Four related benzazepine derivatives in a reaction pathway leading to a benzazepine carboxylic acid: hydrogen-bonded assembly in zero, one, two and three dimensions

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Received 10 March 2014

Accepted 18 March 2014

(2*R**,4*S**)-Methyl 2,3,4,5-tetrahydro-1,4-epoxy-1*H*-benz[*b*]azepine-2-carboxylate, C₁₂H₁₃NO₃, (I), and its reduction product (2*R**,4*S**)-methyl 4-hydroxy-2,3,4,5-tetrahydro-1*H*-benz[*b*]azepine-2-carboxylate, C₁₂H₁₅NO₃, (II), both crystallize as single enantiomers in the space group *P*₂₁2₁2₁, while the hydrolysis product (2*RS*,4*SR*)-4-hydroxy-2,3,4,5-tetrahydro-1*H*-benz[*b*]azepine-2-carboxylic acid, C₁₁H₁₃NO₃, (III), and the lactone (2*RS*,5*SR*)-8-(trifluoromethoxy)-5,6-dihydro-1*H*-2,5-methanobenz[*e*][1,4]oxazocin-3(2*H*)-one, C₁₂H₁₀F₃NO₃, (IV), both crystallize as racemic mixtures in the space group *P*₂₁/*c*. The molecules of compound (IV) are linked into centrosymmetric *R*₂²(10) dimers by N—H...O hydrogen bonds, and those of compound (I) are linked into chains by C—H... π (arene) hydrogen bonds. A combination of O—H...O and O—H...N hydrogen bonds links the molecules of compound (III) into sheets containing equal numbers of *R*₄⁴(14) and *R*₄⁴(26) rings, and a combination of C—H... π (arene) hydrogen bonds and three-centre O—H...(N,O) hydrogen bonds links the molecules of compound (II) into a three-dimensional framework structure. Comparisons are made with some related compounds.

Keywords: crystal structure; hydrogen bonding; benzazepine derivatives; reaction pathway; supramolecular assembly.

1. Introduction

We report here the molecular and supramolecular structures of a series of four closely related benzazepine derivatives, corresponding to the intermediates (2*R**,4*S**)-methyl 2,3,4,5-tetrahydro-1,4-epoxy-1*H*-benz[*b*]azepine-2-carboxylate, (I), and (2*R**,4*S**)-methyl 4-hydroxy-2,3,4,5-tetrahydro-1*H*-benz[*b*]azepine-2-carboxylate, (II), in the synthetic sequence from

a 2-allylaniline towards the formation of (2*RS*,4*SR*)-4-hydroxy-2,3,4,5-tetrahydro-1*H*-benz[*b*]azepine-2-carboxylic acid, (III), together with that of a related tricyclic by-product (2*RS*,5*SR*)-8-(trifluoromethoxy)-5,6-dihydro-1*H*-2,5-methanobenz[*e*][1,4]oxazocin-3(2*H*)-one, (IV) (see Scheme 1). Compounds of this type are of importance because of their potential value as antiparasitic agents (Gómez-Ayala *et al.*, 2010). In this synthetic methodology (Gómez Ayala *et al.*, 2006; Acosta, Palma & Bahsas, 2010; Acosta Quintero *et al.*, 2012), methyl 2-[(2-allylphenyl)amino]acetate was oxidized by aqueous hydrogen peroxide in the presence of a catalytic quantity of sodium tungstate to form the epoxide (I). Reduction of (I) with zinc and mixed acetic and hydrochloric acids gave the alcohol (II), hydrolysis of which gave the hydroxy acid (III). On the other hand, similar reduction of the trifluoromethoxy derivative (V), analogous to (I) (see Scheme 1), gave as a minor by-product the tricyclic lactone (IV), in addition to the expected alcohol (VI), with a product ratio of *ca* 1:6, but unfortunately, all attempts to separate these compounds, either by column chromatography or by recrystallization, were unsuccessful. Lactones such as (IV) could also be envisaged as arising by an intramolecular esterification reaction of the corresponding hydroxy acid. Benzazepin-4-ols similar to compounds (II) and (III) have recently been described having either vinyl substituents (Acosta *et al.*, 2009) or thienyl substituents (Blanco *et al.*, 2009) at position 2.

Scheme 1

2. Experimental

2.1. Synthesis and crystallization

For the synthesis of compound (I), sodium tungstate dihydrate (10 mol%), followed by 30% aqueous hydrogen

Table 1
Experimental details.

	(I)	(II)	(III)	(IV)
Crystal data				
Chemical formula	C ₁₂ H ₁₃ NO ₃	C ₁₂ H ₁₅ NO ₃	C ₁₁ H ₁₃ NO ₃	C ₁₂ H ₁₀ F ₃ NO ₃
<i>M_r</i>	219.23	221.25	207.22	273.21
Crystal system, space group	Orthorhombic, <i>P</i> ₂ ₁ ₂ ₁	Orthorhombic, <i>P</i> ₂ ₁ ₂ ₁	Monoclinic, <i>P</i> ₂ ₁ / <i>c</i>	Monoclinic, <i>P</i> ₂ ₁ / <i>c</i>
Temperature (K)	120	120	120	120
<i>a</i> , <i>b</i> , <i>c</i> (Å)	6.8549 (6), 11.4483 (12), 13.1369 (14)	6.2528 (13), 10.758 (3), 15.927 (5)	9.4389 (5), 11.9081 (5), 9.2702 (4)	15.0601 (8), 9.2204 (5), 8.072 (4)
α , β , γ (°)	90, 90, 90	90, 90, 90	90, 108.275 (3), 90	90, 91.668 (10), 90
<i>V</i> (Å ³)	1030.94 (18)	1071.4 (5)	989.41 (8)	1120.4 (6)
<i>Z</i>	4	4	4	4
Radiation type	Mo <i>K</i> α	Mo <i>K</i> α	Mo <i>K</i> α	Mo <i>K</i> α
μ (mm ⁻¹)	0.10	0.10	0.10	0.15
Crystal size (mm)	0.22 × 0.20 × 0.12	0.25 × 0.16 × 0.12	0.25 × 0.22 × 0.18	0.28 × 0.21 × 0.19
Data collection				
Diffractometer	Bruker–Nonius KappaCCD diffractometer	Bruker–Nonius KappaCCD diffractometer	Bruker–Nonius KappaCCD diffractometer	Bruker–Nonius KappaCCD diffractometer
Absorption correction	Multi-scan (<i>SADABS</i> ; Sheldrick, 2003)	Multi-scan (<i>SADABS</i> ; Sheldrick, 2003)	Multi-scan (<i>SADABS</i> ; Sheldrick, 2003)	Multi-scan (<i>SADABS</i> ; Sheldrick, 2003)
<i>T</i> _{min} , <i>T</i> _{max}	0.835, 0.988	0.616, 0.988	0.724, 0.982	0.788, 0.972
No. of measured, independent and observed [<i>I</i> > 2σ(<i>I</i>)] reflections	12257, 1375, 1089	12235, 1424, 1117	16576, 2260, 1411	18683, 2567, 1854
<i>R</i> _{int}	0.077	0.090	0.075	0.055
(sin θ /λ) _{max} (Å ⁻¹)	0.650	0.650	0.650	0.650
Refinement				
<i>R</i> [<i>F</i> ² > 2σ(<i>F</i> ²)], <i>wR</i> (<i>F</i> ²), <i>S</i>	0.043, 0.083, 1.15	0.069, 0.187, 1.19	0.048, 0.119, 1.08	0.043, 0.105, 1.07
No. of reflections	1375	1424	2260	2567
No. of parameters	146	146	136	172
H-atom treatment	H-atom parameters constrained	H-atom parameters constrained	H-atom parameters constrained	H-atom parameters constrained
Δρ _{max} , Δρ _{min} (e Å ⁻³)	0.20, -0.21	0.58, -0.34	0.25, -0.29	0.21, -0.31

Computer programs: *COLLECT* (Hooft, 1998), *DIRAX/LSQ* (Duisenberg *et al.*, 2000), *EVALCCD* (Duisenberg *et al.*, 2003), *SIR2004* (Burla *et al.*, 2005), *SHELXL97* (Sheldrick, 2008) and *PLATON* (Spek, 2009).

peroxide solution (16 mmol), were added to a stirred and cooled (273 K) solution of methyl 2-[(2-allylphenyl)amino]-acetate (4 mmol) in methanol (25 ml). The resulting mixture was then stirred at ambient temperature for 18 h and monitored by thin-layer chromatography (TLC). The mixture was filtered and the solvent was removed under reduced pressure. Toluene (15 ml) was added to the black solid residue and the resulting solution was heated under reflux for 6 h. After cooling the solution to ambient temperature, the solvent was removed under reduced pressure and the crude product was subjected to column chromatographic purification over silica gel using heptane–ethyl acetate (3:1 *v/v*) as eluent. Crystallization from heptane, at ambient temperature and in the presence of air, gave colourless crystals of compound (I) suitable for single-crystal X-ray diffraction (yield 48%, m.p. 388–389 K). HRMS, *m/z* found 219.0899, C₁₂H₁₃NO₃ requires 219.0895. For the synthesis of compounds (II) and (IV), zinc powder (40 mmol), glacial acetic acid (28 mmol) and concentrated hydrochloric acid (28 mmol) were added to stirred and cooled (273 K) solutions of the corresponding (2*RS*,4*SR*)-methyl 2,3,4,5-tetrahydro-1,4-epoxybenz[*b*]azepine-2-carboxylates, prepared as for (I) (2 mmol) in methanol (10 ml). The resulting mixtures were stirred at 273 K for 1.5 h and monitored by TLC. Each mixture was filtered and the filtrate was basified to pH 8 with aqueous ammonia solution (25%), and then extracted with ethyl acetate (3 × 40 ml). For each, the combined organic extracts were dried over anhy-

drous sodium sulfate and then the solvent was removed under reduced pressure. For (II), the resulting crude product was purified by silica-gel column chromatography using heptane–ethyl acetate as eluent (from 3:1 to 1:1 *v/v*). Crystallization from heptane–ethyl acetate (30:1 *v/v*) at ambient temperature and in the presence of air gave colourless crystals of (II) suitable for single-crystal X-ray diffraction (yield 87%, m.p. 398–399 K). HRMS, *m/z* found 221.1054, C₁₂H₁₅NO₃ requires 221.1052. The trifluoromethoxy analogue was shown by ¹H NMR spectroscopy to consist of a 6.1:1 mixture of compounds (VI) and (IV), with a combined yield of 91%, corresponding to yields of 78 and 13% for (VI) and (IV), respectively. This mixture was recrystallized from heptane–ethyl acetate (30:1 *v/v*) in the presence of activated carbon with the aim of removing the minor product; the crystals which resulted had a sharp m.p. of 345–346 K, but proved to be still a mixture of (IV) and (VI), as the crystal selected for single-crystal X-ray diffraction proved to be of compound (IV), rather than the expected (VI). For (IV), MS (70 eV), *m/z* (%) 273 (*M*⁺, 40), 228 (100), 214 (28), 202 (34), 201 (31), 188 (6); no HRMS data were obtained for this compound. For (VI), HRMS, *m/z* found 305.0871, C₁₃H₁₄F₃NO₄ requires 305.0875. Because no satisfactory bulk separation of compounds (IV) and (VI) could be achieved, the individual m.p. values could not be determined. For the synthesis of compound (III), aqueous sodium hydroxide solution (1 mol dm⁻³, 0.55 mmol) was added to a stirred solution of compound (II) (0.50 mmol)

Figure 1

The molecular structure of the (2*R*,4*S*) enantiomer of compound (I), showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 30% probability level.

in methanol (1 ml). The reaction mixture was stirred at 273 K for 30 min. Then hydrochloric acid solution (1 mol dm⁻³) was added slowly to the reaction mixture until a pH of 3.5 was achieved, and the reaction product was extracted with ethyl acetate (3 × 50 ml). The combined organic extracts were dried over anhydrous sodium sulfate and then the solvent was removed under reduced pressure. The resulting crude product was purified by crystallization, at ambient temperature and in air, from ethyl acetate–methanol (20:1 *v/v*) to give colourless crystals of (III) suitable for single-crystal X-ray diffraction (yield 84%, m.p. 437–438 K). HRMS, *m/z* found 207.0905, C₁₁H₁₃NO₃ requires 207.0895.

2.2. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 1. All H atoms were located in difference maps and subsequently treated as riding atoms. H atoms bonded to C atoms were permitted to ride in geometrically idealized positions, with C–H = 0.95 (aromatic), 0.98

Figure 3

The molecular structure of the (2*R*,4*S*) enantiomer of compound (III), showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 30% probability level.

(CH₃), 0.99 (CH₂) or 1.00 Å (aliphatic C–H) and with $U_{\text{iso}}(\text{H}) = kU_{\text{eq}}(\text{C})$, where $k = 1.5$ for the methyl groups, which were permitted to rotate but not to tilt, and 1.2 for all other H atoms bonded to C atoms. H atoms bonded to N atoms were permitted to ride at the positions located in difference maps, with $U_{\text{iso}}(\text{H}) = 1.2U_{\text{eq}}(\text{N})$, giving the N–H distances shown in Table 2. Several low-angle reflections which had been partially or completely attenuated by the beam stop were omitted from the final refinements, *viz.* for (I), 101, 012 and 002; for (II), 012; for (III), 011, 110 and -111 ; for (IV), 011 and 200. The values of the Flack x parameters (Flack, 1983) for compounds (I) and (II) were indeterminate (Flack & Bernardinelli, 2000), with values of -1.0 (14) for 975 Bijvoet pairs (99.3% coverage) and 1 (3) for 983 Bijvoet pairs (96.8% coverage), respectively; accordingly, the Friedel-equivalent reflections were merged prior to the final refinements and the reference molecules for (I) and (II) were selected as those having the *R* configuration at atom C2.

Figure 2

The molecular structure of the (2*R*,4*S*) enantiomer of compound (II), showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 30% probability level.

Figure 4

The molecular structure of the (2*R*,5*S*) enantiomer of compound (IV), showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 30% probability level.

Figure 5

Part of the crystal structure of compound (IV), showing the formation of a centrosymmetric $R_2^2(10)$ dimer built from paired N—H...O hydrogen bonds. For the sake of clarity, H atoms not involved in the motif shown have been omitted. Atoms marked with an asterisk (*) are at the symmetry position $(-x + 1, -y + 1, -z + 1)$.

3. Results and discussion

In each of compounds (I)–(IV), the molecule contains two stereogenic centres and the relative stereochemistry at these two centres is the same in each of compounds (I)–(IV). The purposes of the present study are threefold: firstly, to confirm the integrity of the relative stereochemistries of compounds (I)–(IV) during the transformations described (Scheme 1), as noted above; secondly, to show how minor changes of substituent and/or functionality on a common fused-ring skeleton can lead to significant changes in the patterns of supramolecular assembly; and thirdly, to establish definitively the molecular constitution of compound (IV). For each compound, the reference molecule was selected to be one having the *R* configuration at atom C2; on this basis, the reference molecules in compounds (I)–(III) all have the *S* configuration at atom C4, while the reference molecule of compound (IV) has the *S* configuration at the corresponding atom, here labelled C5 (*cf.* Figs. 1–4). Compounds (III) and (IV) both crystallize in the space group $P2_1/c$ as racemic mixtures, but compounds (I) and (II) both crystallize in the Sohnke space group $P2_12_12_1$. Hence, in the absence of inversion twinning, for which no evidence was found, each crystal of compounds (I) and (II) contains only a single enantiomer. In the absence of significant resonant scattering, it was not possible to determine the absolute configurations of the molecules of (I) and (II) in the crystals selected for data collection, and hence the configuration of the reference mol-

Table 2

Hydrogen bonds and short intramolecular contacts ($\text{\AA}$, $^\circ$) for compounds (I)–(IV).

Cg1 represents the centroid of the C5A/C6–C9/C9A ring.

Compound	$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
(I)	$C7-H7\cdots Cg1^i$	0.95	2.48	3.409 (3)	165
(II)	$O4-N41\cdots O21^{ii}$	0.98	2.31	3.178 (6)	147
	$O4-N41\cdots N1^{ii}$	0.98	2.48	3.334 (6)	145
	$C9-C9\cdots Cg1^{iii}$	0.95	2.55	3.350 (5)	142
(III)	$N1-H1\cdots O21$	0.86	2.12	2.644 (2)	119
	$O22-H22\cdots O4^{iv}$	0.92	1.75	2.665 (2)	172
	$O4-H41\cdots N1^v$	0.82	2.05	2.859 (2)	167
(IV)	$N1-H1\cdots O31^{vi}$	0.96	2.03	2.970 (2)	166

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

Table 3

Selected bond lengths ($\text{\AA}$) for compounds (I)–(III).

Parameter	(I)	(II)	(III)
C21—O21	1.203 (3)	1.211 (6)	1.211 (2)
C21—O22	1.346 (3)	1.318 (6)	1.329 (2)

The corresponding values for compound (IV) are C3—O31 = 1.212 (2) $\text{\AA}$ and C3—O4 = 1.343 (2) $\text{\AA}$.

ecules have been assigned to match those selected for the reference molecules in compounds (III) and (IV). In view of both of the synthetic procedures employed for the production of compounds (I) and (II), which utilize no enantioselective reagents, and of the racemic nature of compounds (II) and (IV), it seems probable that compounds (I) and (II) are both formed in solution as racemic mixtures, but that they crystallize as conglomerates rather than as racemates.

The H atom of the carboxylic acid group in compound (III) is fully ordered and the C21—O21 and C21—O22 bond lengths are similar to the corresponding distances in the esters, compounds (I) and (II) (Table 3), and fully consistent with the location of the carboxylic acid H atom as deduced from a difference map. Despite the markedly pyramidal geometry at

Figure 6

A stereoview of part of the crystal structure of compound (I), showing the formation of a chain along $[100]$ built from C—H... π (arene) hydrogen bonds. For the sake of clarity, H atoms not involved in the motif shown have been omitted.

Figure 7

A stereoview of part of the crystal structure of compound (III), showing the formation of a hydrogen-bonded sheet parallel to (100) and built from $R_4^d(14)$ and $R_4^d(26)$ rings. For the sake of clarity, H atoms bonded to C or N atoms have been omitted.

atom N1, with a sum of the interbond angles of 330° [corresponding values for (II) and (IV) are 343° and 345° , respectively], there is no evidence for any zwitterion formation by transfer of a proton from atom O22 to atom N1. The remaining bond lengths in compounds (I)–(IV) present no unexpected features.

The hydrogen-bonded supramolecular assembly in compounds (I)–(IV) is of considerable interest, as the resulting supramolecular structures range from a simple dimer in compound (IV), via a chain in compound (I) and a sheet in compound (III), to a three-dimensional framework structure

Figure 8

A projection of a sheet in compound (III), parallel to (100) and viewed along [001], showing the puckering of the sheet. For the sake of clarity, H atoms bonded to C or N atoms have been omitted.

in compound (II). It may be noted here that while the structures of (I)–(IV) encompass a variety of hydrogen-bond types, aromatic π – π stacking interactions are absent from all of the structures reported here. It is convenient to consider the supramolecular assembly in (I)–(IV) in order of increasing complexity.

The crystal structure of compound (IV) contains just one type of hydrogen bond (Table 2) and inversion-related pairs of $N-H \cdots O$ hydrogen bonds link the molecules into centrosymmetric dimers characterized by an $R_2^2(10)$ (Bernstein *et al.*, 1995) motif (Fig. 5). There are no direction-specific interactions between adjacent dimers, so that the assembly is finite and can be regarded as zero-dimensional. The supramolecular assembly in compound (I) is again determined by just one type of hydrogen bond, this time of the $C-H \cdots \pi(\text{arene})$ type (Table 2), which links molecules related by the 2_1 screw axis along $(x, \frac{1}{4}, \frac{1}{2})$ to form a chain running parallel to the [100] direction (Fig. 6).

The supramolecular assembly in compound (III) is determined by two hydrogen bonds, one each of the $O-H \cdots N$ and $O-H \cdots O$ types, both of which are nearly linear (Table 2). The $N-H$ bond plays no part in the supramolecular assembly, making only a short intramolecular contact with the carbonyl O atom, in which the $N-H \cdots O$ angle (Table 2) is too small for this to be regarded as a structurally significant interaction, but there are no other potential acceptors within range of atom N1 for plausible intermolecular hydrogen-bond formation. The action of the $O-H \cdots N$ hydrogen bond, in which the hydroxy group provides the donor, is to link molecules related

Figure 9

Part of the crystal structure of compound (II), showing the formation of a chain of rings along [010] built from three-centre $O-H \cdots (N,O)$ hydrogen bonds. For the sake of clarity, H atoms not involved in the motif shown have been omitted. Atoms marked with an asterisk (*) or a hash (#) are at the symmetry positions $(-x+1, y-\frac{1}{2}, -z+\frac{1}{2})$ and $(-x+1, y+\frac{1}{2}, -z+\frac{1}{2})$, respectively.

Figure 10

A stereoview of part of the crystal structure of compound (II), showing the formation of a chain along [100] built from C—H... π (arene) hydrogen bonds. For the sake of clarity, H atoms not involved in the motif shown have been omitted.

by the *c*-glide plane at $y = \frac{1}{2}$ into a $C(6)$ (Bernstein *et al.*, 1995) chain running parallel to the [001] direction. The O—H...O hydrogen bond, where the carboxylic acid group provides the donor, links molecules related by the 2_1 screw axis along $(0, y, \frac{1}{4})$ into a $C(7)$ chain running parallel to the [010] direction. The combination of the two hydrogen bonds generates a sheet lying parallel to (100) and built from centrosymmetric $R_4^4(14)$ and $R_4^4(26)$ rings arranged in a chessboard pattern (Fig. 7). The smaller rings are centred at $(0, m, \frac{1}{2} + n)$ and $(0, \frac{1}{2} + m, n)$, and the larger rings are centred at $(0, m, n)$ and $(0, \frac{1}{2} + m, \frac{1}{2} + n)$, where m and n represent integers in all cases. Although both types of ring in the reference sheet are centred at $x = 0$, the sheet is markedly puckered, and it occupies the entire domain of x (Fig. 8); there are no direction-specific interactions between adjacent sheets. Four molecules, arranged in two inversion-related pairs, contribute to each type of ring. In the smaller $R_4^4(14)$ ring, each of the four component molecules acts as both a hydrogen-bond donor and as a hydrogen-bond acceptor, but in the larger $R_4^4(26)$ ring, one pair of inversion-related molecules acts as a twofold

donor of hydrogen bonds while the other pair acts as a twofold acceptor (Fig. 7).

There are only two independent hydrogen bonds in the structure of compound (II); one is a planar three-centre O—H... π (N,O) hydrogen bond and the other is a C—H... π (arene) hydrogen bond (Table 2). However, these two interactions generate a three-dimensional framework structure, whose formation is readily analysed in terms of three one-dimensional substructures (Ferguson *et al.*, 1998*a,b*; Gregson *et al.*, 2000). The three-centre hydrogen bond, when acting alone, links molecules related by the 2_1 screw axis along $(\frac{1}{2}, y, \frac{1}{4})$ into a $C(6)C(7)[R_1^2(5)]$ chain of rings (Bernstein *et al.*, 1995) running parallel to the [010] direction (Fig. 9). The C—H... π (arene) hydrogen bond, again when acting alone, links molecules related by the 2_1 screw axis along $(x, \frac{3}{4}, 0)$ into a chain running parallel to the [100] direction (Fig. 10). In combination, the two types of hydrogen bond generate a chain running parallel to the [001] direction in which the O—H... π (N,O) and C—H... π (arene) hydrogen bonds alternate (Fig. 11). The combination of the chains along [100], [010] and [001] is sufficient to generate a continuous three-dimensional structure.

Scheme 2

It is of interest briefly to compare the supramolecular assembly in compounds (I)–(IV) reported here with that in some related compounds. In simple 1,4-epoxy-1-benzazepines analogous to compound (I), the direction-specific intermolecular interactions are generally restricted to C—H...O and C—H... π (arene) hydrogen bonds, along with aromatic π – π stacking interactions but, nonetheless, these interactions can give rise to supramolecular assembly in zero, one, two or three dimensions (*e.g.* Gómez *et al.*, 2008, 2009; Acosta, Palma, Bahsas *et al.*, 2010; Sanabria *et al.*, 2010). Compounds (VII)–(IX) (see Scheme 2) (Acosta *et al.*, 2009), which are analogues of compound (II), are isomorphous but not strictly isostructural, as small variations in the unit-cell dimensions preclude in the structure of compound (IX) one of the intermolecular interactions present in the structures of compounds (VII) and (VIII). In the structure of (IX), a combination of O—H...N and N—H...O hydrogen bonds gives rise to a chain of edge-

Figure 11

A stereoview of part of the crystal structure of compound (II), showing the formation of a chain along [001] in which the O—H... π (N,O) and C—H... π (arene) hydrogen bonds alternate. For the sake of clarity, H atoms not involved in the motif shown have been omitted.

Figure 12

Part of the crystal structure of compound (XII), showing the formation of a $C(8)C(9)[R_2^2(10)]$ chain of rings running parallel to $[001]$. The original atomic coordinates (Coda *et al.*, 1986) were used, modified by translations to assemble the asymmetric unit into a single molecule. H atoms bonded to O atoms are in positions calculated by assuming O—H distances of 0.85 Å and linear O—H...O hydrogen bonds. For the sake of clarity, the unit-cell outline has been omitted. Atoms marked with an asterisk (*) or a hash (#) are at the symmetry positions $(-x + \frac{3}{2}, -y, z - \frac{1}{2})$ and $(-x + \frac{3}{2}, -y, z + \frac{1}{2})$, respectively.

fused $R_3^3(10)$ rings; similar chains are present also in compounds (VII) and (VIII) where, in addition, they are linked into sheets by C—H... π (arene) hydrogen bonds. Compounds (X) and (XI) both crystallize with $Z' = 2$ in the space group $P\bar{1}$ (Blanco *et al.*, 2012); in both compounds, the hydroxy H atoms are all disordered over two sites with equal occupancy, and O—H...O hydrogen bonds give rise to $C_4^4(8)$ chains within which the locations of the hydroxy H atoms are fully correlated, but with no necessary correlation of the directions of the hydrogen bonds in adjacent chains. An isolated example of a 1-benzazepine derivative carrying both a hydroxy substituent and a non-esterified carboxylic acid group, and hence comparable with compound (III), is provided by 1-acetyl-4-benzoyl-2-hydroxy-2,3,4,5-tetrahydro-1*H*-benz[*b*]azepine-5-carboxylic acid, (XII) [Cambridge Structural Database (CSD; Allen, 2002) refcode DOJJER; Coda *et al.*, 1986]. Unfortunately, the atomic coordinates deposited in the CSD do not include any H atoms, while the non-H atoms of the asymmetric unit are distributed amongst three separate molecules. However, the C—O distances of the carboxylic acid group (1.211 and 1.320 Å, no s.u. values available) indicate the presence of an un-ionized —COOH

group. Based on this conclusion and an examination of the intermolecular N...O and O...O distances, the main features of the supramolecular assembly can be deduced, despite the absence of any H-atom coordinates; the carboxylic acid OH group acts as hydrogen-bond donor to the amidic O atom, and the hydroxy group acts as a hydrogen-bond donor to the carbonyl O atom of the carboxylic acid group, but the N atom plays no part in the supramolecular assembly. Overall, molecules related by a 2_1 screw axis along $[001]$ are linked by these two hydrogen bonds to form a $C(8)C(9)[R_2^2(10)]$ chain of rings running parallel to the $[001]$ direction (Fig. 12).

In summary, we have demonstrated the preservation of the relative stereochemistry throughout the reaction sequence from compound (I), we have established the molecular constitution of compound (IV) and we have shown how minor changes in molecular constitution in the related compounds (I)–(XII) can lead to marked changes in supramolecular assembly.

The authors thank ‘Centro de Instrumentación Científico-Técnica of Universidad de Jaén’ and the staff for data collection. AP, SAG and CMS thank Colciencias for financial support (grant No. 1102–521–28229). JC thanks the Consejería de Innovación, Ciencia y Empresa (Junta de Andalucía, Spain) and the Universidad de Jaén for financial support.

Supporting information for this paper is available from the IUCr electronic archives (Reference: SK3540).

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supplementary materials

Acta Cryst. (2014). **C70**, 408–415 [doi:10.1107/S2053229614006007]

Four related benzazepine derivatives in a reaction pathway leading to a benzazepine carboxylic acid: hydrogen-bonded assembly in zero, one, two and three dimensions

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Computing details

For all compounds, data collection: *COLLECT* (Hooft, 1998); cell refinement: *DIRAX/LSQ* (Duisenberg *et al.*, 2000); data reduction: *EVALCCD* (Duisenberg *et al.*, 2003); program(s) used to solve structure: *SIR2004* (Burla *et al.*, 2005); program(s) used to refine structure: *SHELXL97* (Sheldrick, 2008); molecular graphics: *PLATON* (Spek, 2009). Software used to prepare material for publication: *SHELXL97* (Sheldrick, 2008) and *PLATON* (Spek, 2009) for (I); *SHELXL97* (Sheldrick, 2008) and *PLATON* (Spek, 2009) for (II), (III), (IV).

(I) (2*R**,4*S**)-Methyl 2,3,4,5-tetrahydro-1,4-epoxy-1*H*-benz[*b*]azepine-2-carboxylate

Crystal data

$C_{12}H_{13}NO_3$	$F(000) = 464$
$M_r = 219.23$	$D_x = 1.413 \text{ Mg m}^{-3}$
Orthorhombic, $P2_12_12_1$	Mo $K\alpha$ radiation, $\lambda = 0.71073 \text{ \AA}$
Hall symbol: P 2ac 2ab	Cell parameters from 1378 reflections
$a = 6.8549 (6) \text{ \AA}$	$\theta = 3.1\text{--}27.5^\circ$
$b = 11.4483 (12) \text{ \AA}$	$\mu = 0.10 \text{ mm}^{-1}$
$c = 13.1369 (14) \text{ \AA}$	$T = 120 \text{ K}$
$V = 1030.94 (18) \text{ \AA}^3$	Block, colourless
$Z = 4$	$0.22 \times 0.20 \times 0.12 \text{ mm}$

Data collection

Bruker–Nonius KappaCCD diffractometer	$T_{\min} = 0.835$, $T_{\max} = 0.988$
Radiation source: Bruker–Nonius FR591 rotating anode	12257 measured reflections
Graphite monochromator	1375 independent reflections
Detector resolution: $9.091 \text{ pixels mm}^{-1}$	1089 reflections with $I > 2\sigma(I)$
φ & ω scans	$R_{\text{int}} = 0.077$
Absorption correction: multi-scan (<i>SADABS</i> ; Sheldrick, 2003)	$\theta_{\max} = 27.5^\circ$, $\theta_{\min} = 3.5^\circ$
	$h = -8 \rightarrow 8$
	$k = -14 \rightarrow 13$
	$l = -17 \rightarrow 16$

Refinement

Refinement on F^2	146 parameters
Least-squares matrix: full	0 restraints
$R[F^2 > 2\sigma(F^2)] = 0.043$	Primary atom site location: structure-invariant direct methods
$wR(F^2) = 0.083$	Secondary atom site location: difference Fourier map
$S = 1.15$	
1375 reflections	

Hydrogen site location: inferred from
neighbouring sites
H-atom parameters constrained

$$w = 1/[\sigma^2(F_o^2) + (0.0318P)^2 + 0.2372P]$$

$$\text{where } P = (F_o^2 + 2F_c^2)/3$$

$$(\Delta/\sigma)_{\max} = 0.001$$

$$\Delta\rho_{\max} = 0.20 \text{ e } \text{\AA}^{-3}$$

$$\Delta\rho_{\min} = -0.21 \text{ e } \text{\AA}^{-3}$$

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters ($\text{\AA}^2$)

	x	y	z	$U_{\text{iso}}^*/U_{\text{eq}}$
N1	0.5882 (3)	0.53959 (17)	0.62664 (15)	0.0169 (5)
C2	0.7808 (4)	0.4788 (2)	0.63363 (18)	0.0172 (6)
H2	0.8029	0.4283	0.5726	0.021*
C3	0.7668 (4)	0.4041 (2)	0.73108 (18)	0.0207 (6)
H3A	0.7548	0.3201	0.7144	0.025*
H3B	0.8824	0.4158	0.7751	0.025*
C4	0.5806 (4)	0.4499 (2)	0.78270 (18)	0.0203 (6)
H4	0.6023	0.4608	0.8574	0.024*
C5	0.4015 (4)	0.3748 (2)	0.76360 (17)	0.0208 (6)
H5A	0.4294	0.2928	0.7828	0.025*
H5B	0.2915	0.4029	0.8059	0.025*
C5A	0.3467 (4)	0.3809 (2)	0.65235 (18)	0.0169 (5)
C6	0.2051 (4)	0.3078 (2)	0.61025 (19)	0.0188 (6)
H6	0.1366	0.2547	0.6528	0.023*
C7	0.1629 (4)	0.3117 (2)	0.50650 (19)	0.0196 (6)
H7	0.0650	0.2623	0.4789	0.024*
C8	0.2638 (4)	0.3878 (2)	0.44358 (19)	0.0190 (5)
H8	0.2374	0.3891	0.3726	0.023*
C9	0.4031 (4)	0.4619 (2)	0.48420 (18)	0.0174 (6)
H9	0.4719	0.5144	0.4413	0.021*
C9A	0.4419 (4)	0.4592 (2)	0.58782 (17)	0.0147 (5)
O14	0.5459 (3)	0.56224 (15)	0.73310 (12)	0.0193 (4)
C21	0.9367 (4)	0.5730 (2)	0.64079 (19)	0.0176 (5)
O21	1.0154 (3)	0.60550 (17)	0.71760 (13)	0.0269 (5)
O22	0.9732 (3)	0.61892 (15)	0.54844 (12)	0.0210 (4)
C22	1.1153 (4)	0.7122 (2)	0.5470 (2)	0.0247 (6)
H22A	1.0672	0.7780	0.5876	0.037*
H22B	1.1366	0.7378	0.4767	0.037*
H22C	1.2386	0.6841	0.5757	0.037*

Atomic displacement parameters ($\text{\AA}^2$)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
N1	0.0182 (11)	0.0168 (11)	0.0156 (10)	0.0001 (9)	0.0006 (9)	−0.0026 (9)
C2	0.0162 (13)	0.0163 (13)	0.0190 (12)	0.0030 (10)	−0.0024 (11)	−0.0005 (11)
C3	0.0244 (13)	0.0191 (14)	0.0186 (12)	−0.0001 (12)	−0.0036 (12)	0.0026 (11)
C4	0.0287 (15)	0.0187 (13)	0.0135 (11)	0.0007 (12)	0.0005 (11)	0.0009 (10)
C5	0.0266 (14)	0.0203 (13)	0.0155 (12)	−0.0030 (12)	0.0055 (11)	−0.0004 (11)
C5A	0.0184 (13)	0.0140 (12)	0.0184 (12)	0.0055 (11)	0.0041 (10)	−0.0011 (11)
C6	0.0175 (13)	0.0156 (13)	0.0233 (13)	−0.0006 (11)	0.0049 (11)	0.0001 (11)
C7	0.0158 (13)	0.0166 (13)	0.0264 (13)	0.0000 (11)	−0.0007 (11)	−0.0043 (11)

C8	0.0187 (12)	0.0182 (12)	0.0202 (12)	0.0038 (12)	−0.0013 (11)	−0.0022 (12)
C9	0.0156 (12)	0.0160 (13)	0.0207 (13)	0.0032 (11)	−0.0014 (10)	0.0052 (10)
C9A	0.0137 (12)	0.0113 (12)	0.0192 (12)	0.0025 (10)	0.0003 (10)	−0.0004 (10)
O14	0.0247 (10)	0.0185 (9)	0.0149 (9)	0.0019 (8)	0.0020 (8)	−0.0034 (7)
C21	0.0160 (12)	0.0174 (12)	0.0195 (12)	0.0043 (11)	0.0006 (11)	−0.0025 (10)
O21	0.0277 (10)	0.0335 (11)	0.0195 (9)	−0.0079 (9)	−0.0050 (9)	−0.0052 (9)
O22	0.0224 (9)	0.0216 (9)	0.0189 (8)	−0.0067 (9)	−0.0019 (8)	−0.0006 (8)
C22	0.0236 (14)	0.0214 (13)	0.0292 (14)	−0.0066 (12)	0.0018 (12)	−0.0018 (12)

Geometric parameters (Å, °)

N1—O14	1.452 (2)	C5A—C6	1.396 (4)
N1—C9A	1.454 (3)	C6—C7	1.394 (3)
N1—C2	1.496 (3)	C6—H6	0.9500
C2—C21	1.521 (3)	C7—C8	1.386 (4)
C2—C3	1.543 (3)	C7—H7	0.9500
C2—H2	1.0000	C8—C9	1.384 (4)
C3—C4	1.537 (4)	C8—H8	0.9500
C3—H3A	0.9900	C9—C9A	1.387 (3)
C3—H3B	0.9900	C9—H9	0.9500
C4—O14	1.461 (3)	C21—O21	1.203 (3)
C4—C5	1.520 (4)	C21—O22	1.346 (3)
C4—H4	1.0000	O22—C22	1.446 (3)
C5—C5A	1.511 (3)	C22—H22A	0.9800
C5—H5A	0.9900	C22—H22B	0.9800
C5—H5B	0.9900	C22—H22C	0.9800
C5A—C9A	1.395 (3)		
O14—N1—C9A	108.26 (17)	C9A—C5A—C5	120.1 (2)
O14—N1—C2	101.56 (17)	C6—C5A—C5	121.9 (2)
C9A—N1—C2	109.64 (18)	C7—C6—C5A	120.8 (2)
N1—C2—C21	107.10 (19)	C7—C6—H6	119.6
N1—C2—C3	104.7 (2)	C5A—C6—H6	119.6
C21—C2—C3	112.7 (2)	C8—C7—C6	120.0 (3)
N1—C2—H2	110.7	C8—C7—H7	120.0
C21—C2—H2	110.7	C6—C7—H7	120.0
C3—C2—H2	110.7	C9—C8—C7	120.0 (2)
C4—C3—C2	103.2 (2)	C9—C8—H8	120.0
C4—C3—H3A	111.1	C7—C8—H8	120.0
C2—C3—H3A	111.1	C8—C9—C9A	119.8 (2)
C4—C3—H3B	111.1	C8—C9—H9	120.1
C2—C3—H3B	111.1	C9A—C9—H9	120.1
H3A—C3—H3B	109.1	C9—C9A—C5A	121.4 (2)
O14—C4—C5	107.0 (2)	C9—C9A—N1	117.5 (2)
O14—C4—C3	103.83 (19)	C5A—C9A—N1	121.1 (2)
C5—C4—C3	113.9 (2)	N1—O14—C4	103.88 (17)
O14—C4—H4	110.6	O21—C21—O22	123.5 (2)
C5—C4—H4	110.6	O21—C21—C2	125.9 (2)
C3—C4—H4	110.6	O22—C21—C2	110.6 (2)
C5A—C5—C4	109.5 (2)	C21—O22—C22	115.18 (19)

C5A—C5—H5A	109.8	O22—C22—H22A	109.5
C4—C5—H5A	109.8	O22—C22—H22B	109.5
C5A—C5—H5B	109.8	H22A—C22—H22B	109.5
C4—C5—H5B	109.8	O22—C22—H22C	109.5
H5A—C5—H5B	108.2	H22A—C22—H22C	109.5
C9A—C5A—C6	118.0 (2)	H22B—C22—H22C	109.5
O14—N1—C2—C21	−83.6 (2)	C6—C5A—C9A—C9	−2.3 (4)
C9A—N1—C2—C21	162.07 (19)	C5—C5A—C9A—C9	176.1 (2)
O14—N1—C2—C3	36.3 (2)	C6—C5A—C9A—N1	178.8 (2)
C9A—N1—C2—C3	−78.1 (2)	C5—C5A—C9A—N1	−2.8 (3)
N1—C2—C3—C4	−11.5 (2)	O14—N1—C9A—C9	154.2 (2)
C21—C2—C3—C4	104.5 (2)	C2—N1—C9A—C9	−95.8 (3)
C2—C3—C4—O14	−17.3 (2)	O14—N1—C9A—C5A	−26.9 (3)
C2—C3—C4—C5	98.7 (2)	C2—N1—C9A—C5A	83.1 (3)
O14—C4—C5—C5A	47.3 (2)	C9A—N1—O14—C4	66.8 (2)
C3—C4—C5—C5A	−66.8 (3)	C2—N1—O14—C4	−48.6 (2)
C4—C5—C5A—C9A	−7.6 (3)	C5—C4—O14—N1	−79.5 (2)
C4—C5—C5A—C6	170.8 (2)	C3—C4—O14—N1	41.2 (2)
C9A—C5A—C6—C7	1.1 (4)	N1—C2—C21—O21	99.8 (3)
C5—C5A—C6—C7	−177.3 (2)	C3—C2—C21—O21	−14.8 (3)
C5A—C6—C7—C8	0.8 (4)	N1—C2—C21—O22	−78.7 (2)
C6—C7—C8—C9	−1.6 (4)	C3—C2—C21—O22	166.7 (2)
C7—C8—C9—C9A	0.4 (4)	O21—C21—O22—C22	−0.3 (3)
C8—C9—C9A—C5A	1.6 (4)	C2—C21—O22—C22	178.2 (2)
C8—C9—C9A—N1	−179.4 (2)		

Hydrogen-bond geometry (Å, °)

<i>D</i> —H $\cdots$ <i>A</i>	<i>D</i> —H	H $\cdots$ <i>A</i>	<i>D</i> $\cdots$ <i>A</i>	<i>D</i> —H $\cdots$ <i>A</i>
C7—H7 $\cdots$ Cg1 ⁱ	0.95	2.48	3.409 (3)	165

Symmetry code: (i) $x-1/2, -y+1/2, -z+1$.

(II) (2*R**,4*S**)-Methyl 4-hydroxy-2,3,4,5-tetrahydro-1*H*-benz[*b*]azepine-2-carboxylate

Crystal data

C₁₂H₁₅NO₃

M_r = 221.25

Orthorhombic, *P*2₁2₁2₁

Hall symbol: *P* 2ac 2ab

a = 6.2528 (13) Å

b = 10.758 (3) Å

c = 15.927 (5) Å

V = 1071.4 (5) Å³

Z = 4

F(000) = 472

D_x = 1.372 Mg m^{−3}

Mo *K*α radiation, λ = 0.71073 Å

Cell parameters from 1425 reflections

θ = 3.1–27.5°

μ = 0.10 mm^{−1}

T = 120 K

Block, colourless

0.25 × 0.16 × 0.12 mm

Data collection

Bruker–Nonius KappaCCD
 diffractometer
 Radiation source: Bruker–Nonius FR591
 rotating anode
 Graphite monochromator
 Detector resolution: 9.091 pixels mm⁻¹
 φ & ω scans
 Absorption correction: multi-scan
 (SADABS; Sheldrick, 2003)

$T_{\min} = 0.616$, $T_{\max} = 0.988$
 12235 measured reflections
 1424 independent reflections
 1117 reflections with $I > 2\sigma(I)$
 $R_{\text{int}} = 0.090$
 $\theta_{\max} = 27.5^\circ$, $\theta_{\min} = 3.5^\circ$
 $h = -7 \rightarrow 7$
 $k = -13 \rightarrow 12$
 $l = -20 \rightarrow 20$

Refinement

Refinement on F^2
 Least-squares matrix: full
 $R[F^2 > 2\sigma(F^2)] = 0.069$
 $wR(F^2) = 0.187$
 $S = 1.19$
 1424 reflections
 146 parameters
 0 restraints
 Primary atom site location: structure-invariant
 direct methods

Secondary atom site location: difference Fourier
 map
 Hydrogen site location: inferred from
 neighbouring sites
 H-atom parameters constrained
 $w = 1/[\sigma^2(F_o^2) + (0.0725P)^2 + 1.5397P]$
 where $P = (F_o^2 + 2F_c^2)/3$
 $(\Delta/\sigma)_{\max} = 0.001$
 $\Delta\rho_{\max} = 0.58 \text{ e } \text{\AA}^{-3}$
 $\Delta\rho_{\min} = -0.34 \text{ e } \text{\AA}^{-3}$

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters ($\text{\AA}^2$)

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
N1	0.7715 (6)	0.7491 (4)	0.1659 (2)	0.0189 (8)
H1	0.8771	0.8002	0.1540	0.023*
C2	0.7976 (7)	0.6958 (4)	0.2502 (3)	0.0181 (10)
H2	0.8697	0.6133	0.2443	0.022*
C3	0.5864 (7)	0.6757 (5)	0.2961 (3)	0.0222 (10)
H3A	0.6164	0.6534	0.3553	0.027*
H3B	0.5046	0.7545	0.2962	0.027*
C4	0.4505 (8)	0.5742 (5)	0.2565 (3)	0.0247 (11)
H4	0.5356	0.4958	0.2519	0.030*
O4	0.2758 (6)	0.5563 (4)	0.3138 (2)	0.0399 (11)
H41	0.2102	0.4751	0.3032	0.060*
C5	0.3632 (8)	0.6105 (5)	0.1700 (3)	0.0260 (11)
H5A	0.2400	0.5561	0.1569	0.031*
H5B	0.3093	0.6969	0.1731	0.031*
C5A	0.5220 (7)	0.6021 (5)	0.0987 (3)	0.0198 (9)
C6	0.4727 (8)	0.5318 (5)	0.0278 (3)	0.0236 (10)
H6	0.3446	0.4842	0.0276	0.028*
C7	0.6033 (8)	0.5284 (5)	-0.0425 (3)	0.0236 (11)
H7	0.5622	0.4820	-0.0907	0.028*
C8	0.7956 (8)	0.5938 (4)	-0.0416 (3)	0.0205 (10)
H8	0.8881	0.5914	-0.0889	0.025*
C9	0.8512 (8)	0.6625 (4)	0.0288 (3)	0.0192 (10)
H9	0.9825	0.7069	0.0294	0.023*
C9A	0.7168 (8)	0.6674 (4)	0.0988 (3)	0.0177 (9)
C21	0.9463 (8)	0.7813 (4)	0.2990 (3)	0.0232 (10)
O21	1.0501 (9)	0.8637 (4)	0.2670 (2)	0.0466 (12)

O22	0.9470 (6)	0.7562 (3)	0.38004 (19)	0.0253 (8)
C22	1.1035 (8)	0.8224 (5)	0.4304 (3)	0.0275 (12)
H22A	1.2479	0.8008	0.4114	0.041*
H22B	1.0870	0.7990	0.4895	0.041*
H22C	1.0814	0.9122	0.4243	0.041*

Atomic displacement parameters ($\text{\AA}^2$)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
N1	0.022 (2)	0.0165 (18)	0.0184 (19)	−0.0040 (18)	0.0017 (15)	0.0002 (16)
C2	0.016 (2)	0.025 (2)	0.0129 (19)	−0.004 (2)	−0.0003 (18)	−0.0010 (18)
C3	0.013 (2)	0.029 (3)	0.024 (2)	−0.003 (2)	0.0037 (19)	−0.001 (2)
C4	0.016 (2)	0.040 (3)	0.018 (2)	−0.009 (2)	0.0044 (19)	0.002 (2)
O4	0.023 (2)	0.064 (3)	0.033 (2)	−0.014 (2)	0.0091 (17)	0.000 (2)
C5	0.013 (2)	0.043 (3)	0.022 (2)	−0.002 (2)	0.0022 (19)	−0.002 (2)
C5A	0.012 (2)	0.027 (2)	0.020 (2)	0.0001 (19)	−0.0006 (18)	0.0016 (18)
C6	0.017 (2)	0.026 (2)	0.028 (2)	0.000 (2)	−0.005 (2)	0.003 (2)
C7	0.029 (3)	0.022 (2)	0.019 (2)	0.003 (2)	−0.007 (2)	−0.0046 (19)
C8	0.021 (2)	0.024 (2)	0.017 (2)	0.003 (2)	0.0002 (19)	0.0014 (18)
C9	0.015 (2)	0.017 (2)	0.025 (2)	0.0032 (18)	−0.0001 (19)	0.0035 (19)
C9A	0.020 (2)	0.018 (2)	0.015 (2)	0.000 (2)	−0.0032 (18)	0.0018 (17)
C21	0.023 (2)	0.024 (2)	0.023 (2)	−0.005 (2)	0.005 (2)	−0.0032 (19)
O21	0.073 (3)	0.042 (2)	0.0241 (19)	−0.037 (2)	−0.001 (2)	−0.0010 (17)
O22	0.0260 (17)	0.0295 (18)	0.0204 (16)	−0.0080 (17)	−0.0034 (14)	−0.0028 (14)
C22	0.025 (3)	0.033 (3)	0.024 (2)	−0.007 (2)	−0.005 (2)	−0.008 (2)

Geometric parameters ($\text{\AA}$, $^\circ$)

N1—C9A	1.426 (6)	C5A—C6	1.394 (6)
N1—C2	1.469 (5)	C5A—C9A	1.406 (7)
N1—H1	0.8798	C6—C7	1.386 (7)
C2—C21	1.522 (7)	C6—H6	0.9500
C2—C3	1.525 (6)	C7—C8	1.393 (7)
C2—H2	1.0000	C7—H7	0.9500
C3—C4	1.521 (7)	C8—C9	1.387 (6)
C3—H3A	0.9900	C8—H8	0.9500
C3—H3B	0.9900	C9—C9A	1.397 (6)
C4—O4	1.436 (6)	C9—H9	0.9500
C4—C5	1.533 (7)	C21—O21	1.211 (6)
C4—H4	1.0000	C21—O22	1.318 (6)
O4—H41	0.9800	O22—C22	1.452 (6)
C5—C5A	1.512 (6)	C22—H22A	0.9800
C5—H5A	0.9900	C22—H22B	0.9800
C5—H5B	0.9900	C22—H22C	0.9800
C9A—N1—C2	118.1 (4)	C6—C5A—C9A	117.6 (4)
C9A—N1—H1	113.8	C6—C5A—C5	119.7 (4)
C2—N1—H1	111.0	C9A—C5A—C5	122.6 (4)
N1—C2—C21	107.4 (4)	C7—C6—C5A	122.6 (4)
N1—C2—C3	113.4 (4)	C7—C6—H6	118.7

C21—C2—C3	111.7 (4)	C5A—C6—H6	118.7
N1—C2—H2	108.1	C6—C7—C8	119.1 (4)
C21—C2—H2	108.1	C6—C7—H7	120.5
C3—C2—H2	108.1	C8—C7—H7	120.5
C4—C3—C2	112.7 (4)	C9—C8—C7	119.6 (4)
C4—C3—H3A	109.0	C9—C8—H8	120.2
C2—C3—H3A	109.0	C7—C8—H8	120.2
C4—C3—H3B	109.0	C8—C9—C9A	120.9 (4)
C2—C3—H3B	109.0	C8—C9—H9	119.5
H3A—C3—H3B	107.8	C9A—C9—H9	119.5
O4—C4—C3	104.9 (4)	C9—C9A—C5A	120.1 (4)
O4—C4—C5	109.5 (4)	C9—C9A—N1	118.5 (4)
C3—C4—C5	112.9 (4)	C5A—C9A—N1	121.1 (4)
O4—C4—H4	109.8	O21—C21—O22	124.1 (5)
C3—C4—H4	109.8	O21—C21—C2	123.7 (4)
C5—C4—H4	109.8	O22—C21—C2	112.2 (4)
C4—O4—H41	109.2	C21—O22—C22	116.2 (4)
C5A—C5—C4	115.3 (4)	O22—C22—H22A	109.5
C5A—C5—H5A	108.5	O22—C22—H22B	109.5
C4—C5—H5A	108.5	H22A—C22—H22B	109.5
C5A—C5—H5B	108.5	O22—C22—H22C	109.5
C4—C5—H5B	108.5	H22A—C22—H22C	109.5
H5A—C5—H5B	107.5	H22B—C22—H22C	109.5
C9A—N1—C2—C21	154.8 (4)	C8—C9—C9A—C5A	0.0 (7)
C9A—N1—C2—C3	−81.3 (5)	C8—C9—C9A—N1	−173.8 (4)
N1—C2—C3—C4	68.2 (5)	C6—C5A—C9A—C9	1.4 (6)
C21—C2—C3—C4	−170.3 (4)	C5—C5A—C9A—C9	−175.9 (4)
C2—C3—C4—O4	172.1 (4)	C6—C5A—C9A—N1	175.0 (4)
C2—C3—C4—C5	−68.7 (5)	C5—C5A—C9A—N1	−2.2 (7)
O4—C4—C5—C5A	−165.8 (4)	C2—N1—C9A—C9	−123.1 (5)
C3—C4—C5—C5A	77.6 (6)	C2—N1—C9A—C5A	63.2 (6)
C4—C5—C5A—C6	125.6 (5)	N1—C2—C21—O21	−12.0 (7)
C4—C5—C5A—C9A	−57.3 (6)	C3—C2—C21—O21	−136.9 (5)
C9A—C5A—C6—C7	−2.7 (7)	N1—C2—C21—O22	167.3 (4)
C5—C5A—C6—C7	174.6 (5)	C3—C2—C21—O22	42.4 (6)
C5A—C6—C7—C8	2.5 (7)	O21—C21—O22—C22	−8.0 (8)
C6—C7—C8—C9	−1.0 (7)	C2—C21—O22—C22	172.6 (4)
C7—C8—C9—C9A	−0.2 (7)		

Hydrogen-bond geometry (Å, °)

<i>D</i> —H $\cdots$ <i>A</i>	<i>D</i> —H	H $\cdots$ <i>A</i>	<i>D</i> $\cdots$ <i>A</i>	<i>D</i> —H $\cdots$ <i>A</i>
O4—H41 $\cdots$ O21 ⁱ	0.98	2.31	3.178 (6)	147
O4—H41 $\cdots$ N1 ⁱ	0.98	2.48	3.334 (6)	145
C9—H9 $\cdots$ Cg1 ⁱⁱ	0.95	2.55	3.350 (5)	142

Symmetry codes: (i) $-x+1, y-1/2, -z+1/2$; (ii) $x+1/2, -y+3/2, -z$.

(III) (2*RS*,4*SR*)-4-Hydroxy-2,3,4,5-tetrahydro-1*H*-benz[*b*]azepine-2-carboxylic acid

Crystal data

$C_{11}H_{13}NO_3$	$F(000) = 440$
$M_r = 207.22$	$D_x = 1.391 \text{ Mg m}^{-3}$
Monoclinic, $P2_1/c$	Mo $K\alpha$ radiation, $\lambda = 0.71073 \text{ \AA}$
Hall symbol: -P 2ybc	Cell parameters from 2263 reflections
$a = 9.4389 (5) \text{ \AA}$	$\theta = 2.8\text{--}27.5^\circ$
$b = 11.9081 (5) \text{ \AA}$	$\mu = 0.10 \text{ mm}^{-1}$
$c = 9.2702 (4) \text{ \AA}$	$T = 120 \text{ K}$
$\beta = 108.275 (3)^\circ$	Block, colourless
$V = 989.41 (8) \text{ \AA}^3$	$0.25 \times 0.22 \times 0.18 \text{ mm}$
$Z = 4$	

Data collection

Bruker–Nonius KappaCCD	$T_{\min} = 0.724$, $T_{\max} = 0.982$
diffractometer	16576 measured reflections
Radiation source: Bruker–Nonius FR591	2260 independent reflections
rotating anode	1411 reflections with $I > 2\sigma(I)$
Graphite monochromator	$R_{\text{int}} = 0.075$
Detector resolution: $9.091 \text{ pixels mm}^{-1}$	$\theta_{\max} = 27.5^\circ$, $\theta_{\min} = 4.1^\circ$
φ & ω scans	$h = -12 \rightarrow 12$
Absorption correction: multi-scan	$k = -15 \rightarrow 15$
(<i>SADABS</i> ; Sheldrick, 2003)	$l = -12 \rightarrow 12$

Refinement

Refinement on F^2	Secondary atom site location: difference Fourier
Least-squares matrix: full	map
$R[F^2 > 2\sigma(F^2)] = 0.048$	Hydrogen site location: inferred from
$wR(F^2) = 0.119$	neighbouring sites
$S = 1.08$	H-atom parameters constrained
2260 reflections	$w = 1/[\sigma^2(F_o^2) + (0.0438P)^2 + 0.515P]$
136 parameters	where $P = (F_o^2 + 2F_c^2)/3$
0 restraints	$(\Delta/\sigma)_{\max} = 0.001$
Primary atom site location: structure-invariant	$\Delta\rho_{\max} = 0.25 \text{ e \AA}^{-3}$
direct methods	$\Delta\rho_{\min} = -0.29 \text{ e \AA}^{-3}$

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters ($\text{\AA}^2$)

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
N1	0.31915 (16)	0.43639 (13)	0.16425 (18)	0.0189 (4)
H1	0.3134	0.4850	0.0940	0.023*
C2	0.2315 (2)	0.48806 (16)	0.2543 (2)	0.0186 (4)
H2	0.3009	0.5322	0.3390	0.022*
C3	0.1533 (2)	0.39999 (17)	0.3228 (2)	0.0198 (4)
H3A	0.0871	0.4389	0.3710	0.024*
H3B	0.0897	0.3527	0.2398	0.024*
C4	0.2594 (2)	0.32434 (16)	0.4402 (2)	0.0189 (4)
H4	0.3155	0.3707	0.5299	0.023*
O4	0.16312 (14)	0.24735 (12)	0.48549 (16)	0.0218 (3)
H41	0.2150	0.2023	0.5464	0.033*
C5	0.3703 (2)	0.25765 (16)	0.3849 (2)	0.0198 (4)
H5A	0.4141	0.1985	0.4608	0.024*

H5B	0.3141	0.2194	0.2892	0.024*
C5A	0.4971 (2)	0.32279 (16)	0.3567 (2)	0.0188 (4)
C6	0.6453 (2)	0.29549 (18)	0.4340 (2)	0.0227 (5)
H6	0.6661	0.2395	0.5108	0.027*
C7	0.7634 (2)	0.34807 (18)	0.4015 (2)	0.0245 (5)
H7	0.8634	0.3273	0.4547	0.029*
C8	0.7343 (2)	0.43083 (18)	0.2911 (2)	0.0242 (5)
H8	0.8142	0.4665	0.2672	0.029*
C9	0.5879 (2)	0.46130 (17)	0.2155 (2)	0.0225 (5)
H9	0.5680	0.5189	0.1409	0.027*
C9A	0.4699 (2)	0.40855 (16)	0.2477 (2)	0.0189 (4)
C21	0.1217 (2)	0.56892 (16)	0.1495 (2)	0.0191 (4)
O21	0.12155 (15)	0.58915 (11)	0.02143 (16)	0.0235 (4)
O22	0.03051 (15)	0.61649 (12)	0.21547 (16)	0.0243 (3)
H22	−0.0291	0.6663	0.1471	0.029*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
N1	0.0193 (9)	0.0187 (9)	0.0184 (9)	0.0008 (7)	0.0056 (7)	0.0019 (7)
C2	0.0176 (10)	0.0184 (10)	0.0193 (10)	0.0008 (8)	0.0050 (8)	−0.0019 (8)
C3	0.0173 (9)	0.0208 (10)	0.0209 (10)	0.0000 (8)	0.0056 (8)	0.0011 (8)
C4	0.0199 (10)	0.0176 (10)	0.0198 (10)	−0.0033 (8)	0.0071 (8)	−0.0010 (8)
O4	0.0200 (7)	0.0221 (7)	0.0222 (8)	−0.0018 (6)	0.0054 (6)	0.0039 (6)
C5	0.0216 (10)	0.0184 (10)	0.0200 (11)	0.0012 (8)	0.0074 (8)	0.0011 (8)
C5A	0.0198 (10)	0.0191 (10)	0.0191 (10)	0.0014 (8)	0.0082 (8)	−0.0020 (8)
C6	0.0239 (11)	0.0224 (11)	0.0215 (11)	0.0034 (9)	0.0066 (9)	0.0011 (9)
C7	0.0178 (10)	0.0279 (11)	0.0254 (12)	0.0037 (9)	0.0036 (8)	−0.0033 (9)
C8	0.0210 (10)	0.0257 (11)	0.0268 (11)	−0.0038 (9)	0.0088 (9)	−0.0043 (9)
C9	0.0248 (11)	0.0218 (11)	0.0221 (11)	0.0003 (9)	0.0091 (9)	0.0010 (9)
C9A	0.0194 (10)	0.0188 (10)	0.0181 (10)	0.0020 (8)	0.0053 (8)	−0.0026 (8)
C21	0.0185 (10)	0.0154 (10)	0.0219 (11)	−0.0023 (8)	0.0040 (8)	−0.0026 (8)
O21	0.0236 (8)	0.0232 (8)	0.0235 (8)	0.0007 (6)	0.0070 (6)	0.0029 (6)
O22	0.0257 (8)	0.0245 (8)	0.0231 (8)	0.0077 (6)	0.0082 (6)	0.0019 (6)

Geometric parameters (Å, °)

N1—C9A	1.429 (2)	C5—H5B	0.9900
N1—C2	1.481 (2)	C5A—C6	1.395 (3)
N1—H1	0.8600	C5A—C9A	1.403 (3)
C2—C21	1.521 (3)	C6—C7	1.392 (3)
C2—C3	1.530 (3)	C6—H6	0.9500
C2—H2	1.0000	C7—C8	1.385 (3)
C3—C4	1.522 (3)	C7—H7	0.9500
C3—H3A	0.9900	C8—C9	1.388 (3)
C3—H3B	0.9900	C8—H8	0.9500
C4—O4	1.443 (2)	C9—C9A	1.390 (3)
C4—C5	1.525 (3)	C9—H9	0.9500
C4—H4	1.0000	C21—O21	1.211 (2)
O4—H41	0.8201	C21—O22	1.329 (2)

C5—C5A	1.516 (3)	O22—H22	0.9200
C5—H5A	0.9900		
C9A—N1—C2	115.39 (15)	C5A—C5—H5B	108.1
C9A—N1—H1	112.4	C4—C5—H5B	108.1
C2—N1—H1	103.5	H5A—C5—H5B	107.3
N1—C2—C21	107.00 (15)	C6—C5A—C9A	117.82 (18)
N1—C2—C3	112.13 (16)	C6—C5A—C5	120.72 (18)
C21—C2—C3	112.21 (15)	C9A—C5A—C5	121.40 (17)
N1—C2—H2	108.5	C7—C6—C5A	121.77 (19)
C21—C2—H2	108.5	C7—C6—H6	119.1
C3—C2—H2	108.5	C5A—C6—H6	119.1
C4—C3—C2	114.04 (16)	C8—C7—C6	119.57 (19)
C4—C3—H3A	108.7	C8—C7—H7	120.2
C2—C3—H3A	108.7	C6—C7—H7	120.2
C4—C3—H3B	108.7	C7—C8—C9	119.62 (19)
C2—C3—H3B	108.7	C7—C8—H8	120.2
H3A—C3—H3B	107.6	C9—C8—H8	120.2
O4—C4—C3	104.53 (15)	C8—C9—C9A	120.77 (19)
O4—C4—C5	109.15 (15)	C8—C9—H9	119.6
C3—C4—C5	115.79 (16)	C9A—C9—H9	119.6
O4—C4—H4	109.1	C9—C9A—C5A	120.41 (17)
C3—C4—H4	109.1	C9—C9A—N1	120.50 (18)
C5—C4—H4	109.1	C5A—C9A—N1	118.99 (17)
C4—O4—H41	108.7	O21—C21—O22	124.37 (18)
C5A—C5—C4	116.98 (16)	O21—C21—C2	122.89 (18)
C5A—C5—H5A	108.1	O22—C21—C2	112.71 (17)
C4—C5—H5A	108.1	C21—O22—H22	107.6
C9A—N1—C2—C21	147.73 (16)	C7—C8—C9—C9A	−1.0 (3)
C9A—N1—C2—C3	−88.84 (19)	C8—C9—C9A—C5A	−0.5 (3)
N1—C2—C3—C4	65.2 (2)	C8—C9—C9A—N1	−176.90 (18)
C21—C2—C3—C4	−174.35 (16)	C6—C5A—C9A—C9	2.0 (3)
C2—C3—C4—O4	−178.50 (16)	C5—C5A—C9A—C9	−175.05 (18)
C2—C3—C4—C5	−58.4 (2)	C6—C5A—C9A—N1	178.51 (17)
O4—C4—C5—C5A	−170.24 (16)	C5—C5A—C9A—N1	1.4 (3)
C3—C4—C5—C5A	72.2 (2)	C2—N1—C9A—C9	−116.1 (2)
C4—C5—C5A—C6	121.5 (2)	C2—N1—C9A—C5A	67.4 (2)
C4—C5—C5A—C9A	−61.5 (3)	N1—C2—C21—O21	−5.3 (2)
C9A—C5A—C6—C7	−2.2 (3)	C3—C2—C21—O21	−128.6 (2)
C5—C5A—C6—C7	174.87 (19)	N1—C2—C21—O22	176.63 (15)
C5A—C6—C7—C8	0.8 (3)	C3—C2—C21—O22	53.3 (2)
C6—C7—C8—C9	0.8 (3)		

Hydrogen-bond geometry (Å, °)

<i>D</i> —H··· <i>A</i>	<i>D</i> —H	H··· <i>A</i>	<i>D</i> ··· <i>A</i>	<i>D</i> —H··· <i>A</i>
N1—H1···O21	0.86	2.12	2.644 (2)	119

O22—H22···O4 ⁱ	0.92	1.75	2.665 (2)	172
O4—H41···N1 ⁱⁱ	0.82	2.05	2.859 (2)	167

Symmetry codes: (i) $-x, y+1/2, -z+1/2$; (ii) $x, -y+1/2, z+1/2$.

(IV) (2*RS*,5*SR*)-8-(trifluoromethoxy)-5,6-dihydro-1*H*-2,5-methanobenz[e][1,4]oxazocin-3(2*H*)-one

Crystal data

C₁₂H₁₀F₃NO₃

$M_r = 273.21$

Monoclinic, $P2_1/c$

Hall symbol: $-P\ 2_1bc$

$a = 15.0601$ (8) Å

$b = 9.2204$ (5) Å

$c = 8.072$ (4) Å

$\beta = 91.668$ (10)°

$V = 1120.4$ (6) Å³

$Z = 4$

$F(000) = 560$

$D_x = 1.620$ Mg m⁻³

Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å

Cell parameters from 2569 reflections

$\theta = 2.7\text{--}27.5^\circ$

$\mu = 0.15$ mm⁻¹

$T = 120$ K

Block, colourless

$0.28 \times 0.21 \times 0.19$ mm

Data collection

Bruker–Nonius KappaCCD

diffractometer

Radiation source: Bruker–Nonius FR591

rotating anode

Graphite monochromator

Detector resolution: 9.091 pixels mm⁻¹

φ & ω scans

Absorption correction: multi-scan

(*SADABS*; Sheldrick, 2003)

$T_{\min} = 0.788, T_{\max} = 0.972$

18683 measured reflections

2567 independent reflections

1854 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.055$

$\theta_{\max} = 27.5^\circ, \theta_{\min} = 3.5^\circ$

$h = -19 \rightarrow 19$

$k = -11 \rightarrow 11$

$l = -10 \rightarrow 10$

Refinement

Refinement on F^2

Least-squares matrix: full

$R[F^2 > 2\sigma(F^2)] = 0.043$

$wR(F^2) = 0.105$

$S = 1.07$

2567 reflections

172 parameters

0 restraints

Primary atom site location: structure-invariant

direct methods

Secondary atom site location: difference Fourier map

Hydrogen site location: inferred from neighbouring sites

H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0431P)^2 + 0.5504P]$

where $P = (F_o^2 + 2F_c^2)/3$

$(\Delta/\sigma)_{\max} = 0.001$

$\Delta\rho_{\max} = 0.21$ e Å⁻³

$\Delta\rho_{\min} = -0.31$ e Å⁻³

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å²)

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
N1	0.61135 (10)	0.59820 (16)	0.61634 (18)	0.0218 (3)
H1	0.5681	0.6279	0.5337	0.026*
C2	0.57188 (12)	0.50477 (19)	0.7412 (2)	0.0219 (4)
H2	0.5080	0.5308	0.7543	0.026*
C3	0.58000 (12)	0.3450 (2)	0.6930 (2)	0.0222 (4)
O31	0.53420 (8)	0.27667 (14)	0.59480 (16)	0.0271 (3)
O4	0.65026 (8)	0.28484 (14)	0.77298 (15)	0.0242 (3)
C5	0.69319 (12)	0.3941 (2)	0.8832 (2)	0.0233 (4)
H5	0.7107	0.3484	0.9917	0.028*

C6	0.77490 (12)	0.4539 (2)	0.8014 (2)	0.0245 (4)
H6A	0.8216	0.3784	0.8087	0.029*
H6B	0.7965	0.5374	0.8683	0.029*
C6A	0.76701 (12)	0.5033 (2)	0.6213 (2)	0.0208 (4)
C7	0.84494 (12)	0.4894 (2)	0.5318 (2)	0.0216 (4)
H7	0.8955	0.4445	0.5829	0.026*
C8	0.85009 (12)	0.53906 (19)	0.3717 (2)	0.0219 (4)
C9	0.77828 (12)	0.6040 (2)	0.2918 (2)	0.0235 (4)
H9	0.7826	0.6400	0.1820	0.028*
C10	0.70001 (12)	0.61538 (19)	0.3759 (2)	0.0219 (4)
H10	0.6495	0.6564	0.3205	0.026*
C10A	0.69255 (12)	0.56800 (18)	0.5413 (2)	0.0201 (4)
C25	0.62034 (12)	0.5060 (2)	0.9089 (2)	0.0234 (4)
H25A	0.5807	0.4766	0.9986	0.028*
H25B	0.6456	0.6029	0.9346	0.028*
O81	0.93234 (8)	0.53034 (14)	0.28898 (15)	0.0254 (3)
C81	0.95115 (12)	0.4006 (2)	0.2242 (2)	0.0258 (4)
F81	0.96324 (8)	0.29714 (13)	0.33838 (14)	0.0348 (3)
F82	1.02571 (7)	0.41217 (13)	0.14159 (14)	0.0351 (3)
F83	0.88729 (8)	0.35243 (14)	0.11937 (14)	0.0361 (3)

Atomic displacement parameters ($\text{\AA}^2$)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
N1	0.0216 (8)	0.0206 (8)	0.0233 (7)	0.0026 (6)	0.0026 (6)	0.0023 (6)
C2	0.0210 (9)	0.0196 (9)	0.0255 (9)	0.0005 (7)	0.0056 (7)	−0.0005 (7)
C3	0.0205 (9)	0.0220 (9)	0.0246 (9)	0.0004 (7)	0.0070 (7)	0.0019 (8)
O31	0.0256 (7)	0.0224 (7)	0.0333 (7)	−0.0016 (5)	0.0018 (6)	−0.0026 (6)
O4	0.0258 (7)	0.0200 (6)	0.0270 (7)	0.0039 (5)	0.0026 (5)	−0.0001 (5)
C5	0.0270 (10)	0.0232 (9)	0.0199 (8)	0.0007 (8)	0.0015 (7)	−0.0003 (7)
C6	0.0223 (9)	0.0327 (10)	0.0187 (8)	0.0025 (8)	0.0014 (7)	0.0033 (8)
C6A	0.0230 (9)	0.0200 (9)	0.0195 (9)	−0.0014 (7)	0.0017 (7)	−0.0003 (7)
C7	0.0220 (9)	0.0212 (9)	0.0214 (9)	−0.0011 (7)	−0.0008 (7)	−0.0005 (7)
C8	0.0223 (9)	0.0215 (9)	0.0222 (9)	−0.0040 (7)	0.0065 (7)	−0.0026 (7)
C9	0.0319 (10)	0.0200 (9)	0.0187 (8)	−0.0018 (8)	0.0022 (8)	0.0009 (7)
C10	0.0250 (9)	0.0188 (9)	0.0217 (9)	0.0007 (7)	−0.0018 (7)	0.0010 (7)
C10A	0.0223 (9)	0.0155 (8)	0.0224 (9)	−0.0013 (7)	0.0019 (7)	−0.0031 (7)
C25	0.0259 (9)	0.0213 (9)	0.0234 (9)	0.0007 (7)	0.0064 (7)	−0.0002 (7)
O81	0.0241 (7)	0.0261 (7)	0.0266 (7)	−0.0042 (5)	0.0091 (5)	−0.0010 (6)
C81	0.0243 (10)	0.0318 (11)	0.0215 (9)	−0.0023 (8)	0.0041 (8)	−0.0005 (8)
F81	0.0403 (7)	0.0338 (7)	0.0308 (6)	0.0084 (5)	0.0097 (5)	0.0075 (5)
F82	0.0282 (6)	0.0467 (8)	0.0312 (6)	−0.0012 (5)	0.0138 (5)	−0.0013 (5)
F83	0.0319 (6)	0.0459 (7)	0.0304 (6)	−0.0013 (5)	−0.0010 (5)	−0.0135 (6)

Geometric parameters ($\text{\AA}$, $^\circ$)

N1—C10A	1.408 (2)	C6A—C10A	1.410 (2)
N1—C2	1.465 (2)	C7—C8	1.375 (3)
N1—H1	0.9581	C7—H7	0.9500
C2—C25	1.520 (3)	C8—C9	1.380 (3)

C2—C3	1.530 (2)	C8—O81	1.427 (2)
C2—H2	1.0000	C9—C10	1.381 (3)
C3—O31	1.212 (2)	C9—H9	0.9500
C3—O4	1.343 (2)	C10—C10A	1.413 (3)
O4—C5	1.481 (2)	C10—H10	0.9500
C5—C6	1.517 (3)	C25—H25A	0.9900
C5—C25	1.525 (3)	C25—H25B	0.9900
C5—H5	1.0000	O81—C81	1.340 (2)
C6—C6A	1.525 (2)	C81—F82	1.327 (2)
C6—H6A	0.9900	C81—F81	1.335 (2)
C6—H6B	0.9900	C81—F83	1.338 (2)
C6A—C7	1.402 (2)		
C10A—N1—C2	123.67 (14)	C8—C7—C6A	121.66 (17)
C10A—N1—H1	109.8	C8—C7—H7	119.2
C2—N1—H1	111.5	C6A—C7—H7	119.2
N1—C2—C25	114.48 (15)	C7—C8—C9	121.26 (17)
N1—C2—C3	110.77 (14)	C7—C8—O81	119.63 (16)
C25—C2—C3	101.19 (14)	C9—C8—O81	119.03 (15)
N1—C2—H2	110.0	C8—C9—C10	118.16 (16)
C25—C2—H2	110.0	C8—C9—H9	120.9
C3—C2—H2	110.0	C10—C9—H9	120.9
O31—C3—O4	121.68 (17)	C9—C10—C10A	122.23 (16)
O31—C3—C2	128.21 (17)	C9—C10—H10	118.9
O4—C3—C2	110.08 (15)	C10A—C10—H10	118.9
C3—O4—C5	109.39 (14)	N1—C10A—C6A	125.15 (16)
O4—C5—C6	109.33 (14)	N1—C10A—C10	116.06 (16)
O4—C5—C25	103.83 (14)	C6A—C10A—C10	118.68 (16)
C6—C5—C25	114.17 (16)	C2—C25—C5	101.68 (14)
O4—C5—H5	109.8	C2—C25—H25A	111.4
C6—C5—H5	109.8	C5—C25—H25A	111.4
C25—C5—H5	109.8	C2—C25—H25B	111.4
C5—C6—C6A	118.80 (15)	C5—C25—H25B	111.4
C5—C6—H6A	107.6	H25A—C25—H25B	109.3
C6A—C6—H6A	107.6	C81—O81—C8	115.44 (14)
C5—C6—H6B	107.6	F82—C81—F81	107.71 (15)
C6A—C6—H6B	107.6	F82—C81—F83	108.21 (15)
H6A—C6—H6B	107.0	F81—C81—F83	106.30 (16)
C7—C6A—C10A	117.96 (15)	F82—C81—O81	108.41 (15)
C7—C6A—C6	114.90 (15)	F81—C81—O81	113.23 (15)
C10A—C6A—C6	127.02 (16)	F83—C81—O81	112.76 (16)
C10A—N1—C2—C25	71.1 (2)	O81—C8—C9—C10	−178.06 (15)
C10A—N1—C2—C3	−42.5 (2)	C8—C9—C10—C10A	2.5 (3)
N1—C2—C3—O31	−79.9 (2)	C2—N1—C10A—C6A	−36.1 (3)
C25—C2—C3—O31	158.32 (18)	C2—N1—C10A—C10	147.94 (16)
N1—C2—C3—O4	97.98 (17)	C7—C6A—C10A—N1	−175.86 (16)
C25—C2—C3—O4	−23.81 (18)	C6—C6A—C10A—N1	−0.1 (3)
O31—C3—O4—C5	179.70 (16)	C7—C6A—C10A—C10	0.0 (3)

C2—C3—O4—C5	1.67 (18)	C6—C6A—C10A—C10	175.80 (17)
C3—O4—C5—C6	−100.92 (16)	C9—C10—C10A—N1	174.42 (16)
C3—O4—C5—C25	21.31 (18)	C9—C10—C10A—C6A	−1.8 (3)
O4—C5—C6—C6A	48.3 (2)	N1—C2—C25—C5	−84.37 (17)
C25—C5—C6—C6A	−67.5 (2)	C3—C2—C25—C5	34.79 (17)
C5—C6—C6A—C7	−150.27 (17)	O4—C5—C25—C2	−34.96 (17)
C5—C6—C6A—C10A	33.8 (3)	C6—C5—C25—C2	84.00 (17)
C10A—C6A—C7—C8	1.1 (3)	C7—C8—O81—C81	80.9 (2)
C6—C6A—C7—C8	−175.20 (17)	C9—C8—O81—C81	−102.34 (19)
C6A—C7—C8—C9	−0.4 (3)	C8—O81—C81—F82	175.46 (13)
C6A—C7—C8—O81	176.27 (16)	C8—O81—C81—F81	−65.1 (2)
C7—C8—C9—C10	−1.3 (3)	C8—O81—C81—F83	55.7 (2)

Hydrogen-bond geometry (Å, °)

<i>D</i> —H $\cdots$ <i>A</i>	<i>D</i> —H	H $\cdots$ <i>A</i>	<i>D</i> $\cdots$ <i>A</i>	<i>D</i> —H $\cdots$ <i>A</i>
N1—H1 $\cdots$ O31 ⁱ	0.96	2.03	2.970 (2)	166

Symmetry code: (i) $-x+1, -y+1, -z+1$.

Selected bond lengths (Å) for compounds (I)–(III)

Parameter	(I)	(II)	(III)
C21—O21	1.203 (3)	1.211 (6)	1.211 (2)
C21—O22	1.346 (3)	1.318 (6)	1.329 (2)

The corresponding values for compound (IV) are C3—O31 = 1.212 (2) Å and C3—O4 = 1.343 (2) Å.

Hydrogen bonds and short intramolecular contacts (Å, °) for compounds (I)–(IV)

Compound	<i>D</i> —H $\cdots$ <i>A</i>	<i>D</i> —H	H $\cdots$ <i>A</i>	<i>D</i> $\cdots$ <i>A</i>	<i>D</i> —H $\cdots$ <i>A</i>
(I)	C7—H7 $\cdots$ Cg1 ⁱ	0.95	2.48	3.409 (3)	165
(II)	O4—N41 $\cdots$ O21 ⁱⁱ	0.98	2.31	3.178 (6)	147
	O4—N41 $\cdots$ N1 ⁱⁱ	0.98	2.48	3.334 (6)	145
	C9—C9 $\cdots$ Cg1 ⁱⁱⁱ	0.95	2.55	3.350 (5)	142
(III)	N1—H1 $\cdots$ O21	0.86	2.12	2.644 (2)	119
	O22—H22 $\cdots$ O4 ^{iv}	0.92	1.75	2.665 (2)	172
	O4—H41 $\cdots$ N1 ^v	0.82	2.05	2.859 (2)	167
(IV)	N1—H1 $\cdots$ O31 ^{vi}	0.96	2.03	2.970 (2)	166

Cg1 represents the centroid of the C5A/C6—C9/C9A ring. Symmetry codes: (i) $x-1/2, -y+1/2, -z+1$; (ii) $-x+1, y-1/2, -z+1/2$; (iii) $x+1/2, -y+3/2, -z$; (iv) $-x, y+1/2, -z+1/2$; (v) $x, -y+1/2, z+1/2$; (vi) $-x+1, -y+1, -z+1$.