

## Polyfluorocarbanion Chemistry. Part II.<sup>1,2</sup> Fluoride-initiated Reactions of Hexafluoropropene with Pentafluoropyridine and Tetrafluoropyridine-4-carbonitrile †

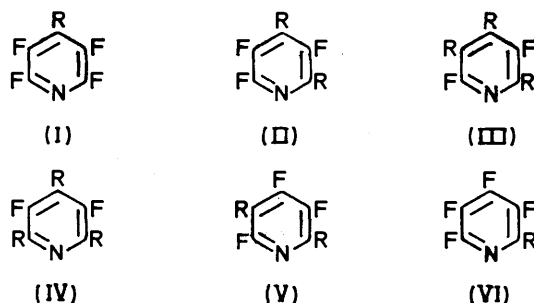
By Colin J. Drayton, William T. Flowers, and Robert N. Haszeldine,\* Department of Chemistry, The University of Manchester Institute of Science and Technology, Manchester M60 1QD

Hexafluoropropene reacts with pentafluoropyridine in a dipolar aprotic solvent in the presence of caesium fluoride to give one mono- (4-), two di- (2,4- and 2,5-), and two tri- (2,4,5- and 2,4,6-) substituted derivatives. The 2,5- and 2,4,5-compounds, unexpected by analogy with other nucleophilic attacks on pentafluoropyridine, are regarded as arising by kinetically controlled reaction to give the 2,4,5-compound, which then undergoes intermolecular rearrangement to the products ultimately obtained by thermodynamic control. The relative stabilisation of the postulated anionic intermediates by  $\alpha$ -fluorine or -perfluoroalkyl groups can be deduced. The heptafluoroisopropyl carbanion reacts with tetrafluoropyridine-4-carbonitrile to give one di- (2,5-), two tri- (2,3,5- and 2,3,6-), and the tetra-substituted derivatives. <sup>19</sup>F N.m.r. results indicate the occurrence of strong through-space coupling in these compounds.

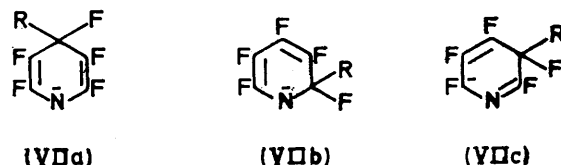
PENTAFLUOROPYRIDINE, the subject of much study in recent years, undergoes ready nucleophilic displacement of fluorine with a variety of nucleophiles. Nucleophiles such as methoxide ion and ammonia can effect poly-substitution as far as the trisubstituted derivatives<sup>3</sup> and only the 2,4,6-isomer is thus obtained. Independently of others,<sup>4,5</sup> we have investigated in some detail the reactions of pentafluoropyridine and related compounds with the heptafluoroisopropyl carbanion derived from hexafluoropropene and fluoride ion,<sup>6</sup> and in particular noted the formation of the 2,5-isomer which is important in the mechanistic interpretation of the reaction.<sup>2</sup> Our results are in general agreement with those already published;<sup>5</sup> we now report the basis on which our original structure determination was made, together with the mechanistic conclusions.

**Pentafluoropyridine.**—Pentafluoropyridine reacted at 70° in a sealed tube with hexafluoropropene in the presence of a small quantity of caesium fluoride when an aprotic solvent (*e.g.* tetramethylene sulphone) was present (Table I), but in the absence of solvent the reactants were recovered almost quantitatively. Three products were separated and identified: the expected 4-heptafluoroisopropyl and 2,4-bis(heptafluoroisopropyl) compounds (I) and (II) and the unexpected 2,4,5-tris(heptafluoroisopropyl) derivative (III) [note: R = CF(CF<sub>3</sub>)<sub>2</sub> throughout this paper]. Use of *N*-methyl-2-pyrrolidone as solvent gave a much improved yield of (III), together with a small amount of a fourth compound, the expected perfluoro-(2,4,6-tri-isopropylpyridine) (IV), which we, also,<sup>5</sup> were unable to separate completely from the isomeric (III). When the product mixture from the reaction in tetramethylene sulphone was treated with more hexafluoropropene, besides an increase in the yields of the trisubstituted derivatives,

the 2,5-disubstituted isomer (V) was isolated. In no reaction was any of the 2-isomer (VI)<sup>7</sup> detected. In spite of the bulky nature of the attacking nucleophile, (CF<sub>3</sub>)<sub>2</sub>CF<sup>-</sup>, initial attack takes place predominantly and perhaps exclusively at the 4-position, indicating that



stabilisation of the negative charge in the intermediate carbanion by *para*-nitrogen (VIIa) is more important than by *ortho*-nitrogen (VIIb) or by *ortho*- or *para*-fluorine (VIIc).



Attack by a further heptafluoroisopropyl carbanion on the 4-compound (I) takes place at the 2-position to give the 2,4-compound (II). Steric reasons apart, this would indicate that stabilisation by *ortho*-nitrogen (VIIIa) is more effective than stabilisation by *ortho*-iso-C<sub>3</sub>F<sub>7</sub> (VIIIb).

In spite of the considerable steric interaction between

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<sup>1</sup> Part I, C. J. Drayton, W. T. Flowers, and R. N. Haszeldine, *J. Chem. Soc. (C)*, 1971, 2750.

<sup>2</sup> C. J. Drayton, W. T. Flowers, and R. N. Haszeldine, *Chem. Comm.*, 1970, 662.

<sup>3</sup> R. D. Chambers, J. Hutchinson, and W. K. R. Musgrave, *J. Chem. Soc.*, 1964, 3736; R. E. Banks, J. E. Burgess, W. M. Cheng, and R. N. Haszeldine, *ibid.*, 1965, 575; R. E. Banks, R. N. Haszeldine, and I. M. Young, unpublished results; I. M. Young, Ph.D. Thesis, Manchester, 1966.

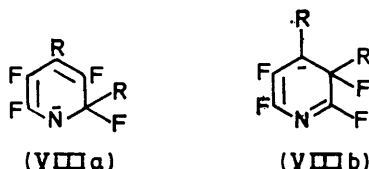
<sup>4</sup> H. C. Fielding, B.P. 1,133,492/1968.

<sup>5</sup> R. D. Chambers, R. A. Storey, and W. K. R. Musgrave, *Chem. Comm.*, 1966, 384; R. D. Chambers, J. A. Jackson, W. K. R. Musgrave, and R. A. Storey, *J. Chem. Soc. (C)*, 1968, 2221; R. D. Chambers, R. P. Corbally, and W. K. R. Musgrave, *Chem. Comm.*, 1969, 127; *J.C.S. Perkin I*, 1972, 1281.

<sup>6</sup> Part III, C. J. Drayton, W. T. Flowers, and R. N. Haszeldine, following paper; C. J. Drayton, Ph.D. Thesis, Manchester, 1970.

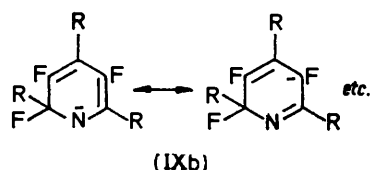
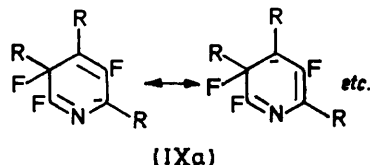
<sup>7</sup> R. E. Banks, K. Mullen, W. J. Nicholson, C. Oppenheim, and A. Prakash, *J.C.S. Perkin I*, 1972, 1098.

two adjacent iso-C<sub>3</sub>F<sub>7</sub> groups,<sup>8</sup> the third heptafluoroisopropyl carbanion attacks at the 5-position in preference

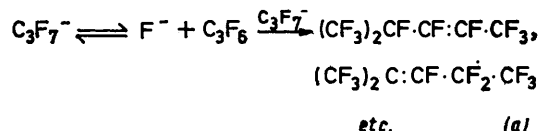


to the 6-position. This suggests that intermediate carbanion (IXa) is more stable than (IXb) and hence that whereas one perfluoroisopropyl group is less stabilising than a ring nitrogen, the effect of two such groups is sufficient to permit substitution at the 5-position. In the tetrafluoropyrimidine series,<sup>1</sup> no abnormal substitution was detected; in that case *two* ring nitrogens were available to overcome the effect of the two perfluoroisopropyl groups.

That the 2,4,5-isomer (III) is the initial product arising by kinetic control and is converted by thermodynamic control into the 2,4,6-isomer is further supported by the observation that fluoride ion at 170–190 °C converts the 2,4,5-compound into the 2,4-, the



2,5-, and the 2,4,6-substituted compounds (Table 2). Isolation of the anionically produced dimers and trimers of hexafluoropropene<sup>9</sup> also shows that loss of C<sub>3</sub>F<sub>7</sub><sup>-</sup> from (III) has occurred [reaction (a)].

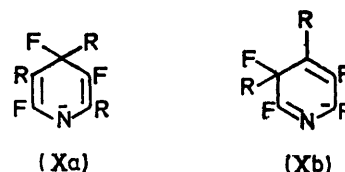


At 70° rearrangement of the 2,4,5-isomer to the 2,4,6-isomer takes place much more slowly and results, additionally, in the formation of 2*H*-heptafluoropropane *via* attack of C<sub>3</sub>F<sub>7</sub><sup>-</sup> on the solvent. We therefore conclude, in agreement with other experiments in which carbanion traps were used,<sup>5</sup> that the rearrangement is an intermolecular process proceeding *via* the C<sub>3</sub>F<sub>7</sub><sup>-</sup> ion.

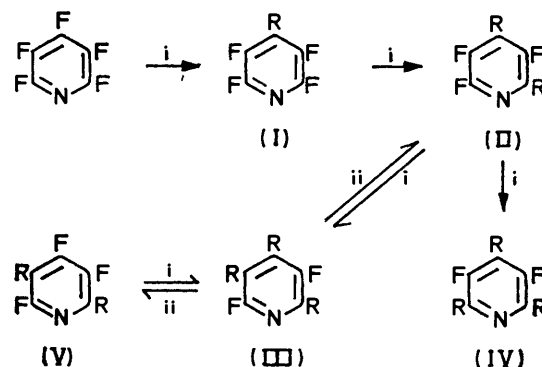
Both the 4- and the 5-heptafluoroisopropyl group in (III) are thus susceptible to nucleophilic displacement. In (Xa) the negative charge can be stabilised by *para*-

<sup>8</sup> R. D. Chambers, J. A. H. MacBride, and W. K. R. Musgrave, *J. Chem. Soc. (C)*, 1968, 2116; R. D. Chambers, J. A. Jackson, W. K. R. Musgrave, L. H. Sutcliffe, and G. J. T. Tiddy, *Tetrahedron*, 1970, 26, 71.

nitrogen and *ortho*-C<sub>3</sub>F<sub>7</sub> and in (Xb) by *ortho*- and *para*-C<sub>3</sub>F<sub>7</sub>; nitrogen is thus again more effective than C<sub>3</sub>F<sub>7</sub> in this respect.

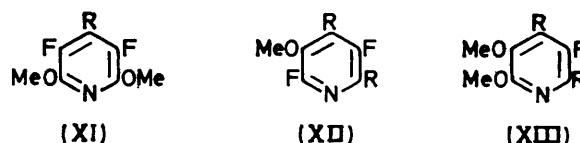


We therefore conclude that the reaction of C<sub>3</sub>F<sub>7</sub><sup>-</sup> with pentafluoropyridine proceeds as in the Scheme.



SCHEME i, C<sub>3</sub>F<sub>7</sub><sup>-</sup>, -F<sup>-</sup>; ii, F<sup>-</sup>, -C<sub>3</sub>F<sub>7</sub><sup>-</sup>

**Reactions with Methoxide Ion.**—The 4-compound (I) reacts with 2 mol. equiv. of methoxide to give a good yield of 3,5-difluoro-4-heptafluoroisopropyl-2,6-dimethoxypyridine (XI), the structure of which was confirmed by <sup>19</sup>F n.m.r. The absence of attack by methoxide at position 3 or 5 again demonstrates that ring



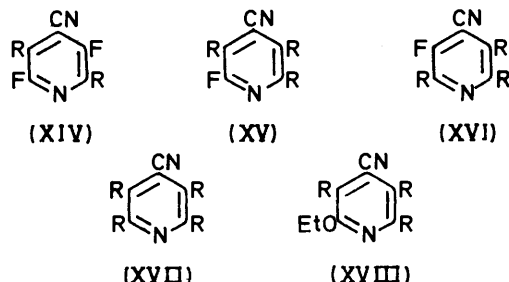
nitrogen is better able to stabilise the negatively charged intermediate than is the heptafluoroisopropyl group.

Mass spectrometry showed that reaction of the 2,4-compound (II) with 1 mol. equiv. of methoxide ion gave dimethoxy- and monomethoxy-compounds, and unchanged material. The <sup>19</sup>F n.m.r. spectrum of the mixture was rather complex, but from the positions and couplings of the ring fluorine atoms the compounds (XII) and (XIII) were deduced to be present, indicating that methoxide attacks preferentially at the 5-position as does C<sub>3</sub>F<sub>7</sub><sup>-</sup>, a further indication of the activating influence of the isopropyl group on the 5-fluorine atom.

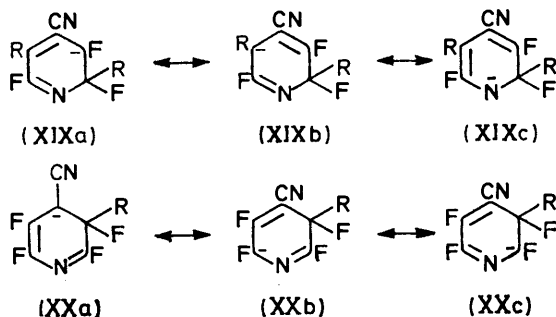
**Tetrafluoropyridine-4-carbonitrile.**—Here all ring fluorines are *ortho* either to the cyano-group or to the ring nitrogen; the  $\sigma$ -complex intermediate arising by attack at the 2-(6-) or 3-(5-) position is thereby stabilised and hence the cyano-compound is very reactive towards nucleophiles. Its reaction at 70° in acetonitrile with hexafluoropropene and a small amount of caesium

<sup>9</sup> W. Brunskill, W. T. Flowers, R. Gregory, and R. N. Haszeldine, *Chem. Comm.*, 1970, 1444.

fluoride gave the di-, tri-, and tetra-substituted compounds (XIV)—(XVII) (Table 3).



Reaction proceeded rapidly at room temperature also, but again no trace of monosubstituted product was observed; even with a 1:1 ratio of reactants, only (XIV) and starting material were detected by g.l.c. or by i.r. The monosubstituted compound, assumed to be formed by initial attack *ortho* to the cyano-group, which should be best able to stabilise the intermediate anion, must be so reactive that further carbanion attack occurs immediately to give (XIV), *i.e.* anion stabilisation by  $\text{CF}(\text{CF}_3)_2$  in (XIXb) and by ring nitrogen in (XIXc) far outweighs the stabilisation by CN in (XXa) derived from the parent compound.



The great reactivity of (XIV) towards further nucleophilic attack is amply demonstrated by the ready formation of the two trisubstituted derivatives (XV) and (XVI), despite the steric hindrance between the *ortho*  $\text{CF}(\text{CF}_3)_2$  groups. Both (XV) and (XVI) react rapidly with  $\text{C}_3\text{F}_7^-$  to give the tetrakis-compound (XVII) since the intermediates so obtained are stabilised in every canonical form by CN, ring nitrogen, or  $\text{C}_3\text{F}_7$ . The yield of the 2,3,5-compound (XV) is slightly better than of the 2,3,6-compound (XVI), indicating that attack *ortho* to CN is faster than attack *ortho* to ring nitrogen. The steric interaction in (XVII) is so immense that the molecule probably exists in a fixed state at 35 °C and below.

The high reactivity of the 2,3,5-compound (XV) is shown by its ready reaction with *neutral* or acidic ethanol to give the 6-ethoxy-derivative (XVIII); the 2,3,6-isomer (XVI), similarly heated with ethanol, gives a mixture of the corresponding ethoxy-compound and starting material, a reflection probably of the greater steric barrier to be overcome on attack of a nucleophile

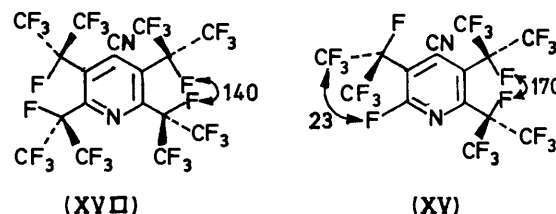
between  $\text{CF}(\text{CF}_3)_2$  and cyano-groups in (XVI) compared with the  $\text{CF}(\text{CF}_3)_2$  group and ring nitrogen in (XV).

*N.m.r.*—The results \* show that the average effects on ring fluorine chemical shift for the introduction of the heptafluoroisopropyl group into a pyridine nucleus are: *ortho*,  $-26.5 \pm 3.8$ ; *meta*,  $-0.6 \pm 3.5$ ; *para*,  $-10.7 \pm 1.9$  p.p.m. These figures established beyond doubt the structures of the 2,5-<sup>2</sup> and 2,4,5-compounds [(V) and (III)], both of which show a ring fluorine atom signal to low field of the reference.

A  $\text{C}_3\text{F}_7$  group on an aromatic nucleus *ortho* to a ring nitrogen and a fluorine atom has been found to have very consistent chemical shift values for the two types of fluorine atom concerned. The averages for ten compounds of this type (including pyridines, pyrimidines, and pyridazines) have been found to be  $108.6 \pm 1.1$  and  $-1.7 \pm 0.7$  p.p.m. for the  $\alpha$ - and  $\beta$ -fluorines, respectively. Similarly the *J* values for the couplings to the *ortho* ring fluorine are  $55 \pm 4$  and  $5.8 \pm 0.6$  Hz for the  $\alpha$ - and  $\beta$ -fluorines, respectively. These latter figures are in close agreement with the results obtained by other workers who suggest that the  $\text{C}_3\text{F}_7$  group in such a position adopts a fixed conformation, free rotation being sterically hindered.<sup>8</sup>

The cyanopyridines (XV), (XVI), and (XVII) gave consistent chemical shift values for two adjacent  $\text{C}_3\text{F}_7$  groups: the  $\alpha$ -fluorines *ortho* to ring nitrogen had an average shift of  $95.3 \pm 2.9$ , while for those *ortho* to the cyano-group the average was  $85.6 \pm 1.0$  p.p.m.; the  $\beta$ -fluorine shifts were  $-5.2 \pm 0.8$  and  $-7.1 \pm 0.8$  p.p.m., respectively. The marked downfield shift for both the  $\alpha$ - and  $\beta$ -fluorines, compared with a  $\text{C}_3\text{F}_7$  group *ortho* to two fluorines ( $103.0 \pm 1.3$  and  $-1.9 \pm 0.1$ )<sup>9</sup> or *ortho* to a ring nitrogen and ring fluorine ( $108.6 \pm 1.1$  and  $-1.7 \pm 0.7$ ) or *ortho* to a cyano-group and ring fluorine ( $93.5 \pm 0.9$  and  $-2.8 \pm 0.6$ ),<sup>6</sup> is caused by the deshielding influence of the  $\text{C}_3\text{F}_7$  groups on each other. The lower chemical shift value for the  $\alpha$ - and  $\beta$ -fluorines *ortho* to a cyano-group is caused by the greater deshielding effect of this group compared with ring nitrogen.

The most interesting feature of the n.m.r. spectra of these three compounds was the very large  $J_{2\alpha,3\alpha}$  value observed in each case. The values for (XV)—(XVII)



were 170, 175, and 140 Hz, respectively. This can only be due to through-space coupling and shows the conformational structure quite conclusively, as illustrated. The somewhat greater  $J_{2\alpha,3\alpha}$  value for (XV) may reflect the different spatial arrangement of the  $\text{C}_3\text{F}_7$  group at

\* N.m.r. and mass spectral data are available as Supplementary Publication No. SUP 21322 (4 pp.). For details of Supplementary Publications see Notice to Authors No. 7 in *J.C.S. Perkin I*, 1974, Index issue.

the 5-position, F-5 $\alpha$  pushing the CN group nearer the 3-C<sub>3</sub>F<sub>7</sub> group, which in turn is forced nearer the 2-C<sub>3</sub>F<sub>7</sub> group, causing a greater through-space coupling.

Coupling constants of such a large magnitude are rare, but a few involving F,F-coupling have been reported,<sup>10</sup> and it was shown that through-space interaction of the fluorine nuclei *via* the non-bonding electrons provided the most suitable explanation.

Some asymmetry was observed in the spectrum of both (XV) and its ethoxy-derivative (XVIII), indicating that other conformational isomers may also be present to a small extent. However, no variable temperature measurements have been performed on these compounds and so no definite conclusions can yet be drawn, although the isomerism could involve different conformations of the 5-C<sub>3</sub>F<sub>7</sub> group.

The spectrum of (XV) was difficult to interpret, and complete analysis has not yet been possible. From the measurements that were made, however, it is probable that this compound exists in two forms at 35° in a *ca.* 1:1 ratio, possessing different conformations of the 3-C<sub>3</sub>F<sub>7</sub> group.

**Mass Spectra.**—The mass spectra of all the compounds ‡ show strong parent ions ( $M^+$ ) and strong ions due to  $(M - CF_3)^+$  and  $(M - C_2F_5)^+$ . Compounds (I), (II), (V), and (IV) all have  $(M - C_2F_5)^+$  as the base ion, but the more strained (III) and all the cyanopyridines (XIV)—(XVII) have  $CF_3^+$  as the base ion. Metastable transitions observed in every spectrum except that of (XVII) were:  $M^+ \rightarrow (M - CF_3)^+ + CF_3^+$ ;  $(M - CF_3)^+ \rightarrow (M - C_2F_5)^+ + CF_2^+$ . Additional metastable transitions due to loss of  $CF_2$ ,  $CF_4$ , or  $C_2F_4$  from various ions were also observed in some spectra. The spectrum of (XVII) only showed transitions caused by  $M^+ \rightarrow (M - CF_3)^+ + CF_3^+$  and  $(M - CF_3)^+ \rightarrow (M - C_2F_5)^+ + CF_3^+$ .

**U.v.**—Compared with the other pyridines, the intensities of the higher wavelength bands in the u.v. spectrum of (XVII) are much reduced (Table 4), and the lower wavelength band is greatly increased in intensity and shifted towards the red. This effect was also observed for tetrakis(heptafluoroisopropyl)pyrimidine<sup>1</sup> and may likewise be attributed to distortion of the aromatic ring. The observed red shift and decrease in extinction coefficient in some highly distorted benzenes have been attributed to ring strain and departure from coplanarity.<sup>11</sup> It has been deduced that one such compound, 1,2,4,5-tetra-*t*-butylbenzene, is warped into a boat shape by the strain.<sup>12</sup> Molecular models indicate that a  $CF(CF_3)_2$  group is more bulky than a  $CMe_3$  group, and hence the cyanopyridine (XVII) should be very distorted.

## EXPERIMENTAL

Hexafluoropropene was manipulated in a Pyrex vacuum system. Reactions were carried out in 300 ml Pyrex tubes

<sup>10</sup> K. L. Servis and K.-N. Fang, *J. Amer. Chem. Soc.*, 1968, **90**, 6712.

<sup>11</sup> H. Rapoport and G. Smolinsky, *J. Amer. Chem. Soc.*, 1957, **79**, 5831.

sealed *in vacuo*. Products were separated by distillation (Ernst Haage 100 cm column of the spinning-band type, equivalent to 60 theoretical plates) or g.l.c. [Pye 104 or Griffin and George D6 gas density balance (analytical separation) and Pye 105, Perkin-Elmer F21, or Varian Aerograph A700 (preparative separation)]. Products were identified by elemental analysis, i.r. spectroscopy (Perkin-Elmer 257), u.v. spectroscopy (Hilger and Watts Ultrascan), <sup>19</sup>F n.m.r. spectroscopy [Perkin-Elmer R10 operating at 56.46 and 60 MHz for <sup>19</sup>F and <sup>1</sup>H respectively (both at 35 °C); positive values of chemical shifts are in p.p.m. to high field of external trifluoroacetic acid or external benzene] and mass spectrometry (A.E.I. MS902 operating at 70 eV).

Pentafluoropyridine and tetrafluoropyridine-4-carbonitrile were prepared as previously described.<sup>13</sup> Tetramethylene sulphone and *N*-methyl-2-pyrrolidone were dried by adding benzene, distilling off the benzene-water azeotrope, and distilling *in vacuo*. Acetonitrile was dried over MgSO<sub>4</sub>, distilled, and stored over molecular sieves (Linde type 4A).

B.p.s, analyses, etc. are given in Table 4.

**Reaction of Pentafluoropyridine with Hexafluoropropene.**—(a) 1:3 Ratio in tetramethylene sulphone. Hexafluoropropene (13.5 g, 90 mmol), pentafluoropyridine (5.1 g, 30 mmol), dried caesium fluoride (*ca.* 0.5 g), and tetramethylene sulphone (10 ml), heated for 20 h at 70° with continuous end-over-end rotation, gave hexafluoropropene (0.7 g, 5% recovery) and liquid product which was poured into water (50 ml). The lower layer was separated, further washed with water (50 ml), analysed by g.l.c. (2 m polyethylene glycol adipate; 60°), and distilled to give: (i) hexafluoropropene dimers (5.8 g), b.p. 45–52°, (ii) hexafluoropropene trimers (1.6 g), b.p. 108–115°, (iii) an intermediate fraction (1.8 g), b.p. 116–129°, and (iv) perfluoro-(4-isopropylpyridine) (5.2 g), as a liquid, b.p. 129–130° at 758 mmHg. The pot residue (2.7 g) was shown by g.l.c. to contain three components, one of which corresponded to (iv). The residues from several similar experiments were combined and separated by preparative g.l.c. (8 m silicone elastomer 30; 60°) to give, in increasing order of retention time: (iv) perfluoro-(4-isopropylpyridine), (v) perfluoro-(2,4-di-isopropylpyridine) as a liquid, b.p. 158–159° at 755 mmHg, and (vi) perfluoro-(2,4,5-tri-isopropylpyridine) as a crystalline solid, m.p. 30–31°, b.p. 181–182° at 753 mmHg. The yields of the three products, calculated from g.l.c., are given in Table 1.

(b) 1:9 Ratio in tetramethylene sulphone in two steps. Pentafluoropyridine and hexafluoropropene were caused to react together as in (a) (same quantities), and the gaseous material was transferred to a vacuum system as before. More hexafluoropropene (13.5 g, 90 mmol) was then condensed into the tube and its contents. The tube was resealed, heated at 70° for a further 20 h with constant shaking, then worked up as before to give a lower fluorocarbon layer (29.0 g), distilled to give (i) hexafluoropropene dimers (5.7 g), (ii) hexafluoropropene trimers (9.7 g), (iii) perfluoro-(4-isopropylpyridine) (0.5 g), b.p. 128–129°, (iv) an intermediate fraction (1.2 g), b.p. 129–158°, (v) perfluoro(diisopropylpyridine)s (3.5 g), b.p. 158–162°, (vi) a second

<sup>12</sup> C. Hoogzand and W. Hübel, *Tetrahedron Letters*, 1961, 637; E. M. Arnett and J. M. Bollinger, *ibid.*, 1964, 3803.

<sup>13</sup> R. E. Banks, R. N. Haszeldine, J. V. Latham, and I. M. Young, *J. Chem. Soc.*, 1965, 594; R. E. Banks, R. N. Haszeldine, and I. M. Young, *J. Chem. Soc. (C)*, 1967, 2089.

intermediate fraction (1.2 g), b.p. 162–180°, and (vii) perfluoro(tri-isopropylpyridine)s (2.0 g), b.p. 180–183°. The pot residue (2.9 g) contained almost pure perfluoro(tri-isopropylpyridine)s. G.l.c. analysis of fraction (v) showed it to contain two components, one of which corresponded to perfluoro-(2,4-di-isopropylpyridine). Similarly, g.l.c. analysis of fraction (vii) showed two components to be present, one corresponding to perfluoro-(2,4,5-tri-isopropylpyridine).

The mass spectrum of the crude product showed peaks up to an  $m/e$  value of 769 indicating that some perfluoro-(tetra-isopropylpyridine) had been produced, but this was not isolated.

Fraction (v) (3.4 g) could not be separated by preparative g.l.c., but was redistilled to give (viii) perfluoro(di-isopropylpyridine)s, as a mixture (2.2 g), b.p. 158–162°. The pot residue (1.2 g) contained pure perfluoro-(2,5-di-isopropylpyridine) as a liquid, b.p. 161–162° at 762 mmHg.

TABLE 1

Reaction of hexafluoropropene with pentafluoropyridine <sup>a</sup>

| Ratio of<br>C <sub>3</sub> F <sub>6</sub> to<br>C <sub>5</sub> F <sub>5</sub> N | Solvent   | Overall<br>yield<br>(%) <sup>b</sup> | C <sub>3</sub> F <sub>6</sub><br>recovered<br>(%) | C <sub>3</sub> F <sub>6</sub><br>oligomers<br>(%) <sup>c</sup> | C <sub>5</sub> F <sub>5</sub> N<br>recovered<br>(%) | (I)<br>(%) <sup>b</sup> | (II)<br>(%) <sup>b</sup> | (V)<br>(%) <sup>b</sup> | (III)<br>(%) <sup>b</sup> | (IV)<br>(%) <sup>b</sup> |
|---|---|--------------------------------------|---|--|---|-------------------------|--------------------------|-------------------------|---------------------------|--------------------------|
| 3:1   | [CH <sub>2</sub> ] <sub>4</sub> SO <sub>2</sub>     | 91                                   | 5   | 57   | 0   | 80                      | 8                        | 0                       | 3                         | 0                        |
| 3:1   | O <sub>2</sub> C[CH <sub>2</sub> ] <sub>3</sub> NMe | 73                                   | 1   | 35   | 0   | 26                      | 7                        | 0                       | 35                        | 5                        |
| 3:1<br>twice <sup>d</sup>   | [CH <sub>2</sub> ] <sub>4</sub> SO <sub>2</sub>     | 88                                   | 3   | 57   | 0   | 13                      | 8                        | 25                      | 30                        | 12                       |
| 3:1   | None  | 93                                   | 96  | 0  | 93  | 0                       | 0                        | 0                       | 0                         | 0                        |

<sup>a</sup> All reactions carried out at 70° for 20 h with continuous shaking. <sup>b</sup> Based on pentafluoropyridine loaded. <sup>c</sup> Based on C<sub>3</sub>F<sub>6</sub> loaded. <sup>d</sup> See text for explanation. Yields from analytical g.l.c.

Fraction (vii) and the pot residue were combined and separated by preparative g.l.c. (10 m silicone elastomer 30; 100°) to give, in increasing order of retention time, (ix) perfluoro-(2,4,5-tri-isopropylpyridine) and (x) perfluoro-(2,4,6-tri-isopropylpyridine) as a liquid, b.p. 182–183° at 759 mmHg. Analytical g.l.c. showed this last component to contain 10% of the 2,4,5-isomer as impurity.

Reactions of hexafluoropropene with pentafluoropyridine using *N*-methyl-2-pyrrolidone as solvent were performed under conditions similar to (a) and the results are given in Table 1.

(c) *No solvent*. Reaction (a), repeated in the absence of solvent, gave unchanged hexafluoropropene (13.0 g, 96%) and pentafluoropyridine (4.7 g, 93%).

*Reaction of Perfluoro-(2,4,5-tri-isopropylpyridine) with Caesium Fluoride*.—(a) *At 70°*. Perfluoro-(2,4,5-tri-isopropylpyridine) (1.86 g, 3 mmol), *N*-methyl-2-pyrrolidone (5 ml), and dried caesium fluoride (*ca.* 0.5 g), shaken together at 70° for 102 h, gave 2*H*-perfluoropropane (0.03 g, 7% based on the initial pyridine) and after washing the contents of the tube with water, a fluorocarbon layer (1.05 g) shown by g.l.c. to contain hexafluoropropene dimers (9% yield based on initial pyridine), perfluoro-(2,4-di-isopropylpyridine) (10%), perfluoro-(2,5-di-isopropylpyridine) (16%), perfluoro-(2,4,5-tri-isopropylpyridine) (30%), and perfluoro-(2,4,6-tri-isopropylpyridine) (5%).

(b) *At 170–190°*. Reaction (a), repeated with tetramethylene sulphone at 177°, gave no volatile material; the tube contents were poured into water and the lower layer was separated (1.55 g) and analysed by g.l.c. (8 m silicone elastomer 30; 100°). The products were hexafluoropropene dimers (24% yield based on initial pyridine), hexafluoropropene trimers (27%), perfluoro-(2,4-di-isopropylpyridine) (38%), perfluoro-(2,5-di-isopropylpyridine) (40%), and perfluoro-(2,4,6-tri-isopropylpyridine) (12%).

The results of similar experiments with tetramethylene sulphone at 190° and *N*-methyl-2-pyrrolidone at 186° are given in Table 2.

*Reaction of Perfluoro-(4-isopropylpyridine) with Sodium Methoxide*.—Perfluoro-(4-isopropylpyridine) (1.91 g, 6 mmol) was added to sodium methoxide [sodium (0.28 g, 12 mg atom) in dry methanol (5 ml)]. The mixture was heated under reflux for 2 h, poured into water (50 ml), and extracted with ether (2 × 25 ml). Drying and distillation gave 3,5-difluoro-4-heptafluoroisopropyl-2,6-dimethoxy-pyridine (1.54 g, 74%) as a viscous liquid, b.p. 108–110° at 12 mmHg.

*Reaction of Perfluoro-(2,4-di-isopropylpyridine) with Sodium Methoxide*.—Perfluoro-(2,4-di-isopropylpyridine) (1.88 g, 4 mmol) was added to sodium methoxide [sodium (0.09 g, 4 mg atom) in dry methanol (5 ml)]. The mixture

was heated under reflux for 2 h and poured into water (50 ml), and the lower layer (1.66 g) was shown by quantitative g.l.c. (2 m polyethylene glycol adipate; 80°) to contain three components. Mass spectrometry and n.m.r. spectroscopy of the mixture showed these to be 3,6-difluoro-2,4-bis(heptafluoroisopropyl)-5-methoxypyridine (11% yield based on initial material), 3-fluoro-2,4-bis(heptafluoroisopropyl)-5,6-dimethoxypyridine (39%), and perfluoro-(2,4-di-isopropylpyridine) (36% unchanged).

TABLE 2

Reaction of perfluoro-(2,4,5-tri-isopropylpyridine) (III) with fluoride ion <sup>a</sup>

| Solvent   | Temp.<br>(°C) | C <sub>3</sub> F <sub>6</sub><br>oligomers<br>(%) <sup>b</sup> | (II)<br>(%) <sup>b</sup> | (V)<br>(%) <sup>b</sup> | (III)<br>(%) <sup>b</sup> | (IV)<br>(%) <sup>b</sup> |
|---|---------------|--|--------------------------|-------------------------|---------------------------|--------------------------|
| [CH <sub>2</sub> ] <sub>4</sub> SO <sub>2</sub>     | 177           | 51   | 38                       | 40                      | 0                         | 12                       |
| [CH <sub>2</sub> ] <sub>4</sub> SO <sub>2</sub>     | 190           | 23   | 25                       | 32                      | 7                         | 22                       |
| O <sub>2</sub> C[CH <sub>2</sub> ] <sub>3</sub> NMe | 186           | 16   | 17                       | 26                      | 15                        | 27                       |

<sup>a</sup> All reactions for 20 h with shaking. <sup>b</sup> Based on (III) loaded. Yields from analytical g.l.c.

*Reaction of Tetrafluoropyridine-4-carbonitrile with Hexafluoropropene*.—(a) *1:3 Ratio in acetonitrile*. Tetrafluoropyridine-4-carbonitrile (5.3 g, 30 mmol) in dry acetonitrile (10 ml) containing dried caesium fluoride (*ca.* 0.5 g) and hexafluoropropene (13.5 g, 90 mmol) were heated (20 h at 70°) with continuous end-over-end rotation to give hexafluoropropene (0.2 g) and a liquid. This was distilled to give (i) hexafluoropropene dimers and trimers and acetonitrile (12.5 g), b.p. 45–115°, and (ii) a fluorocarbon mixture (13.4 g), b.p. 116° at 762 mmHg and 140° as 0.01

mmHg, which was shown by g.l.c. (3 m trixylyl phosphate; 80°) to contain five components. These were separated by preparative g.l.c. (7 m trixylyl phosphate; 150°) to give, in increasing order of retention time: (i) 2,3,5,6-tetrakis(heptafluoroisopropyl)pyridine-4-carbonitrile as a crystalline solid, m.p. 57–58°, (ii) 6-fluoro-2,3,5-tris(heptafluoroisopropyl)pyridine-4-carbonitrile as an impure waxy solid of indeterminate m.p., (iii) 5-fluoro-2,3,6-tris(heptafluoroisopropyl)pyridine-4-carbonitrile as a crystalline solid, m.p. 63–64°, (iv) 3,6-difluoro-2,5-bis(heptafluoroisopropyl)pyridine-4-carbonitrile as a liquid, b.p. 193–194° at 764 mmHg, and (v) tetrafluoropyridine-4-carbonitrile. The order of

45–115°, and the residual viscous liquid was washed out with acetone. The solution was cooled in ice, and the resultant crystals filtered off and washed with ice-cold acetone to give tetrakis(heptafluoroisopropyl)pyridine-4-carbonitrile (8.3 g, 71%), m.p. 57–58°.

*Reaction of 6-Fluoro-2,3,5-tris(heptafluoroisopropyl)pyridine-4-carbonitrile with Ethanol.*—6-Fluoro-2,3,5-tris(heptafluoroisopropyl)pyridine-4-carbonitrile from the last experiment [fraction (a) (ii)], warmed with ethanol until dissolution occurred, then cooled in ice, gave 6-ethoxy-2,3,5-tris(heptafluoroisopropyl)pyridine-4-carbonitrile as a crystalline solid, m.p. 74–75°.

TABLE 3  
Reaction of hexafluoropropene with tetrafluoropyridine-4-carbonitrile <sup>a</sup>

| Ratio of<br>C <sub>3</sub> F <sub>6</sub> to nitrile | Solvent | Temp.<br>(°C) | Overall<br>yield<br>(%) <sup>b</sup> | C <sub>3</sub> F <sub>6</sub><br>recovered<br>(%) | C <sub>3</sub> F <sub>6</sub><br>oligomers<br>(%) <sup>c</sup> | Nitrile<br>recovered<br>(%) | (XIV)<br>(%) <sup>b</sup> | (XV)<br>(%) <sup>b</sup> | (XVI)<br>(%) <sup>b</sup> | (XVII)<br>(%) <sup>b</sup> |
|--|---------|---------------|--------------------------------------|---|--|-----------------------------|---------------------------|--------------------------|---------------------------|----------------------------|
| 1 : 1  | MeCN    | 20            | 92                                   | 0   | 0  | 41                          | 49                        | 1                        | 1                         | 0                          |
| 1 : 1  | MeCN    | 70            | 89                                   | 1   | 0  | 40                          | 46                        | 1                        | 1                         | 1                          |
| 3 : 1  | MeCN    | 70            | 86                                   | 2   | 25   | 8                           | 50                        | 9                        | 7                         | 12                         |
| 6 : 1  | MeCN    | 70            | 81                                   | 3   | 43   | 0                           | 36                        | 10                       | 7                         | 28                         |

<sup>a</sup> All reactions shaken for 20 h. <sup>b</sup> Based on nitrile loaded. <sup>c</sup> Based on C<sub>3</sub>F<sub>6</sub> loaded. Yields from analytical g.l.c.

TABLE 4  
B.p.s, analyses, and u.v. data

| Compound | Formula   | B.p. (°C)<br>[mmHg]                            | Found (%) |     |      | Required (%) |     |      | $\lambda_{\max.}/\text{nm}$ (s)          |
|----------|---|--|-----------|-----|------|--------------|-----|------|--|
|          |   |  | C         | N   | F    | C            | N   | F    |  |
| (I)      | C <sub>8</sub> F <sub>11</sub> N                                | 129 [758] <sup>a</sup><br>(14–15) <sup>*</sup> | 30.0      | 4.7 | 65.5 | 30.1         | 4.4 | 65.5 | 280 (3860)                               |
| (II)     | C <sub>11</sub> F <sub>17</sub> N                               | 158 [755] <sup>b</sup>                         | 28.3      | 3.0 | 69.1 | 28.2         | 3.0 | 68.9 | 274 (4650)                               |
| (V)      | C <sub>11</sub> F <sub>17</sub> N                               | 161 [762]                                      | 28.1      | 2.7 | 68.9 | 28.2         | 3.0 | 68.9 | 265 (3990)                               |
| (III)    | C <sub>14</sub> F <sub>23</sub> N                               | 181 [753]<br>(30–31) <sup>*c</sup>             | 27.3      | 2.3 | 70.8 | 27.2         | 2.3 | 70.5 | 286 (6730)                               |
| (IV)     | C <sub>14</sub> F <sub>23</sub> N                               | 182 [759] <sup>d</sup>                         | 27.2      | 2.4 | 70.5 | 27.2         | 2.3 | 70.5 |  |
| (XI)     | C <sub>10</sub> F <sub>9</sub> H <sub>6</sub> NO <sub>2</sub>   | 108 [12]                                       | 35.3      | 4.4 |      | 35.0 †       | 4.1 |      |  |
| (XIV)    | C <sub>12</sub> F <sub>19</sub> N <sub>2</sub>                  | 193 [764]                                      | 30.3      | 5.9 | 64.0 | 30.3         | 5.7 | 63.9 | 218 (6600)<br>288 (6730)<br>295 (6900)   |
| (XVI)    | C <sub>15</sub> F <sub>22</sub> N <sub>2</sub>                  | (63–64) <sup>*</sup>                           | 28.6      | 4.6 | 67.0 | 28.8         | 4.5 | 66.8 | 291 (3520)                               |
| (XVII)   | C <sub>18</sub> F <sub>28</sub> N <sub>2</sub>                  | (57–58) <sup>*</sup>                           | 27.6      | 3.6 | 68.9 | 27.9         | 3.6 | 68.5 | 214 (29,600)<br>264 (1590)<br>299 (1640) |
| (XVIII)  | C <sub>17</sub> H <sub>5</sub> F <sub>21</sub> N <sub>2</sub> O | (74–75) <sup>*</sup>                           | 31.3      | 4.3 | 61.2 | 31.3 ‡       | 4.3 | 61.2 | 216 (26,100)<br>243 (8320)<br>311 (4980) |

<sup>\*</sup> M.p. † Found: H, 2.0; required 1.8. ‡ Found: H, 0.8; required 0.8.

Lit.<sup>6</sup> b.p.s: <sup>a</sup> 128–129 [760]; <sup>b</sup> 158 [763]; <sup>c</sup> 182 [763] (31–31.5); <sup>d</sup> 176–178 [758] (25–25.5).<sup>\*</sup>

elution from the column is the reverse of the order of b.p., as discussed for the related benzonitriles.<sup>6</sup>

Similar reactions performed using 1 : 1 and 1 : 6 ratios of reactants, at 20–70°, are summarised in Table 3.

(b) *Overall 1 : 12 ratio in acetonitrile.* Tetrafluoropyridine-4-carbonitrile (2.6 g, 15 mmol), dry acetonitrile (10 ml), dried caesium fluoride (ca. 0.5 g), and hexafluoropropene (13.5 g, 90 mmol) were heated for 20 h at 70° in a 300 ml tube with constant shaking, then sealed with more hexafluoropropene (13.5 g, 90 mmol) and heated for 20 h at 70°. The liquid contents were distilled to remove hexafluoropropene dimers and trimers and acetonitrile (b.p.

*Reaction of 5-Fluoro-2,3,6-tris(heptafluoroisopropyl)pyridine-4-carbonitrile with Ethanol.* 5-Fluoro-2,3,6-tris(heptafluoroisopropyl)pyridine-4-carbonitrile (0.20 g), warmed with ethanol (5 ml), then cooled in ice and poured into water (20 ml), gave a lower layer (0.16 g), analysis of which by n.m.r. spectroscopy, mass spectrometry, and g.l.c. showed it to be a mixture of the initial pyridine and its ethoxy-derivative ( $M^+$  626 and 652, respectively).

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