 3090(w); UV 203 and 265 nm (ethanol): F(v)c, 2,4-difluoropyridine (14), b.p. 107° (Found: C, 50.9; H, 2.6; F, 32.6; N, 11.8. $C_5H_3F_2N$ requires C, 52.2; H, 2.6; F, 33.0; N, 12.2%) (m/e 115 [M], 96 [M-F]; 88 [M-HCN]); ir 1405(m), 1480(m), 1575(s), 1605(s), 3080(w); UV 255, 249, 246 (shoulder), 244, 207 nm (ethanol); described in a patent [13].

Fraction G contained 4 major components separated by glc (a, 130°, 20) into:- G(i), 2,3,6-trifluoropyridine (3; fraction E(iii)b): G(ii), 2,5-difluoropyridine (15) [2] b.p. 120°; G(iii), 2,3-difluoropyridine (6; fraction F(ii)b): G(iv), 2,6-difluoropyridine (7; fraction F(ii)c). Fraction H was viscous and probably contained some dimeric material.

Fluorination of Pyridine over Cobaltic Fluoride Pyridine (150 g) was dripped during 3 h in a stream of nitrogen (10 ℓh^{-1}) into reactor b held at 140-165°. The reactor was swept with nitrogen (25 ℓh^{-1}) for 2 h further. The products, trapped at -78°, were washed quickly with cold water, dried (50 g), and distilled through a small vacuum-jacketed column. The distillate b.p. <118° (>90%) was separated by glc (p, 70°, 60) into four fractions J-M.

Fraction J, (9.5 g) was essentially one compound,purified by glc (b, 50°, 10) to give octafluoro-1-trifluoromethylpyrrolidine (16) b.p. 36° [5].

Fraction K (6.0 g) had 2 major components isolated by glc (b, 50°, 10) as K(i), 5H-decafluoro-2-azahex-2(Z)-ene (IV; fractions B and C): and K(ii), 3H-heptafluoro-1-trifluoromethylpyrrolidine (17) nc, b.p. 59-60° (Found: C, 22.8; H, 0.4; F, 71.7. $C_5HF_{10}N$ requires C, 22.65; H, 0.4; F, 71.7%) (m/e 246 [M-F]).

Fraction L (11.0 g) contained 2 major components, separated (c, 50°, 10) into L(i), 4H-decafluoropiperidine (18), nc, b.p. 111-112° (Found: C, 22.3; H, 0.4; F, 71.6% m/e 246 [M-F]; 227 [$M-F_2$]) ir 2980 (vw); with 30% aqueous KI, this gave an iodine colour after 5 min, which had become intense after 40 min [cf. 5] : L(ii) (19), unknown, b.p. 116-117° (Found: C, 22.7, 23.5; H, 0.2; N, 3.4. $C_8HF_{16}N$ requires C, 23.15; H, 0.2; N, 3.4%) (m/e 396 [M-F]; 346 [$M-CF_3$]; 314 [$M-C_2HF_4$]; 296 [$M-C_2F_5$]); with 30% aqueous KI, this gave only the slightest yellow colour after 24 h.

Fraction D (13.0 g) was highly complex with many components, but no major ones.

Fluorination of Pentafluoropyridine (2) over Potassium Tetrafluorocobaltate This (8.0 g) in a nitrogen stream (1 ℓh^{-1}) was dripped during 1 h into Reactor c which was at 220°. The reactor was swept with nitrogen for 1 h further, and the products (7.7 g) separated by glc (b, 70°, 10) to give (i) nonafluoroazacyclohex-1-ene (20) [5], b.p. 40° (m/e 226 [M-F]); (ii) undecafluoro-2-azahex-2-ene (I; fraction A): and starting material (2) in proportions 5:3:12.

When the total product of the above fluorination was refluorinated under identical conditions the same products were recovered in the approximate ratio 20:I:2 = 1:1:2.

Fluorination of 2,3,5,6-Tetrafluoropyridine (12) over Potassium Tetrafluorocobaltate 12 (4.0 g) treated as for the fluorination of 2 (above) gave products (3.8 g), separated by glc (a, 130°, 15) into the 2 major components: (i) 5H-octafluoro-2-azahex-2(Z), 4(Z)-diene (VI; fraction Dii): (ii) 4H-hexafluoroazacyclohexa-1,3-diene (4; fraction E(iii)c) in approximately 1:1 ratio. Refluorination of the total product under identical conditions gave VI and 4 in the ratio 5:1.

Fluorination of Undecafluoropiperidine (21) over Potassium Tetrafluorocobaltate When 21 (2.0 g) was fluorinated as for pentafluoropyridine (2), only unchanged 21 was recovered (1.9 g).

Hydrolysis of 4H-Hexafluoroazacyclohexa-1,3-diene (4) Compound 4 (2.0 g) was shaken vigorously with water (2 cm^3) for 16 h at 15°. The solid formed was filtered off and sublimed (100°/12 mm) to give 3,5,5,6,6-pentafluoropiperid-3-ene-2-one (22) nc (1.8 g), m.p. 86.5-87.5° (Found: C, 32.1; H, 1.1; F, 50.9; N, 7.5. $C_5H_2F_5NO$ requires C, 32.1; H, 1.1; F, 50.8; N, 7.5%) (m/e 167 [M-HF]; 149 [$M-F_2$]; 146 [$M-C_2HO$]; 139 [M-CHFO]) ir 1675(s), 1725(s), 2840, 2900, 3100, 3200(b); UV 238 (shoulder) 215 nm (ethanol).

Fraction E(iii) from pyridine/$KCoF_4$ also contained a little crystalline 22 on occasions, almost certainly due to hydrolysis of the compound 4 present by traces of moisture.

Hydrogenation of Compound 22 Diethyl ether (20 cm^3) containing 22 (0.50 g), and palladium on charcoal catalyst (10%; 0.1 g) were shaken in a hydrogen atmosphere (1 atm.) for 24 h (140 cm^3 absorbed). The catalyst was filtered off and the solvent evaporated, the residual solid being sublimed (80°/12 mm) to give 3,5,5,6,6-pentafluoropiperid-2-one (23) nc (0.45 g), m.p. 95° (Found: C, 31.8; H, 2.0; F, 48.8. $C_5H_4F_5NO$ requires C, 31.8; H, 2.1; F, 50.2%); ir 1680-1750(b), 2850-2970(b), 3100-3250(b). Compound 23 was contaminated by a few % of the analogous 5,5,6,6-tetrafluoride.

ACKNOWLEDGEMENTS

For the work in this and the previous paper [2] we thank, for their assistance, Dr. A.M.G. Macdonald (elemental analysis), Dr. J. Burdon (nmr) and Dr. J.R. Majer (mass spectrometry).

REFERENCES

1 P.L. Coe, J.C. Tatlow and M. Wyatt, J. Chem. Soc. Perkin I, (1974) 1732.

2 R.G. Plevey, R.W. Rendell and J.C. Tatlow, J. Fluorine Chem., 21 (1982) 159.

3 J. Burdon, D.J. Gilman, C.R. Patrick, M. Stacey, and J.C. Tatlow, Nature, 186 (1960) 231: R.D. Chambers, J. Hutchinson, and W.K.R. Musgrave, J. Chem. Soc., (1964) 3573.

4 R.D. Chambers, F.G. Drakesmith, and W.K.R. Musgrave, J. Chem. Soc., (1965) 5045.

5 R.E. Banks, W.M. Cheng and R.N. Haszeldine, J. Chem. Soc., (1962) 3407.

6 J. Burdon, I.W. Parsons and J.C. Tatlow, Tetrahedron, 28 (1972) 43.

7 J. Burdon and I.W. Parsons, Tetrahedron, 31 (1975) 2401; 36 (1980) 1423.

8 M. Stacey and J.C. Tatlow, Advances in Fluorine Chemistry, Butterworths, London, 1 (1960) 166.

9 R.G. Plevey, R.W. Rendell and J.C. Tatlow, J. Fluorine Chem., forthcoming paper.

10 G.C. Finger, L.D. Starr, A. Roe, and W.J. Link, J. Org. Chem., 27 (1962) 3965.

11 J. Hamer, W.J. Link, A. Jurjevich, and T.L. Vigo, Rec. Trav. Chim., 81 (1962) 1058.

12 R.E. Banks, J.E. Burgess, W.M. Cheng and R.N. Haszeldine, J. Chem. Soc., (1965) 575.

13 A. Nicholson (to I.C.I. Ltd.), Ger. Offen. 2,128,540 (1971); Chem. Abs., 76 (1972) 59469.

14 J. Freear and A.E. Tipping, J. Chem. Soc.(C), (1968) 1096.

15 J.W. Emsley, J. Feeney and L.H. Sutcliffe, High Resolution Nuclear Magnetic Resonance Spectroscopy, Pergamon, London, 1966, Vol. 2.

16 C.H. Dungan and J.R. Van Wazer, Compilation of Reported ^{19}F Nmr Chemical Shifts, Wiley-Interscience, New York, 1970.

17 P.B. Desai, J. Chem. Soc. Perkin I, (1973) 1865.