Polyhalogenoheterocyclic Compounds. Part 33.[1] Mechanism of Thermal Rearrangements of Perfluoropyridazine and Perfluoroalkylpyridazines

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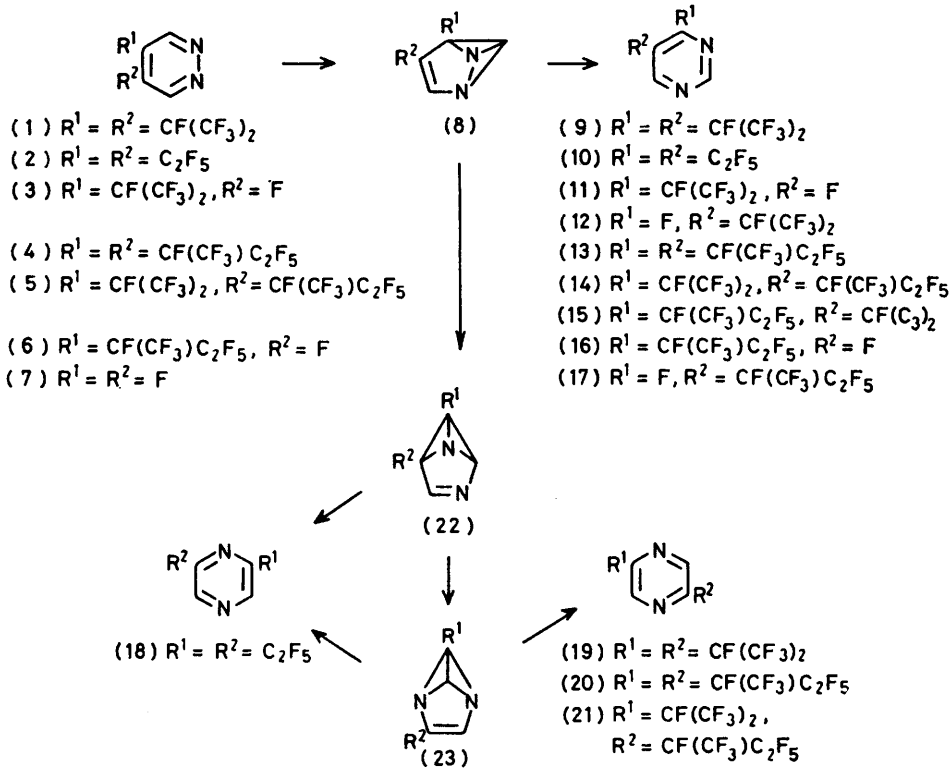
Rearrangement of perfluoro-4,5-di-s-butylpyridazine (4) to a mixture of perfluoro-4,5-di-s-butylpyrimidine (13) and -2,5-di-s-butylpyrazine (20), occurs at 300 °C, in a sealed tube. Cross-over experiments between various fluorinated pyridazine derivatives and, also, doubly ^{15}N-labelled derivatives, rule out any rearrangement mechanism involving a cycloaddition process. Compound (4) and other fluorinated compounds act as promoters for the rearrangement of various fluorinated pyridazine derivatives and this process is now most reasonably regarded as a free-radical promoted formation of valence isomers.

EARLIER in this series we described the fascinating rearrangements of perfluorinated pyridazine derivatives, *e.g.* (1)—(3), to the corresponding pyrimidine derivatives (9)—(12) and, in certain cases, pyrazine derivatives.[2] Highly specific subtituent patterns in the products were observed and a process involving the formation and rearrangement of diazabenzvalenes was advanced (Scheme 1) to account for these products. More recently other workers, whilst reporting unusual metathesis reactions of trichloro-*s*-triazine and related systems,[3] implied that the reactions of perfluoropyridazine derivatives reported by us, could involve cycloaddition processes. Therefore, we attempted cross-over experiments to probe this possibility, and this and subsequent work is described herein.



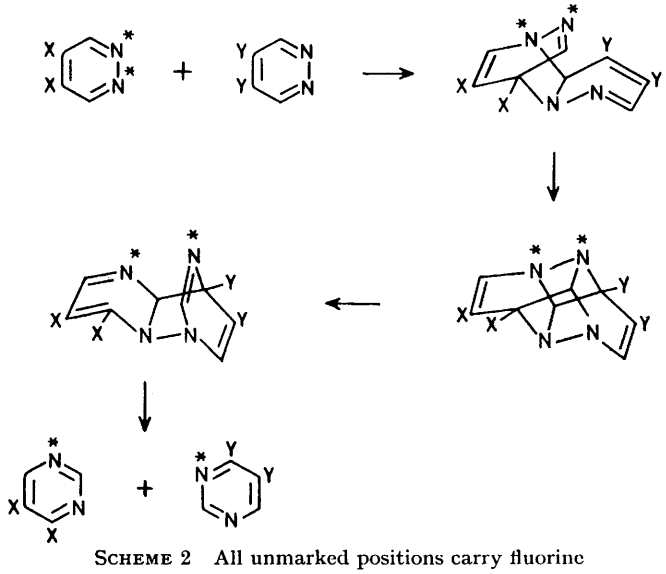
SCHEME 1 All unmarked positions carry fluorine

Earlier experiments were carried out using flow systems in nitrogen, but the perfluorodi-isopropyl derivative (1) rearranged surprisingly readily in a sealed tube at 370 °C.[2] We now find that the perfluorodi-s-butyl derivative (4) rearranges even more readily, *e.g.* 300 °C in a sealed tube. In this case, a mixture of the pyrimidine (13) and the pyrazine (20) was obtained. Compound (4), at the lower temperatures used for rearrangements in sealed tubes, is the first system to give significant amounts of a pyrazine derivative, although the pyrazines (18) and (19) were obtained in flow systems using higher temperatures. Compound (6) gave equal amounts of the pyrimidine derivatives (16) and (17) in a sealed tube reaction, *i.e.* corresponding to earlier results obtained with compound (3) in a flow system.

The perfluoroisopropyl derivatives (1) and (3) and the

perfluoro-s-butyl derivatives (4) and (6) are, therefore, ideal systems for cross-over experiments. Mixtures of (1) and (4) were heated at 350 °C and (3) and (6) at 400 °C and, in each case, no evidence of any products requiring the cross-over of perfluoroalkyl groups was observed. As a further test, we synthesised the mixed derivative (5), containing both a perfluoroisopropyl and a perfluoro-s-butyl group which, on heating, gave an equal mixture of the pyrimidine derivatives (14) and (15), together with a small amount of the pyrazine derivative (21). M.s.–g.l.c. showed no trace of products containing two perfluoroisopropyl or perfluoro-s-butyl groups.

These results clearly eliminate the possibility of cross-over of perfluoroalkyl groups, but there still remains the intriguing possibility of a cycloaddition process, as outlined in Scheme 2, which *exchanges nitrogen atoms*, without exchanging perfluoroalkyl groups. To probe this further possibility, we synthesised a sample of doubly ^{15}N-labelled perfluorodi-isopropylpyridazine from hydrazine [4,5] that was 95.4% labelled in ^{15}N (Scheme 3). The doubly labelled sample of (24) was diluted with unlabelled material for the rest of the process and a sample of (1) containing 50% of the doubly labelled isomer was obtained for the cross-over experiment. This material was heated with an excess of the perfluoro-di-s-butylpyridazine (4) at 300 °C and the product was analysed by m.s.–g.l.c. The pyrimidine derivative (9), contained in the product showed an amost identical proportion of the doubly labelled isomer as the starting material (1), whereas, if the process outlined in Scheme 3 occurred, only the *singly* labelled product would be obtained. As a result of these experiments we can now rule out cross-over products of any type.



SCHEME 2 All unmarked positions carry fluorine

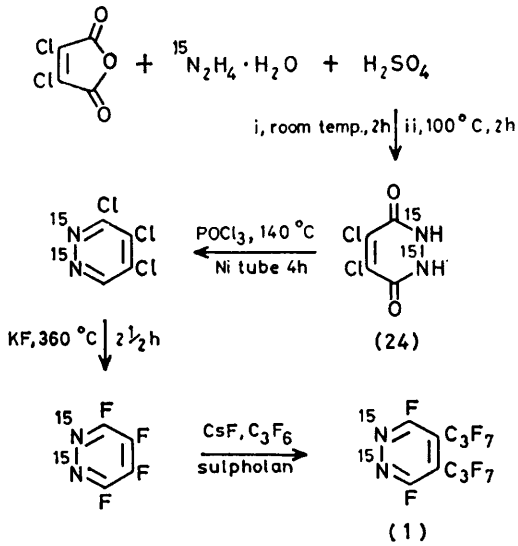
However, in the course of these experiments, we made some disconcerting observations, since it appeared that rearrangement of the perfluorodi-isopropyl derivative (1) occurred more readily at 350 °C in the presence of (4) than when heated alone under these conditions. These suspicions were clearly confirmed by a similar experiment at 300 °C, in which (1) was only 8% rearranged when heated alone. In contrast, an equimolar mixture of (1) and (4) at 300 °C gave a 91% conversion of (1) into the pyrimidine (9). An even clearer example of the role of (4) as a promoter occurred with tetrafluoropyridazine (7) at 300 °C, a temperature at which no significant rearrangement occurs when (7) is heated alone. However, the effect of added (4) (Table 1) is quite dramatic and, in the presence of an excess of (7), there was even more of rearranged (7) than of the perfluorodi s-butyl derivative (4). It appears that (4) promotes the rearrangement of (7) while, conversely, (7) inhibits the rearrangement of (4).

Other compounds were able to promote rearrangement of tetrafluoropyridazine, but less effectively than (4), *e.g.* compound (5) acted as a promoter at 300 °C while the perfluorodi-isopropyl derivative (1) had some effect at 350 °C. Also, rearrangement of the perfluoroisopropyl derivative (3) occurred more readily at 400 °C in the presence of the perfluoro-s-butyl derivative (6). A series of compounds that were effective promoters for the rearrangement of tetrafluoropyridazine (7) is shown in Scheme 4 and compounds that were found to be ineffective are also shown. Compounds (4), (5), (1), and (25) obviously have, in common, a high degree of crowding and the fact that a valence isomer of a crowded fluorocarbon system has been obtained in a thermally induced process [6] encouraged us to think in terms of

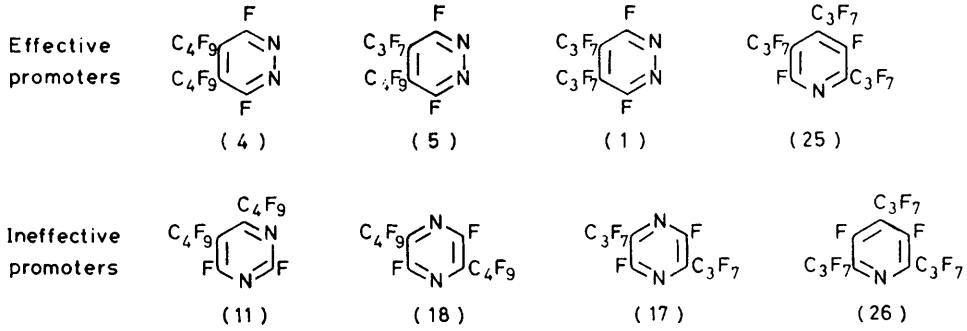
TABLE 1

Heating mixtures of (7) and (4) at 300 °C for 16 h

Molar ratio of reactants (7) : (4)	[Number of mol (7) rearranged]/ [Number of mol (4) rearranged]	[Number of mol (7) rearranged]/ [Number of mol (4) initially present]
1 : 1	0.31	0.26
4 : 1	1.29	1.06
10 : 1	2.73	1.44



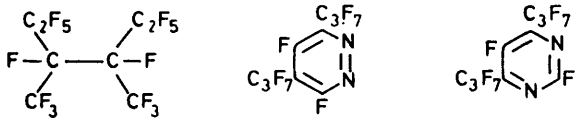
SCHEME 3



SCHEME 4 Promoters for the rearrangement of tetrafluoropyridazine (7)

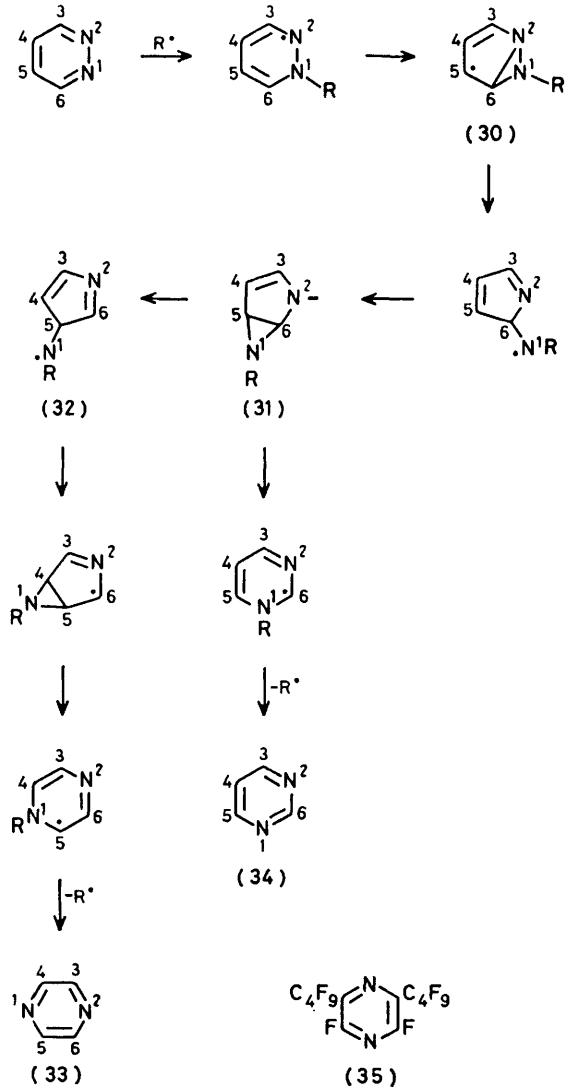
possible thermal sensitisations.[7] It should be remembered that the rearrangements described above are of very high yields. We were eventually able to test the possibility of thermal sensitisation with the use of the highly crowded, but saturated, system (27),[8] which clearly contains one element of the structure of (4). Surprisingly, (27) acted as a very effective promoter for the isomerisation of tetrafluoropyridazine (7) at 300 °C. Further experiments also demonstrated similar promotion of the rearrangement of (1) and (3). Indeed, using (27) we have now promoted the rearrangement of (28) to (29), a process that we have previously attempted unsuccessfully.[2]

Clearly, the possibility of a thermal sensitisation process, that we advanced earlier, could not be extended to include (27) and the only reasonable connection linking the promoters contained in Scheme 4 with (27) must be



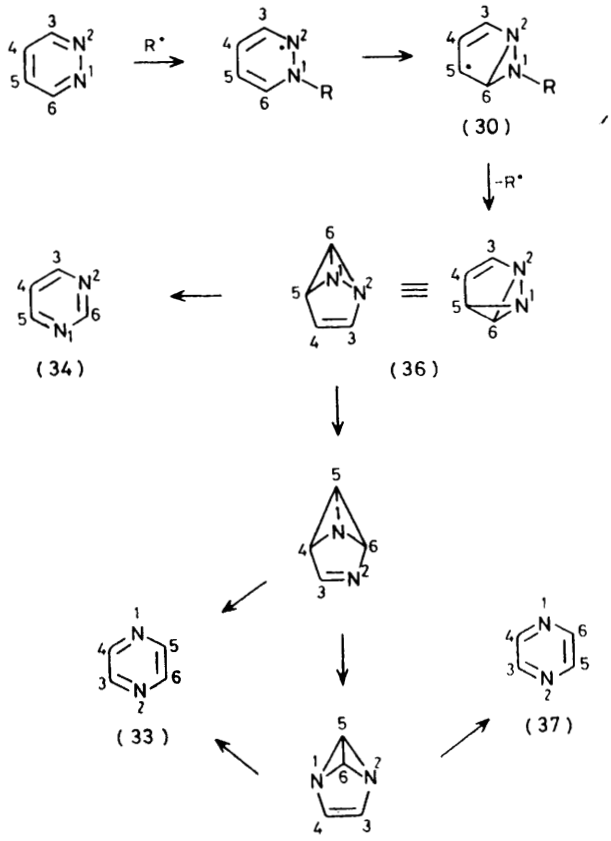
that, being crowded molecules, fission into radicals is possible. Consequently, we need to explain how radicals, in what must be a highly efficient long-chain process, can promote the rearrangements shown in Scheme 1. Whatever mechanism is suggested, it must account for the following: (*a*) pyridazine derivatives containing substituents with larger steric requirements undergo rearrangement more readily and, at the same time, produce more pyrazine derivatives; (*b*) no rearrangement of pyrimidines or pyrazines, either singly or with added promoters, has been observed; and (*c*) highly specific substitution patterns are observed for pyrimidines and equal amounts of two isomers are obtained for the perfluoroalkylpyrimidines [(11) and (12)] and [(16) and (17)].

The fact that rearrangement does not occur with fluorinated pyrimidines or pyrazines suggests that the radical attack occurs at nitrogen in the pyridazine system. There then appears to be two possibilities for further progress, as shown in Schemes 5 and 6. Scheme 5 involves a ' ring-walk ' mechanism, similar to that put forward by Alder and his co-workers [9] to account for the rearrangement of azulene to naphthalene. While (34) is in satisfactory agreement with the substitution pattern in the observed pyrimidine products, we are unable to account for the pattern of the pyrazine products on this basis. Further ring-walk from (31) to (32) would lead to the pyrazine (33), which is in contrast to the substitution patterns for (19)—(21) contained in Scheme 1. We



SCHEME 5

have also eliminated any possibility of further rearrangement of the pyrazines corresponding to (33) giving the observed products, since (35) does not rearrange either



SCHEME 6

with or without added promoter. The evidence, therefore, points to the route illustrated in Scheme 6, as being more likely. In this, the intermediate (30) (common to both Schemes) simply loses the initiator radical to form the valence isomer (36), which corresponds to the diazabenzvalene (8) initially proposed in Scheme 1, *i.e.* we have a radical-catalysed valence-isomerisation. After formation of (36), the route to (34), (33), or (37) is identical with that shown in Scheme 1.

On the basis of the mechanism shown in Scheme 6, a perfluoroalkyl group at the 4- or 5-positions would lead to a mixture of pyrimidines, with a perfluoroalkyl group at either of the 4- or 5-positions since, clearly, the radical attack could occur at N-1 or N-2. However, it appears that, for (28), where there is a perfluoroalkyl group at the 3-position, attack occurs entirely at N-1 so that the perfluoroalkyl substituents in the product (29) correspond to the 3- and 5-positions in (34) (Scheme 6).

We have repeated the flow pyrolyses in a stream of nitrogen, carried out earlier, and have now demonstrated that, even under these conditions, rearrangement of tetrafluoropyridazine (7) may be promoted by the presence of (1) and (27). At 600 °C there was no conversion of (7) alone, but conversions of 30% with (1) at 600 °C and 14% with (27) at 550 °C were obtained.

EXPERIMENTAL

^{19}F N.m.r. spectra were recorded using a Varian A56/60D or a Brüker HX90E spectrometer with $CFCl_3$ as external standard; upfield shifts are quoted as positive; all values are in p.p.m. Mass spectra were recorded using an A.E.I. MS9 spectrometer or a VG Micromass 12B spectrometer linked with a gas chromatograph. I.r. spectra were recorded using a Perkin-Elmer 577 and, where indicated by an asterisk, are available in Supplementary Publication No. SUP 22992 (3 pp.).* U.v. spectra were recorded on a Unicam SP8000 or Beckmann 25 spectrophotometer. G.l.c. was carried out using a Varian Aerograph 920 instrument fitted with a gas density balance detector.

Caesium fluoride and potassium fluoride were dried by heating under reduced pressure with frequent agitation and periodic grinding in a glove bag, followed by storage under dry nitrogen. Sulpholan was redistilled under reduced pressure and stored over a molecular sieve. Apparatus used for the polyfluoroalkylation reactions was as described previously.[10]

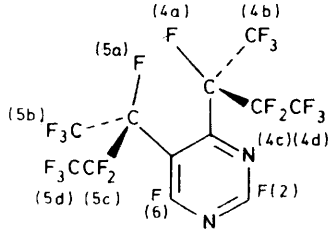
Static pyrolyses were performed in sealed nickel tubes (*ca.* 90 ml capacity) flushed with dry nitrogen. Unless otherwise stated, the tube was placed in a pre-heated furnace for 16 h and, after cooling, it was opened and the contents removed by transference under reduced pressure into a trap cooled in liquid air.

Perfluoro-4-isopropyl-5-s-butylpyridazine * (5).—A mixture of perfluoro-4-s-butylpyridazine (6) [11] (9.34 g, 26.5 mmol) caesium fluoride (3.3 g, 21.7 mmol), and sulpholan (10 ml) was stirred at room temperature under an atmosphere of hexafluoropropene (5.7 g, 37.9 mmol) for 2 h. The product (13.84 g) was removed by distillation under reduced pressure and shown by g.l.c. (trixylenyl phosphate, 100 °C) to contain one major component (93%), which was purified by preparative g.l.c. and identified as *perfluoro-4-isopropyl-5-s-butylpyridazine* * (5), b.p. 177—178 °C (Found: C, 26.1; F, 67.8; N, 6.0%; M^+, 502. $C_{11}F_{18}N_2$ requires C, 26.3; F, 68.1; N, 5.6%; *M*, 502); δ_F 69.9 (m, 3-F and 6-F), 73.1 and 73.8 (br overlapping, 4b-F_6 and 5b-F_3), 82.0 (m, 5d-F_3), 115.2 (br, m, 5c-F_2), and 167.9 and 172.5 [AB, *J ca.* 225 Hz due to ' through-space ' coupling [12] between 4a-F and 5a-F. This coupling has not previously been observed in the perfluoro-4,5-dialkylpyridazine derivatives (1) and (4) because of the equivalence of the tertiary fluorine atoms]; $\lambda_{max.}$ (cyclohexane) 279 (ε 4 700) and 340 nm (ε 370).

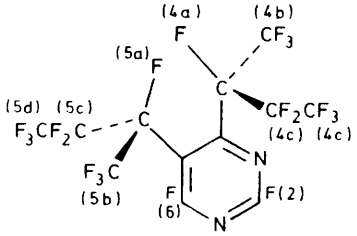
Static Pyrolysis of Single Compounds.—(a) *Perfluoro-4,5-di-s-butylpyridazine* (4). This reaction was performed at various temperatures and the optimum was found to be 300 °C. Heating compound (4) [11] (1.12 g) for 16 h at 300 °C gave a yellow liquid (0.94 g) shown by m.s.–g.l.c. (trixylenyl phosphate, 90 °C) to contain two isomeric major components (M^+, 552) (8% and 85% of mixture). These were separated by preparative-scale g.l.c. The smaller component was shown by comparison with ^{19}F n.m.r. spectra, to be mainly perfluoro-2,5-di-s-butylpyrazine (10).[13] The major component was identified as *perfluoro-4,5-di-s-butylpyrimidine* * (13), b.p. 174 °C (Found: C, 26.1; F, 68.3; N, 5.5%; M^+, 552. $C_{12}F_{20}N_2$ requires C, 26.1; F, 68.8; N, 5.1%; *M*, 552), δ_F 36.8 (m, 6-F), 40.1 (s, 2-F), 71.6 (s, 4b-F_3), 73.9 and 75.3 (br, 5b-F_3), 81.8 (br, 4d-F_3 and 5d-F_3), 116.9 (br m, 4c-F_2 and 5c-F_2), and 175.4 (br, 4a-F and 5a-F); $\lambda_{max.}$ (cyclohexane) 250 nm (ε 4 000). The presence

* For details of Supplementary Publications see Notes to Authors in *J. Chem. Soc., Perkin Trans. 1*, 1980, Index issue.

of two ^{19}F n.m.r. signals for the 5b-CF_3 group in (13), each integrating as 1.5 F atoms, can be explained by the existence of the two diastereoisomers (13a) and (13b). By analogy with the perfluorodi-isopropyl derivative (9) [2] the most favourable conformations for (13a) and (13b) should be those shown in the Figure, with the CF_3 and C_2F_5 groups in the 4-substituent flanking the ring nitrogen. Unlike (9), this cannot be confirmed by a large 'through-space' coupling between the tertiary fluorine atoms 4a and 5a, as they are accidentally equivalent, but the complex splitting of 6-F supports this view On heating (13), increased rotation of the perfluoroalkyl groups appears to diminish the difference in the environment of the 5b-CF_3 group in (13a) and (13b), as at 140 °C the two signals merge to give a broad signal at δ 74.3. Heating (4) (1.55 g) at 350 °C gave a mixture (1.17 g) containing (20) (14%), (13) (80%), and numerous minor components. Compounds (20) and (13)



(13a)

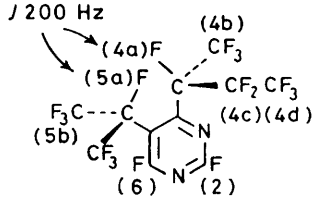


(13b)

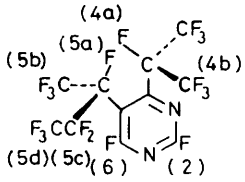
FIGURE

were both unchanged when heated at 300 °C for 16 h. The following experiments were carried out and the products identified in a manner similar to that described above.

(b) *Perfluoro-4-isopropyl-5-s-butylpyridazine* (5). Compound (5) (1.12 g), at 300 °C for 16 h, gave a yellow liquid (0.93 g) containing four isomeric components with M^+ 502 [3, 44, 43, and 4% respectively, the latter being identified as (5)], and a large number of minor components. The first isomeric product had g.l.c. retention time and m.s. identical with that of perfluoro-2-isopropyl-5-s-butylpyrazine (21), obtained by photolysis of (5) (see below). The two major products were purified by preparative-scale g.l.c. and identified as *perfluoro-5-isopropyl-4-s-butylpyrimidine* * (15), b.p. 163 °C (Found: C, 26.4; F, 68.1; N, 5.4%; M^+, 502. $C_{11}F_{18}N_2$ requires C, 26.3; F, 68.1; N, 5.6%; *M*, 502), δ_F 35.8 (sept, *J* 30 Hz, 6-F), 37.3 (s, 2-F), 69.0 (s, 4b-F_3), 72.3 (d, *J* 30 Hz, 5b'-F_3), 73.7 (br, 5b''-F_3), 78.8 (s, 4d-F_3), 112.2 and 116.5 (AB, *J* 295 Hz, geminal coupling in 4c-F_2), 168.6 and 174.3 (AB, *J* 202 Hz, 'through-space' coupling between 4a-F and 5a-F), $\lambda_{max.}$ (cyclohexane) 250 nm (ε 3 900) and *perfluoro-4-isopropyl-5-s-butylpyrimidine* * (14), b.p. 163 °C (Found: C, 26.0; F, 68.0; N, 5.9%; M^+, 502), δ_F 34.3 (sext, *J* 34 Hz, 6-F), 37.0 (s, 2-F), 71.1 (s, 4b-F_6), 72.1 (br d, *J* 30 Hz, 5b-F_3), 79.4 (br s, 5d-F_3), 113.2 (d, *J* 38 Hz of m) and 116.3 (d, *J* 42 Hz of q, *J* 14 Hz of m) comprising an AB system due to a geminal coupling of 300 Hz



(15)



(14)

in 5c-F_2, and 172.7 (br s, 4a-F and 5a-F); $\lambda_{max.}$ (cyclohexane) 250 nm (ε 3 700). Structures (15) and (14) were assigned on the assumption that the most favourable conformations are those shown, based on the fact that perfluoroalkyl groups flanking the ring nitrogen give sharp signals, uncoupled to other parts of the molecule.[2,14] Thus, in (15) 4b-F_3 and 4d-F_3 give sharp singlets and 4c-F_2 shows only geminal coupling, whereas the two 5b-CF_3 groups are non-equivalent and also couple with 6-F, splitting it into a septet. In contrast, in (14) the 4b-CF_3 groups give a sharp singlet while 5b-F_3 and 5c-F_2 couple with 6-F, splitting it into a sextet. In (15) a large 'through-space' coupling [2] of 200 Hz is observed between the adjacent tertiary F atoms 4a-F and 5a-F and is only consistent with the assigned conformation, but in (14) 4a-F and 5a-F are accidentally equivalent [*cf.* (13)].

(c) *Perfluoro-4,5-di-isopropylpyridazine* (1). Compound (1) (1.35 g), at 350 °C for 16 h, gave a liquid (1.19 g) containing mainly perfluoro-4,5-di-isopropylpyrimidine (9) [2] (49%) and (1) (46%) with several minor defluorinated impurities. A pure sample of (9) was obtained by preparative-scale g.l.c. to confirm its identity. At 300 °C (1) (1.25 g) gave a solid product (1.13 g) containing only (9) (8%) and (1).

(d) *Perfluoro-4-s-butylpyridazine* (6). Compound (6) (1.30 g) at 400 °C for 16 h, gave a liquid (0.94 g) containing two components, with M^+ 314 and 352 respectively, in the ratio 6 : 94. The major component was purified by preparative-scale g.l.c. and shown by ^{19}F n.m.r. to be a *ca.* 1 : 1 mixture of perfluoro-4-s-butylpyrimidine (16),[11] δ 46.2 (d, 2-F), 70.6 (d, 6-F), 74.1 (s, 4b-F_3), 82.2 (br m, 4d-F_3), 121.6 (br m, 4c-F_2), 153.0 (br, 5-F), and 187.7 (d, 4a-F) and perfluoro-5-s-butylpyrimidine (17), δ 38.4 (s, 2-F), 43.7 and 45.4 (br, 4-F and 6-F), 75.3 (s, 5b-F_3), 82.2 (br m, 5d-F_3), 121.6 (br m, 5c-F_2), and 182.7 (d, 5a-F). Heating (6) (1.44 g) at 350 °C for 16 h gave a liquid (1.11 g) containing only 32% of the mixture of pyrimidine derivatives (16) and (17) and 68% (6).

(e) *Perfluoro-4-isopropylpyridazine* (3). Compound (3) (1.34 g), at 400 °C for 16 h, gave a liquid (1.08 g) containing mainly (3) (83%) with 16% of an isomeric component (M^+ 302). The latter was purified by preparative-scale g.l.c. and shown by ^{19}F n.m.r. to be a *ca.* 3.4 mixture of perfluoro-4-isopropylpyrimidine (11) [2] and perfluoro-5-isopropylpyrimidine (12).[2]

Static Pyrolysis of Mixtures.—(a) *Perfluoro-4,5-di-s-butylpyridazine* (4) *and perfluoro-4,5-di-isopropylpyridazine* (1). Compounds (4) (1.51 g, 2.73 mmol) and (1) (1.20 g, 2.65 mmol) were heated together for 16 h at 350 °C and the liquid product (2.42 g) investigated by g.l.c.–m.s. (trixylenyl

phosphate, 80 °C; and silicone gum-rubber, 100 °C). This showed the major components to be perfluoro-2,5-di-s-butylpyrazine (20) (7.5% by wt.), perfluoro-4,5-di-isopropylpyrimidine (9) (46%), and perfluoro-4,5-di-s-butylpyrimidine (13) (40%). No cross-over products with M^+ 502 were observed. When (4) (1.25 g, 2.26 mmol) and (1) (1.03 g, 2.28 mmol) were heated at 300 °C the product (1.94 g) contained mainly (18) (2.5% by wt.), (7) (44%), (11) (45%), (1) (4%), and (4) (2%). The following experiments were carried out and the products identified in a manner similar to that described above.

(b) *Perfluoro-4-s-butylpyridazine* (6) *and perfluoro-4-isopropylpyridazine* (3). Compounds (6) (0.38 g, 1.08 mmol) and (3) (1.26 g, 4.17 mmol), at 400 °C for 16 h, gave a liquid (1.08 g) containing the perfluoro-isopropylpyrimidines (11) and (12) (24% by wt.), the perfluoro-s-butylpyrimidines (16) and (17) (10.5%), (3) (46%), and (6) (19.5%).

(c) *Perfluoro-4,5-di-s-butylpyridazine* (4) *and tetrafluoropyridazine* (7). Compounds (4) (1.96 g, 3.55 mmol) and (7) (0.53 g, 3.49 mmol), at 300 °C for 16 h, gave a liquid (2.09 g) containing mainly perfluoro-2,5-di-s-butylpyrazine (20) (6.5% by wt.), perfluoro-4,5-di-s-butylpyrimidine (13) (70%), (4) (1.5%), tetrafluoropyrimidine [15] (6.5%), and (7) (13.5%).

When (4) (1.19 g, 2.16 mmol) and (7) (1.32 g, 8.68 mmol) were used, the product (2.20 g) containing the same components in percentages of 4, 40, 2, 15, and 38 respectively. Using 0.67 g (1.21 mmol) of (4) and 1.86 g (12.24 mmol) of (7) the product (1.69 g) contained the same components in percentages of 2, 19.5, 3, 16, and 59 respectively.

Compounds (4) (1.15 g, 2.08 mmol) and (7) (0.31 g, 2.04 mmol) were also sealed at atmospheric pressure in a Pyrex tube and heated at 300 °C for 16 h. The product (1.17 g) contained the above components in percentages of 5, 69, 6, 4, and 8 respectively.

The product mixtures from the above experiments were separated by preparative-scale g.l.c. and the identity of the tetrafluoropyrimidine confirmed by comparison of the spectra with those of an authentic sample.

(d) *Perfluoro-4,5-di-isopropylpyridazine* (1) *and tetrafluoropyridazine* (7). Compounds (1) (2.31 g, 5.11 mmol) and (7) (0.86 g, 5.65 mmol), at 350 °C for 16 h, gave a liquid (2.94 g) containing perfluoro-4,5-di-isopropylpyrimidine (7) (41% by wt.), (1) (37%), tetrafluoropyrimidine (2%), and (7) (20%).

(e) *Perfluoro-4-isopropyl-5-s-butylpyridazine* (5) *and tetrafluoropyridazine* (7). Compounds (5) (0.69 g, 1.37 mmol) and (7) (1.44 g, 9.47 mmol), at 300 °C for 16 h, gave a liquid (2.04 g) containing perfluoro-2-isopropyl-5-s-butylpyrazine (21) (1% by wt.), the pyrimidine derivatives (15) and (14) (25%), (5) (8%), tetrafluoropyrimidine (12%), and (7) (54%).

(f) *Perfluoro-2,4,5-tri-isopropylpyridine* (25) *and tetrafluoropyridazine* (7). Compounds (25) [16] (2.04 g, 3.29 mmol) and (7) (1.06 g, 6.97 mmol), at 300 °C for 16 h, gave a liquid (2.92 g) containing tetrafluoropyrimidine (7% by wt.), (7) (23%), and (25) (70%).

(g) *Perfluoro-3,4-dimethylhexane* (27) *and tetrafluoropyridazine* (7). Compounds (27) [8] (1.19 g, 2.72 mmol) and (7) (1.14 g, 7.50 mmol), at 300 °C for 16 h, gave a liquid (2.17 g) containing a volatile component (4.5% by wt., highest mass 201, probably M^+ − F from C_4F_9H), (27) (51%), tetrafluoropyrimidine (13%), and (7) (31%). When tetrafluoropyridazine (7) was heated at 300 °C with perfluoro-4,5-di-s-butylpyrimidine (13), perfluoro-2,5-di-s-butylpyrazine (20), perfluoro-2,5-di-isopropylpyrazine (19), perfluoro-2,4,6-tri-isopropylpyridine (26), and perfluoro-1-methyldecalin, no rearrangement was observed.

(h) *Perfluoro-2,4,5-tri-isopropylpyridine* (25) *and perfluoro-4,5-di-isopropylpyridazine* (1). Compounds (25) (1.15 g, 1.86 mmol) and (1) (0.83 g, 1.84 mmol), at 300 °C for 16 h, gave a liquid (1.82 g) containing mainly (25) (62% by wt.) and perfluoro-4,5-di-isopropylpyrimidine (9) (36%).

(i) *Perfluoro-3,4-dimethylhexane* (27) *and perfluoro-4,5-di-isopropylpyridazine* (1). Compounds (27) (0.70 g, 1.60 mmol) and (1) (1.30 g, 2.88 mmol), at 300 °C for 16 h, gave a liquid (1.60 g) containing the volatile component observed previously and tentatively identified as C_4F_9H (8% by wt.), (27) (27%), perfluoro-4,5-di-isopropylpyrimidine (9) (40%), and (1) (25%).

(j) *Perfluoro-4-isopropylpyridazine* (3) *and perfluoro-3,4-dimethylhexane* (27). Compounds (27) (2.17 g, 4.95 mmol) and (3) (2.35 g, 7.79 mmol), at 300 °C for 42 h, gave a liquid (4.06 g) containing the volatile component observed previously (7% by wt.), (27) (44%), a mixture of the perfluoro-isopropylpyrimidines (44%) and (3), (5%). The pyrimidines were separated from the others by preparative-scale g.l.c. and shown by ^{19}F n.m.r. to be a 1 : 1 mixture of compounds (11) and (12).

(k) *Perfluoro-3,5-di-isopropylpyridazine* (28) *and perfluoro-3,4-dimethylhexane* (27). Compounds (27) (1.74 g, 3.97 mmol) and (28) [5] (1.44 g, 3.19 mmol), at 300 °C for 16 h, gave a liquid (2.97 g) containing (27), an isomer of (28) (M^+ 452), and (28) itself, in the ratio 37 : 63, and several minor components. The isomeric product was obtained pure by preparative-scale g.l.c. and identified as perfluoro-4,6-di-isopropylpyrimidine (29).[17]

When (27) was heated with perfluoro-4,5-di-s-butylpyrimidine (11) at 300 or 350 °C, and perfluoro-2,6-di-s-butylpyrazine (35) at 300 °C, no rearrangement was observed.

Synthesis of ^{15}N*-Labelled Perfluoro-4,5-di-isopropylpyridazine* (1).—An aqueous solution of hydrazine (95.4%) labelled with ^{15}N (obtained from Prochem Ltd.) (0.23 g, 6.76 mmol) was diluted to 15 ml (volume) and acidified with concentrated H_2SO_4. Dichloromaleic anhydride (1.20 g, 7.19 mmol) was added and the mixture stirred for 2 h at room temperature and 2 h at 100 °C, allowed to cool overnight, and the solid product removed by filtration washed with a little cold water, and identified as 4,5-dichlorodihydroxypyridazine (24) (1.01 g, 82% yield) (tautomeric mixture). The labelled (24) was mixed with an unlabelled sample (0.99 g), sealed in a dry nickel tube with freshly distilled phosphoryl chloride (20 ml), and heated at 140 °C for 4 h. After cooling, the tube contents were poured out and excess of phosphoryl chloride was removed under reduced pressure. The tube was washed out with cold sodium hydrogencarbonate solution, which was then added to the residue from above. The tube and aqueous phase were extracted thoroughly with dichloromethane, which was then washed, dried, and the solvent removed under reduced pressure to leave an off-white solid (2.31 g). Sublimation under reduced pressure (0.05 mm, 80 °C) gave tetrachloropyridazine (2.01 g, 84%). This was converted first into tetrafluoropyridazine (7) and then into perfluoro-4,5-di-isopropylpyridazine (1) by published methods.[4,5]

Cross-over Experiment.—A sample of ^{15}N-labelled (1) (0.1 g) from above was added to perfluoro-4,5-di-s-butylpyridazine (4) (0.54 g) and the mixture analysed by g.l.c.–m.s. The peak due to (1) showed M^+ at 452 (unlabelled) and 454 (doubly ^{15}N-labelled) of about equal intensity, with no significant M^+ at 453 (singly labelled). A sample of this

mixture (0.58 g) was then rearranged by heating at 300 °C for 16 h and the product (0.31 g) examined by g.l.c.–m.s. (di-isodecyl phthalate, 90 °C). The perfluoro-4,5-di-isopropylpyrimidine (9) in the mixture also showed M^+ at 452 and 454 of *ca.* equal intensity, with no significant M^+ at 453. No labelling was detectable in the perfluoro-4,5-di-s-butylpyrimidine (13).

Flow Pyrolyses.—(a) *Perfluoro-4,5-di-isopropylpyridazine* (1). Compound (1) (2.53 g) was passed as a vapour in a stream of dry nitrogen through a silica tube loosely packed with silica wool at 600 °C (contrast time *ca.* 30 s). The brown liquid pyrolysate (2.16 g) was shown by g.l.c.–m.s. (trixylenyl phosphate, 90 °C) to contain perfluoro-2,5-di-isopropylpyrazine (19) (8%), perfluoro-4,5-di-isopropylpyrimidine (9) (52%), recovered (1) (8%), and numerous fragmentation products. An experiment with tetrafluoropyridazine (7) under identical conditions resulted in a 95% recovery of (7).

(b) *Perfluoro-4,5-di-isopropylpyridazine* (1) *and tetrafluoropyridazine* (7). Compounds (1) (2.10 g, 4.65 mmol) and (7) (1.00 g, 6.58 mmol) were passed simultaneously as a vapour in a stream of dry nitrogen through a silica tube loosely packed with silica wool, at 600 °C (contact time *ca.* 30 s). The pyrolysate (2.95 g) was shown by g.l.c.–m.s. (trixylenyl phosphate) to contain (19) (3.5%), (9) (22.3%), (1) (14.5%), tetrafluoropyrimidine (12.2%), (7) (28.1%), and numerous minor fragmentation products.

(c) *Perfluoro-3,4-dimethylhexane* (27) *and tetrafluoropyridazine* (7). Compounds (27) (6.05 g, 13.8 mmol) and (7) (1.61 g, 10.6 mmol) were passed simultaneously as a vapour in a stream of dry nitrogen through a silica tube, loosely packed with silica wool, at 550 °C. The pyrolysate (3.77 g) separated, on standing, into two layers. The lower layer (2.33 g) was shown by g.l.c. to contain mainly a large number of very volatile fragmentation products. The upper layer was shown by g.l.c.–m.s. (silicone gum-rubber, 80 °C) to contain volatiles (10%), tetrafluoropyrimidine (14%), and (7) (76%).

Photolysis of Perfluoro-4-isopropyl-5-s-butylpyridazine (5).—This reaction is analogous to others carried out previously in this laboratory.[13] Compound (5) (2.38 g) was sealed in a silica tube (36 × 3.9 cm) under high vacuum and irradiated for between 100 and 170 h in a Hanovia Reading reactor, employing two Hanovia U.V.S. 500 medium pressure mercury lamps. The liquid product (2.11 g) was removed by vacuum transfer into a trap cooled in liquid air and shown by g.l.c. (di-isodecyl phthalate, 90 °C) to contain three components in the ratio 59 : 7 : 34, the latter being identified as (5). The mixture was separated by preparative scale g.l.c. and the two products identified (in order of retention time) as *perfluoro-2-isopropyl-5-s-butylpyrazine* * (10), b.p. 155 °C (Found: C, 26.6; N, 5.6; F, 68.2%; M^+, 502. $C_{11}F_{18}N_2$ requires C, 26.3; N, 5.6; F, 68.1%; *M*, 502), δ_F 74.2 (br s, 5b-F_3), 76.0 (br, 3- or 6-F), 76.4 (m, 2b-F_6), 76.8 (br, 3- or 6-F), 82.3 (m, 5d-F_3), 121.4 (br m, 5c-F_2), and 187.0 (br, 2a-F and 5a-F); $\lambda_{max.}$ (cyclohexane) 280 nm (ε 8 600) and *perfluoro-2-isopropyl-6-s-butylpyrazine*, * b.p. 158 °C (Found: C, 26.0; N, 5.9; F, 67.7%; M^+, 502), δ 65.1 and 65.9 (overlapping pair of d *J ca.* 60 Hz, 3-F and 5-F), 73.9 (s, 6b-F_3), 76.1 (s, 2b-F_6), 81.6 (s, 6d-F_3), 120.1 and 122.3 (AB, *J* 296 Hz, geminal coupling in 6c-F_2), and 186.3 and 187.3 (overlapping pair of d, *J ca.* 60 Hz, 2a-F and 6a-F); $\lambda_{max.}$ (cyclohexane) 273 nm (ε 6 600).

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