Reaction of 2-amino-4-imino-2-perfluoropentene with ethylenediamine and diethylenetriamine

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The transamination of 2-amino-4-imino-2-perfluoropentene with ethylenediamine gives the corresponding 6-fluoro-5,7-bis(trifluoromethyl)-2,3-dihydro-1*H*-1,4-diazepine. The transamination of 2-amino-4-imino-2-perfluoropentene by diethylenetriamine is accompanied by intramolecular nucleophilic substitution of the α-fluorine atom to form 1,9-bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino[1,2-*a*]pyrazine whose structure was established by an X-ray structural investigation. Several salts of this bicyclic compound and its complex with BF_3 have been described.

Key words: 2-amino-4-imino-2-perfluoropentene; β-aminovinylimine; ethylenediamine; diethylenetriamine; transamination; *N*-heterocycles; intramolecular nucleophilic substitution.

In our opinion, 2-amino-4-imino-2-perfluoropentene (**1**), which is an aza analog of heptafluoroacetylacetone,[1] should possess the synthetic potential of fluoroalkyl-containing β-aminovinylketones. In particular, it should be able to undergo transamination, which is typical of the latter.[2,3]

Here we study the reaction of aminovinylimine **1** with ethylenediamine (EDA) and diethylenetriamine (DETA). It was found that **1** reacts with EDA to give the respective 1,4-diazepine (**2**), which was obtained previously[4] from 2-perfluoropentene and EDA. The assumption that the basicity of the reacting amine affects the possibility of replacement of the vinylic F atom by an H atom (*cf.* Ref. 4) has now been confirmed by the formation of compound **3** when 6-fluorodiazepine **2** is heated with the more basic DETA (Scheme 1).

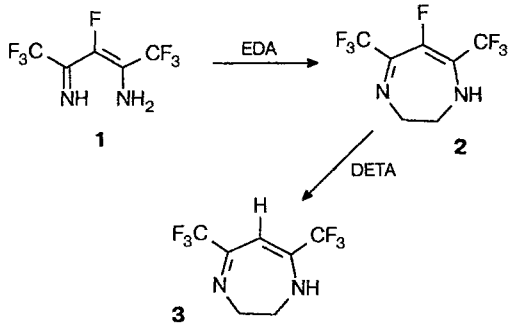
However, transamination of compound **2** with diethylenetriamine does not occur.

Compound **1** reacts with DETA (Scheme 2) to give 1,9-bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino-[1,2-*a*]pyrazine (**5**), which follows unambiguously from the X-ray structural study.

The physicochemical characteristics of compound **5** coincide with those of the product of the reaction of 2-perfluoropentene with DETA, which was earlier[4] regarded as having the structure of monocyclic 2,4-bis(trifluoromethyl)[10]-1,4-diene-N_3. Apparently, the initially formed macrocyclic compound **4** is transformed into product **5** due to nucleophilic substitution of the fluorine atom.

The general view of molecule **5** is presented in Fig. 1. The bond angles are given in Tables 1 and 2, and

Scheme 1



Scheme 2

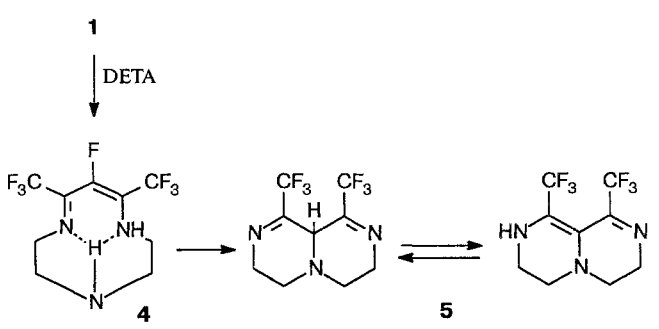


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Table 1. Bond lengths (d) in structure **5**

Bond	d/Å	Bond	d/Å
C(8)—F(1)	1.347 (5)	C(5)—N(3)	1.368 (5)
C(8)—F(2)	1.317 (6)	C(6)—N(3)	1.434 (6)
C(8)—F(3)	1.420 (23)	C(2)—C(1)	1.536 (7)
C(9)—F(4)	1.307 (6)	C(4)—C(3)	1.462 (5)
C(9)—F(5)	1.353 (12)	C(8)—C(3)	1.504 (5)
C(9)—F(6)	1.375 (5)	C(5)—C(4)	1.384 (5)
C(1)—N(1)	1.469 (5)	C(9)—C(5)	1.472 (6)
C(4)—N(1)	1.403 (5)	C(7)—C(6)	1.542 (6)
C(7)—N(1)	1.459 (5)	F(3')—C(8)	1.297 (16)
C(2)—N(2)	1.499 (5)	F(5')—C(9)	1.355 (17)
C(3)—N(2)	1.269 (5)		

the atomic coordinates appear in Table 3.

In the crystalline state, compound **5** exists in the β-diimine form, but the presence of a strong band of NH stretching vibrations (3280 cm^{-1}) in the IR spectrum of this compound suggests the possibility of tautomeric transformations. In fact, compound **5** has the amino-vinylimine structure in a $CDCl_3$ solution, since the ^1H NMR spectrum contains a signal for NH and three multiplet signals for CH_2 protons at δ 3.10 (CH_2NCH_2), 3.42 (CH_2NH), and 3.76 ($CH_2N{=}C$). The two latter signals become averaged when CD_3COOD is added to a solution of **5**. As a consequence, four CH_2 groups are represented in the spectrum by two triplet signals at δ 3.10 and 3.60, J = 4.6 Hz. The ^{19}F NMR spectrum of compound **5** contains two quartets for the CF_3 groups, which coalesce to give a singlet (63.7 ppm) when CD_3COOD is added.

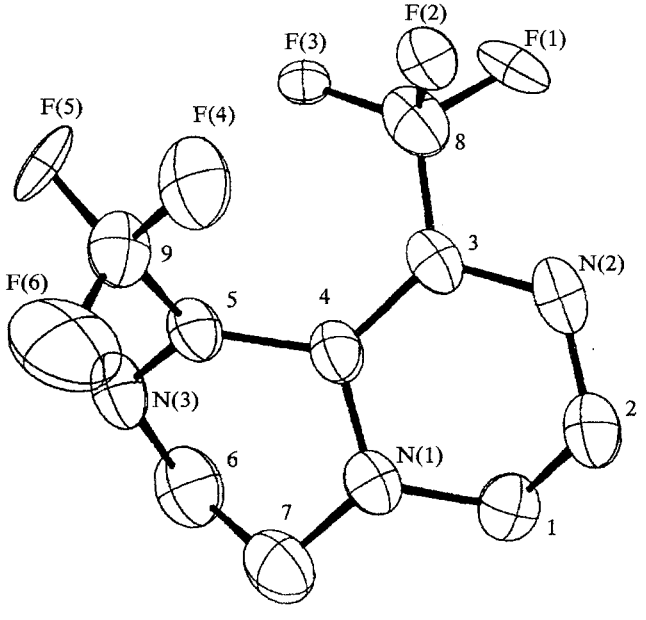


Fig. 1. Structure of molecule **5**.

Table 2. Bond angles (ω) in structure **5**

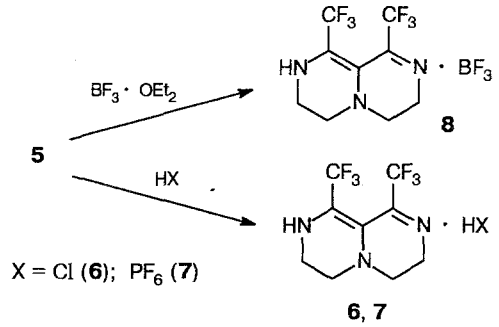
Angle	ω/deg	Angle	ω/deg
C(4)—N(1)—C(1)	116.4 (3)	F(2)—C(8)—F(1(	104.8 (4)
C(7)—N(1)—C(1)	113.3 (3)	F(3)—C(8)—F(1)	101.2 (11)
C(7)—N(1)—C(4)	115.8 (3)	F(3)—C(8)—F(2)	119.1 (10)
C(3)—N(2)—C(2)	113.5 (3)	C(3)—C(8)—F(1)	114.6 (3)
C(6)—N(3)—C(5)	118.7 (3)	C(3)—C(8)—F(2)	114.4 (3)
C(2)—C(1)—N(1)	110.4 (4)	C(3)—C(8)—F(3)	102.4 (9)
C(1)—C(2)—N(2)	107.4 (3)	F(3')—C(8)—F(1)	106.2 (8)
C(4)—C(3)—N(2)	123.7 (4)	F(3')—C(8)—F(2)	102.4 (10)
C(8)—C(3)—N(2)	111.7 (3)	F(3')—C(8)—C(3)	113.3 (7)
C(8)—C(3)—C(4)	123.8 (3)	F(5)—C(9)—F(4)	108.2 (7)
C(3)—C(4)—N(1)	113.8 (3)	F(6)—C(9)—F(4)	106.8 (4)
C(5)—C(4)—N(1)	118.4 (3)	F(6)—C(9)—F(5)	103.1 (8)
C(5)—C(4)—C(3)	127.8 (4)	C(5)—C(9)—F(4)	116.4 (3)
C(4)—C(5)—N(3)	122.3 (4)	C(5)—C(9)—F(5)	109.5 (7)
C(9)—C(5)—N(3)	113.9 (3)	C(5)—C(9)—F(6)	111.9 (4)
C(9)—C(5)—C(4)	123.8 (4)	F(5')—C(9)—F(4)	104.9 (9)
C(7)—C(6)—N(3)	109.9 (4)	F(5')—C(9)—F(6)	103.8 (9)
C(6)—C(7)—N(1)	106.6 (3)	F(5')—C(9)—C(5)	112.1 (9)

Table 3. Atomic coordinates (×10^3)

Atom	x	y	z
H(1)	8019 (3)	5557 (5)	7761 (6)
H'(1)	8011 (3)	4075 (5)	6555 (6)
H(2)	6863 (4)	5674 (4)	4778 (6)
H'(2)	6248 (4)	5811 (4)	6518 (6)
H(4)	5656 (3)	3225 (3)	8430 (5)
H(6)	7719 (3)	4042 (5)	13148 (6)
H'(6)	7960 (3)	2742 (5)	11789 (6)
H(7)	8414 (3)	4878 (4)	10648 (6)
H'(7)	7224 (3)	5482 (4)	10482 (6)
F(1)	5396 (2)	1015 (2)	6942 (4)
F(2)	4658 (3)	2003 (3)	4602 (5)
F(3)	6288 (18)	1278 (22)	5073 (33)
F(4)	4379 (2)	2965 (3)	7983 (4)
F(5)	4590 (9)	3480 (17)	10764 (16)
F(6)	4838 (3)	1498 (3)	10031 (5)
F(5')	4540 (14)	3492 (21)	10689 (26)
F(3')	6016 (15)	1276 (15)	4718 (24)
N(1)	7332 (2)	3966 (3)	8688 (4)
N(2)	6084 (3)	3952 (3)	5198 (4)
N(3)	6508 (3)	3203 (4)	11490 (4)
C(1)	7591 (3)	4704 (5)	7223 (6)
C(2)	6667 (4)	5161 (4)	5874 (6)
C(3)	5977 (3)	3176 (4)	6432 (5)
C(4)	6394 (3)	3415 (3)	8330 (5)
C(5)	5986 (3)	3130 (4)	9755 (5)
C(6)	7511 (3)	3598 (5)	11838 (6)
C(7)	7655 (3)	4608 (4)	10424 (6)
C(8)	5523 (4)	1888 (4)	5696 (6)
C(9)	4954 (3)	2787 (4)	9564 (6)

Compound **5** forms deeply colored salts with mineral acids (**6, 7**) and a complex with BF_3 (**8**), all of which are unstable in aqueous media, evidently, due to hydrolytic

Scheme 3



cleavage of the C=N bond (Scheme 3). The time required for the decomposition decreases significantly in the series **8**→**7**→**6**; the latter compound decomposes in 2—3 weeks in air at 20 °C without a solvent.

Thus, as was expected, the action of EDA and DETA on **1** results in the transamination which is so characteristic of fluoroalkyl-containing β-aminovinyl-ketones.[2,3] However, the presence of an active vinylic halogen atom in compound **1** leads to a result that is nontrivial for the chemistry of fluorine-containing β-diketones and their amino derivatives, *viz.*, the formation of 1,9-bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino[1,2-*a*]pyrazine.

Experimental

IR spectra for suspensions of the compounds in vaseline oil were recorded on a Specord IR-75 spectrophotometer in the range of 400—4000 cm^{-1}. ^1H NMR spectra were obtained on a Tesla BS-567A spectrometer (100 MHz) in acetone-d_6 relative to TMS. ^{19}F NMR spectra were recorded on a Tesla BS-587 spectrometer (75 MHz) in acetone-d_6 relative to $CFCl_3$. The mass spectrum of compound **8** was recorded on a Varian MAT-311a instrument at 70 eV impact energy, using direct injection of the material into the ionic source. Column chromatography was performed on L 100/250 silica gel.

X-ray diffraction data for compound **5** (a prismatic crystal, 0.1×0.1×0.2 mm) were obtained on a Philips PW-1100 automatic diffractometer (Mo-Kα radiation, graphite monochromator, ω/2θ-scanning, $8° \le \theta \le 16°$). The crystals are monoclinic; at 20 °C, a = 14.116(4) Å, b = 10.128(3) Å, c = 7.699(2) Å, β = 103.54(3)°; V = 1070.1(9) Å^3, $P2_1/a$, d_{calc} = 1.708 g cm^{-3}, Z = 4. A total of 2748 independent reflections in the range of $2° \le \theta \le 30°$ were measured. Further calculations and refinements made use of 1608 reflections with $I \ge 2.5\sigma(I)$. The structure was solved by the direct method using the SHELX program package. The following function was minimized:

$$\Sigma w(|F_0|-|F_c|)^2,$$

where $w = \sigma^{-2}(F_0)$.

Fluorine atoms are located in a random manner with a population factor of 0.5.

The positions of all of the H atoms were calculated and refined isotropically. The final divergence factors were R_w = 0.061.

2-Amino-4-imino-2-perfluoropentene (1) was obtained by the procedure in Ref. 1.

6-Fluoro-5,7-bis(trifluoromethyl)-2,3-dihydro-1*H*-1,4-diazepine (2). A mixture of compound **1** (1.1 g, 5 mmol) and anhydrous EDA (0.3 g, 5 mmol) in anhydrous EtOH (50 mL) was refluxed for 16 h. When NH_3 evolution ceased, the solvent was removed *in vacuo*, and the residue was recrystallized from hexane to give 0.8 g (65 %) of compound **2**, m.p. 98—99 °C. Found (%): C, 33.65; H, 2.31; F, 53.10; N, 10.95. $C_7H_5F_7N_2$. Calculated (%): C, 33.61; H, 2.07; F, 53.17; N, 11.20. The physicochemical constants were in agreement with the literature data.[4]

5,7-Bis(trifluoromethyl)-2,3-dihydro-1*H*-1,4-diazepine (3). A mixture of compound **2** (1.25 g, 5 mmol) and anhydrous DETA (2.5 g, 25 mmol) in $CHCl_3$ (30 mL) was refluxed for 30 h. The resulting precipitate of $[NH_3(CH_2)_2NH_2(CH_2)_2NH_3]F_3$ was filtered off. Removal of the solvent, column chromatography with $CHCl_3$ as the eluent, and recrystallization from hexane yielded 1.0 g (86 %) of compound **3**, m.p. 109—110 °C. Found (%): C, 36.11; H, 2.73; F, 49.03; N, 12.35. $C_7H_6F_6N_2$. Calculated (%): C, 36.22; H, 2.60; F, 49.11; N, 12.07. The physicochemical constants were in agreement with the literature data.[6]

1,9-Bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino-[1,2-*a*]pyrazine (5). A mixture of compound **1** (1.1 g, 5 mmol) and anhydrous DETA (0.5 g, 5 mmol) in anhydrous EtOH (50 mL) was refluxed for 24 h. Removal of the solvent and column chromatography with CH_2Cl_2 as the eluent, followed by recrystallization from CCl_4, yielded 0.6 g (44 %) of compound **5**, m.p. 129—130 °C. Found (%): C, 39.14; H, 3.65; F, 41.83; N, 14.97. $C_9H_9F_6N_3$. Calculated (%): C, 39.57; H, 3.32; F, 41.73; N, 15.38. IR, ν/cm^{-1}: 3280, 1580 (NH); 1600 (C=N) (*cf.* Ref. 4). ^1H NMR ($CDCl_3$), δ: 3.10 (m, 4 H, CH_2NCH_2); 3.42 (m, 2 H, CH_2NH); 3.76 (m, 2 H, $CH_2N{=}C$); 1.64 (br.s, 1 H, NH). ^{19}F NMR, δ: −63.1 (q, J = 11 Hz, CF_3); −64.4 (q, J = 11 Hz, CF_3).

1,9-Bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino-[1,2-*a*]pyrazine monohydrochloride (6). Gaseous HCl was passed through a solution of compound **5** (1.37 g, 5 mmol) in ether (50 mL). The dark-red precipitate was filtered off, washed with ether, and dried *in vacuo* to give 1.3 g (84 %) of salt **6**, m.p. 120 °C (decomp.). Found (%): C, 34.70; H, 3.61; F, 36.52; Cl, 11.64; N, 13.48. $C_9H_9F_6N_3 \cdot HCl$. Calculated (%): C, 34.91; H, 3.26; F, 36.81; Cl, 11.45; N, 13.57. IR, ν/cm^{-1}: 2700 ($C{=}N^+H$); 3300, 1585 (NH); 1610 (C=C). ^1H NMR, δ: 3.5 (t, J = 4.4 Hz, 4 H, CH_2NCH_2); 3.96 (t, J = 4.4 Hz, 4 H, $CH_2{-}N^+$); 1.3 (m, 1 H, NH or CH). ^{19}F NMR, δ: −63.6 (s).

1,9-Bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino-[1,2-*a*]pyrazine hexafluorophosphate (7). A solution of $NaPF_6$ (1.68 g, 10 mmol) in methanol (20 mL) saturated with gaseous HCl was added to a solution of compound **5** (1.37 g, 5 mmol) in MeOH (30 mL). The red precipitate was filtered off and washed with $CHCl_3$ to give 1.7 g (81 %) of compound **7**, m.p. 198—199 °C. Found (%): C, 26.04; H, 2.61; F, 53.86; N, 10.24. $C_9H_9F_6N_3 \cdot HPF_6$. Calculated (%): C, 25.79; H, 2.41; F, 54.39; N, 10.02. IR, ν/cm^{-1}: 3350, 3630, 1520 (NH); 2650 ($C{=}NH^+$); 1640, 1540 (C=C); 530, 550 (PF_6^-). ^1H NMR, δ: 3.02 (t, J = 4.6 Hz, 4 H, CH_2NCH_2); 3.48 (t, J = 4.6 Hz, 4 H, $CH_2{-}N^+$); 1.2 (m, 1 H, NH or CH). ^{19}F NMR, δ: −63.6 (s, 6 F, 2 CF_3); −74.7 (s, 6 F, PF_6).

1,9-Bis(trifluoromethyl)-3,4,6,7-tetrahydro-2*H*-pyrazino-[1,2-*a*]pyrazine-trifluoroborane (8). $BF_3 \cdot OEt_2$ was added dropwise to compound **5** (1.37 g, 5 mmol) in ether (50 mL) until a violet precipitate formed. The latter was filtered off, washed with ether, and dried *in vacuo* to give 1.2 g (88 %) of

compound **8**, m.p. 178—180 °C. Found (%): C, 31.39; H, 2.91; F, 50.21; N, 12.52. $C_9H_9F_6N_3 \cdot BF_3$. Calculated (%): C, 31.70; H, 2.66; F, 50.14; N, 12.32. IR, ν/cm^{-1}: 3280, 1520 (NH); 1540 sh, 3050 (C=C); 1000—1060 (BF_3). ^1H NMR, δ: 3.10 (t, J = 4.6 Hz, 4 H, CH_2NCH_2); 3.60 (t, J = 4.6 Hz, 4 H, $CH_2—N^+$). ^{19}F NMR, δ: −60.3 (s, 6 F, 2 CF_3); −158.2 (s, 3 F, BF_3). MS, m/z (I (%)): 273 (100) $[M—BF_3]^+$.

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Synthesis and properties of 1,2,4-triazolo[4,3-*d*]-1,2,4-triazolo-[3,4-*f*]furazano[3,4-*b*]pyrazines

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New methods for the synthesis of 1,2,4-triazolo[4,3-*d*]-1,2,4-triazolo[3,4-*f*]furazano[3,4-*b*]pyrazines with functional substituents of various types are proposed and some properties of these compounds are studied.

Key words: 1,2,4-triazolo[4,3-*d*]-1,2,4-triazolo[3,4-*f*]furazano[3,4-*b*]pyrazines; heterocyclization reactions; methods of synthesis.

1,2,4-Triazolo[3,4-*c*]benzopyrazines are of interest as biologically active compounds having diuretic, antiallergic, and antihypertonic action.[1,2] In order to expand the range of compounds of this type we synthesized fused 1,2,4-triazolo[4,3-*d*]-1,2,4-triazolo[3,4-*f*]furazano[3,4-*b*]pyrazines (TTFP) with various functional substituents (Scheme 1).

TTFP are formed by reactions of dihydrazinofurazano[3,4-*b*]pyrazine derivative (**3**) with hydrochlorides of carboximidates in glacial AcOH at 60—116 °C. The products of cyclization of compounds **4** and **6** were obtained in 70—80 % yields. Some properties of the synthesized TTFP were studied. It was found that the amino groups in diamine **4** can be transformed into nitro groups upon the action of 30 % H_2O_2 in concentrated H_2SO_4. Treatment of diester **6** with a mixture of concentrated HNO_3 and H_2SO_4 afforded the tetranitro derivative (**7**) in 67 % yield. Hydrolysis of compound **7** in aqueous KOH gave the dipotassium salt (**8**) in 91 % yield. Nitration of salt **8** with concentrated HNO_3 made it possible to synthesize the bis(trinitromethyl) derivative (**9**). Fluorination of

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