

3-Deoxy-D-galactono-1,4-lactone (3-deoxy-D-xylo-hexono-1,4-lactone)

Francesco Punzo,^{a*‡} David J. Watkin,^b David Hotchkiss^c and George W. J. Fleet^c

^aDipartimento di Scienze Chimiche, Facoltà di Farmacia, Università di Catania, Viale A. Doria 6, 95125 Catania, Italy, ^bDepartment of Chemical Crystallography, Chemical Research Laboratory, Mansfield Road, Oxford OX1 3TA, England, and ^cDepartment of Organic Chemistry, Chemical Research Laboratory, Mansfield Road, Oxford OX1 3TA, England

‡ Visiting Scientist at the Department of Chemical Crystallography, Chemical Research Laboratory, Mansfield Road, Oxford OX1 3TA, England

Correspondence e-mail: fpunzo@unict.it

Key indicators

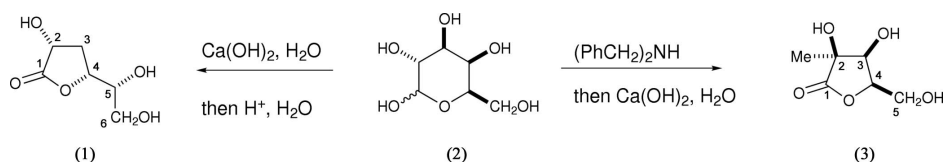
Single-crystal X-ray study
 T = 100 K
 Mean $\sigma(C-C)$ = 0.002 Å
 R factor = 0.024
 wR factor = 0.059
 Data-to-parameter ratio = 9.4

For details of how these key indicators were automatically derived from the article, see <http://journals.iucr.org/e>.

On the basis of the known absolute configuration of D-galactose, the structural study of 3-deoxy-D-xylo-galactono-1,4-lactone, C₆H₁₀O₅, a valuable synthetic intermediate, allowed the unambiguous confirmation that the chiral centre at position 2 has the *R* configuration. This centre is formed during synthesis of the title compound from D-galactose under environmentally friendly conditions. Three symmetry-independent intermolecular hydrogen bonds link the molecules into layers parallel to the *ac* plane.

Comment

A number of useful synthetic carbohydrate scaffolds, including several branched carbohydrate lactones (Monneret & Florent, 1994) can be obtained by the treatment of hexoses with aqueous calcium hydroxide (Bols, 1996). In recent times, the deoxy lactone (1), also known as α -D-galactometasaccharinic acid, has usually been obtained by a three-step synthesis from D-galactonolactone involving organic solvents and reagents (Bock *et al.*, 1981, 1986; Choquet-Farnier *et al.*, 1997). However, a green aqueous procedure allows preparation of lactone (1) directly by treatment of galactose (2) with aqueous calcium hydroxide (Whistler & BeMiller, 1963; Kiliani & Kleeman, 1884). This is the preferred route, not only because of the environmentally friendly conditions, but also due to the low cost of galactose (2), the starting material, whose price represents just a small fraction of the cost of D-galactonolactone. It is noteworthy that completely different products arise if sugar (2) is treated with a secondary amine such as dibenzylamine prior to the reaction with calcium hydroxide; in that case the major isolated product is the branched lyxono-1,4-lactone (3) (Punzo *et al.*, 2006).



Lactone (1) can be readily obtained and has a great potential as a chiral building block for the synthesis of complex highly functionalized targets. It has already been used for the synthesis of carnitine (Bols *et al.*, 1992) and hydroxylated azepanes (Anderson *et al.*, 2000); it can also prove useful for synthesis of bulgecinines and other highly substituted prolines and pyrrolidines.

This paper reports the crystal structure of (1), prepared from galactose and calcium hydroxide, and unambiguously establishes the relative stereochemistry (Fig. 1). The use of D-

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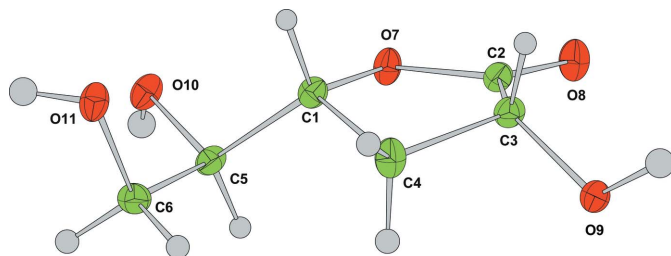


Figure 1
The molecular structure of (1), showing displacement ellipsoids drawn at the 50% probability level. H atoms are drawn as small circles of arbitrary radii.

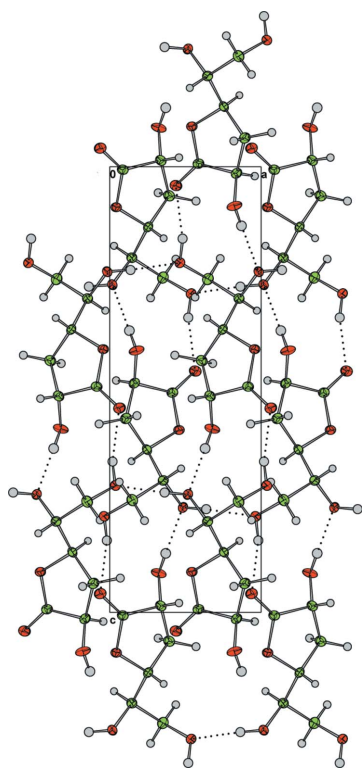


Figure 2
Packing diagram of (1), viewed down the *b* axis. Hydrogen bonds are shown as dotted lines.

galactose as starting material defines the absolute configuration of the two stereogenic centres at C4 and C5; the present structural study establishes unambiguously that the chiral centre at C2 has the *R* configuration.

The packing of (1) is shown in Fig. 2. Each of the three symmetry-independent 'active' H atoms in the molecule of (1) is involved in hydrogen bonding (Table 2). Atoms H11 and H9 form the hydrogen bonds which link molecules into double chains along the *c* axis. These chains are further aggregated into layers parallel to the *ac* plane via hydrogen bonds involving H10.

Experimental

The title compound [m.p. 414–415 K, $[\alpha]_{21}^D -43.8$ (*c* 1.24 in water)] was synthesized according to Sowden *et al.* (1957) [literature m.p. 415–416 K, $[\alpha]_{25}^D -47.8$ (*c* 1 in water); Sowden, 1957; Sowden *et al.*,

1957)]. It was then dissolved in methanol in a small sealed glass flask and left for 24 h in an oven at 313 K and for a further night at room temperature. Thereafter, the flask was opened to let the solvent slowly evaporate and colourless prismatic crystals were formed. A suitable piece was cut from a larger crystal.

Crystal data

$C_6H_{10}O_5$
 $M_r = 162.14$
Orthorhombic, $P2_12_12_1$
 $a = 5.3320$ (2) Å
 $b = 8.4865$ (3) Å
 $c = 15.7238$ (8) Å
 $V = 711.50$ (5) Å³
 $Z = 4$
 $D_x = 1.514$ Mg m⁻³

Mo $K\alpha$ radiation
Cell parameters from 787 reflections
 $\theta = 5.1$ – 27.5°
 $\mu = 0.13$ mm⁻¹
 $T = 100$ K
Prism, colourless
 $0.60 \times 0.50 \times 0.40$ mm

Data collection

Nonius KappaCCD diffractometer
 ω scans
Absorption correction: multi-scan
(*DENZO/SCALEPACK*;
Otwinowski & Minor, 1997)
 $T_{\min} = 0.935$, $T_{\max} = 0.948$
1521 measured reflections

942 independent reflections
896 reflections with $I > 2\sigma(I)$
 $R_{\text{int}} = 0.010$
 $\theta_{\max} = 27.4^\circ$
 $h = -6 \rightarrow 6$
 $k = -10 \rightarrow 10$
 $l = -20 \rightarrow 20$

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.024$
 $wR(F^2) = 0.059$
 $S = 1.05$
942 reflections
100 parameters
H-atom parameters constrained

$w = 1/[\sigma^2(F^2) + (0.01P)^2 + 0.2P]$
where $P = [\max(F_o^2, 0) + 2F_c^2]/3$
 $(\Delta/\sigma)_{\max} < 0.001$
 $\Delta\rho_{\max} = 0.18$ e Å⁻³
 $\Delta\rho_{\min} = -0.20$ e Å⁻³

Table 1

Selected geometric parameters (Å, °).

C1–C5	1.5147 (19)	O7–C2	1.3417 (16)
C1–O7	1.4782 (18)	C2–C3	1.521 (2)
C1–C4	1.528 (2)	C2–O8	1.2126 (18)
C5–C6	1.518 (2)	C3–C4	1.519 (2)
C5–O10	1.4285 (17)	C3–O9	1.4107 (16)
C6–O11	1.4357 (18)		
C5–C1–O7	108.12 (12)	O7–C2–C3	110.84 (12)
C5–C1–C4	114.28 (12)	O7–C2–O8	121.20 (14)
O7–C1–C4	104.57 (10)	C3–C2–O8	127.95 (13)
C1–C5–C6	111.45 (13)	C2–C3–C4	102.58 (11)
C1–C5–O10	109.23 (11)	C2–C3–O9	111.85 (12)
C6–C5–O10	109.87 (11)	C4–C3–O9	111.85 (12)
C5–C6–O11	111.07 (12)	C1–C4–C3	103.33 (12)
C1–O7–C2	110.07 (11)		

Table 2

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>
O10–H10...O11 ⁱ	0.86	1.83	2.6814 (15)	177
O11–H11...O8 ⁱⁱ	0.86	1.90	2.7384 (13)	166
O9–H9...O10 ⁱⁱⁱ	0.88	1.83	2.6966 (14)	167

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

H atoms were located in a difference map, but those attached to C atoms were repositioned geometrically. The H atoms were initially refined with soft restraints on the bond lengths and angles to regu-

larize their geometry ($C-H = 0.93-98 \text{ \AA}$ and $O-H = 0.82 \text{ \AA}$) and isotropic displacement parameters [$U_{iso}(H) = 1.2-1.5U_{eq}(C,O)$], after which their positions were refined with riding constraints. In the absence of significant anomalous scattering, Friedel pairs were merged.

Data collection: *COLLECT* (Nonius, 2001); cell refinement: *DENZO/SCALEPACK* (Otwinowski & Minor, 1997); data reduction: *DENZO/SCALEPACK*; program(s) used to solve structure: *SIR92* (Altomare *et al.*, 1994); program(s) used to refine structure: *CRYSTALS* (Betteridge *et al.*, 2003); molecular graphics: *CAMERON* (Watkin *et al.*, 1996); software used to prepare material for publication: *CRYSTALS*.

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Crystal data

$C_6H_{10}O_5$	$D_x = 1.514 \text{ Mg m}^{-3}$
$M_r = 162.14$	Mo $K\alpha$ radiation, $\lambda = 0.71073 \text{ \AA}$
Orthorhombic, $P2_12_12_1$	Cell parameters from 787 reflections
$a = 5.3320 (2) \text{ \AA}$	$\theta = 5.1\text{--}27.5^\circ$
$b = 8.4865 (3) \text{ \AA}$	$\mu = 0.13 \text{ mm}^{-1}$
$c = 15.7238 (8) \text{ \AA}$	$T = 100 \text{ K}$
$V = 711.50 (5) \text{ \AA}^3$	Prism, colourless
$Z = 4$	$0.60 \times 0.50 \times 0.40 \text{ mm}$
$F(000) = 344$	

Data collection

Nonius Kappa CCD diffractometer	1521 measured reflections
Graphite monochromator	942 independent reflections
ω scans	896 reflections with $I > 2\sigma(I)$
Absorption correction: multi-scan (DENZO/SCALEPACK; Otwinowski & Minor, 1997)	$R_{\text{int}} = 0.010$
$T_{\text{min}} = 0.935$, $T_{\text{max}} = 0.948$	$\theta_{\text{max}} = 27.4^\circ$, $\theta_{\text{min}} = 5.2^\circ$
	$h = -6 \rightarrow 6$
	$k = -10 \rightarrow 10$
	$l = -20 \rightarrow 20$

Refinement

Refinement on F^2	Primary atom site location: structure-invariant direct methods
Least-squares matrix: full	Hydrogen site location: inferred from neighbouring sites
$R[F^2 > 2\sigma(F^2)] = 0.024$	H-atom parameters constrained
$wR(F^2) = 0.059$	$w = 1/[\sigma^2(F^2) + (0.01P)^2 + 0.2P]$
$S = 1.05$	where $P = [\max(F_o^2, 0) + 2F_c^2]/3$
942 reflections	$(\Delta/\sigma)_{\text{max}} < 0.001$
100 parameters	$\Delta\rho_{\text{max}} = 0.18 \text{ e \AA}^{-3}$
0 restraints	$\Delta\rho_{\text{min}} = -0.20 \text{ e \AA}^{-3}$

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (\AA^2)

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
C1	0.2537 (3)	0.48508 (18)	0.13488 (8)	0.0128
C5	0.1466 (3)	0.38063 (17)	0.20404 (9)	0.0132
C6	0.3508 (3)	0.28675 (17)	0.24829 (9)	0.0150
O11	0.5368 (2)	0.38909 (12)	0.28445 (6)	0.0161
O10	0.0167 (2)	0.47603 (12)	0.26456 (6)	0.0152

O7	0.0425 (2)	0.56286 (12)	0.09076 (6)	0.0147
C2	0.0865 (3)	0.56805 (16)	0.00679 (9)	0.0136
C3	0.3376 (3)	0.49259 (17)	-0.01439 (8)	0.0141
C4	0.3926 (3)	0.39601 (19)	0.06479 (9)	0.0170
O9	0.3231 (2)	0.39745 (12)	-0.08780 (6)	0.0183
O8	-0.0638 (2)	0.62617 (12)	-0.04183 (6)	0.0187
H1	0.3564	0.5673	0.1606	0.0150*
H5	0.0291	0.3090	0.1773	0.0154*
H61	0.4367	0.2198	0.2072	0.0185*
H62	0.2698	0.2217	0.2943	0.0191*
H3	0.4581	0.5767	-0.0206	0.0171*
H41	0.3208	0.2890	0.0583	0.0204*
H42	0.5707	0.3891	0.0770	0.0200*
H10	-0.1376	0.4487	0.2687	0.0258*
H11	0.5184	0.3894	0.3385	0.0266*
H9	0.3699	0.4526	-0.1325	0.0289*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
C1	0.0112 (7)	0.0146 (7)	0.0127 (6)	0.0008 (6)	-0.0023 (6)	-0.0006 (6)
C5	0.0132 (7)	0.0141 (7)	0.0122 (6)	-0.0022 (6)	0.0003 (6)	-0.0028 (5)
C6	0.0149 (7)	0.0136 (7)	0.0166 (6)	-0.0004 (6)	-0.0015 (7)	0.0001 (6)
O11	0.0123 (5)	0.0238 (5)	0.0122 (4)	-0.0021 (5)	-0.0010 (4)	0.0002 (4)
O10	0.0116 (5)	0.0206 (5)	0.0132 (5)	-0.0001 (4)	0.0015 (4)	-0.0038 (4)
O7	0.0145 (5)	0.0189 (5)	0.0107 (4)	0.0046 (5)	0.0003 (5)	-0.0004 (4)
C2	0.0155 (7)	0.0135 (7)	0.0118 (6)	-0.0012 (6)	0.0007 (6)	-0.0013 (6)
C3	0.0145 (7)	0.0146 (7)	0.0131 (6)	-0.0003 (6)	0.0022 (6)	-0.0016 (6)
C4	0.0155 (8)	0.0215 (7)	0.0139 (6)	0.0049 (7)	0.0014 (6)	0.0008 (6)
O9	0.0287 (6)	0.0148 (5)	0.0114 (4)	-0.0004 (5)	0.0058 (5)	-0.0019 (4)
O8	0.0178 (6)	0.0243 (6)	0.0139 (5)	0.0034 (5)	-0.0011 (5)	0.0013 (5)

Geometric parameters (Å, °)

C1—C5	1.5147 (19)	O10—H10	0.857
C1—O7	1.4782 (18)	O7—C2	1.3417 (16)
C1—C4	1.528 (2)	C2—C3	1.521 (2)
C1—H1	0.975	C2—O8	1.2126 (18)
C5—C6	1.518 (2)	C3—C4	1.519 (2)
C5—O10	1.4285 (17)	C3—O9	1.4107 (16)
C5—H5	0.969	C3—H3	0.965
C6—O11	1.4357 (18)	C4—H41	0.991
C6—H61	0.975	C4—H42	0.971
C6—H62	1.008	O9—H9	0.880
O11—H11	0.855		
C5—C1—O7	108.12 (12)	C5—O10—H10	111.2
C5—C1—C4	114.28 (12)	C1—O7—C2	110.07 (11)

O7—C1—C4	104.57 (10)	O7—C2—C3	110.84 (12)
C5—C1—H1	109.4	O7—C2—O8	121.20 (14)
O7—C1—H1	107.7	C3—C2—O8	127.95 (13)
C4—C1—H1	112.4	C2—C3—C4	102.58 (11)
C1—C5—C6	111.45 (13)	C2—C3—O9	111.85 (12)
C1—C5—O10	109.23 (11)	C4—C3—O9	111.85 (12)
C6—C5—O10	109.87 (11)	C2—C3—H3	107.2
C1—C5—H5	107.4	C4—C3—H3	110.7
C6—C5—H5	109.5	O9—C3—H3	112.1
O10—C5—H5	109.3	C1—C4—C3	103.33 (12)
C5—C6—O11	111.07 (12)	C1—C4—H41	109.9
C5—C6—H61	109.8	C3—C4—H41	109.6
O11—C6—H61	106.9	C1—C4—H42	111.2
C5—C6—H62	108.0	C3—C4—H42	112.6
O11—C6—H62	110.1	H41—C4—H42	110.1
H61—C6—H62	111.0	C3—O9—H9	109.5
C6—O11—H11	108.4		

Hydrogen-bond geometry (\AA , $^\circ$)

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
O10—H10 \cdots O11 ⁱ	0.86	1.83	2.6814 (15)	177
O11—H11 \cdots O8 ⁱⁱ	0.86	1.90	2.7384 (13)	166
O9—H9 \cdots O10 ⁱⁱⁱ	0.88	1.83	2.6966 (14)	167

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