

1,2:3,4-Di-O-isopropylidene- α -D-tagatofuranoseDavid J. Watkin,^{a*} Andreas F. G. Glawar,^a Raquel Soengas,^b Ulla P. Skytte,^c Mark R. Wormald,^d Raymond A. Dwek^d and George W. J. Fleet^b^aDepartment of Chemical Crystallography, Chemical Research Laboratory, Oxford University, Mansfield Road, Oxford OX1 3TA, England, ^bDepartment of Organic Chemistry, Chemical Research Laboratory, Oxford University, Mansfield Road, Oxford OX1 3TA, England, ^cArla Foods Ingredients, Viby J, DK-8260 Denmark, and ^dGlycobiology Institute, Department of Biochemistry, Oxford University, South Parks Road, Oxford OX1 3QU, EnglandCorrespondence e-mail:
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Key indicators

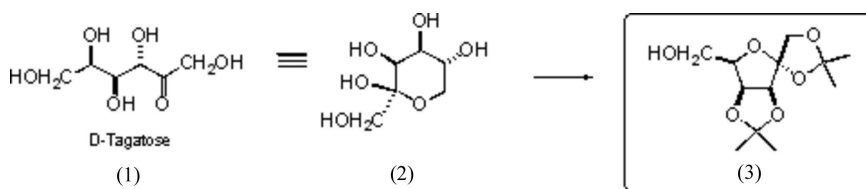
Single-crystal X-ray study
 $T = 190\text{ K}$
Mean $\sigma(\text{C}-\text{C}) = 0.002\text{ \AA}$
 R factor = 0.036
 wR factor = 0.087
Data-to-parameter ratio = 13.7For details of how these key indicators were automatically derived from the article, see <http://journals.iucr.org/e>.The crystal structure of diacetone tagatose, $\text{C}_{12}\text{H}_{20}\text{O}_6$, establishes the stereochemistry of the anomeric spiroacetal as 1,2:3,4-di-O-isopropylidene- α -D-tagatofuranose. Molecules are linked by $\text{O}-\text{H}\cdots\text{O}$ hydrogen bonds [$\text{O}\cdots\text{O} = 2.862(2)\text{ \AA}$] to form chains running parallel to the b axis.

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Comment

Carbohydrates provide a rich source of chirons (Lichtenthaler & Peters, 2004). D-Tagatose, (1), is the first example for more than 50 years of a sugar that has changed its status from rare (\$5,000 per lb) to common (\$2.5 per lb). The driving force for the production of large quantities of hitherto scarce carbohydrates is their potential as enhanced dietary targets. D-Tagatose is a healthy sweetener prepared cheaply from galactose (Beadle *et al.*, 1992). Its use as a dietary substitute in soft drinks and ready-to-eat cereals (Skytte, 2002) is rapidly increasing. So far, there has been little exploitation of tagatose as a chiral building block, although recently the easy preparation of branched sugar lactones by the Kiliani cyanohydrin reaction on D-tagatose has been reported (Soengas, Izumori *et al.*, 2005); the structures of the diacetonide products could only be firmly established by X-ray crystallographic analysis (Harding *et al.*, 2005; Shallard-Brown *et al.*, 2004). For a sugar to be used as a chiral starting material in organic synthesis, it must not only be cheap but also efficiently protected (Bols, 1996).The first reports of the protection of tagatose, (1), with acetone (Reichstein & Bosshard, 1934; Barnett & Reichstein, 1937) gave no indication of the chemistry at the anomeric position of the diacetonide, (3). Otherwise, compound (3) has only been prepared by lengthy synthesis from D-fructose (Cubero *et al.*, 1988); the enantiomer of (3) was derived from a multi-step procedure from L-sorbose (Furneaux *et al.*, 1993). No previous publication has provided any evidence for the anomeric configuration of the diacetonide, (3). In recent studies, treatment of tagatose, (1), which exists in both its crystalline form and in solution in the pyranose form, (2), with acetone produces high yields of crystalline (3) (Soengas, Wormald *et al.*, 2005). The present report of the crystal

structure of (3) unequivocally establishes the anomeric configuration of the diacetone, (3), as the β -form.

The crystal structure of (3) consists of O—H...O hydrogen-bonded chains running parallel to the b axis (Table 1 and Fig. 2). There are no other short intermolecular contacts. Atoms C17 and C18 refined to have very anisotropic displacement parameters. A difference electron-density map phased on all the structure except for atoms C17 and C18 showed only a single elongated peak at these sites, indicating that the anisotropic displacement parameter model would be appropriate. The large anisotropic displacement parameters for these atoms are due to disorder of these atoms arising from out-of-plane displacements of atoms in the adjacent ring, and in particular of O15. A single-temperature experiment cannot resolve static from dynamic disorder.

Experimental

The title material (Soengas, Wormald *et al.*, 2005) was crystallized from petroleum ether (333–353 K).

Crystal data

$C_{12}H_{20}O_6$
 $M_r = 260.29$
 Orthorhombic, $P2_12_12_1$
 $a = 5.8241$ (1) Å
 $b = 8.4972$ (2) Å
 $c = 27.1899$ (7) Å
 $V = 1345.59$ (5) Å³
 $Z = 4$
 $D_x = 1.285$ Mg m⁻³

Mo $K\alpha$ radiation
 Cell parameters from 1961 reflections
 $\theta = 5\text{--}30^\circ$
 $\mu = 0.10$ mm⁻¹
 $T = 190$ K
 Prism, colourless
 $0.60 \times 0.20 \times 0.20$ mm

Data collection

Nonius KappaCCD area-detector diffractometer
 ω scans
 Absorption correction: multi-scan (DENZO/SCALEPACK; Otwinowski & Minor, 1997)
 $T_{\min} = 0.84$, $T_{\max} = 0.98$
 7561 measured reflections

2239 independent reflections
 1980 reflections with $I > 2\sigma(I)$
 $R_{\text{int}} = 0.027$
 $\theta_{\text{max}} = 30.0^\circ$
 $h = -8 \rightarrow 8$
 $k = -11 \rightarrow 11$
 $l = -37 \rightarrow 37$

Refinement

Refinement on F^2
 $R[F^2 > 2\sigma(F^2)] = 0.036$
 $wR(F^2) = 0.087$
 $S = 0.97$
 2239 reflections
 163 parameters
 H-atom parameters constrained

$w = 1/[\sigma^2(F^2) + (0.04P)^2 + 0.29P]$
 where $P = (\max(F_o^2, 0) + 2F_c^2)/3$
 $(\Delta/\sigma)_{\text{max}} < 0.001$
 $\Delta\rho_{\text{max}} = 0.31$ e Å⁻³
 $\Delta\rho_{\text{min}} = -0.18$ e Å⁻³

Table 1

Hydrogen-bond geometry (Å, °).

$D\text{--}H\cdots A$	$D\text{--}H$	$H\cdots A$	$D\cdots A$	$D\text{--}H\cdots A$
O7—H15...O15 ⁱ	0.81	2.06	2.862 (2)	167

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

In the absence of significant anomalous scattering, Friedel pairs were merged and the absolute configuration was assigned from known chiral centres. The relatively large ratio of minimum to maximum corrections applied in the multi-scan process (1:1.16) is due to the prismatic shape of the crystal. The H atoms were all located in a difference map, but those attached to C atoms were repositioned

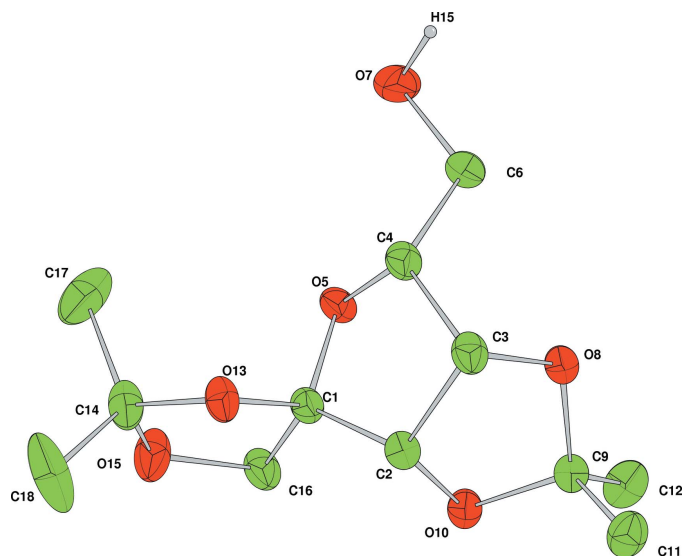


Figure 1

A view of the title compound, with displacement ellipsoids drawn at the 50% probability level. H atoms (except for the hydroxyl atom H15) have been omitted for clarity; atom H15 is shown as a sphere of arbitrary radius.

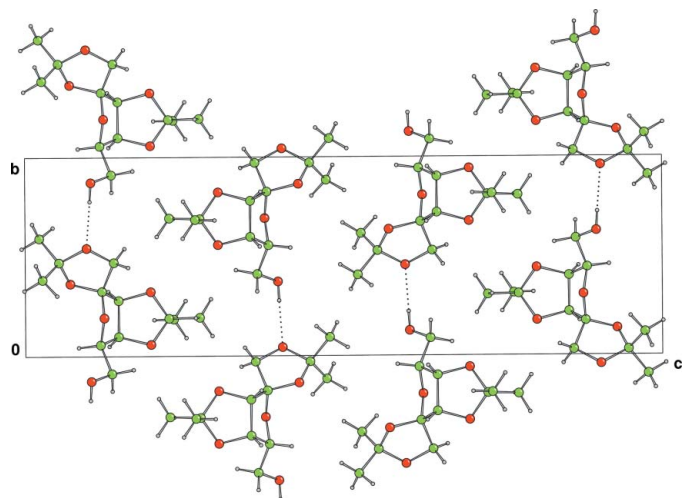


Figure 2

A diagram showing a projection along the a axis of the title compound, with hydrogen bonds indicated as dotted lines.

geometrically. The H atoms were initially refined with soft restraints on their bond lengths and angles to regularize their geometry (C—H distances in the range 0.93–0.98 Å and O—H distances of 0.82 Å) and displacement parameters [$U_{\text{iso}}(\text{H})$ in the range 1.2–1.5 times U_{eq} of the parent atom], after which they were refined with riding constraints.

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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supporting information

Acta Cryst. (2005). E61, o2891–o2893 [https://doi.org/10.1107/S1600536805025092]

1,2:3,4-Di-O-isopropylidene- α -D-tagatofuranose

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$C_{12}H_{20}O_6$

$M_r = 260.29$

Orthorhombic, $P2_12_12_1$

Hall symbol: P 2ac 2ab

$a = 5.8241$ (1) Å

$b = 8.4972$ (2) Å

$c = 27.1899$ (7) Å

$V = 1345.59$ (5) Å³

$Z = 4$

$F(000) = 560$

$D_x = 1.285$ Mg m⁻³

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

Cell parameters from 1961 reflections

$\theta = 5$ – 30°

$\mu = 0.10$ mm⁻¹

$T = 190$ K

Prism, colourless

$0.60 \times 0.20 \times 0.20$ mm

Data collection

Nonius KappaCCD area-detector
diffractometer

Graphite monochromator

ω scans

Absorption correction: multi-scan

(DENZO/SCALEPACK; Otwinowski & Minor,
1997)

$T_{\min} = 0.84$, $T_{\max} = 0.98$

7561 measured reflections

2239 independent reflections

1980 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.027$

$\theta_{\max} = 30.0^\circ$, $\theta_{\min} = 5.1^\circ$

$h = -8 \rightarrow 8$

$k = -11 \rightarrow 11$

$l = -37 \rightarrow 37$

Refinement

Refinement on F^2

Least-squares matrix: full

$R[F^2 > 2\sigma(F^2)] = 0.036$

$wR(F^2) = 0.087$

$S = 0.97$

2239 reflections

163 parameters

0 restraints

Primary atom site location: structure-invariant
direct methods

Hydrogen site location: inferred from
neighbouring sites

H-atom parameters constrained

$w = 1/[\sigma^2(F^2) + (0.04P)^2 + 0.29P]$

where $P = (\max(F_o^2, 0) + 2F_c^2)/3$

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

$\Delta\rho_{\max} = 0.31$ e Å⁻³

$\Delta\rho_{\min} = -0.18$ e Å⁻³

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

	<i>x</i>	<i>y</i>	<i>z</i>	$U_{\text{iso}}^*/U_{\text{eq}}$
C1	0.8104 (3)	0.67374 (17)	0.62049 (5)	0.0221
C2	0.5871 (3)	0.71970 (17)	0.64639 (5)	0.0253
C3	0.5892 (3)	0.90127 (17)	0.64648 (5)	0.0264

C4	0.8065 (3)	0.94288 (17)	0.61795 (5)	0.0256
O5	0.95355 (19)	0.80726 (12)	0.62382 (4)	0.0237
C6	0.9294 (4)	1.08802 (18)	0.63558 (6)	0.0348
O7	1.1138 (3)	1.12609 (14)	0.60326 (5)	0.0445
O8	0.6151 (2)	0.94136 (13)	0.69726 (4)	0.0291
C9	0.5377 (3)	0.81064 (19)	0.72565 (5)	0.0249
O10	0.6022 (2)	0.67635 (12)	0.69686 (4)	0.0308
C11	0.2794 (3)	0.8147 (2)	0.73296 (6)	0.0324
C12	0.6658 (3)	0.8066 (2)	0.77381 (6)	0.0339
O13	0.7586 (2)	0.63541 (13)	0.57085 (4)	0.0278
C14	0.9287 (3)	0.52851 (19)	0.55314 (6)	0.0331
O15	1.0252 (3)	0.45663 (14)	0.59641 (4)	0.0413
C16	0.9356 (3)	0.52887 (17)	0.63902 (6)	0.0284
C17	1.1201 (4)	0.6157 (3)	0.52718 (8)	0.0539
C18	0.8104 (6)	0.4066 (3)	0.52222 (10)	0.0721
H21	0.4514	0.6744	0.6302	0.0359*
H31	0.4509	0.9496	0.6316	0.0365*
H41	0.7674	0.9559	0.5835	0.0352*
H61	0.8183	1.1751	0.6360	0.0488*
H62	0.9859	1.0683	0.6693	0.0490*
H111	0.2308	0.7218	0.7514	0.0568*
H112	0.2002	0.8174	0.7024	0.0569*
H113	0.2387	0.9082	0.7525	0.0565*
H121	0.6235	0.7138	0.7913	0.0598*
H122	0.8263	0.8083	0.7675	0.0608*
H123	0.6238	0.8987	0.7933	0.0594*
H161	0.8265	0.4586	0.6557	0.0409*
H162	1.0590	0.5539	0.6614	0.0421*
H181	0.9248	0.3339	0.5111	0.1291*
H182	0.7341	0.4578	0.4946	0.1288*
H183	0.6983	0.3525	0.5434	0.1289*
H15	1.1118	1.2217	0.6016	0.0793*
H171	1.2372	0.5416	0.5168	0.0958*
H172	1.0592	0.6686	0.4986	0.0958*
H173	1.1836	0.6950	0.5500	0.0968*

Atomic displacement parameters (\AA^2)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
C1	0.0280 (7)	0.0193 (6)	0.0190 (6)	0.0001 (6)	-0.0002 (6)	-0.0015 (5)
C2	0.0276 (7)	0.0233 (6)	0.0250 (6)	-0.0002 (6)	0.0016 (7)	-0.0024 (5)
C3	0.0303 (8)	0.0236 (7)	0.0252 (6)	0.0064 (7)	-0.0007 (7)	-0.0004 (5)
C4	0.0340 (8)	0.0193 (6)	0.0236 (6)	0.0055 (7)	0.0010 (7)	0.0023 (5)
O5	0.0268 (5)	0.0165 (4)	0.0279 (5)	0.0014 (5)	-0.0001 (4)	-0.0005 (4)
C6	0.0465 (11)	0.0196 (6)	0.0382 (8)	-0.0008 (8)	0.0129 (9)	0.0003 (6)
O7	0.0510 (8)	0.0227 (5)	0.0599 (8)	0.0018 (6)	0.0241 (7)	0.0059 (6)
O8	0.0398 (6)	0.0226 (5)	0.0248 (5)	-0.0013 (5)	0.0066 (5)	-0.0033 (4)
C9	0.0265 (7)	0.0238 (6)	0.0243 (6)	0.0003 (7)	0.0029 (6)	-0.0024 (6)

O10	0.0449 (7)	0.0229 (5)	0.0245 (5)	0.0028 (6)	0.0091 (5)	-0.0001 (4)
C11	0.0260 (8)	0.0407 (9)	0.0305 (7)	-0.0009 (8)	0.0016 (6)	-0.0045 (7)
C12	0.0273 (7)	0.0457 (9)	0.0286 (7)	-0.0001 (8)	-0.0010 (6)	0.0004 (7)
O13	0.0340 (6)	0.0280 (5)	0.0214 (5)	0.0051 (5)	-0.0024 (5)	-0.0055 (4)
C14	0.0438 (10)	0.0302 (8)	0.0252 (7)	0.0105 (8)	0.0017 (7)	-0.0039 (6)
O15	0.0630 (9)	0.0325 (6)	0.0284 (5)	0.0227 (7)	0.0122 (6)	0.0056 (5)
C16	0.0400 (9)	0.0198 (6)	0.0252 (6)	0.0057 (7)	-0.0009 (7)	-0.0003 (5)
C17	0.0534 (12)	0.0664 (14)	0.0420 (10)	0.0165 (12)	0.0199 (10)	0.0190 (10)
C18	0.0824 (19)	0.0585 (14)	0.0755 (16)	0.0166 (15)	-0.0150 (15)	-0.0442 (13)

Geometric parameters (Å, °)

C1—C2	1.530 (2)	C9—C12	1.507 (2)
C1—O5	1.4108 (18)	C11—H111	0.978
C1—O13	1.4209 (16)	C11—H112	0.951
C1—C16	1.517 (2)	C11—H113	0.985
C2—C3	1.543 (2)	C12—H121	0.953
C2—O10	1.4235 (18)	C12—H122	0.950
C2—H21	0.983	C12—H123	0.977
C3—C4	1.526 (2)	O13—C14	1.428 (2)
C3—O8	1.4302 (18)	C14—O15	1.4399 (19)
C3—H31	0.990	C14—C17	1.513 (3)
C4—O5	1.4448 (18)	C14—C18	1.501 (3)
C4—C6	1.505 (2)	O15—C16	1.4110 (19)
C4—H41	0.969	C16—H161	0.983
C6—O7	1.425 (2)	C16—H162	0.966
C6—H61	0.983	C17—H171	0.970
C6—H62	0.989	C17—H172	0.964
O7—H15	0.814	C17—H173	0.988
O8—C9	1.4256 (19)	C18—H181	0.957
C9—O10	1.4339 (18)	C18—H182	0.975
C9—C11	1.518 (2)	C18—H183	0.984
C2—C1—O5	105.52 (11)	C9—O10—C2	107.71 (11)
C2—C1—O13	108.37 (13)	C9—C11—H111	109.6
O5—C1—O13	111.77 (11)	C9—C11—H112	111.5
C2—C1—C16	117.58 (13)	H111—C11—H112	109.2
O5—C1—C16	110.31 (13)	C9—C11—H113	109.1
O13—C1—C16	103.39 (11)	H111—C11—H113	107.7
C1—C2—C3	104.43 (14)	H112—C11—H113	109.6
C1—C2—O10	108.97 (13)	C9—C12—H121	109.0
C3—C2—O10	104.88 (12)	C9—C12—H122	109.2
C1—C2—H21	112.1	H121—C12—H122	111.0
C3—C2—H21	113.5	C9—C12—H123	109.2
O10—C2—H21	112.4	H121—C12—H123	109.1
C2—C3—C4	103.75 (14)	H122—C12—H123	109.4
C2—C3—O8	103.92 (12)	C1—O13—C14	108.59 (12)
C4—C3—O8	110.39 (14)	O13—C14—O15	105.38 (11)

C2—C3—H31	114.1	O13—C14—C17	110.92 (14)
C4—C3—H31	111.7	O15—C14—C17	107.53 (16)
O8—C3—H31	112.4	O13—C14—C18	108.04 (17)
C3—C4—O5	104.52 (11)	O15—C14—C18	110.12 (17)
C3—C4—C6	115.00 (13)	C17—C14—C18	114.48 (19)
O5—C4—C6	109.66 (14)	C14—O15—C16	110.00 (12)
C3—C4—H41	108.8	C1—C16—O15	104.95 (12)
O5—C4—H41	109.7	C1—C16—H161	109.6
C6—C4—H41	109.0	O15—C16—H161	110.7
C4—O5—C1	106.49 (11)	C1—C16—H162	112.9
C4—C6—O7	110.38 (13)	O15—C16—H162	109.8
C4—C6—H61	107.9	H161—C16—H162	108.9
O7—C6—H61	109.4	C14—C17—H171	109.6
C4—C6—H62	108.4	C14—C17—H172	109.4
O7—C6—H62	111.1	H171—C17—H172	109.1
H61—C6—H62	109.6	C14—C17—H173	108.5
C6—O7—H15	104.5	H171—C17—H173	111.2
C3—O8—C9	107.69 (11)	H172—C17—H173	109.0
O8—C9—O10	103.99 (10)	C14—C18—H181	107.6
O8—C9—C11	111.48 (15)	C14—C18—H182	109.4
O10—C9—C11	110.43 (15)	H181—C18—H182	111.3
O8—C9—C12	109.38 (13)	C14—C18—H183	107.4
O10—C9—C12	109.06 (14)	H181—C18—H183	110.2
C11—C9—C12	112.17 (13)	H182—C18—H183	110.9

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>
O7—H15 \cdots O15 ⁱ	0.81	2.06	2.862 (2)	167

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