Reaction of perfluoro-2-methylpent-2-ene with ethylenediamine and hexamethylenediamine

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Reaction of perfluoro-2-methylpent-2-ene with ethylenediamine and hexamethylenediamine results in 9-fluoro-5,9-bis(pentafluoroethyl)-6,8,8-tris(trifluoromethyl)-1,4-diazabicyclo[5.2.0]nona-4,6-diene, whose structure was confirmed by X-ray analysis, and 11-pentafluoroethyl-10-trifluoromethyl-1,8-diazabicyclo[7.2.0]undeca-8,10-diene, respectively. The reaction pathways are discussed.

Key words: nucleophilic substitution and addition, cyclization, perfluoro-2-methylpent-2-ene, ethylenediamine, hexamethylenediamine.

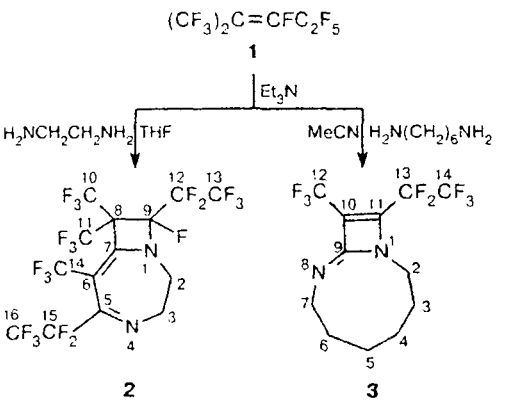
The introduction of perfluoroalkyl groups into heterocyclic compounds substantially increases in some cases the biological activity of these systems, which provides the basis for the development of new-generation materials for agriculture and medicine.[1–3] These intermediates are prepared either by direct introduction of a perfluoroalkyl group into a heterocyclic ring or by constructing a heterocyclic system, for example, by condensation of 1,2- or 1,3-dicarbonyl compounds containing perfluoroalkyl groups with diamines.[4] In recent years, an approach based on reactions of internal perfluoroolefins with binucleophilic reagents has been developed.[4] Variation of the perfluoroalkyl groups at the multiple bond permits the synthesis of heterocyclic compounds with various perfluoroalkyl groups and the use of various binucleophilic reagents provides the possibility of preparing various heterocycles.[5–8]

In the present work, we studied the reactions of perfluoro-2-methylpent-2-ene (**1**) with ethylenediamine and hexamethylenediamine.

Results and Discussion

According to published data, the reaction of compound **1** with ethylenediamine could be expected to result in 7-fluoro-5-pentafluoroethyl-6-trifluoromethyl-2,3-dihydro-1*H*-1,4-diazepine[8] or an azetine derivative.[9] However, we found that this reaction in the presence of Et_3N affords 9-fluoro-5,9-bis(pentafluoroethyl)-6,8,8-tris(trifluoromethyl)-1,4-diazabicyclo[5.2.0]nona-4,6-diene (**2**). When compound **1** reacted with hexamethylenediamine, 11-(pentafluoroethyl)-10-trifluoromethyl-1,8-diazabicyclo[7.2.0]undeca-8,10-diene (**3**) (Scheme 1) was obtained.

Scheme 1



To determine exactly the structure of compound **2**, we performed X-ray diffraction analysis (Fig. 1, Table 1). X-ray diffraction data show that the conformation of the molecules of **2** is close to that typical of nonconjugated dienes; the N(4)=C(5)—C(6)=C(7) torsion angle is 37.3(5)°. However, the C(5)—C(6) bond length, 1.481(4) Å, corresponds to the standard length of the single bond in the C=C—C=C fragment (1.478(12) Å)[10]. The heptadiene ring has a boat shape. The C(8)—C(9) bond in the planar (±0.006 Å) azetidine ring is lengthened to 1.589(4) Å, apparently, for steric reasons. The length of a similar tetrasubstituted bond in an identical azetidine ring was found[11] to be 1.609(2) Å. It should be noted that the N(1)—C(9) bond, whose length is 1.410(4) Å, is shorter than the shortest[12] (1.468(2) Å) of these bonds in compounds with a 2-methylideneazetidine fragment listed in the Cambridge Data Bank.[13]

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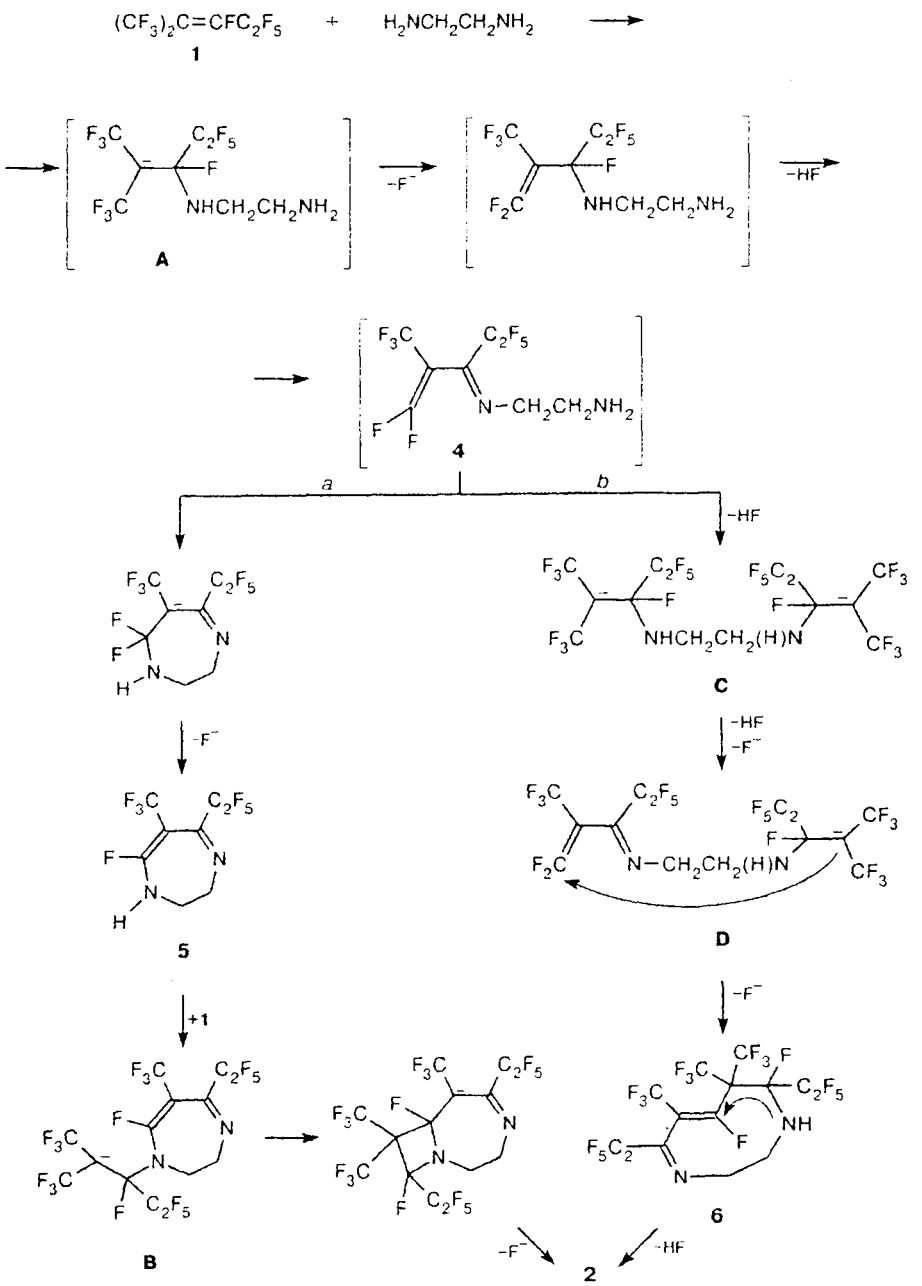
It can be suggested that compound **2** is formed according to Scheme 2. Apparently, ethylenediamine attacks initially the C atom of the double bond to give anion **A**. Elimination of the F^- anion from the CF_3 group and elimination of hydrogen fluoride affords *N*-(2-(trifluoromethyl)perfluoropent-1-en-3-ylidene)ethylene-1,2-diamine (**4**). Subsequent transformations of this compound can follow different pathways. For instance, one pathway (*a*) includes intramolecular nucleophilic cyclization, resulting in 7-fluoro-5-pentafluoroethyl-6-trifluoromethyl-2,3-dihydro-1*H*-1,4-diazepine (**5**). This product can act under the reaction conditions as an N-nucleophile; it reacts with a second molecule of olefin **1** to give anion **B**. Intramolecular cyclization of the anion gives compound **2**.

An alternative pathway (*b*) could be the reaction of compound **4** with perfluoroolefin **1** or independent reaction of two amino groups of ethylenediamine with perfluoroolefin **1**, resulting in anions **C** and **D**. Intramolec-

Scheme 2



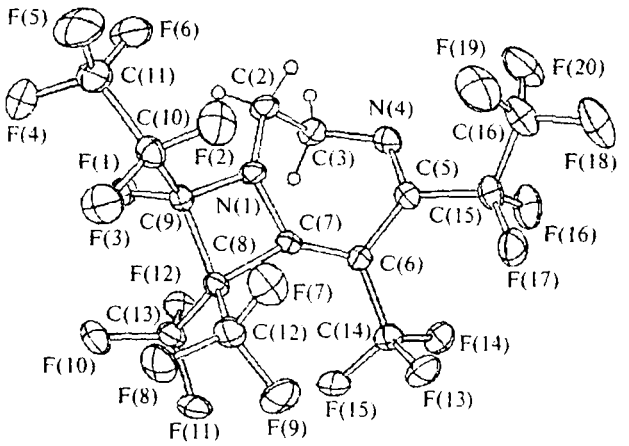


Fig. 1. Crystal structure of compound **2** according to X-ray diffraction data.

Table 1. Coordinates ($\times 10^4$) and equivalent isotropic thermal parameters (U_{eq}) of nonhydrogen atoms in compound **2**

Atom	*x*	*y*	*z*	$U_{eq} \cdot 10^3/Å^2$
N(1)	927(3)	8986(1)	11942(2)	48(1)
C(2)	−464(4)	9282(2)	12231(4)	60(1)
C(3)	309(5)	9728(2)	13329(3)	62(1)
N(4)	1110(4)	9394(1)	14537(3)	58(1)
C(5)	2509(4)	9116(1)	14759(3)	49(1)
C(6)	3521(4)	9056(1)	13911(3)	45(1)
C(7)	2665(4)	8993(1)	12625(3)	41(1)
C(8)	3037(4)	8861(1)	11382(3)	45(1)
C(9)	999(4)	8854(1)	10717(3)	44(1)
C(10)	−21(5)	8285(2)	10001(3)	60(1)
C(11)	−1899(6)	8404(2)	9111(4)	82(1)
C(12)	4047(5)	8274(2)	11401(4)	61(1)
C(13)	3776(5)	9402(2)	10850(4)	59(1)
C(14)	5436(4)	9094(2)	14498(3)	61(1)
C(15)	3075(6)	8767(2)	16052(3)	65(1)
C(16)	1679(8)	8390(2)	16258(5)	97(2)
F(1)	379(2)	9327(1)	9850(2)	63(1)
F(2)	−51(4)	7879(1)	10883(3)	97(1)
F(3)	752(3)	8038(1)	9259(2)	94(1)
F(4)	−1987(4)	8702(2)	8065(3)	122(1)
F(5)	−2678(4)	7868(2)	8741(3)	121(1)
F(6)	−2714(3)	8712(2)	9706(3)	101(1)
F(7)	3348(3)	7800(1)	11750(2)	84(1)
F(8)	4140(3)	8157(1)	10266(2)	85(1)
F(9)	5651(3)	8317(1)	12257(3)	90(1)
F(10)	3275(3)	9368(1)	9570(2)	81(1)
F(11)	5481(3)	9414(1)	11310(3)	88(1)
F(12)	3251(3)	9929(1)	11149(2)	72(1)
F(13)	6259(3)	8564(1)	14756(2)	85(1)
F(14)	5915(3)	9400(1)	15629(2)	81(1)
F(15)	6081(3)	9409(1)	13744(2)	80(1)
F(16)	3679(4)	9155(1)	17059(2)	102(1)
F(17)	4358(3)	8374(1)	16150(2)	87(1)
F(18)	2353(6)	7998(2)	17221(4)	141(1)
F(19)	857(5)	8067(2)	15213(4)	141(1)
F(20)	566(5)	8728(2)	16548(4)	142(1)

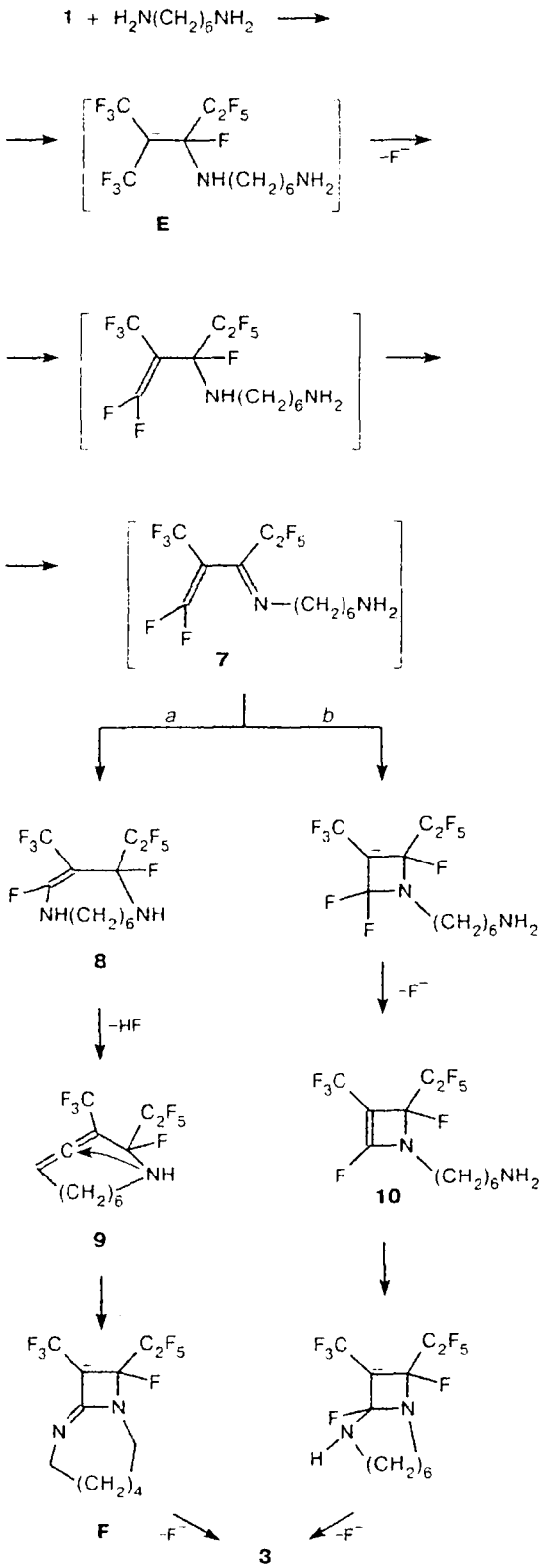
ular nucleophilic cyclization gives rise to 7,9-difluoro-5,9-bis(pentafluoroethyl)-6,8,8-tris(trifluoromethyl)-2,3,8,9-tetrahydro-1*H*-1,4-diazonine (**6**). A similar interaction of a C-carbanion of type **A** with a multiple bond has been described previously in relation to the reactions of dimethylamine and pyrrolidine with hexafluoropropylene trimer, which result in the formation of a 5-membered heterocyclic system.[14,15] The intramolecular nucleophilic attack by the N-nucleophile (NH group) on the C=C bond in compound **6** would give the reaction product. A similar cyclization has previously been reported[8,10] for the formation of 1,9-bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino[1,2-*a*]pyrazine upon the reaction of perfluoropent-2-ene with diethylenetriamine.

Apparently, the reaction of compound **1** with hexamethylenediamine also occurs *via* an anion of type **A** (anion **E**) (Scheme 3). Elimination of the F^- ion from the CF_3 group affords *N*-(2-(trifluoromethyl)perfluoropent-1-en-3-ylidene)hexane-1,6-diamine (**7**). Subsequent transformations could be described, for example, by the following schemes. According to one transformation pathway (pathway *a*), intramolecular cyclization occurs, giving rise to 2,4-difluoro-4-pentafluoroethyl-3-trifluoromethyl-1,5-diazacycloundec-2-ene (**8**). On treatment with triethylamine, compound **8** eliminates HF to give 4-fluoro-4-pentafluoroethyl-3-trifluoromethyl-1,5-diazacycloundeca-1,2-diene (**9**), which undergoes intramolecular cyclization due to the attack by the N-nucleophilic center generated from the NH group on the C atom of the N=C=C group to give anion **F**. Elimination of the F^- ion from anion **F** affords the reaction product **3**. The decision between the possible structures **3** and **9** could be based on the data of IR and ^{13}C NMR spectroscopy. The IR spectrum of compound **3** exhibits absorption bands at 1640 cm^{-1} (C=C) and 1550 cm^{-1} (C=N), whereas the band at 1950—2050 cm^{-1} (which would correspond to the C=C=N group in compound **9**[16]) is missing. Analysis of the ^{13}C NMR spectrum of compound **3** shows that the signal at δ 138.5 (q, $^3J_{C,F}$ = 6.3 Hz) corresponds to the C atom located in position 9, whereas for compounds such as *tert*-butyl(heptafluoroethyl-2-trifluoromethylpent-1-enylidene)amine and isopropyl(heptafluoro-2-trifluoromethylpent-1-enylidene)amine (containing the C=C=N fragment), the signals at δ 157 (s) and 157.2 (s) characterize[17] the C atom of the C=C=N group.

According to another scheme (pathway *b*), cyclization occurs due to the inner N-nucleophilic center, which results in the formation of compound **10** *via* the corresponding carbanion. The subsequent intramolecular cyclization and elimination of F^- yield product **3**.

The first steps of the formation of compounds **2** and **3** are identical for both diamines, while the distinctions arising in subsequent steps are associated with the size of the ring to be closed. In the case of ethylenediamine, the presence of the terminal amino group affords a plausible

Scheme 3



7-membered ring, while in the case of hexamethylenediamine, the terminal amino group would lead to an unfavorable (entropy factor) 11-membered ring (pathway *a* in Scheme 3) and therefore cyclization can involve the "internal" NH group.

Thus, the reactions of perfluoro-2-methylpent-2-ene with ethylenediamine display a specific type of behavior; the formation of a heterocyclic system involves two molecules of the initial perfluoroolefin and one ethylenediamine molecule, whereas in the case of hexamethylenediamine, the reaction with 1 : 1 stoichiometry affords a bicyclic compound containing 4- and 9-membered rings.

Experimental

^1H, ^{13}C, and ^{19}F NMR spectra were recorded on a Bruker WP 200 SY spectrometer (200, 50, and 188 MHz, respectively) with Me_4Si and C_6F_6 as internal standards; IR spectra were measured on a Specord M-80 spectrometer (CCl_4). Mass spectra were run on a VG 707 OE GC/MS instrument with an energy of ionizing electrons of 70 eV. The melting points were determined on a Koffler hot stage.

Single-crystal X-ray diffraction analysis of compound **2** was performed on a SYNTEX $P2_1$ diffractometer (Cu-Kα radiation, graphite monochromator). The crystals of compound **2** are monoclinic: a = 8.351(4) Å, b = 21.841(9) Å, c = 11.083(6) Å, β = 111.42(4)°, V = 1882(2) Å^3, space group $P2_1/n$, Z = 4, $C_{14}H_4F_{20}N_2$, μ = 2.459 mm^{-1}, d_{calc} = 2.048 g cm^{-3}. A crystal with dimensions 0.5×0.7×1.0 mm was placed into a polyethylene capillary. The intensities of 3490 independent reflections with $2\theta < 140°$ were measured using the $\theta/2\theta$ scan mode. The structure was solved by the direct method using the SHELXS-86 program package. The final refinement of the parameters was performed by the least-squares method in the full-matrix anisotropic (or isotropic for H atoms) approximation using the SHELXL-97 program package to wR_2 = 0.1654, S = 1.031 (R = 0.0571 over $2650F > 4\sigma$). The resulting coordinates and equivalent thermal factors for nonhydrogen atoms are presented in Table 1.

5,9-Bis(pentafluoroethyl)-6,8,8-tris(trifluoromethyl)-9-fluoro-1,4-diazabicyclo[5.2.0]nona-4,6-diene (2). Ethylenediamine (3 g, 50 mmol) was added over a period of 0.5 h with stirring and cooling to −30 °C to a solution of compound **1** (15 g, 50 mmol) and Et_3N (10.1 g, 100 mmol) in THF (40 mL). Then the temperature was raised to −20 °C and the mixture was kept for 2 h and poured in water. The product was extracted with CH_2Cl_2 and the extract was dried with $MgSO_4$. After evaporation of the solvent, the residue was passed through a column with silica gel in the hexane–CH_2Cl_2 system (5 : 1) to give compound **2**, yield 8.7 g (60%), m.p. 56–57 °C (from hexane). IR, ν/cm^{-1}: 1250–1150 (C–F); 1620 (C=N); 1676 (C=C); 2980 (C–H). MS, m/z (I_{rel}(%)): 580 $[M]^+$ (73.40), 561 $[M - F]^+$ (75.52), 552 $[M - CH_2CH_2]^+$ (33.54), 532 $[M - CH_2CH_2 - HF]^+$ (18.35), 511 $[M - CF_3]^+$ (23.63), 461 $[M - C_2F_5]^+$ (100), 441 $[M - C_2F_5 - HF]^+$ (11.00), 416 $[M - C_2F_5CF{=}N]^+$ (2.70), 402 $[M - C_2F_5CF{=}NCH_2]^+$ (4.98), 314 $[C_2F_5CFNC(CF_3)_2C]^+$ (2.20), 192 $[C_2F_5CF{=}NCH_2CH_2]^+$ (50.79), 178 $[C_2F_5CF{=}NCH_2]^+$ (15.43), 164 $[C_2F_5CF{=}N]^+$ (1.68), 145 $[C_2F_5CN]^+$ (0.78), 119 $[C_2F_5]^+$ (7.76), 100 $[CF_2{=}CF_2]^+$ (1.34), 69 $[CF_3]^+$ (40.20). Found: mol. weight 580.0047. $C_{14}H_4F_{20}N_2$. Calculated: mol. weight 580.0055.

^{19}F NMR ($(CD_3)_2CO$), δ: 107.6 (3 F, F-14); 100.4 (3 F, F-12); 98.3 (3 F, F-13); 82.4 (3 F, F-11); 81.3 (3 F, F-16); 48.9 and 46.5 (2 F, F-15, AB system, $J_{F,F}$ = 286.1 Hz); 45.8 and 40.6 (2 F, F-10, AB system, $J_{F,F}$ = 293.6 Hz); 25.5 (F-9, 1 F). ^{13}C NMR (CD_2Cl_2), δ: 153.9 (C-5, $^2J_{C,F}$ = 46.2 Hz); 146.5 (C-7); 118.4 (C-12, $^1J_{C,F}$ = 285.2 Hz); 118.2 (C-13, $^1J_{C,F}$ = 283.6 Hz); 117.2 (C-16, $^1J_{C,F}$ = 286.5 Hz, $^2J_{C,F}$ = 40.1 Hz); 116.1 (C-11, $^1J_{C,F}$ = 290.7 Hz, $^2J_{C,F}$ = 39.1 Hz); 113.2 (C-6, $^2J_{C,F}$ = 35.1 Hz); 108.1 (C-15, $^1J_{C,F}$ = 269.2 Hz, $^2J_{C,F}$ = 34.8 Hz); 103.2 (C-15, $^1J_{C,F}$ = 261.8 Hz, $^2J_{C,F}$ = 35.1 Hz); 102.5 (C-9, $^1J_{C,F}$ = 289.3 Hz, $^2J_{C,F}$ = 39.1 Hz); 98.1 (C-8, $^2J_{C,F}$ = 38.6 Hz); 28.1 (C-2); 21.1 (C-3).

11-Pentafluoroethyl-10-trifluoromethyl-1,8-diazabicyclo-[7.2.0]undeca-8,10-diene (3). A mixture of compound **1** (6 g, 20 mmol), hexamethylenediamine (2.32 g, 20 mmol), and triethylamine (4.1 g, 40 mmol) in 15 mL of MeCN was stirred for 1 h, and then heated at 45 °C for 4 h. The reaction mixture was poured in water, the voluminous precipitate was filtered off and dissolved in CH_2Cl_2, and the solution was dried with $MgSO_4$. After evaporation of the solvent, the residue was distilled *in vacuo* to give 3.5 g (52%) of compound **3**, b.p. 113–115 °C (0.4 Torr). IR, ν/cm^{-1}: 1250–1150 (C–F); 1340 (C–N); 1400, 1460 (C–N); 1550 (C=N); 1640 (C=C); 2930 (C–H). ^{19}F NMR ($(CD_3)_2CO$), δ: 108.3 (3 F, F-12); 83.3 (3 F, F-14); 50.4 (2 F, F-13). ^{13}C NMR (CD_2Cl_2), δ: 150.2 (C-2, $^2J_{C,F}$ = 29.2 Hz); 148.5 (C-4, $^3J_{C,F}$ = 6.3 Hz); 124.4 (C-13, $^1J_{C,F}$ = 266.4 Hz); 119.3 (C-15, $^1J_{C,F}$ = 286 Hz, $^2J_{C,F}$ = 39.1 Hz); 111.4 (C-14, $^1J_{C,F}$ = 261.8 Hz, $^2J_{C,F}$ = 35.1 Hz); 93.5 (C-3, $^2J_{C,F}$ = 36.3 Hz); 63.4 (C-2, C-7); 44.5 (C-3, C-6); 19.3 (C-4, C-5). Found (%): C, 42.76, 42.45; H, 3.23, 3.12; F, 45.12, 45.34; N, 8.21. $C_{12}H_{12}F_8N_2$. Calculated (%): C, 42.86; H, 3.60; F, 45.20; N, 8.33. Found: mol. weight 336. $C_{14}H_4F_{20}N_2$. Calculated: mol. weight 336.

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