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The Crystal and Molecular Structure of Benzylpenicillin 1′-Diethyl Carbonate Ester

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The crystal structure of benzylpenicillin 1′-diethyl carbonate ester, $C_{21}H_{26}N_2O_7S$, has been determined and refined from three-dimensional X-ray diffractometer data. The unit cell is monoclinic, space group $P2_1$, with $a = 13{\cdot}307\ (6)$, $b = 8{\cdot}511\ (2)$, $c = 10{\cdot}300\ (3)$ Å, $\beta = 92{\cdot}45\ (3)°$ and $Z = 2$. The refinement was carried out by the least-squares method to a final linear R value of 0·040 for the 1928 significant observed reflexions. The packing in the crystal structure gives rise to short (2·844 Å) CO···C intermolecular contacts.

Introduction

Bacampicillin {1′-(ethoxycarbonyloxy)ethyl 6-[D-α-amino(phenyl)acetamido]penicillanate} (Fig. 1) is a new, orally well absorbed ampicillin derivative (Bodin *et al.*, 1975) with a novel type of hydrolysable ester group containing a chiral centre.

Bacampicillin is prepared from potassium benzylpenicillin (natural product) and racemic α-chlorodiethyl carbonate with benzylpenicillin 1′-diethyl carbonate ester as an intermediate. The product is obtained as a mixture of diastereoisomers relative to the chiral centre in the ester group.

The X-ray analysis was undertaken in order (*a*) to

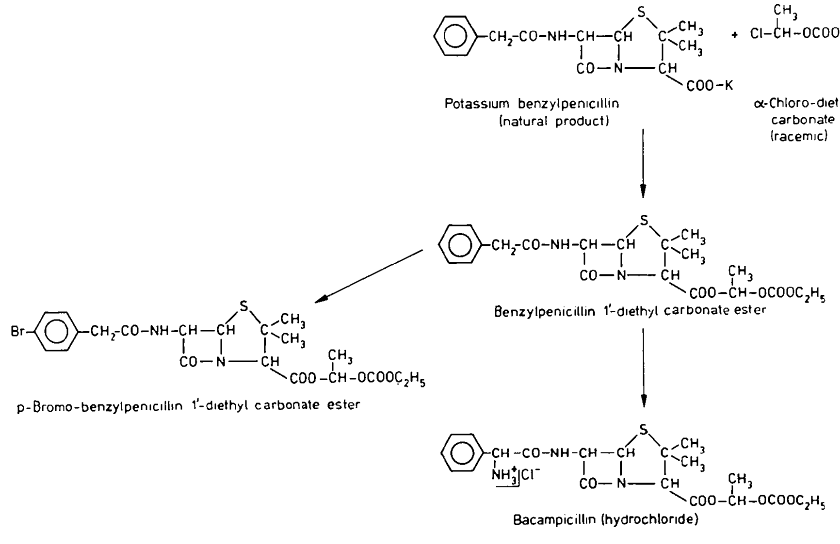

Fig. 1. Schematic figure showing the preparation of bacampicillin and *p*-bromobenzylpenicillin 1′-diethyl carbonate ester.

determine the absolute configuration of the chiral centre in the carbonate group and (*b*) to learn from molecular packing in diethyl carbonate ester crystals of penicillins why the two diastereoisomers differ markedly in crystallization. Since the intermediate is very convenient for the separation of the diastereoisomers, we have investigated one of the epimers of the benzylpenicillin ester and its *p*-bromo derivative (*cf.* Fig. 1). Here are presented the results of the study of benzylpenicillin 1′-diethyl carbonate ester. The description of the structure of the *p*-bromobenzylpenicillin 1′-diethyl carbonate ester has been published elsewhere (Csöregh & Palm, 1976).

Experimental

The crystals of benzylpenicillin 1′-diethyl carbonate ester (BPE) were prepared in the laboratories of ASTRA Läkemedel AB (Kovacs, Kovacs, Ekström, Csöregh & Palm, 1977). Preliminary rotation, de Jong–Bouman and precession photographs established that the crystals are monoclinic with the probable space group $P2_1$ (or $P2_1/m$). Unit-cell dimensions at 25 °C were determined by least-squares fitting of the cell

Table 1. *Fractional atomic coordinates* ($\times 10^4$) *for non-hydrogen atoms, with estimated standard deviations in parentheses*

	x	*y*	*z*
N(1)	1275 (2)	5305 (4)	494 (3)
C(2)	2351 (3)	5635 (5)	558 (3)
C(3)	2779 (3)	4831 (5)	1841 (3)
S(4)	1738 (1)	5000 (0)	2983 (1)
C(5)	764 (3)	5400 (5)	1725 (3)
C(6)	85 (3)	4021 (6)	1244 (4)
C(7)	804 (3)	3933 (5)	105 (4)
O(8)	956 (3)	3038 (5)	−773 (3)
C(9)	3704 (3)	5640 (7)	2453 (5)
C(10)	3004 (4)	3113 (6)	1576 (5)
C(11)	2503 (3)	7396 (5)	545 (3)
O(12)	1912 (2)	8337 (4)	919 (3)
O(13)	3407 (2)	7758 (4)	100 (3)
N(14)	38 (3)	2684 (5)	2070 (3)
C(15)	−822 (3)	2029 (5)	2458 (3)
O(16)	−1639 (2)	2429 (5)	2029 (3)
C(17)	−707 (3)	730 (6)	3464 (4)
C(18)	312 (3)	568 (5)	4160 (4)
C(19)	497 (4)	1288 (6)	5362 (4)
C(20)	1426 (5)	1163 (8)	5995 (4)
C(21)	2187 (5)	358 (9)	5410 (5)
C(22)	2015 (4)	−328 (7)	4221 (6)
C(23)	1082 (4)	−226 (6)	3613 (4)
C(24)	3484 (5)	10056 (9)	−1243 (6)
C(25)	3654 (3)	9401 (5)	83 (5)
O(26)	4712 (2)	9461 (4)	413 (3)
C(27)	4941 (3)	9535 (6)	1710 (4)
O(28)	4373 (3)	9536 (5)	2545 (3)
O(29)	5940 (3)	9537 (6)	1820 (4)
C(30)	6352 (5)	9665 (14)	3166 (8)
C(31)	6354 (8)	11172 (16)	3684 (8)

Table 2. *Fractional atomic coordinates* ($\times 10^3$) *for hydrogen atoms, with estimated standard deviations in parentheses*

	x	*y*	*z*
H(2)	266 (3)	523 (5)	−16 (4)
H(5)	45 (4)	641 (6)	184 (4)
H(6)	−64 (3)	433 (5)	103 (4)
H(91)	362 (3)	676 (6)	270 (4)
H(92)	389 (3)	522 (5)	324 (4)
H(93)	431 (3)	578 (5)	186 (4)
H(101)	356 (3)	293 (5)	95 (4)
H(102)	237 (3)	244 (6)	111 (4)
H(103)	322 (3)	257 (6)	238 (4)
H(14)	50 (4)	232 (6)	233 (4)
H(171)	−127 (3)	104 (5)	421 (4)
H(172)	−89 (3)	−40 (6)	292 (4)
H(19)	−8 (3)	192 (5)	575 (4)
H(20)	154 (3)	161 (5)	681 (4)
H(21)	275 (4)	27 (5)	581 (4)
H(22)	233 (3)	−80 (6)	376 (4)
H(23)	94 (3)	−64 (6)	284 (4)
H(241)	395 (4)	955 (6)	−178 (4)
H(242)	273 (3)	973 (6)	−153 (4)
H(243)	375 (4)	1093 (6)	−126 (4)
H(25)	327 (3)	999 (6)	72 (4)
H(301)	629 (4)	890 (6)	386 (5)
H(302)	701 (4)	940 (6)	295 (4)
H(311)	672 (3)	1107 (5)	457 (4)
H(312)	561 (4)	1136 (5)	389 (4)
H(313)	653 (4)	1167 (6)	308 (5)

Table 3. *Intramolecular bond distances* (Å), *with estimated standard deviations in parentheses*

N(1)–C(2)	1·458 (5)	C(2)–H(2)	0·93 (4)
C(2)–C(3)	1·573 (5)	C(5)–H(5)	0·97 (5)
C(3)–S(4)	1·861 (4)	C(6)–H(6)	1·02 (4)
S(4)–C(5)	1·825 (4)	C(9)–H(91)	0·99 (5)
C(5)–N(1)	1·466 (4)	C(9)–H(92)	0·91 (5)
C(2)–C(11)	1·513 (6)	C(9)–H(93)	1·04 (4)
C(3)–C(9)	1·523 (6)	C(10)–H(101)	1·01 (4)
C(3)–C(10)	1·520 (7)	C(10)–H(102)	1·11 (5)
C(5)–C(6)	1·550 (6)	C(10)–H(103)	0·98 (5)
C(6)–C(7)	1·547 (6)	N(14)–H(14)	0·73 (6)
C(7)–O(8)	1·206 (6)	C(17)–H(171)	1·13 (4)
N(1)–C(7)	1·377 (5)	C(17)–H(172)	1·13 (5)
C(6)–N(14)	1·424 (6)	C(19)–H(19)	1·03 (4)
C(11)–O(12)	1·198 (5)	C(20)–H(20)	0·93 (5)
C(11)–O(13)	1·341 (5)	C(21)–H(21)	0·84 (5)
N(14)–C(15)	1·349 (6)	C(22)–H(22)	0·76 (5)
C(15)–O(16)	1·205 (5)	C(23)–H(23)	0·88 (5)
C(15)–C(17)	1·518 (6)	C(24)–H(241)	0·95 (5)
C(17)–C(18)	1·513 (6)	C(24)–H(242)	1·07 (4)
C(18)–C(19)	1·394 (6)	C(24)–H(243)	0·82 (6)
C(19)–C(20)	1·377 (8)	C(25)–H(25)	0·99 (5)
C(20)–C(21)	1·382 (9)	C(30)–H(301)	0·97 (6)
C(21)–C(22)	1·367 (8)	C(30)–H(302)	0·94 (6)
C(22)–C(23)	1·369 (8)	C(31)–H(311)	1·02 (5)
C(18)–C(23)	1·369 (7)	C(31)–H(312)	1·03 (6)
O(13)–C(25)	1·437 (5)	C(31)–H(313)	0·80 (5)
C(24)–C(25)	1·484 (8)		
C(25)–O(26)	1·435 (5)		
O(26)–C(27)	1·359 (5)		
C(27)–O(28)	1·169 (6)		
C(27)–O(29)	1·329 (6)		
O(29)–C(30)	1·473 (9)		
C(30)–C(31)	1·389 (17)		

parameters to powder data from a Guinier photograph, with KCl ($a = 6{\cdot}29194$ Å) as an internal standard. Three-dimensional X-ray diffraction data were collected from a single crystal with approximate dimensions 0·14 × 0·37 × 0·12 mm, by means of a PW 1100 diffractometer using graphite-monochromatized Cu $K\alpha$ radiation. The intensities of 2224 independent reflexions with $\theta \leq 65°$ were collected, of which 1928 had $I > 3\sigma(I_{\rm net})$. The calculation of $\sigma(I_{\rm net})$ was based on conventional counter statistics. In the subsequent calculations, the 1928 net intensities corrected for Lorentz–polarization, absorption ($\mu = 15{\cdot}6$ cm^{-1}) and extinction effects were used.

Structure determination and refinement

Preliminary structure factor phases were derived by direct methods. 300 $|E|$ values ($|E| \geq 1{\cdot}43$) and the 1800 best triple relations among them were used to generate 16 trial phase sets by the program system *MULTAN* (Main, Woolfson & Germain, 1971). Simultaneously, the position of the S atom was calculated from an E-Patterson map, based on 244 $|E|$ values ($|E| > 1{\cdot}5$). The E map for the solution with the best figure of merit showed a double image of the structure. However, four peaks – the S atom and three other atoms – were selected from the double-image E map and refined by a full matrix least-squares procedure. The remainder of the structure, *i.e.* the 27 non-hydrogen atoms and the 26 H atoms, were obtained by conventional difference syntheses. In the last refinement of the structure the real and imaginary components of the anomalous dispersion correction for S were included in the structure factor calculations. All non-hydrogen atoms were allowed to vibrate aniso-

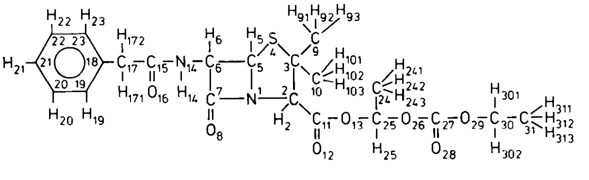

Fig. 2. Schematic drawing of the benzylpenicillin 1′-diethyl carbonate ester molecule with atoms numbered for reference in the text.

Table 4. *Intramolecular bond angles* (°), *with estimated standard deviations in parentheses*

C(2)–N(1)–C(5)	116·2 (3)	C(20)–C(21)–C(22)	120·3 (6)	C(15)–C(17)–H(171)	104 (3)
C(2)–N(1)–C(7)	127·6 (4)	C(21)–C(22)–C(23)	119·8 (6)	C(15)–C(17)–H(172)	105 (3)
C(5)–N(1)–C(7)	94·4 (3)	C(22)–C(23)–C(18)	121·6 (5)	C(18)–C(17)–H(171)	108 (3)
N(1)–C(2)–C(3)	105·9 (3)	O(13)–C(25)–C(24)	110·6 (5)	C(18)–C(17)–H(172)	109 (3)
N(1)–C(2)–C(11)	108·8 (4)	O(13)–C(25)–O(26)	104·7 (4)	H(171)–C(17)–H(172)	114 (3)
C(3)–C(2)–C(11)	113·3 (3)	C(24)–C(25)–O(26)	108·3 (4)	C(18)–C(19)–H(19)	118 (3)
C(2)–C(3)–C(9)	114·1 (4)	C(25)–O(26)–C(27)	114·3 (4)	C(20)–C(19)–H(19)	122 (3)
C(2)–C(3)–C(10)	109·6 (4)	O(26)–C(27)–O(28)	126·8 (4)	C(19)–C(20)–H(20)	120 (3)
C(2)–C(3)–S(4)	104·2 (3)	O(26)–C(27)–O(29)	105·4 (4)	C(21)–C(20)–H(20)	120 (3)
S(4)–C(3)–C(9)	108·3 (3)	O(28)–C(27)–O(29)	127·8 (5)	C(20)–C(21)–H(21)	119 (3)
S(4)–C(3)–C(10)	110·2 (3)	C(27)–O(29)–C(30)	114·3 (5)	C(22)–C(21)–H(21)	121 (3)
C(9)–C(3)–C(10)	110·3 (4)	O(29)–C(30)–C(31)	115·1 (9)	C(21)–C(22)–H(22)	135 (4)
C(3)–S(4)–C(5)	95·2 (2)			C(23)–C(22)–H(22)	105 (4)
S(4)–C(5)–N(1)	105·2 (3)	N(1)–C(2)–H(2)	111 (3)	C(22)–C(23)–H(23)	123 (3)
S(4)–C(5)–C(6)	118·2 (3)	C(3)–C(2)–H(2)	111 (3)	C(18)–C(23)–H(23)	116 (3)
N(1)–C(5)–C(6)	88·1 (3)	C(11)–C(2)–H(2)	107 (3)	C(25)–C(24)–H(241)	107 (3)
C(5)–C(6)–C(7)	84·7 (3)	N(1)–C(5)–H(5)	112 (3)	C(25)–C(24)–H(242)	105 (3)
C(5)–C(6)–N(14)	117·0 (4)	S(4)–C(5)–H(5)	112 (3)	C(25)–C(24)–H(243)	108 (3)
C(7)–C(6)–N(14)	117·3 (4)	C(6)–C(5)–H(5)	118 (4)	H(241)–C(24)–H(242)	110 (4)
N(1)–C(7)–C(6)	91·5 (4)	C(5)–C(6)–H(6)	114 (3)	H(241)–C(24)–H(243)	96 (5)
N(1)–C(7)–O(8)	131·7 (4)	C(7)–C(6)–H(6)	117 (3)	H(242)–C(24)–H(243)	129 (5)
C(6)–C(7)–O(8)	136·7 (5)	N(14)–C(6)–H(6)	106 (3)	O(13)–C(25)–H(25)	111 (3)
C(2)–C(11)–O(12)	124·8 (4)	C(3)–C(9)–H(91)	116 (3)	C(24)–C(25)–H(25)	111 (3)
C(2)–C(11)–O(13)	110·7 (4)	C(3)–C(9)–H(92)	112 (3)	O(26)–C(25)–H(25)	111 (3)
O(12)–C(11)–O(13)	124·6 (4)	C(3)–C(9)–H(93)	116 (3)	O(29)–C(30)–H(301)	127 (4)
C(11)–O(13)–C(25)	115·9 (4)	H(91)–C(9)–H(92)	100 (4)	O(29)–C(30)–H(302)	94 (3)
C(6)–N(14)–C(15)	124·5 (4)	H(91)–C(9)–H(93)	100 (4)	C(31)–C(30)–H(301)	110 (4)
N(14)–C(15)–O(16)	122·6 (4)	H(92)–C(9)–H(93)	112 (4)	C(31)–C(30)–H(302)	109 (4)
N(14)–C(15)–C(17)	116·2 (4)	C(3)–C(10)–H(101)	115 (3)	H(301)–C(30)–H(302)	97 (5)
O(16)–C(15)–C(17)	121·3 (4)	C(3)–C(10)–H(102)	115 (3)	C(30)–C(31)–H(311)	105 (3)
C(15)–C(17)–C(18)	116·9 (4)	C(3)–C(10)–H(103)	111 (3)	C(30)–C(31)–H(312)	104 (3)
C(17)–C(18)–C(19)	120·1 (4)	H(101)–C(10)–H(102)	102 (4)	C(30)–C(31)–H(313)	101 (4)
C(17)–C(18)–C(23)	121·4 (4)	H(101)–C(10)–H(103)	106 (4)	H(311)–C(31)–H(312)	105 (4)
C(19)–C(18)–C(23)	118·4 (4)	H(102)–C(10)–H(103)	108 (4)	H(311)–C(31)–H(313)	127 (5)
C(18)–C(19)–C(20)	120·5 (5)	C(6)–N(14)–H(14)	120 (4)	H(312)–C(31)–H(313)	113 (5)
C(19)–C(20)–C(21)	119·5 (5)	C(15)–N(14)–H(14)	115 (4)		

tropically, while the H atoms were given isotropic temperature factors, B, with a fixed value of 4·0 $Å^2$ as obtained from a Wilson plot. The unweighted final reliability index R for all the 1928 reflexions became 0·0395. The scattering factors and the real and imaginary dispersion corrections for S were those given in *International Tables for X-ray Crystallography* (1974). The fractional atomic coordinates, bond lengths and bond angles are listed in Tables 1–4.* The atomic labels used are shown in Fig. 2.

Discussion

A stereoscopic view of the BPE crystal structure is displayed in Fig. 3. A remarkable feature of this structure is that there is no hydrogen bond from the N(14)–H imino group to any of the four carbonyl O atoms of the molecule. The shortest intermolecular N(H)···O distance, N(14)···O(12^i), is 3·98 Å. In the crystal structures of penicillins the carboxyl, or carboxylate group, and both the N atoms and the carbonyl O atom of the exocyclic amide group regularly take part in hydrogen bonding (Sweet, 1972). But in three penicillin esters known to the authors: cloxacillin methyl ester (Blanpain & Durant, 1976), *p*-bromobenzylpenicillin 1'-diethyl carbonate ester (Csöregh & Palm, 1976), and the present compound, the crystal structure is held together by other types of intermolecular interaction than hydrogen bonding.

The intermolecular contact distances less than 3·6 Å are listed in Table 6. The shortest non-bonded C···O distance, 2·844 (5) Å, is between the carboxylate carbon, C(11), and the carbonyl O atom, O(16^i), belonging to the exocyclic amide group. It is significantly shorter than 3·1 Å, the sum of the van der Waals radii (Pauling, 1960). This contact appears to be a dipole–dipole interaction of the type discussed by Bolton (1964). The C atom of the close approach, C(11), belongs to a second carbonyl group, and in addition is attached to an electron-withdrawing substituent, O(13). The C=O···C angle is 131·4°.

The structural and conformational features of the BPE molecule are illustrated in Fig. 4. The thiazolidine ring is slightly puckered, with C(2) 0·51 Å out of the plane of the other four atoms (*cf.* Table 5). The

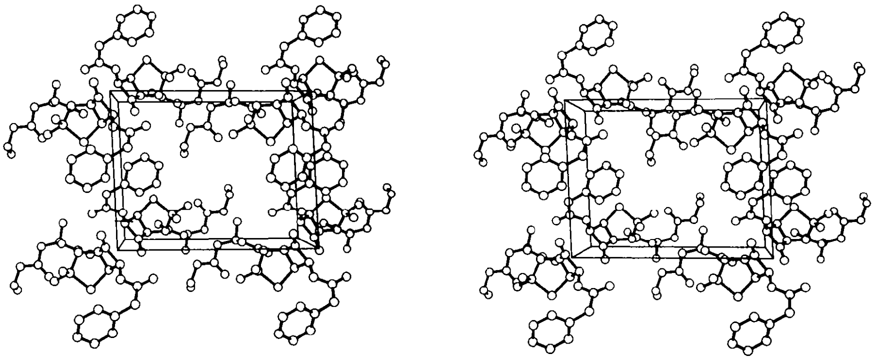

Fig. 3. Stereoscopic packing diagram of the crystal structure.

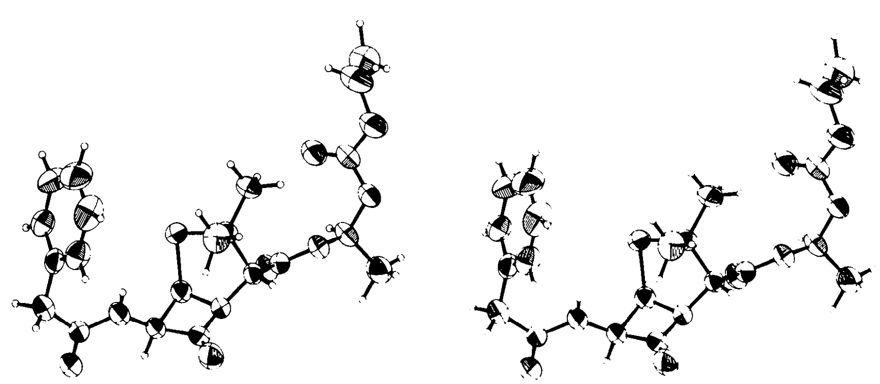

Fig. 4. Stereoscopic view of the benzylpenicillin 1'-diethyl carbonate ester molecule. The non-hydrogen atoms are represented by their thermal ellipsoids, while the hydrogens are drawn with constant radii.

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* Lists of structure factors and anisotropic thermal parameters have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 32434 (4 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 13 White Friars, Chester CH1 1NZ, England.

C—S—C angle is 95·2°; the carboxylate carbon, C(11), is in an equatorial position, in agreement with the conformation found in the benzylpenicillin ion (Crowfoot, Bunn, Rogers-Low & Turner-Jones, 1949), phenoxymethylpenicillin (Abrahamsson, Crowfoot Hodgkin & Maslen, 1963), cloxacillin methyl ester (Blanpain & Durant, 1976) and *p*-bromobenzylpenicillin 1′-diethyl carbonate ester (Csöregh & Palm, 1976).

Within the *β*-lactam part of the BPE molecule four atoms of the amide linkage, C(6), C(7), O(8) and N(1), are coplanar (*cf.* Table 5), while C(5) is displaced from this plane by 0·24 Å towards the S atom. The angle between the planes of the thiazolidine ring and the *β*-lactam is 68·9°. The amide N in the *β*-lactam ring, N(1), and its three substituents, C(2), C(5) and C(7), form a pyramid with a height of 0·38 Å. The sum of the bond angles around N(1) is 338·2°.

Table 5. *Equations of the least-squares planes and deviations of the atoms from the planes*

The planes are expressed as $Ax + By + Cz = D$, where x, y and z are in Å along the axes a^*, b and c. The atoms indicated with asterisks were omitted from the calculations of the least-squares planes. A negative sign means that the atom lies between the plane and the origin.

(1) Thiazolidine ring: LS plane through the atoms N(1), C(3), S(4) and C(5)

A = 0·175	N(1)	−0·016 Å	C(7)*	−1·295 Å
B = 0·983	C(2)*	0·510	O(8)*	−2·061
C = 0·058	C(3)	0·012	C(9)*	0·937
D = 4·775	S(4)	−0·017	C(10)*	−1·390
	C(5)	0·020	C(11)*	2·017
	C(6)*	−1·317		

The r.m.s. deviation from the plane of the atoms without asterisks is 0·016 Å.

(2) *β*-Lactam: LS plane through the atoms N(1), C(6), C(7) and O(8)

A = −0·652	N(1)	−0·003 Å	C(7)	0·011 Å
B = 0·515	C(5)*	−0·240	O(8)	−0·005
C = −0·556	C(6)	−0·003		
D = 0·983				

The r.m.s. deviation from the plane of the atoms without asterisks is 0·006 Å.

(3) Exocyclic amide bond: LS plane through the atoms N(14), C(15), O(16) and C(17)

A = −0·049	C(6)*	0·144 Å	O(16)	−0·001 Å
B = 0·680	N(14)	−0·001	C(17)	−0·001
C = 0·732	C(15)	0·004	C(18)*	0·322
D = 3·110				

The r.m.s. deviation from the plane of the atoms without asterisks is 0·002 Å.

Angles between the planes (with estimated standard deviations in parentheses)

Planes	Angles (°)
1–2	68·9 (7)
1–3	45·4 (4)
2–3	88·5 (7)

The four atoms N(14), C(15), O(16) and C(17), belonging to the exocyclic amide group, are also coplanar; they adopt a conformation similar to that found in other penicillins which minimizes the interaction between the amide carbonyl and the rest of the molecule (Sweet, 1972). As a result, N(14), the only proton donor in the BPE molecule, becomes almost inaccessible for intermolecular interaction, and, instead of hydrogen bonding, electrostatic CO···C interactions stabilize the crystal structure as described above. The plane of the exocyclic amide link is nearly perpendicular to the plane of the *β*-lactam group (Table 5).

The molecular geometry of the penicillanate moiety found in the present study agrees well with those of cloxacillin methyl ester (Blanpain & Durant, 1976) and *p*-bromobenzylpenicillin 1′-diethyl carbonate ester (Csöregh & Palm, 1976). The bond lengths and angles also agree within a few standard deviations with the values published for two ampicillin structures: ampicillin trihydrate (James, Hall & Hodgkin, 1968) and ampicillin anhydrate (Boles & Girven, 1976), except for the angles within the five-membered ring. These differences can possibly be explained by different conformations of the thiazolidine rings in ampicillins and in the present molecule.

Table 6. *Intermolecular distances less than 3·6 Å between non-hydrogen atoms*

The estimated standard deviations are given in parentheses. Atom B is generated from the coordinates of Table 1 by using the unit-cell translation shown together with the following symmetry operations:

Superscipt	Atom at
None	x, y, z
(i)	$-x, \frac{1}{2} + y, -z$

A B	Unit-cell translation along axes a	b	c	Distance (Å)
C(11)–O(16$^{\mathrm{i}}$)	(0,	0,	0)	2·844 (5)
O(12)–O(16$^{\mathrm{i}}$)	(0,	0,	0)	3·139 (5)
O(13)–O(16$^{\mathrm{i}}$)	(0,	0,	0)	3·159 (4)
C(2)–O(16$^{\mathrm{i}}$)	(0,	0,	0)	3·180 (5)
N(1)–O(16$^{\mathrm{i}}$)	(0,	0,	0)	3·219 (5)
O(12)–C(23)	(0,	1,	0)	3·268 (5)
C(5)–O(8$^{\mathrm{i}}$)	(0,	0,	0)	3·324 (6)
O(16)–C(24$^{\mathrm{i}}$)	(0,	−1,	0)	3·393 (8)
O(16)–C(31)	(−1,	−1,	0)	3·402 (11)
N(1)–C(15$^{\mathrm{i}}$)	(0,	0,	0)	3·407 (5)
C(6)–O(12$^{\mathrm{i}}$)	(0,	−1,	0)	3·444 (5)
O(13)–O(29$^{\mathrm{i}}$)	(1,	−1,	0)	3·511 (6)
C(2)–O(29$^{\mathrm{i}}$)	(1,	−1,	0)	3·538 (6)
C(5)–C(19$^{\mathrm{i}}$)	(0,	0,	1)	3·580 (6)
O(12)–C(22)	(0,	1,	0)	3·583 (7)

The six C atoms in the aromatic C(18)–C(23) ring are coplanar within 0·02 Å; the r.m.s. deviation of these atoms from their best plane is 0·007 Å. The C–C distances in this phenyl ring range between 1·367 (8) and 1·394 (6) Å (average 1·376 Å) and are somewhat below normal. This shortening may be due to thermal motion. The r.m.s. deviation from 120° for the angles within the aromatic ring is 1·0°.

In the carboxylate group and in the diethyl carbonate ester chain the three C–O single-bond lengths between the O atoms and the sp^2-hybridized C atoms range between 1·329 and 1·359 Å, with a mean value of 1·343 Å, which agrees well with the value 1·34 (2) Å suggested by Lide (1962) for such bonds. The values of 1·437 (5) and 1·435 (5) Å for the C(sp^3)–O single-bond distance are compatible with the usual value, 1·426 (5) Å (Sutton, 1965). The short C–O double-bond length [1·169 (6) Å] in the carbonate group is in accordance with the values found earlier in this type of organic carbonate (Brown, 1954; Sørensen, 1971; Cser, 1974). C(30) and C(31), at the end of the ester chain, have rather high thermal parameters. This probably explains the unusual bond distances O(29)–C(30) [1·47 (1) Å] and C(30)–C(31) [1·39 (2) Å]. It should be noted that we have also found similar deviations from the usual values for the same bonds in *p*-bromobenzylpenicillin 1′-diethyl carbonate ester (Csöregh & Palm, 1976).

In the ester chain, atom C(25) is a chiral centre with a methyl group, a H atom and two stereochemically different O atoms as substituents. The absolute configuration is *S* (IUPAC, 1970), which could be deduced from the molecular geometry, because the BPE molecule contains three more chiral centres with the absolute configurations: C(2)(*S*), C(5)(*R*), and C(6)(*R*).

It is difficult to deduce the packing in the crystal structure with C(25) in the *R* configuration. It has proved to be experimentally difficult to obtain crystals of that diastereoisomer. In the C(25)(*R*) form the ester chain will, to some extent, sterically hinder the electrostatic intermolecular interactions which seem to play an important role in the crystal structure of the C(25)(*S*) form.

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The Crystal Structure of a Lithium–Nickel Molybdate, $Li_2Ni_2Mo_3O_{12}$, and the Systematics of the Structure Type

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$Li_2Ni_2Mo_3O_{12}$ is orthorhombic, $a = 10{\cdot}423$ (3), $b = 17{\cdot}525$ (4), $c = 5{\cdot}074$ (1) Å, space group *Pmcn* with $Z = 4$. 2717 independent reflexions were collected and the structure was refined to an R value of 0·053. The average Mo–O and (Ni,Li)–O distances are 1·774 and 2·097 Å, respectively. The close-packed sheets of O are composed of three-square-wide bands of Wells's No. 9 regular net, held together by semi-regular single chains of triangles. There are two identical sheets in the stacking sequence, and the regular and semi-regular voids between the O atoms are filled by the cations: Ni and Li occupy, in various proportions, the trigonal prism ($M1$), the distorted ($M2$) and the regular ($M3$) trigonal antiprisms, and Mo occupies the elongated tetrahedral voids.

Experimental

Single crystals of $Li_2Ni_2Mo_3O_{12}$ were produced accidentally during an attempt to grow nickel-olivine crystals by a flux method (Ozima & Zoltai, 1976). One of these crystals, 0·07 × 0·07 × 0·08 mm, was mounted on an automated, four-circle Rigaku diffractometer and three-dimensional intensities were collected with Mo $K\alpha$ radiation, monochromated by a graphite plate. The intensities of the reflexions were collected in the ω–2θ mode. The intensities of three standard reflexions were checked after every 50 measurements. 2980 independent intensities were collected up to $2\theta = 80°$. Of these, 2717 intensities were sufficiently strong for consideration. All intensities were corrected for Lorentz and polarization effects, but no corrections were made for primary and secondary extinction, or for absorption. The last appeared to be unnecessary as the crystal was almost an equidimensional cube.

The unit-cell parameters were calculated and refined by a least-squares analysis of the 2θ values of 38 high-angle reflexions. The unit translations obtained are: $a = 10{\cdot}423$ (3), $b = 17{\cdot}525$ (4) and $c = 5{\cdot}074$ (1) Å.

Other crystallographic data determined and calculated are: space group *Pmcn* (No. 62), $Z = 4$, $D_x = 4{\cdot}372$, $D_m = 4{\cdot}36$ g cm^{-3}, $\mu_c = 83{\cdot}5$ cm^{-1} for Mo $K\alpha$ ($\lambda = 0{\cdot}7107$ Å) radiation.

Structure determination and refinement

Three-dimensional Patterson maps were computed and were solved for the Mo and Ni atomic coordinates by recognition of the vectors of these relatively heavy atoms. The locations of the O and Li atoms were obtained from a Fourier difference synthesis. The structure was subsequently refined by minimizing $\Sigma\ (|F_o| - |F_c|)^2$ through full-matrix least-squares calculations based on the 2717 observed intensities. Anisotropic thermal parameters for Mo, Ni and O and isotropic thermal parameters for Li were also calculated. The final R value obtained was 0·053. The atomic coordinates are given in Table 1.

The Ni–Li distribution pattern in $M1$, $M2$ and $M3$ sites was also determined. The $M1$ site is occupied by Li and the $M2$ and $M3$ sites by Ni and Li in the ratio Ni : Li 0·731 : 0·269 and 0·538 : 0·462 respectively.

The analysis of the list of observed and calculated

Table 1. *Atomic coordinates* ($\times 10^4$)

	x	y	z
Mo(1)	7500	0565 (0)	7158 (1)
Mo(2)	4738 (0)	1564 (0)	2211 (1)
$M2$-Ni	4284 (1)	0265 (1)	7475 (2)
$M3$-Ni	7500	2506 (1)	3919 (4)
O(1)	2500	0065 (4)	5632 (12)
O(2)	7500	1544 (3)	6358 (12)
O(3)	6176 (4)	2048 (2)	1400 (8)
O(4)	3774 (5)	2135 (3)	4202 (10)
O(5)	3866 (4)	1255 (2)	9403 (9)
O(6)	5122 (4)	0745 (2)	4207 (8)
O(7)	6148 (4)	0363 (2)	9185 (8)
$M1$-Li	2500	1951 (10)	5568 (43)
$M2$-Li	4284	0265	7475
$M3$-Li	7500	2506	3919