INTERACTION OF FLUORINE-CONTAINING 1,3-DICARBONYL COMPOUNDS WITH POLYAMINES

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In the reaction of fluorinated copper(II) 1,3-diketonates with diethylenetriamine (or triethylenetetramine) in $CHCl_3$, N,N'-bis(1,3-aminovinylketones) are formed in 21-35% yields. Fluorine-containing 1,3-diketones and 1,3-ketoesters, upon interaction with polyamines without solvent, undergo acid cleavage, forming the corresponding amides. The copper(II) 1,3-ketoesterates are readily cleaved in $CHCl_3$ at 25°C in excess triethylenetetramine or ethylenediamine.

Keywords: copper(II) 1,3-diketonates and 1,3-ketoesterates, fluoroalkyl-containing 1,3-diketones and 1,3-ketoesters, ethylenediamine, diethylenetriamine, triethylenetetramine, N,N'-bis(1,3-aminovinylketones), acid cleavage.

By condensation of trifluoroacetylacetone (TFAA) with diethylenetriamine (dien) or triethylenetetramine (trien) in an aprotic solvent (absolute alcohols), the corresponding pentadentate and hexadentate N,N'-bis(1,3-aminovinylketones) have been obtained in yields of 29-36% [1, 2]. In an acidic aqueous medium on an Ni^{2+} matrix, the base that is the trien derivative is converted to a complex of the tetradentate macrocyclic ligand [1], the same as the TFAA with trien under these conditions [3, 4]. No data have been reported on the interaction of fluorine-containing 1,3-dicarbonyl compounds with polyamines under other conditions.

Previously we had shown the nontrivial occurrence of the reaction of fluorinated 1,3-dicarbonyl compounds [5] and their copper chelates [6] upon fusion with ethylenediamine (en) perchlorate monohydrate or with excess en in an aprotic solvent.

In the work reported here, we investigated reactions of the fluorinated 1,3-diketones 1a, b, the 1,3-ketoester 2b, and their copper chelates 5a, b and 10a, with dien and trien under the conditions described in [5, 6].

We found that, in contrast to the reaction with en [5], 1a, b and 2b at 25 °C under pressure, or upon heating with dien (as the perchlorate monohydrate) do not form cyclic compounds, but give only products of acid cleavage -N,N'-bis(polyfluoroacyl)diethylenetriamines (3a, b).



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At 25°C, there is no appreciable conversion of 1a, b or 2b.

Analogous cleavage takes place in the reaction of 1a with trien perchlorate monohydrate.



The copper 1,3-diketonates 5a, b, the same as in the reaction with en [6], with excess dien (or trien), or their monoprotonated salts in CHCl₃, form the adducts 6a, b and 7a, b, which we were not able to isolate individually from the reaction mixture with the corresponding amine. As proof of their existence, by countersynthesis with an equimolar quantity of the amine, we obtained and characterized (by elemental analysis and IR spectra) the adducts 6a and 7a. Under the conditions of the reaction, 6a, b and 7a, b break down, apparently releasing ligands in the same manner as reported in [6], which are condensed with the polyamine to give, along with a mixture of tarry products that is difficult to interpret, 3a, b and 4a, b and also the N,N'-bis(1,3-aminovinylketones) 8a, b and 9a, b.



This sort of acid cleavage in the reaction of copper diketonates with en had been observed only in the case of copper(II) bis(1,1,2,2-tetrafluoro-5-phenyl-3,5-pentanedionate), which has bulky substituents [6].

The copper 1,3-ketoesterate 10a, with trien in $CHCl_3$, first forms the adduct 11a; however, the product that is recovered in the subsequent conversions with the amine, even at 25°C, becomes the amide 4a.



The greater susceptibility of the fluorinated 1,3-ketoesters to acid cleavage under these conditions in comparison with the 1,3-diketones is further confirmed by the fact that compounds 10a, b with en in CHCl₃, even at 25°C, form the N,N'-bis(polyfluoroacyl)ethylenediamines 13a-c.

$$10a-C \xrightarrow{en}_{25,CHGL_3} 2en \cdot Cu \left(\begin{array}{c} 0 \xrightarrow{R_F} \\ 0 \xrightarrow{en}_{25+62,CHGL_3} \end{array} \right)_2 \xrightarrow{en}_{0Me} \begin{array}{c} 0 \\ R_F \\ 0 \\ 0 \\ (12a-C) \end{array} \right)_2 \xrightarrow{en}_{0Me} \begin{array}{c} 0 \\ R_F \\ 0 \\ 0 \\ (13a-C), 49-55\% \end{array}$$

The absence of cyclic products in these reactions of the fluorinated 1,3-diketones 1a, b and their copper chelates 5a, b with polyamines, in comparison with the analogous reactions with en [5, 6] is evidently due to a combination of an unfavorable entropy factor (the considerably lower conformational rigidity of the reacting amine) and an unfavorable thermodynamic factor (lower degree of conjugation in the final product).

An increase in the number of rotational and vibrational degrees of freedom of the amine reduces the probability of forming the N,N'-bis(1,3-aminovinylketones) 8a, b and 9a, b, thus leading to side processes, mainly acid cleavage of the 1,3-dicarbonyl fragment. The dominance of acid cleavage is obviously due to the higher basicity of the polyamines in comparison with en (for the en, $pK_{a1} = 10.0$ and $pK_{a2} = 7.0$ [7]; for the dien $pK_{a1} = 10.1$, $pK_{a2} = 9.4$, and $pK_{a3} = 4.9$ [8]), while at the same time the greater effective volume of the dien and trien undoubtedly lowers their nucleophilicity. The copper ion has a definite influence on the conformational rigidity of the reacting molecules; and in this connection, interaction of the copper chelates of the 1,3-diketones 5a, b with the polyamines differs favorably from the interaction of the 1,3-diketones 1a, b themselves.

EXPERIMENTAL

The IR spectra were recorded in a Specord IR-75 spectrometer in the 400-4000 cm⁻¹ interval, with the samples suspended in white mineral oil. The PMR spectra were measured in a Tesla BS-567 A spectrometer (100 MHz), in DMSO-d₆, relative to TMS. The column chromatography was carried out on silica gel L 100/250 with MeOH as eluent. The thin-layer chromatography was carried out on Silufol UV-254 plates in MeOH.

Reaction of 1,1,1-Trifluoro-2,4-pentanedione (1a) with Diethylenetriamine. Method 1. A mixture of 2.3 g (15 mmoles) of trifluoroacetylacetone (TFAA) 1a, 2.0 g (5 mmoles) of dien \cdot 3HClO₄, and 1.0 g (10 mmoles) of anhydrous dien was heated at 120-150 °C or on a steam bath (100 °C) for 8 h. The reaction mass was dissolved in a minimum quantity of alcohol, an alcoholic KOH solution was added to bring the pH to 10-11, the reaction mixture was filtered to remove KClO₄, and the solvent was driven off. After column chromatography, obtained 1.85 g of resinous 3a. By reprecipitation from MeOH by adding water, obtained 1.8 g (82%) of 3a, mp 163-165 °C. Found, %: C 32.85; H 3.78; F 39.01; N 14.00. C₈H₁₁F₆N₃O₂. Calculated, %: C 32.55; H 3.76; F 38.61; N 14.24. IR spectrum (ν , cm⁻¹): 3400, 3270, 1520 (NH), 1670 (C=O). PMR spectrum (δ , ppm): 3.20 m (CH₂, 4H), 3.03 m (CH₂, 4H), 1.25 br.s (NH, 3H).

Method 2. A mixture of 0.77 g (0.5 mmole) of **1a** and 0.5 g (0.5 mmole) of anhydrous dien was held 4 days in a capsule at 25°C under an initial pressure $P_i = 6666$ and final pressure $P_f = 3000$ atm. From the resulting resinous product, after column chromatography, recovered 0.4 g (54%) of **3a**, mp 163-165°C.

Reaction of 1,1,2,2-Tetrafluoro-3,5-hexanedione (1b) with Diethylenetriamine. By means of method 1, from 2.6 g (15 mmoles) of **1b**, 2.0 g (5 mmoles) of dien \cdot 3HClO₄, and 1.0 g (10 mmoles) of anhydrous dien, obtained 3.0 g (83%) of 3b, mp 138-139°C. Found, %: C 33.40; H 3.65; F 42.40; N 11.47. C₁₀H₁₃F₈N₃O₂. Calculated, %: C 33.45; H 3.65; F 42.31; N 11.70. IR spectrum (ν , cm⁻¹): 3300, 1520 (NH), 1660 (C=O). PMR spectrum (δ , ppm, *J*, Hz): 6.33 t.t (H(C₂F₂)₂, 2H, $^2J_{\text{HF}} = 51.25$, $^3P_{\text{HF}} = 6.25$), 3.33 m (CH₂, 4H), 2.88 m (CH₂, 4H), 1.23 br.s (NH, 3H).

Reaction of Methyl-3-hydroxy-4,4,5,5-tetrafluoropentenoate (2b) with Diethylenetriamine. Analogously, from 3.0 g (15 mmoles) of **2b**, 2.0 g (5 mmoles) of dien \cdot 3HClO₄, and 1.0 g (10 mmoles) of anhydrous dien, obtained 2.4 g (90%) of **3b**, mp 138-139°C. Found, %: C 33.40; H 3.25; F 42.75; N 11.78. C₁₀H₁₃F₈N₃O₂. Calculated, %: C 33.45; H 3.65; F 42.75; N 11.70.

Reaction of 1,1,1-Trifluoro-2,4-pentanedione (1a) with Triethylenetetramine. Analogously, from 3.1 g (20 mmoles) of 1a, 2.7 g (5 mmoles) of trien \cdot 4HClO₄, and 2.2 g (15 mmoles) of anhydrous trien, obtained 3.2 g (86%) of 4a, mp 143-144°C. Found, %: C 32.00; H 4.68; F 30.18; N 15.56. C₁₀H₁₆F₆N₄O₂. Calculated, %: C 32.44; H 4.36; F 30.79; N 15.13. IR spectrum (ν , cm⁻¹): 3250, 1570 (NH), 1675 (C=O). PMR spectrum (δ , ppm): 2.64 m (CH₂, 4H), 2.97 m (CH₂, 4H), 3.27 m (CH₂, 4H), 9.34 br.s (NH, 2H), 7.03 br.s (NH, 2H).

Reaction of Copper Bis(1,1,1-trifluoro-2,4-pentanedionate (5a) with Diethylenetriamine. *Method 3.* A 3.7g quantity (10 mmoles) of **5a** in 50 ml of CHCl₃ was mixed with 7.5 g (75 mmoles) of anhydrous dien. The mixture was refluxed for 2 h. The colorless lower layer (chloroform) was drawn off; the upper layer (a mixture of $[Cu(dien)_2]^{2+}$, dien, and water from the reaction) was washed with 30 ml of CHCl₃ and then combined with the lower layer, after which the solvent was driven off. After column chromatography, obtained **8a** and **3a**.

The 8a was reprecipitated from CHCl₃ by hexane. Yield 1.1 g (29%), mp 125-126°C. Found, %: C 44.67; H 5.44; F 30.66; N 10.96. $C_{14}H_{19}F_6N_3O_2$. Calculated, %: C 44.80; H 5.10; F 30.40; N 11.20. IR spectrum (ν , cm⁻¹): 3350, 1580 (NH), 1620, 1560 (C=C, C=O). PMR spectrum (δ , ppm): 2.31 s (CH₃, 6H), 3.05 m (CH₂, 4H), 4.09 m (CH₂, 4H), 5.50 s (CH, 2H), 10.96 br.s (NH, 3H). $R_f = 0.82$.

The 3a was reprecipitated from MeOH by water. Yield 0.59 g (20%), mp 163-165°C, $R_f = 0.53$.

Method 4. A mixture of 3.7 g (10 mmoles) of 5a, 4.13 g (40 mmoles) of anhydrous dien, and 4.04 g (10 mmoles) of dien \cdot 3HClO₄ in 50 ml of CHCl₃ was refluxed for 2 h; the chloroform layer was drawn off, and the solvent was removed. After column chromatography and appropriate reprecipitation, analogous to method 3, obtained 1.31 g (35%) of 8a, mp 125-126°C, and 0.47 g (16%) of 3a, mp 163-165°C.

Reaction of Copper Bis(1,1,2,2-tetrafluoro-3,5-hexanedionate) (5b) with Diethylenetriamine. By method 3, from 4.3 g (10 mmoles) of 5b and 7.5 g (75 mmoles) of anhydrous dien, obtained 1.0 g (23%) of 8b and 0.85 g (24%) of 3b, mp 138-139°C, $R_f = 0.56$.

8b, mp 59-60 °C. Found, %: C 43.90; H 4.80; F 34.69; N 10.11. $C_{16}H_{21}F_8N_3O_2$. Calculated, %: C 43.74; H 4.82; F 34.59; N 9.57. IR spectrum (ν , cm⁻¹): 3380, 1575 (NH), 1610, 1530 (C=C, C=O). PMR spectrum (δ , ppm, J, Hz): 2.12 s (CH₃, 6H), 3.40 m (CH₂, 8H), 5.35 s (CH, 2H), 6.60 t.t (H(CF₂)₂, 2H, ²J_{HF} = 50.77; ³J_{HF} = 6.92), 11.12 br.s (NH, 1H), 9.20 br.s (NH, 2H), $R_f = 0.76$.

Reaction of Copper Bis(1,1,1-trifluoro-2,4-pentanedionate) (5a) with Triethylenetetramine. By method 3, from 3.7 g (10 mmoles) of 5a and 7.3 g (50 mmoles) of anhydrous trien, obtained 1.1 g (26%) of 9a and 0.85 g (25%) of 4a, mp 143-144°C, $R_f = 0.41$.

9a, mp 141-142°C. Found, %: C 46.43; H 6.14; F 26.89; N 12.84. $C_{16}H_{24}F_6N_4O_2$. Calculated, %: C 45.93; H 5.78; F 27.24; N 13.39. IR spectrum (ν , cm⁻¹): 3350, 1560 (NH), 1630, 1530 (C=C, C=O). PMR spectrum (δ , ppm): 2.10 s (CH₃, 6H), 2.79 m (CH₂, 6H), 3.45 m (CH₂, 6H), 5.25 s (CH, 2H), 1.23 m (NH, 2H), 10.94 br.s (NH, 2H), $R_f = 0.60$.

By method 4, from 3.7 g (10 mmoles) of 5a, 5.85 g (40 mmoles) of anhydrous trien, and 5.48 g (10 mmoles) of trien \cdot 4HClO₄, obtained 1.34 g (32%) of 9a and 0.68 g (20%) of 4a.

Reaction of Copper Bis(1,1,2,2-tetrafluoro-3,5-hexanedionate) with Triethylenetetramine. By method 3, from 4.3 g (10 mmoles) of 5b and 7.3 g (50 mmoles) of anhydrous trien, obtained 1.0 g (21%) of 9b and 1.1 g (28%) of 4b.

9b, mp 128-130 °C. Found, %: C 44.71; H 5.78; F 31.49; N 12.16. $C_{18}H_{26}F_8N_4O_2$. Calculated, %: C 44.82; H 5.43; F 31.50; N 11.61. IR spectrum (ν , cm⁻¹): 3380, 1550 (NH), 1620, 1530 (C=C, C=O). PMR spectrum (δ , ppm; J, Hz): 2.10 s (CH₃, 6H), 3.38 m (CH₂, 12H), 5.35 s (CH, 2H), 6.62 t.t (H(CF₂)₂, 2H, ²J_{HF} = 52.0, ³J_{HF} = 5.9), 11.02 br.s (NH, 4H). $R_f = 0.58$.

4b, mp 116-117°C. Found, %: C 35.48; H 4.87; F 37.41; N 14.08. $C_{12}H_{18}F_8N_4O_2$. Calculated, %: C 35.83; H 4.51; F 37.78; N 13.93. IR spectrum (ν , cm⁻¹): 3300, 1560 (NH), 1670 (C=O).

Reaction of Copper Bis(ethyl-3-hydroxy-4,4,4-trifluoro-2-butenoate) (10a) with Triethylenetetramine. A mixture of 2.1 g (5 mmoles) of 10a and 3.6 g (25 mmoles) of anhydrous trien in 50 ml of $CHCl_3$ was held 24 h at 25°C; the chloroform layer was drawn off, and the solvent was removed. After column chromatography and reprecipitation from MeOH by water, obtained 0.94 g (51%) of 4a, mp 143-144°C.

Preparation of Adduct 6a. To 0.37 g (1 mmole) of 5a in 10 ml of $CHCl_3$, 0.2 g (2 mmoles) of anhydrous dien was added. Hexane was added to precipitate a violet-colored, oily liquid (bottom layer), which was separated off and vacuum-dried. Obtained 0.57 g (99%) of 6a, T_{decomp} 125-126°C. Found, %: C 37.97; H 6.22; F 19.32; N 14.93. $C_{18}H_{34}F_6N_6O_4Cu$. Calculated, %: C 37.53; H 5.95; F 19.79; N 14.59. IR spectrum (ν , cm⁻¹): 3250, 1530 (NH), 1620 (C=O).

Preparation of Adduct 7a. Analogously, from 0.37 g (1 mmole) of 5a and 0.15 g (1 mmole) of anhydrous trien, obtained 0.44 g (995) of 7a in the form of a violet-colored, oily liquid, T_{decomp} 134-136°C. Found, %: C 37.28; H 5.48; F 21.96; N 11.35. $C_{16}H_{26}F_6N_4O_4Cu$. Calculated, %: C 37.25; H 5.08; F 22.09; N 10.86. IR spectrum (ν , cm⁻¹): 3390, 3220, 1560 (NH), 1620 (C=O).

Preparation of Adduct 11a. Analogously, from 0.42 g (1 mmole) of 10a and 0.15 g (1 mmole) of trien, obtained 0.57 g (99%) of 11a in the form of a blue precipitate, T_{decomp} 138-139°C. Found, %: C 37.96; H 5.69; F 19.34; N 10.15. $C_{18}H_{30}F_6N_4O_6Cu$. Calculated, %: C 37.53; H 5.25; F 19.79; N 9.73. IR spectrum (ν , cm⁻¹): 3450, 3250, 1565 (NH), 1670 (C=O).

Reaction of Copper Bis(methyl-3-hydroxy-4,4,5,5,6,6,7,7-octafluoro-2-heptenoate) (10c) with Ethylenediamine. Upon mixing 3.32 g (5 mmoles) of 10c and 3.0 g (50 mmoles) of en in 30 ml of CHCl₃, obtained stable 12c in the form of a lilac-colored precipitate. This was filtered off, washed with CHCl₃, and vacuum-dried. Obtained 3.9 g (100%) of 12c, T_{decomp}

149-150°C. Found, %: C 30.50; H 3.70; F 3.20; N 7.28. $C_{20}H_{26}F_{16}N_4O_6Cu$. Calculated, %: C 30.56; H 3.33; F 38.67; N 7.13. IR spectrum (ν , cm⁻¹): 3280, 3070, 1560 (NH), 1670 (C=O).

The 12c in CHCl₃ was refluxed 2 h, and the mixture was filtered to remove the unreacted 12c; the filtrate was washed with water, the solvent was driven off, and 13c was precipitated from MeOH by water. Obtained 2.15 g (55%) of 13c, mp 128-129°C. Found, %: 27.77; H 1.56; F 59.38; N 6.00. $C_{12}H_8F_{16}N_2O_2$. Calculated, %: C 27.92; H 1.56; F 58.89; N 5.43. IR spectrum (ν , cm⁻¹): 3300, 1540 (NH), 1685 (C=O). PMR spectrum (δ , ppm, J, Hz): 3.37 br.s (CH₂, 4H), 7.37 t.t (H(CF₂)₂, 2H, ²J_{HF} = 50.45; ³J_{HF} = 5.60), 9.38 br.s (NH, 2H).

Reaction of Copper Bis(methyl-3-hydroxy-4,4,4-trifluoro-2-butenoate) (10a) with Ethylenediamine. A mixture of 2.0 g (5 mmoles) of 10a and 3.0 g (50 mmoles) of en in 50 ml of CHCl₃ was held for 1 day at 25°C. The chloroform layer was separated off, washed with water, and the solvent was driven off; the residue was reprecipitated from MeOH by ether. Obtained 0.62 g (49%) of 13a, mp 168-170°C. Found, %: C 28.69; H 2.37; F 45.42; N 10.89. C₆H₆F₆N₂O₂. Calculated, %: C 28.58; H 2.40; F 45.21; N 11.11. IR spectrum (ν , cm⁻¹): 3200, 1555 (NH), 1700 (C=O). PMR spectrum (δ , ppm): 3.58 br.s (CH₂, 4H), 8.65 br.s (NH, 2H).

Reaction of Copper Bis(methyl-3-hydroxy-4,4,5,5-tetrafluoro-2-pentenoate (10b) with Ethylenediamine. Analogously, from 2.3 g (5 mmoles) of 10b and 3.0 g (50 mmoles) of en, with subsequent reprecipitation from MeOH by water, obtained 0.8 g (51 %) of 13b, mp 154-156°C. Found, %: C 30.82; H 2.61; F 48.45; N 8.46. C₈H₈F₈N₂O₂. Calculated, %: C 30.39; H 2.55; F 48.07; N 8.86. IR spectrum (ν , cm⁻¹): 3300, 1555 (NH), 1690 (C==O). PMR spectrum (δ , ppm, J, Hz): 3.36 br.s (CH₂, 4H), 6.68 t.t (H(CF₂)₂, 2H, ²J_{HF} = 51.60, ³J_{HF} = 5.60), 9.27 br.s (NH, 2H).

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