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CRYSTAL STRUCTURES AND CHARACTERIZATION OF TWO RARE-EARTH-GLUTARATE COORDINATION NETWORKS: ONE-DIMENSIONAL $[\text{Nd}(\text{C}_5\text{H}_6\text{O}_4)(\text{H}_2\text{O})_4] \cdot \text{Cl}$ AND THREE-DIMENSIONAL $[\text{Pr}(\text{C}_5\text{H}_6\text{O}_4)(\text{C}_5\text{H}_7\text{O}_4)(\text{H}_2\text{O})] \cdot \text{H}_2\text{O}$ **S. Hussain¹, I.U. Khan¹, W.T.A. Harrison², M.N. Tahir³**¹*Department of Chemistry, Government College University, Lahore, Pakistan*

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The synthesis, crystal structures, and characterization (IR, TGA/DSC) of $[\text{Nd}(\text{C}_5\text{H}_6\text{O}_4) \cdot (\text{H}_2\text{O})_4] \cdot \text{Cl}$ (**1**) and $\text{Pr}(\text{C}_5\text{H}_6\text{O}_4)(\text{C}_5\text{H}_7\text{O}_4)(\text{H}_2\text{O}) \cdot \text{H}_2\text{O}$ (**2**) are described. Compound **1** is a one-dimensional coordination polymer containing double chains incorporating pairs of edge-sharing NdO_9 polyhedra linked by glutarate dianions. A network of $\text{O} \cdots \text{H} \cdots \text{O}$ and $\text{O} \cdots \text{H} \cdots \text{Cl}$ hydrogen bonds helps to consolidate the structure. Compound **2** is a three-dimensional coordination polymer incorporating chains of edge-sharing PrO_{10} polyhedra. Its glutarate ion adopts an extended conformation, whereas its hydrogen glutarate ion takes on a twisted conformation. $\text{O} \cdots \text{H} \cdots \text{O}$ hydrogen bonds are seen in the crystal structure, which features small channels occupied by water molecules. Crystal data: **1**, $\text{C}_5\text{H}_{14}\text{ClNdO}_8$, $M_r = 381.85$, monoclinic, $P2_1/c$ (No. 14), $a = 8.9763(6) \text{ \AA}$, $b = 15.9277(11) \text{ \AA}$, $c = 8.8690(6) \text{ \AA}$, $\beta = 112.090(2)^\circ$, $V = 1174.94(14) \text{ \AA}^3$, $Z = 4$, $R(F) = 0.016$, $wR(F^2) = 0.037$. **2**, $\text{C}_{10}\text{H}_{17}\text{O}_{10}\text{Pr}$, $M_r = 438.15$, orthorhombic, $Pbca$ (No. 61), $a = 16.3030(7) \text{ \AA}$, $b = 8.6714(4) \text{ \AA}$, $c = 19.3899(8) \text{ \AA}$, $V = 2741.1(2) \text{ \AA}^3$, $Z = 8$, $R(F) = 0.020$, $wR(F^2) = 0.050$.

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Keywords: synthesis, crystal structure, coordination polymer, neodymium, praseodymium.**INTRODUCTION**

Glutaric acid $\text{HO}_2\text{C}(\text{CH}_2)_3\text{CO}_2\text{H}$ (H_2glut or $\text{C}_5\text{H}_8\text{O}_4$) has applications in polymer chemistry [1] and can form liquid crystals [2]. In its doubly-deprotonated form (glu^{2-}), it is a versatile bridging ligand with a flexible backbone and many coordination polymers have been reported in combination with both transition metal and rare-earth cations [3–8].

In this paper, as an extension of these studies, we describe the syntheses, characterizations, and single crystal structures of two rare-earth glutarate networks: $[\text{Nd}(\text{C}_5\text{H}_6\text{O}_4)(\text{H}_2\text{O})_4] \cdot \text{Cl}$ (**1**) and $[\text{Pr}(\text{C}_5\text{H}_6\text{O}_4)(\text{C}_5\text{H}_7\text{O}_4)(\text{H}_2\text{O})] \cdot \text{H}_2\text{O}$ (**2**).

MATERIALS AND METHODS

Synthesis of 1. 0.500 mmol (0.179 g) of $\text{NdCl}_3 \cdot 6\text{H}_2\text{O}$ was dissolved in 10 ml distilled water and 2.00 mmol (0.264 g) of glutaric acid was dissolved in 15 ml ethanol. Five drops of a 1 N NaOH solution was added to raise the pH of the glutaric acid solution. The solutions were mixed and stirred for

1 h at room temperature. The mixture was filtered and kept at room temperature for crystallization. After 10 days, pink blocks of **1** were recovered in 43 % yield by filtration and rinsing with ethanol. Anal. calc. (%) for $C_5H_{15}O_{10}NdCl$: C 14.57, H 3.63; found: C 15.02, H 3.74.

Synthesis of 2. 0.500 mmol (0.187 g) of $PrCl_3 \cdot 6H_2O$ was dissolved in 10 ml distilled water and 2.00 mmol (0.264 g) of glutaric acid was dissolved in 15 ml ethanol. Eight drops of a 1 N NaOH solution was added to raise the pH of the glutaric acid solution. The solutions were mixed and stirred for 1 h at room temperature. The mixture was filtered and kept at room temperature for crystallization. After 10 days, light green needles of **2** were recovered by vacuum filtration and rinsing with ethanol (yield = 48 %). Anal. calc. (%) for $C_{10}H_{16}O_{10}Pr$: C 27.47, H 3.68; found: C 28.12, H 3.85.

Physical measurements. The IR spectra of **1** and **2** were recorded on a Perkin—Elmer FTIR 180 spectrophotometer using KBr pellets over the frequency range 4000—400 cm^{-1} . Elemental analyses for C, H, and N were performed on a Varian Micro-Cube Analyzer. Thermal analyses (25—1200 °C) were recorded under a continuous N_2 flow with a ramp rate of 10 °C \cdot min $^{-1}$ using a DSC/TGA model SDT Q 600, TA Instruments, USA. Alumina crucibles were used for recording the TG-DSC curves.

Crystal structure determinations. Intensity data for **1** (pale pink block, 0.32×0.15×0.14 mm) and **2** (pale green needle, 0.30×0.05×0.05 mm) were collected at room temperature using a Bruker Apex II CCD diffractometer (MoK_{α} radiation, $\lambda = 0.71073$ Å). Multi-scan absorption corrections (transmission-factor ranges for **1** and **2** = 0.317—0.561 and 0.411—0.840 respectively) were made with SADABS [9] during data reduction. The structures were routinely solved by direct methods with SHELXS-97 [7] in space group $P2_1/c$ for **1** and $Pbca$ for **2** and the structural models were developed and refined against $|F|^2$ using SHELXL-97 [10]. For both structures, the C-bound H atoms were geometrically placed (C—H = 0.97 Å) and refined as riding atoms. The water H atoms were located in difference maps and refined as riding atoms in their as-found relative positions. The carboxylic acid H atom in **2** was located in a different map and its position freely was refined. The constraint $U_{iso}(H) = 1.2U_{eq}(\text{carrier})$ was applied in all cases. Molecular graphics were generated with ORTEP-3 [11] and ATOMS [12]. Crystal data for **1** and **2** are summarized in Table 1 and full details are available as supplementary material (CIF format).

Table 1

Crystallographic and data collection parameters

Parameters	1	2
Empirical formula	$C_5H_{14}ClNdO_8$	$C_{10}H_{17}O_{10}Pr$
Formula weight	381.85	438.15
Crystal system	Monoclinic	Orthorhombic
Space group	$P2_1/c$ (No. 14)	$Pbca$ (No. 61)
$a, b, c, \text{Å}$	8.9763(6), 15.927(11), 8.8690(6)	16.3030(7), 8.6714(4), 19.3899(8)
$\beta, \text{deg.}$	112.090(2)	90
$V, \text{Å}^3$	1174.94(14)	2741.1(2)
Z	4	8
$\rho_{\text{calc}}, \text{g/cm}^3$	2.159	2.123
μ, mm^{-1}	4.666	3.605
Data scanned	10837	21847
Unique data	2902	3409
R_{int}	0.025	0.030
$R(F)$	0.016	0.020
$wR(F^2)$	0.037	0.050
Min, max $\Delta\rho, e/\text{Å}^3$	−0.65, +0.75	−0.91, +0.71

RESULTS

Infrared spectra. The IR spectrum of **1** shows strong, sharp bands at 1640 cm^{-1} , 1528 cm^{-1} , and 1437 cm^{-1} , which we attribute to the bridging symmetric, bidentate symmetric, and asymmetric stretching vibrations of the carboxylate group respectively [13]. These assignments are consistent with the different bonding modes of the glutarate ion in the crystal structure of **1** (*vide infra*). The C=O stretch in free glutaric acid occurs at 1699 cm^{-1} . A strong, very broad band centered around 3350 cm^{-1} in **1** corresponds to the O—H vibrations of hydrogen bonded water molecules and a cluster of weak, overlapped bands around 645 cm^{-1} can be tentatively assigned to Nd—O bond vibrations [14].

The corresponding carboxylate peaks for **2** occur at 1661 cm^{-1} , 1530 cm^{-1} , and 1435 cm^{-1} respectively. The very broad water stretch is centered around 3340 cm^{-1} and a group of weak, overlapping peaks corresponding to Pr—O bond vibrations occur around 660 cm^{-1} .

Thermal analysis. TGA for **1** showed thermal stability to about $110\text{ }^{\circ}\text{C}$, followed by a weight loss of 18 %, which was completed by $240\text{ }^{\circ}\text{C}$. This is in good agreement with a decomposition scheme that loses the four water molecules from **1** (calc. = 19 %). The residue is stable until about $350\text{ }^{\circ}\text{C}$, at which point it starts to lose a further ~32 % weight over a broad temperature range to ~ $1200\text{ }^{\circ}\text{C}$ (the limit of operation of the instrument). The calculated total mass loss to give a residue of "NdOCl" is 49 %.

TGA for **2** showed an 8 % weight loss between ~ $80\text{ }^{\circ}\text{C}$ and $150\text{ }^{\circ}\text{C}$ (presumed loss of all water; calc. = 8 %), a further loss of 15 % between $200\text{ }^{\circ}\text{C}$ and $350\text{ }^{\circ}\text{C}$ (intermediate unknown) and then between $400\text{ }^{\circ}\text{C}$ and $1200\text{ }^{\circ}\text{C}$ (the limit of operation of the instrument), another 32 % weight loss (total loss = 55 %). The calculated weight loss for **1** transforming to $1/2\text{ Pr}_2\text{O}_3$ is 63 %.

Crystal structure of 1. Compound **1** is a one-dimensional coordination polymer: its asymmetric unit (Fig. 1) contains one Nd^{3+} ion, one doubly-deprotonated $\text{C}_5\text{H}_6\text{O}_4^{2-}$ glutarate ion, a chloride ion, and four water molecules. When symmetry-generated oxygen atoms are considered, the neodymium ion is coordinated by nine O atoms arising from two O,O-bidentate glutarate ions, an O-monodentate glutarate ion, and four water molecules. The mean Nd—O bond distance is 2.493 \AA (the next-nearest O atom is farther than 4.25 \AA distant) and the bond valence sum (BVS) [15] for the metal ion is 3.28 \AA (expected value = 3.00 \AA). If it is not assumed to be irregular, its coordination geometry can be just described as an extremely distorted capped square anti-prism [16] (Fig. 2), with the square faces defined by O2/O3ⁱ/O5/O6 and O3ⁱⁱ/O4ⁱⁱ/O7/O8 (Table 2, symmetry codes): the dihedral angle between

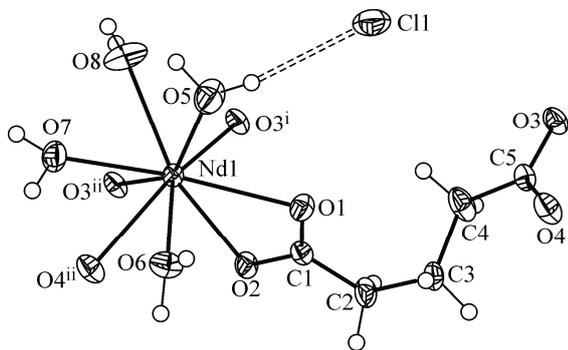


Fig. 1. Asymmetric unit of **1**, with atoms added to complete the Nd coordination polyhedron, showing 50 % displacement ellipsoids. The O—H···Cl hydrogen bond is shown as a double-dashed line. Symmetry codes as in Table 2

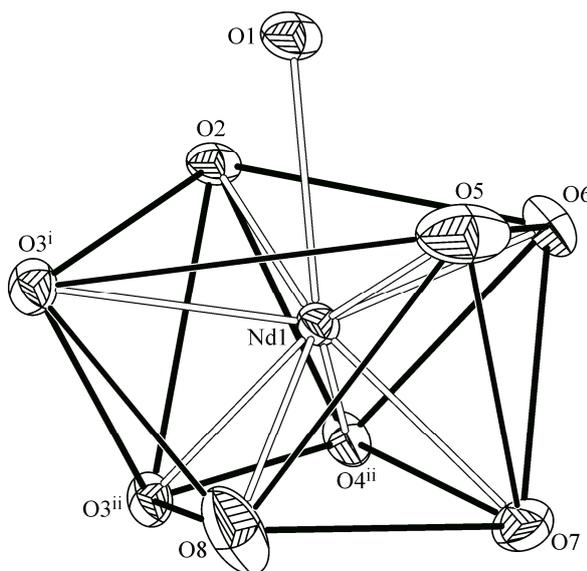


Fig. 2. Nd1 coordination polyhedron in **1**. Symmetry codes as in Table 2

Table 2

Selected bond lengths (Å) and angles (deg.) for **1**

Nd1—O6	2.4433(15)	O5—H5A···C11	0.83	2.36	3.1909(17)	172
Nd1—O3 ⁱ	2.4791(15)	O5—H5B···C11 ⁱⁱⁱ	0.87	2.33	3.1579(18)	158
Nd1—O8	2.4824(16)	O6—H6A···O1 ^{iv}	0.84	1.90	2.733(2)	172
Nd1—O1	2.5229(14)	O6—H6B···C11 ^{iv}	0.89	2.24	3.0930(16)	162
Nd1—O4 ⁱⁱ	2.5484(14)	O7—H7A···O4 ^{iv}	0.86	1.91	2.767(2)	172
Nd1—O7	2.4677(15)	O7—H7B···C11 ⁱⁱ	0.84	2.36	3.1854(16)	166
Nd1—O5	2.4818(16)	O8—H8A···O2 ^v	0.81	1.91	2.679(2)	158
Nd1—O2	2.4838(15)	O8—H8B···C11 ⁱⁱⁱ	0.85	2.31	3.1020(17)	156
Nd1—O3 ⁱⁱ	2.5313(15)					
C1—O1	1.260(2)	C1—C2—C3—C4	−70.1(3)			
C5—O4	1.249(2)	C2—C3—C4—C5	169.90(19)			
C1—O2	1.268(2)					
C5—O3	1.282(2)					

For the hydrogen bonds, the four values correspond to the $D-H$, $H\cdots A$, and $D\cdots A$ separations (Å) and the $D-H\cdots A$ angle (deg), respectively.

Symmetry codes: ⁱ $1-x, 1-y, 1-z$; ⁱⁱ $x, y, z+1$; ⁱⁱⁱ $x, 1/2-y, z+1/2$; ^{iv} $-x, 1-y, 1-z$; ^v $1-x, 1-y, 2-z$.

them is $7.35(5)^\circ$. The faces are displaced by $-1.5556(8)$ Å and $0.8500(8)$ Å respectively from the metal atom, and O1 serves as the capping atom. It is notable that all the water O atoms lie on one side of the coordination sphere.

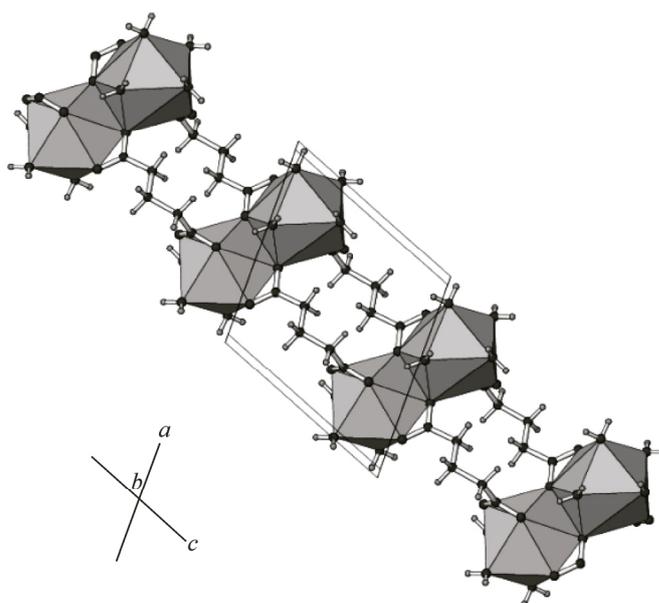
The glutarate ion in **1** is twisted: the C1—C2—C3—C4 fragment has a *gauche* conformation and the C2—C3—C4—C5 fragment has an *anti* conformation (Table 2). The dihedral angle between the C1/O1/O2 and C5/O3/O4 carboxylate groups at each end of the ion is $84.00(16)^\circ$.

The bonding modes of the two carboxylate groups of the glutarate ion are different: the C1/O1/O2 group is chelating bidentate to a single metal ion and the C5/O3/O4 group is bridging bidentate (O, μ^2-O') to two metal ions. The displacements of the chelated metal ions from the C1 and C5 carboxylate groups are $-0.119(9)$ Å and $-0.200(9)$ Å respectively. The C—O bond lengths of the C1-containing carboxylate group are almost the same length, whereas the C—O lengths for the C6 grouping are distinctly different (Table 2), with the longer C6—O3 bond representing the μ^2-O atom, which is consistent with the previous results [6]. In the ligand, the terminal C—C_c ($c = \text{carboxylate}$) bond lengths (mean = 1.496 Å) are slightly shorter than the intermediate bond lengths (mean = 1.520 Å), which follows the trend seen in an analysis of bond lengths in the Cambridge Database [17].

These coordination modes result in [001] double chains of stoichiometry $[\text{Nd}(\text{glu})(\text{H}_2\text{O})_4]^+$ in the crystal of **1** (Fig. 3), in which the NdO_9 polyhedra are linked by their common $\text{O3}^i\cdots\text{O3}^{ii}$ edge and the $\text{Nd1}\cdots\text{Nd1}^v$ separation is $4.1751(3)$ Å. Pairs of glutarate ions fuse the adjacent Nd_2O_{16} units into the [001] chains which are cross-linked by $\text{O—H}\cdots\text{O}$ hydrogen bonds (Table 2) into (010) sheets. The chloride ions in **1** occupy the regions between the (010) sheets and each one accepts five $\text{O—H}\cdots\text{Cl}$ hydrogen bonds (Table 2) from nearby water molecules to provide structural cohesion in the [010] direction. There are no possible metal—chloride-ion interactions in **1**: the shortest $\text{Nd}\cdots\text{Cl}$ separation is greater than 4.6 Å.

Crystal structure of 2. Compound **2** is a three-dimensional coordination polymer: its asymmetric unit contains one Pr^{3+} ion, one doubly-deprotonated $\text{C}_5\text{H}_6\text{O}_4^{2-}$ glutarate (glu^{2-}) ion, one singly-deprotonated $\text{C}_5\text{H}_7\text{O}_4^-$ hydrogen glutarate (Hglu^-) ion, and two water molecules (Fig. 4).

Fig. 3. Fragment of an [001] double chain in **1** showing the edge-shared NdO₉ polyhedra



In the extended structure, the Pr1 atom is coordinated by ten oxygen atoms (Table 3) with a mean separation of 2.581 Å and a BVS of 3.13 Å. These O atoms arise from two bidentate ligands, five monodentate ligands, and one coordinated water molecule (O9). The coordination geometry about the metal ion is well described as a bicapped square anti-prism [18] (Fig. 5), with O1ⁱⁱ/O9/O3ⁱⁱⁱ/O7^v and O2/O8^{iv}/O4ⁱ/O5 forming the square faces: the dihedral angle between them is 3.04(6)°. Pr1 lies roughly equidistant from the square faces, by $-1.2280(9)$ Å from the first and $1.2723(9)$ Å from the second. The capping O1 and O4ⁱⁱⁱ atoms display the two longest Pr—O bond distances (Table 3) and the O1—Pr1—O4ⁱⁱⁱ bond angle is 174.98(5)°.

The glu²⁻ and Hglu⁻ species in **2** have different conformations: the C1 (glutarate) dianion is in an extended conformation, whereas the C6 (hydrogen glutarate) anion is twisted, with the C—C—C—C

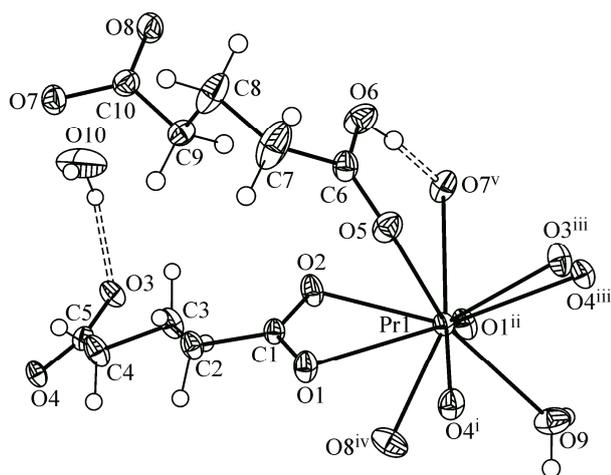


Fig. 4. Asymmetric unit of **2** (50 % displacement ellipsoids) expanded to show the complete metal coordination sphere. The hydrogen bonds are shown as double-dashed lines. Symmetry codes as in Table 3

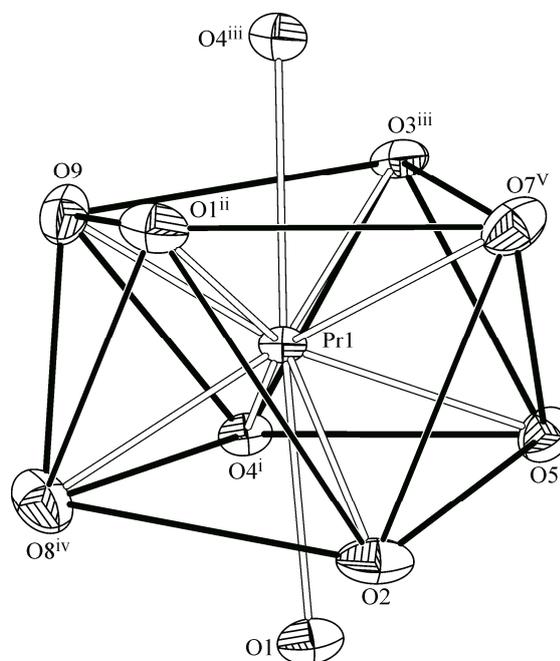


Fig. 5. Pr coordination sphere in **2**. Symmetry codes as in Table 3

Table 3

Selected bond lengths (Å) and angles (deg.) for **2**

Pr1—O4 ⁱ	2.4377(17)	Pr1—O1 ⁱⁱ	2.4416(17)	C1—C2—C3—C4	169.1(2)
Pr1—O3 ⁱⁱⁱ	2.5289(17)	Pr1—O8 ^{iv}	2.5444(18)	C6—C7—C8—C9	61.1(4)
Pr1—O2	2.5482(18)	Pr1—O9	2.5509(18)	C2—C3—C4—C5	-173.5(2)
Pr1—O7 ^v	2.6536(19)	Pr1—O5	2.6554(18)	C7—C8—C9—C10	179.3(2)
Pr1—O1	2.6946(18)	Pr1—O4 ⁱⁱⁱ	2.7508(18)		
C1—O2	1.250(3)	C1—O1	1.277(3)		
C5—O3	1.258(3)	C5—O4	1.272(3)		
C6—O5	1.244(3)	C6—O6	1.282(3)		
C10—O8	1.230(3)	C10—O7	1.294(3)		
		O6—H1...O7 ^v	0.78(3)	1.69(4)	2.464(3)
		O9—H2...O5 ⁱⁱ	0.82	2.02	2.833(3)
		O9—H3...O10 ^{iv}	0.82	1.95	2.760(3)
		O10—H4...O3	0.81	2.06	2.851(3)
		O10—H5...O7	0.81	2.52	3.166(3)

For the hydrogen bonds, the four values correspond to the $D-H$, $H\cdots A$ and $D\cdots A$ separations (Å) and the $D-H\cdots A$ angle (deg), respectively.

Symmetry codes: ⁱ $3/2-x, 1-y, z-1/2$; ⁱⁱ $3/2-x, y-1/2, z$; ⁱⁱⁱ $x, 1/2-y, z-1/2$; ^{iv} $x+1/2, y, 1/2-z$; ^v $1-x, y-1/2, 1/2-z$.

part of the chain incorporating the carboxylic acid group *gauche* and the equivalent grouping incorporating the carboxylate group *anti* (Table 3). The dihedral angle between the C1/O1/O2 and C5/O3/O4 planes is 31.69 (18)°; that between the C6/O5/O6 and C10/O7/O8 planes is 39.1(4)°.

The bonding modes of the ligands in **2** are quite different: the C1 species is bridging bidentate (O, μ^2 -O') from both its carboxylate groups, whereas the C6 species is simple monodentate from its —CO₂H group and bridging monodentate from its —CO₂⁻ group. In the C1 species, the metal ions are displaced by 0.477(11) Å and 0.401(11) Å from their chelating C1 and C5 groups respectively.

The C—O bond lengths in the ligands in **2** are of some interest: for the C1 group of the glutarate ion, the μ^2 -O atom has the longer C—O bond (by about 0.027 Å), which is equivalent to the situation in compound **1**, but for the C5 group, the μ^2 -O atom actually has the slightly shorter C—O bond, by some 0.014 Å. In the hydrogen glutarate ion, the difference between the nominal C6=O5 double-bond and C6—O6H single-bond is 0.038 Å, which is considerably less than the mean value of 0.094 Å from a survey of carboxylic acid structures in the literature [19]. Finally, in the C10 grouping, the C—O bonds show the greatest difference in length, of some 0.064 Å, despite their O atoms having the same bonding modes! The last of these may in part be explained by the fact that O7 accepts a short and (presumably) strong O—H...O hydrogen bond from the C—OH group, with O...O = 2.464(3) Å.

In the crystal of **2**, the PrO₁₀ polyhedra share an edge (*via* O4ⁱ...O4ⁱⁱⁱ) to generate [010] chains (Fig. 6) with Pr1...Pr1^{vi} ($vi = 3/2-x, y-1/2, z$) = 4.3800(3) Å. The bridging ligands link the [010] chains into a three-dimensional coordination network incorporating small [010] channels which are occupied by the O10-water molecules (Fig. 6).

DISCUSSION

So far as we can ascertain, the one-dimensional polymeric crystal structure of **1** is a new structure type. A closely related compound is [Nd(C₅H₆O₄)(H₂O)₄].Cl·2H₂O [20], in which essentially the same polymeric chains as seen in **1** incorporate both chloride ions and two uncoordinated water molecules per formula unit into the inter-chain voids.

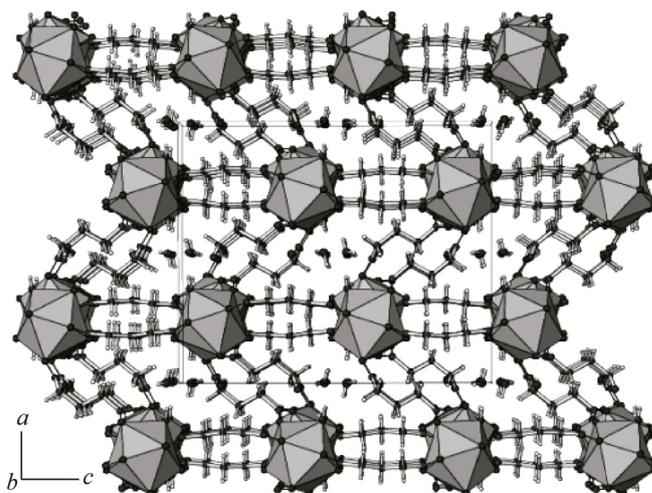


Fig. 6. Unit-cell packing for **2** viewed down [010] showing the small channels occupied by water molecules. The face-sharing PrO_{10} polyhedral chains propagate along [010]

Compound **2** is isostructural with its lanthanum congener [21], in which the mean La—O distance is 2.624 Å, which is the expected trend based on the lanthanide contraction effect [22].

Our survey of 49 rare-earth-glutarate crystal structures (including series of isostructural compounds) in the Cambridge Database (version 5.34 with two updates) revealed that 29 glutarate ions adopt a *gauche-anti* conformation [23] (*i.e.* the modulus of one C—C—C—C torsion angle lies in the range ~55—70° and the other is greater than ~160°), 17 have an *anti-anti* conformation, and just one $[\text{Pr}(\text{C}_5\text{H}_6\text{O}_4)(\text{H}_2\text{O})_2\text{Cl}]_n$ [24] has a *gauche-gauche* conformation. Two isostructural compounds $[\text{M}_2(\text{C}_8\text{H}_4\text{O}_4)(\text{C}_5\text{H}_4\text{O}_4)_2(\text{H}_2\text{O})_2]_n$ (M = Dy, Sm; $\text{C}_8\text{H}_4\text{O}_4$ = benzene 1,3-dicarboxylate) [25] could not be classified, with one *gauche* torsion angle and one of about 120°, which corresponds to an eclipsed conformation.

CONCLUSIONS

The new rare-earth glutarates $[\text{Nd}(\text{C}_5\text{H}_6\text{O}_4)(\text{H}_2\text{O})_4] \cdot \text{Cl}$ (**1**) and $[\text{Pr}(\text{C}_5\text{H}_6\text{O}_4)(\text{C}_5\text{H}_7\text{O}_4)(\text{H}_2\text{O})] \cdot \text{H}_2\text{O}$ (**2**) have been prepared in the form of single crystals and their structures were determined. Compound **1** is a new structure type, although it is closely related to a compound that also contains uncoordinated water molecules. Compound **2** is isostructural with its lanthanum analogue and its mean metal—ligand bond length follows the expected trend of the lanthanide contraction.

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REFERENCES

- Wyatt V.C. // J. Appl. Polymer Sci. – 2012. – **126**. – P. 1784 – 1793.
- Gopunath A.G., Chitravel T., Kavitha C., Prabu N.P.S., Mohan M.L.N.M. // Molec. Cryst. Liq. Cryst. – 2013. – **574**. – P. 19 – 32.
- Gou L., Han Z.X., Hu H.M., Wu Q.R., Yang X.L., Yang Z.H., Wang B.C., Wang F., Yang M.L., Xue G.L. // Inorg. Chim. Acta. – 2010. – **363**. – P. 2590 – 2599.
- Duangthongyou T., Phakawatchai C., Siripaisarnpipat S. // J. Mol. Struct. – 2011. – **987**. – P. 101 – 105.
- Zhen Y.Q., Zhu H.L., Guo X.X., Liu J.Y. // Solid State Sci. – 2013. – **18**. – P. 42 – 49.
- Rahahalia N., Benmerad B., Guehria-Laidouadi A., Dahaoui S., Lecomte C. // Acta Crystallogr. – 2006. – **E62**. – P. m2147 – m2147.
- Wang Z., Bai F.Y., Xing Y.H., Xie Y., Zeng X.Q., Ge M.F., Niu S.Y. // J. Inorg. Organomet. Poly Mat. – 2010. – **20**. – P. 242 – 249.
- Wang C.G., Xing Y.H., Li Z.P., Li J., Zeng X.Q., Ge M.F., Niu S.Y. // J. Mol. Struct. – 2009. – **931**. – P. 76 – 81.

9. *Sheldrick G.M.* SADABS. University of Gottingen, Germany, 2007.
10. *Sheldrick G.M.* // *Acta Crystallogr.* – 2008. – **A64**. – P. 112 – 122.
11. *Farrugia L.J.* // *J. Appl. Cryst.* – 1997. – **30**. – P. 565.
12. ATOMS for Windows., version 6.3. Shape Software Inc., Kingsport, Tennessee, USA.
13. *Cheyne R.W., Smith T.A.D., Trembleau L., Mclaughlin A.C.* // *Nanoscale Res. Lett.* – 2011. – **6**. – P. article 423; DOI 10.1186/1556-276X-6-423.
14. *Singh G.S., Pheko T.* // *Spectrochim. Acta.* – 2008. – **A70**. – P. 595 – 600.
15. *Brown I.D., Altermatt D.* // *Acta Crystallogr.* – 1985. – **B41**. – P. 244 – 247.
16. *Yin W.Y., Tang X.Y., Yang J., Ma Y.S., Yuan R.X.* // *J. Coord. Chem.* – 2010. – **63**. – P. 1157 – 1164.
17. *Allen F.H., Motherwell W.D.S.* // *Acta Crystallogr.* – 2002. – **58**. – P. 407 – 422.
18. *Yang Y.Q., Li C.H., Li W., Yi Z.J.* // *Chin. J. Chem.* – 2010. – **28**. – P. 1385 – 1388.
19. *Allen F.H., Kennard O., Watson D.G., Brammer L., Orpen A.G., Taylor R.* // *J. Chem. Soc. Perkin Trans. 2.* – 1987. – P. S1 – S19.
20. *Legendziewicz J., Keller B., Turowska-Tyrk I., Wojciechowski W.* // *New J. Chem.* – 1999. – **23**. – P. 1097 – 1103; *Marsh R.E.* // *Acta Crystallogr.* – 2005. – **B61**. – P. 359.
21. *Benmerad B., Guehria-Laidoudi A., Balegroune F., Birkedal H., Chapuis G.* // *Acta Crystallogr.* – 2000. – **C56**. – P. 789 – 792.
22. *Gu J.Z., Wu J., Lv D.Y., Tang Y., Zhu K., Wu J.* // *Dalton Trans.* – 2013. – P. 4822 – 4830.
23. *Rather B., Zaworotko M.J.* // *Chem. Commun.* – 2003. – P. 830 – 831.
24. *Bromant C., Nika W., Pantenburg I., Meyer G.* // *Zeit. Anorg. Allg. Chem.* – 2005. – **631**. – P. 2416 – 2422.
25. *Hu D.-X., Luo F., Che Y.-X., Zheng J.-M.* // *Cryst. Growth Des.* – 2007. – **7**. – P. 1733 – 1737.