

Ammonium *N*-acetyl-L-threoninate and methylammonium *N*-acetyl-L-threoninate

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Ammonium *N*-acetyl-L-threoninate, $\text{NH}_4^+\cdot\text{C}_6\text{H}_{10}\text{NO}_4^-$, and methylammonium *N*-acetyl-L-threoninate, $\text{CH}_6\text{N}^+\cdot\text{C}_6\text{H}_{10}\text{NO}_4^-$, crystallize in the orthorhombic $P2_12_12_1$ and monoclinic $P2_1$ space groups, respectively. The two crystals present the same packing features consisting of infinite ribbons of screw-related *N*-acetyl-L-threoninate anions linked together through pairs of hydrogen bonds. The cations interconnect neighbouring ribbons of anions involving all the nitrogen-H atoms in three-dimensional networks of hydrogen bonds. The hydrogen-bond patterns include asymmetric 'three-centred' systems. In both structures, the Thr side chain is in the favoured (g^-g^+) conformation.

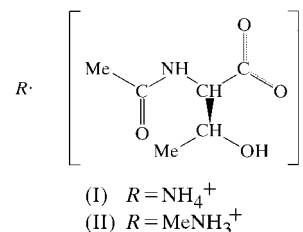
Comment

Detailed investigations of the crystal structures of amino acid and oligopeptide derivatives are a useful step to arrive at the conformational preferences of polypeptide chains in proteins. Threonine (*threo*- α -amino- β -hydroxy-*n*-butyric acid) is an important amino acid necessary in the human diet and a significant constituent of many common proteins (egg albumin and lactalbumin, bovine and human serum albumin, casein, insulin, haemoglobin). Thr is among the amino acids with polar side chains that can favour, by means of intrachain hydrogen bonds, the arrangement of β -turn and β -sheet structures enhancing the folding of globular proteins.

As part of our ongoing research concerning crystallographic, conformational and thermodynamic studies of solid *N*-acetyl derivatives of several amino acids and peptides (Puliti *et al.*, 1996, 1997, 1998, and references therein), we present here the crystal structures of the title salts, (I) and (II).

In the two structures, the geometry and conformation of the *N*-acetyl-L-threoninate moieties do not present any significant discrepancy (Tables 1 and 3): the corresponding bond lengths

and angles differ within three times the s.u.'s. All the values are in the expected ranges (Sequeira *et al.*, 1981; Ashida *et al.*, 1987; Engh & Huber, 1991). The geometry of the carboxyl groups is typical of an ionized form (Parthasarathy *et al.*, 1974): the asymmetry between the two C—O distances and O—C—C angles can be ascribed to the different hydrogen-bonding patterns involving the two carboxylic O atoms (see Tables 2 and 4). In fact, O2 is more strongly involved in hydrogen-bond



interactions in comparison with O1 which shows the shorter distance and the larger angle. In both structures, the acetyl group is oriented to make an almost planar five-membered cyclic system, C1—H3...O3—C3—N1. In this way, an intramolecular C—H...O interaction is formed between the activated C1—H3 group and O3 oxygen (Taylor & Kennard, 1982). Figs. 1 and 2 show perspective views of the asymmetric units of crystals of (I) and (II), respectively, together with the labelling schemes for non-H atoms.

The side-chain conformation of the Thr residue can be described by the torsion angles $\chi_{1,1}$ (N1—C1—C5—C6) and $\chi_{1,2}$ (N1—C1—C5—O4) and is of (g^-g^+) type in both structures (Tables 1 and 3). This conformation with the hydroxyl group in *gauche*⁺ conformation dominates over the (tg^-) one in peptide structures (Benedetti *et al.*, 1983; Doi *et al.*, 1993; Banumathi *et al.*, 1999) and is the most favoured according to conformational energy calculations (Vasquez *et al.*, 1983).

The two packings present strict analogies and are ruled by three-dimensional networks of hydrogen bonds which involve all the donor groups. A view of the packing of (I) is shown in Fig. 3. The *N*-acetyl-L-threoninate ions, related by screw symmetry along the *a* axis, are linked through two hydrogen bonds (O4—H...O2 and N1—H...O4) forming infinite ribbons parallel to the *a* direction. The NH_4^+ cations at a

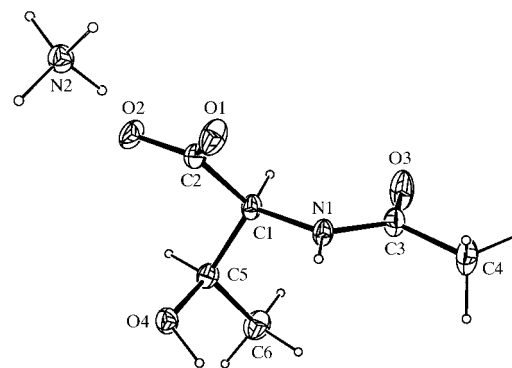


Figure 1
Perspective view of the asymmetric unit of (I) with the atomic labelling for non-H atoms. Displacement ellipsoids are drawn at the 30% probability level.

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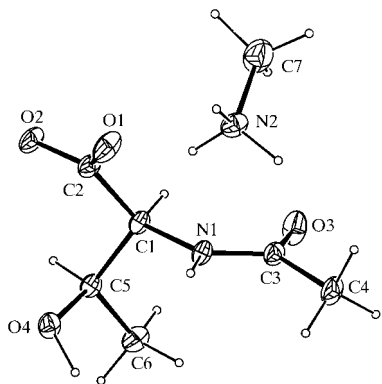


Figure 2

Perspective view of the asymmetric unit of (II) with the atomic labelling for non-H atoms. Displacement ellipsoids are drawn at the 30% probability level.

separation of 4.408 (2) Å alternate with chains of anions. All the ammonium-H atoms are involved in a three-dimensional network of hydrogen bonds that interconnects screw-related Thr⁻ ions of neighbouring ribbons. In particular, the N2—H12 bond is involved in an asymmetric ‘three-centred’ hydrogen-bond system with O1 and O2 as acceptors: the last one corresponding to the weaker component (Taylor *et al.*, 1984; Jeffrey & Saenger, 1991). Details of the hydrogen-bond geometry are reported in Table 2. The shortest methyl–methyl distance is C4···C6(1 - x, ½ + y, ½ - z) = 3.811 (4) Å.

Fig. 4 presents the packing of structure (II) projected along the *b* direction. Also in this crystal, pairs of hydrogen bonds (O4—H···O2 and N1—H···O4) link together the Thr⁻ moieties, related by screw symmetry, forming infinite ribbons of anions that wind parallel to the *b* direction. These ribbons alternate with methylammonium cations whose nitrogen-H atoms are all involved in hydrogen-bond interactions (Table 4). In this structure there are two asymmetric ‘three-centred’

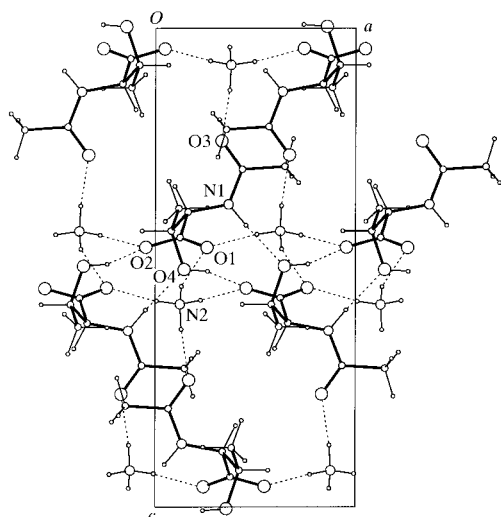


Figure 3

Crystal packing of (I) along the *b* direction. Dashed lines indicate hydrogen bonds.

hydrogen bonds, both involving N2 as donor. One bond is formed by H12 with the acceptors O1 and O4 (weaker component), the other by H13 which is shared between the carboxylic O2 and the acetylic O3 (weaker) atoms of different Thr⁻ moieties (Table 4). The shortest distance between methylammonium N atoms is 4.480 (3) Å and those concerning methyl-C atoms are C4···C6(x, y - 1, z) = 3.956 (5) and C6···C7(x - 1, y, z) = 3.805 (6) Å.

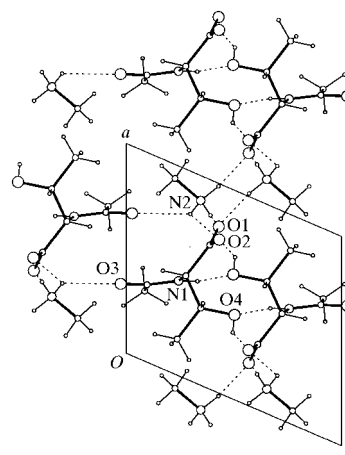


Figure 4

Crystal packing of (II) projected onto the *ac* plane. Dashed lines indicate hydrogen bonds.

Experimental

The compounds (I) and (II) were obtained as secondary products during ammonolysis of the *N*-acetyl-L-threonine ethyl ester using NH₃ or CH₃NH₂ in cold ethanol (Lilley, 1988; Sijpkens, 1990), with the primary goal to prepare the *N*-acetyl-L-threoninamide or -threonin-methylamide. After purification of the products, single crystals of (I) and (II) were obtained by slow evaporation from methyl ethyl ketone–ethyl acetate solutions. The samples of (II) were sealed in glass capillaries with a small amount of mother solution because they are unstable in air at room temperature.

Compound (I)

Crystal data

NH₄⁺·C₆H₁₀NO₄⁻
M_r = 178.19
 Orthorhombic, *P*2₁2₁2₁
a = 7.025 (1) Å
b = 8.0689 (4) Å
c = 16.754 (2) Å
V = 949.7 (2) Å³
Z = 4
D_x = 1.246 Mg m⁻³

Cu Kα radiation
 Cell parameters from 25 reflections
 θ = 29–32°
 μ = 0.889 mm⁻¹
T = 293 K
 Prism, colourless
 0.34 × 0.23 × 0.21 mm

Data collection

Enraf–Nonius CAD-4 diffractometer
 ω–2θ scans as suggested by peak-shape analysis
 1478 measured reflections
 1165 independent reflections
 1154 reflections with *I* > 2σ(*I*)
R_{int} = 0.036

θ_{max} = 75.5°
h = -2 → 8
k = -2 → 10
l = -2 → 21
 4 standard reflections
 frequency: 120 min
 intensity decay: 3%

Refinement

Refinement on F
 $R = 0.036$
 $wR = 0.044$
 $S = 0.964$
 1154 reflections
 111 parameters
 H-atom parameters not refined
 $w = 1/[\sigma^2(F_o) + (0.02F_o)^2 + 4]$
 (Killian & Lawrence, 1969)

$(\Delta/\sigma)_{\max} = 0.003$
 $\Delta\rho_{\max} = 0.18 \text{ e } \text{\AA}^{-3}$
 $\Delta\rho_{\min} = -0.15 \text{ e } \text{\AA}^{-3}$
 Extinction correction: Stout & Jensen (1968)
 Extinction coefficient: $3.23(4) \times 10^{-5}$
 Absolute structure: Rogers (1981)
 Rogers parameter = 0.927 (4)

Table 1

Selected geometric parameters (\AA , $^\circ$) for (I).

O1—C2	1.240 (3)	O4—C5	1.425 (2)
O2—C2	1.262 (2)	N1—C1	1.457 (2)
O3—C3	1.227 (2)	N1—C3	1.326 (2)
C1—N1—C3	122.4 (2)	O3—C3—N1	122.8 (2)
N1—C1—C2	111.2 (2)	O3—C3—C4	121.7 (2)
N1—C1—C5	111.6 (2)	N1—C3—C4	115.6 (2)
O1—C2—O2	123.6 (2)	O4—C5—C1	110.0 (2)
O1—C2—C1	119.7 (2)	O4—C5—C6	111.9 (2)
O2—C2—C1	116.7 (2)	C1—C5—C6	113.5 (2)
C3—N1—C1—C2	-129.8 (2)	N1—C1—C2—O1	1.9 (3)
C1—N1—C3—O3	2.1 (3)	N1—C1—C5—O4	72.1 (2)
C1—N1—C3—C4	-177.2 (2)	N1—C1—C5—C6	-54.1 (2)

Table 2

Hydrogen-bonding and short-contact geometry (\AA , $^\circ$) for (I).

$D-H \cdots A$	$D-H$	$H \cdots A$	$D \cdots A$	$D-H \cdots A$
O4—H1 \cdots O2 ⁱ	0.95	1.75	2.676 (2)	164
N1—H2 \cdots O4 ⁱ	0.95	1.97	2.915 (2)	176
N2—H11 \cdots O1 ⁱⁱ	0.95	1.90	2.831 (2)	167
N2—H12 \cdots O1	0.95	1.94	2.825 (2)	154
N2—H12 \cdots O2	0.95	2.44	3.270 (2)	146
N2—H13 \cdots O2 ⁱⁱⁱ	0.95	1.92	2.862 (2)	171
N2—H14 \cdots O3 ^{iv}	0.95	1.83	2.772 (2)	168
C1—H3 \cdots O3	1.02	2.33	2.778 (2)	105

Symmetry codes: (i) $\frac{1}{2} + x, \frac{1}{2} - y, 1 - z$; (ii) $x - \frac{1}{2}, \frac{3}{2} - y, 1 - z$; (iii) $\frac{1}{2} + x, \frac{3}{2} - y, 1 - z$; (iv) $\frac{1}{2} - x, 1 - y, \frac{1}{2} + z$.

Compound (II)

Crystal data

$\text{CH}_6\text{N}^+ \cdot \text{C}_6\text{H}_{10}\text{NO}_4^-$
 $M_r = 192.21$
 Monoclinic, $P2_1$
 $a = 8.1400(9) \text{ \AA}$
 $b = 7.178(2) \text{ \AA}$
 $c = 9.081(1) \text{ \AA}$
 $\beta = 113.52(1)^\circ$
 $V = 486.5(2) \text{ \AA}^3$
 $Z = 2$

$D_x = 1.312 \text{ Mg m}^{-3}$
 Cu $K\alpha$ radiation
 Cell parameters from 25 reflections
 $\theta = 29\text{--}30^\circ$
 $\mu = 0.905 \text{ mm}^{-1}$
 $T = 293 \text{ K}$
 Prism, colourless
 $0.63 \times 0.34 \times 0.22 \text{ mm}$

Data collection

Enraf–Nonius CAD-4 diffractometer
 ω - 2θ scans as suggested by peak-shape
 Absorption correction: ψ scan (North *et al.*, 1968)
 $T_{\min} = 0.727$, $T_{\max} = 0.819$
 1149 measured reflections
 1086 independent reflections

1079 reflections with $I > 2\sigma(I)$
 $R_{\text{int}} = 0.021$
 $\theta_{\max} = 75^\circ$
 $h = 0 \rightarrow 10$
 $k = 0 \rightarrow 9$
 $l = -11 \rightarrow 11$
 5 standard reflections
 frequency: 180 min
 intensity decay: 2%

Refinement

Refinement on F
 $R = 0.041$
 $wR = 0.049$
 $S = 0.989$
 1079 reflections
 119 parameters
 H-atom parameters not refined
 $w = 1/[\sigma^2(F_o) + (0.02F_o)^2 + 12]$
 (Killian & Lawrence, 1969)

$(\Delta/\sigma)_{\max} < 0.001$
 $\Delta\rho_{\max} = 0.17 \text{ e } \text{\AA}^{-3}$
 $\Delta\rho_{\min} = -0.25 \text{ e } \text{\AA}^{-3}$
 Extinction correction: Stout & Jensen (1968)
 Extinction coefficient: $5.42(13) \times 10^{-5}$
 Absolute structure: Rogers (1981)
 Rogers parameter = 1.023 (8)

Table 3

Selected geometric parameters (\AA , $^\circ$) for (II).

O1—C2	1.251 (3)	N1—C1	1.459 (3)
O2—C2	1.270 (4)	N1—C3	1.326 (3)
O3—C3	1.230 (3)	N2—C7	1.446 (5)
O4—C5	1.430 (3)		
C1—N1—C3	123.2 (2)	O3—C3—N1	123.9 (2)
N1—C1—C2	111.6 (2)	O3—C3—C4	120.7 (3)
N1—C1—C5	111.7 (2)	N1—C3—C4	115.4 (2)
O1—C2—O2	123.9 (3)	O4—C5—C1	110.4 (2)
O1—C2—C1	119.7 (2)	O4—C5—C6	112.1 (2)
O2—C2—C1	116.4 (2)	C1—C5—C6	113.4 (2)
C3—N1—C1—C2	-130.4 (3)	N1—C1—C2—O1	4.5 (3)
C1—N1—C3—O3	1.9 (4)	N1—C1—C5—O4	67.4 (3)
C1—N1—C3—C4	-178.0 (2)	N1—C1—C5—C6	-59.3 (3)

Table 4

Hydrogen-bonding geometry (\AA , $^\circ$) for (II).

$D-H \cdots A$	$D-H$	$H \cdots A$	$D \cdots A$	$D-H \cdots A$
O4—H1 \cdots O2 ⁱ	0.95	1.86	2.710 (3)	148
N1—H2 \cdots O4 ⁱ	0.95	2.02	2.961 (3)	169
N2—H11 \cdots O1 ⁱⁱ	0.95	1.83	2.775 (3)	170
N2—H12 \cdots O1	0.95	2.05	2.903 (3)	149
N2—H12 \cdots O4 ⁱ	0.95	2.58	3.144 (3)	118
N2—H13 \cdots O2 ⁱⁱⁱ	0.95	2.27	2.914 (3)	125
N2—H13 \cdots O3 ^{iv}	0.95	2.38	3.061 (3)	129
C1—H3 \cdots O3	1.02	2.38	2.816 (3)	104

Symmetry codes: (i) $1 - x, y - \frac{1}{2}, 1 - z$; (ii) $2 - x, y - \frac{1}{2}, 1 - z$; (iii) $x, y - 1, z$; (iv) $1 - x, y - \frac{1}{2}, -z$.

Systematic absences and intensity statistics led to the unique assignment of the space group $P2_12_12_1$ for (I) and $P2_1$ for (II).

Both structures were solved using the *SIR92* package (Altomare *et al.*, 1993). All H atoms were clearly observed in difference Fourier maps and included, with expected geometry, in the final refinements as fixed atoms with B_{iso} set equal to B_{eq} of the parent atom. All calculations were performed using *SDP* software (Enraf–Nonius, 1985) on a MicroVAX 3100 computer. The absolute configuration was chosen on the basis of the known configuration of the ethyl ester used in the synthesis.

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Supplementary data for this paper are available from the IUCr electronic archives (Reference: NA1450). Services for accessing these data are described at the back of the journal.

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