# Synthesis and Structure of 2,2,2-Nitrilotriacetyl Chloride with a Flat NC₃ Pyramide

Thomas M. Klapötke, Burkhard Krumm and Richard Moll

Department of Chemistry, Ludwig-Maximilian University of Munich, Butenandtstr. 5 – 13 (D), 81377 Munich, Germany

Reprint requests to Prof. Dr. Thomas M. Klapötke. Fax: +49-89-2180-77492. E-mail: tmk@cup.uni-muenchen.de

*Dedicated to Professor Heinrich Nöth on the occasion of his 85th birthday*

The reaction of 2,2,2-nitrilotriacetic acid with phosphorus pentachloride furnished 2,2,2-nitrilotriacetyl chloride (**1**), a useful chemical intermediate for various further reactions. The compound has been fully characterized by multinuclear NMR spectroscopy, vibrational analysis (IR and Raman), mass spectrometry and elemental analysis. Furthermore, the crystal structure of **1** has been determined and discussed thoroughly, showing a NC₃ unit with an unusual, nearly planar configuration.

## Introduction

The title compound 2,2,2-nitrilotriacetyl chloride (**1**) is useful as a chemical precursor for the preparation of various ester or (carbox-) amide compounds. The former compounds are synthesized using appropriate alcohols and the latter by reaction with suitable amines. The acid chloride **1** is best synthesized from 2,2,2-nitrilotriacetic acid, a very widely used complexant, and has been only briefly described prior to this study [1 – 4]. Our general interest in these types of compounds, especially containing polynitro groups [5 – 7], prompted us to re-investigate 2,2,2-nitrilotriacetyl chloride (**1**). In this contribution, a detailed study of the synthesis, characterization and the crystal structure is presented.

## Results and Discussion

The synthesis of 2,2,2-nitrilotriacetyl chloride (**1**) is performed by a chlorination reaction of 2,2,2-nitrilotriacetic acid with stoichiometric amounts of phosphorus pentachloride (Scheme 1) [1]. The chlorination reaction starts rapidly upon heating the mixture, and therefore a slow and careful heating is recommended to avoid a fierce reaction. The formation of gaseous hydrogen chloride is used to clearly monitor the progress and the end of the reaction. To avoid hydrolysis of the product, a work-up at lower temperatures is required. Therefore, in contrast to the previously reported synthesis [1], the solvent carbon tetrachloride is used instead of benzene, which allows to perform the subsequent work-up at 0 °C.

Multinuclear NMR spectroscopy of **1** showed in the $^1$H NMR spectrum the resonance for the methylene group at 4.08 ppm. The resonances of the $^{13}$C nuclei are found at 171.9 ppm for the carbonyl carbons and at 64.4 ppm for the methylene carbons. The $^{15}$N NMR resonance is observed at $-350.6$ ppm.

The vibrational analysis of the acid chloride **1** revealed C=O stretching vibrations between 1801 and 1766 cm$^{-1}$, in agreement with the typical range and intensities for carboxylic acid chlorides [8]. This stretching vibration shows splitting (in-phase and out-of-phase), both in the Raman (1801 and 1774 cm$^{-1}$) and IR spectra (1797 and 1766 cm$^{-1}$). Compared to the starting material 2,2,2-nitrilotriacetic acid ($\nu$ CO = 1716 cm$^{-1}$), the C=O stretching vibration of the acid chloride **1** is found at higher frequencies. The C–Cl stretching vibration occurs at 782 cm$^{-1}$ (Raman) and 771 cm$^{-1}$ (IR). The bands with high intensity in the Raman spectrum at 450 and 439 cm$^{-1}$ are assigned to the Cl–C=O in-plane deformation vibration [8]. The C–H stretching vibrations were found in the range of 2973 – 2850 cm$^{-1}$.

A single crystal suitable for X-ray diffraction measurements was obtained by re-crystallization of **1** from *n*-hexane (crystallographic refinement parameters and structure data see Experimental Section). Compound **1** crystallizes in the orthorhombic space group *Pbca* with eight formula units per unit cell (Fig. 1). While the starting material 2,2,2-nitrilotriacetic acid [9, 10] exists in a zwitterionic form in the crystal, this is not possible for **1**. The molecule does not display a crystallo-
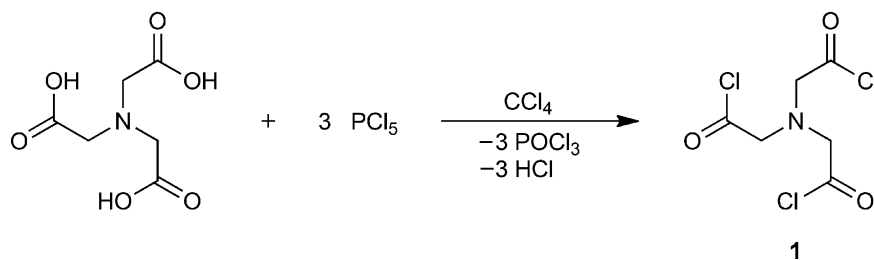
Scheme 1. Synthesis of 2,2,2-nitrilotriacetyl chloride (**1**).
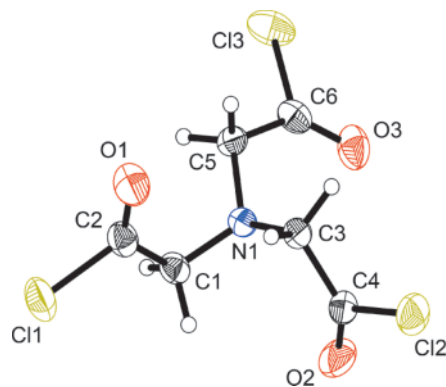


Fig. 1. Molecular structure of **1**. Selected distances (Å) and angles (deg): N1–C1 1.439(3), C1–C2 1.509(3), C2–O1 1.175(3), C2–Cl1 1.779(2), N1–C3 1.450(3), C3–C4 1.497(3), C4–O2 1.170(3), C4–Cl2 1.792(2), N1–C5 1.446(3), C5–C6 1.500(3), C6–O3 1.174(3), C6–Cl3 1.789(2); N1–C1–C2 114.5(2), C1–C2–O1 127.9(2), C1–C2–Cl1 111.5(2), N1–C3–C4 112.3(2), C3–C4–O2 129.5(2), C3–C4–Cl2 109.5(2), N1–C5–C6 111.1(2), C5–C6–O3 128.2(2), C5–C6–Cl3 111.5(2), C1–N1–C3 114.9(2), C1–N1–C5 115.5(2), C3–N1–C5 116.1(2).
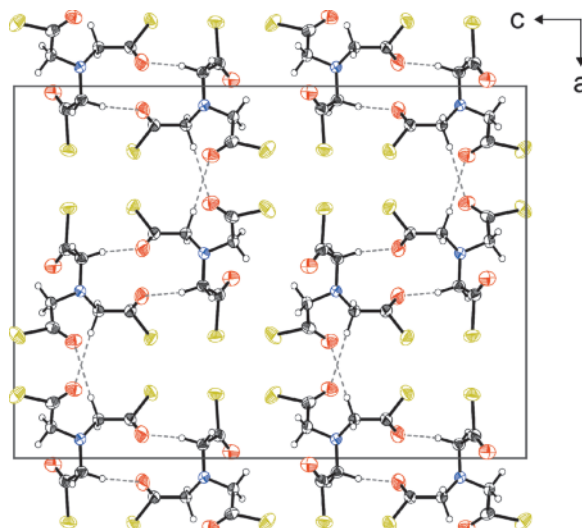


Fig. 2. Unit cell of **1**, viewing direction along the $b$ axis. Dashed lines display intermolecular hydrogen bonds along the $a$ axis (2.52 Å) and $c$ axis (2.61 Å).

graphic threefold axis ($C_3$ symmetry) passing through the amine center, since the acetyl chloride moieties are all inequivalent. The C–N bond lengths are between 1.439(3) and 1.450(3) Å, slightly shorter compared to 2,2,2-nitrilotriacetic acid [10] and to a regular C–N single bond (1.469 Å) [11]. This derives from the partial double bond character of the C–N bond, resulting to some extent in an iminium C–N=C resonance structure.

The central nitrogen atom is bound to three carbon atoms, and the C–N–C angles are in the range of 114.9(2)–116.1(2)°. For the sum of these angles a value of 346.5° is obtained. Therefore, this value is between 360° for an ideal planar arrangement and 328.5° for a pyramidal (pseudotetrahedral) arrange-

ment [12]. The nitrogen atom shows a distance of 0.312(2) Å from the C1 C3 C5 plane. For comparison, the C–N bond lengths and the C–N–C angles of selected trimethyleneamine compounds with a similar bonding situation are shown in Table 1. A view of the unit cell displays intermolecular hydrogen bonding between the molecules of **1** (Fig. 2) with contact distances of 2.52 and 2.61 Å, slightly smaller than the sum of the van der Waals radii for hydrogen and oxygen (2.62 Å) [13, 14].

## Conclusion

2,2,2-Nitrilotriacetyl chloride (**1**), an interesting precursor for further studies, has been prepared and iso-

| | N(CH$_2$COCl)$_3$ (**1**) | N(CH$_2$COOH)$_3$ [10] | N(CH$_2$Cl)$_3$ [15] | N(CH$_2$CF$_3$)$_3$ [16] |
|---|---|---|---|---|
| C–N | 1.439(3) | 1.499(2) | 1.409(4) | 1.460(3) |
| | 1.450(3) | 1.501(2) | 1.411(2) | 1.458(3) |
| | 1.446(3) | 1.499(1) | 1.411(2)[a] | 1.442(3) |
| | | | | |
| C–N–C | 114.9(2) | 113.6(1) | 119.5(2) | 114.5(2) |
| | 115.5(2) | 112.3(1) | 119.6(2) | 115.3(2) |
| | 116.1(2) | 113.2(1) | 119.6(2)[a] | 115.5(2) |
| $\sum$C–N–C[b] | 346.5 | 339.1 | 358.7 | 345.3 |

Table 1. Structural comparison (Å, deg) of the NC$_3$ units of selected, related trimethyleneamine compounds.

[a] Parameters generated by symmetry; [b] sum of all three C–N–C angles.

lated from the chlorination of 2,2,2-nitrilotriacetic acid with phosphorus pentachloride. In the crystal structure the nitrogen atom approaches a nearly planar configuration.

## Experimental Section

*General procedures*

All manipulations of air- and moisture-sensitive materials were performed under an inert atmosphere of dry nitrogen using flame-dried glass vessels and Schlenk techniques [17]. The solvent carbon tetrachloride was dried by standard methods and freshly distilled prior to use. 2,2,2-Nitrilotriacetic acid (Acros Organics) and phosphorus pentachloride (Merck Chemicals) were used as received. Raman spectra were recorded with a Bruker MultiRAM FT-Raman instrument fitted with a liquid nitrogen-cooled germanium detector and an Nd:YAG laser ($\lambda = 1064$ nm, 300 mW). Infrared spectra were measured with a Perkin-Elmer Spectrum BX-FTIR spectrometer equipped with a Smiths DuraSampl*IR* II ATR device. All spectra were recorded at ambient temperature, the samples were neat solids. NMR spectra were recorded of solutions in CDCl$_3$ at 25 °C with a Jeol Eclipse 400 ECX instrument, and chemical shifts were determined with respect to external Me$_4$Si ($^1$H, 400.2 MHz; $^{13}$C, 100.6 MHz), and MeNO$_2$ ($^{15}$N, 40.6 MHz). Mass spectrometric data were obtained with a Jeol MStation JMS 700 spectrometer (DEI+). The fragments are referred to the isotope with the highest natural abundance. Elemental analysis (C/H/N) was performed with an Elementar vario EL analyzer, the halogen (Cl) content was determined by titration using a Metrohm 888 Titrando. The melting point was determined using a Büchi Melting Point B-540 instrument and is uncorrected.

*Synthesis of 2,2,2-nitrilotriacetyl chloride (**1**)*

Into a suspension of 2,2,2-nitrilotriacetic acid (15.0 g, 78.5 mmol) in carbon tetrachloride (65 mL) is slowly added phosphorus pentachloride (49.9 g, 240 mmol) at ambient temperature under exclusion of moisture. After careful and slow heating of the mixture to 50 – 60 °C and stirring for 2 h

at this temperature, additional 100 mL of carbon tetrachloride is added. The reaction mixture is chilled to 0 °C, washed three times with ice-cold 200 mL of water, and dried over anhydrous magnesium sulfate. Removing of the solvent *in vacuo* left a pale-pink solid. Crystallization from *n*-hexane yielded 9.09 g (47 %) of the product as colorless crystalline needles. Melting point: 68 °C (dec.). – Raman: $v = 2973$ (39), 2928 (38), 2890 (17), 2850 (21), 1801 (16), 1774 (16), 1431 (12), 1411 (7), 1397 (10), 1365 (11), 1343 (6), 1331 (5), 1298 (2), 1243 (3), 1179 (3), 1166 (1), 993 (4), 974 (3), 933 (3), 868 (12), 782 (8), 744 (55), 509 (26), 490 (22), 467 (34), 450 (100), 439 (70), 362 (5), 297 (5), 265 (5), 226 (33), 205 (11), 188 (21) cm$^{-1}$. – IR: $v = 2972$ (m), 2928 (m), 2889 (m), 2853 (m), 1858 (w), 1797 (vs), 1766 (vs), 1735 (s), 1427 (m), 1410 (m), 1395 (m), 1364 (m), 1342 (m), 1329 (m), 1298 (w), 1242 (m), 1199 (m), 1178 (m), 1168 (m), 989 (m), 976 (w), 925 (s), 866 (m), 795 (m), 771 (s), 762 (s), 733 (m) cm$^{-1}$. – $^1$H NMR (CDCl$_3$): $\delta = 4.08$ (s, CH$_2$). – $^{13}$C{$^1$H} NMR (CDCl$_3$): $\delta = 171.9$ (COCl), 64.4 (CH$_2$). – $^{15}$N{$^1$H} NMR (CDCl$_3$): $\delta = -350.6$. – MS (DEI+): $m/z$ (%) = 245 (2) [M]$^+$, 182 (67) [M–COCl]$^+$, 154 (100) [(CH$_2$COCl)$_2$/NCH$_2$(COCl)$_2$]$^+$, 126 (57) [(COCl)$_2$]$^+$. – EA for C$_6$H$_6$Cl$_3$NO$_3$ (246.48): calcd. C 29.24, H 2.45, Cl 43.15, N 5.68; found C 29.19, H 2.44, Cl 42.48, N 5.65 %.

*Crystal structure determination of 2,2,2-nitrilotriacetyl chloride (**1**)*

An Oxford Xcalibur3 diffractometer with a CCD area detector was employed for the data collection using Mo$K_\alpha$ radiation ($\lambda = 0.71073$ Å). The structure was solved using Direct Methods (S$_{IR}$2004) [18, 19] and refined by full-matrix least-squares on $F^2$ (S$_{HELXL}$-97) [20, 21]. All non-hydrogen atoms were refined anisotropically. The hydrogen atoms were located in difference Fourier maps and placed with C–H distances of 0.99 Å for the CH$_2$ groups. O$_{RTEP}$ plots are drawn with displacement ellipsoids at the 50 % probability level. *Crystal structure data*: formula: C$_6$H$_6$Cl$_3$NO$_3$; $M_r = 246.48$ g mol$^{-1}$; crystal size: $0.53 \times 0.13 \times 0.11$ mm$^3$; crystal description: colorless rod; crystal system: orthorhombic; space group: *Pbca* (no. 61); $a = 15.8495(7)$; $b = 5.3934(3)$; $c = 23.1697(11)$ Å;

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