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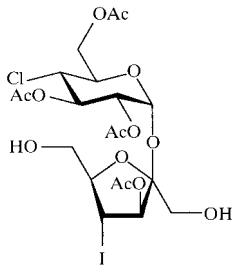
At 160 K, the glucopyranosyl ring of the title compound, $C_{20}H_{28}ClIO_{13}$, has a near-ideal $^4C_1$ conformation and the fructofuranosyl ring has a twist $^4T_3$ conformation. The two hydroxy groups are involved in intra- and intermolecular hydrogen bonds, with the latter interactions linking the molecules into infinite one-dimensional chains. The absolute configuration of the molecule has been determined.

Comment

The Shallenberger and Acree–Kier AH,B,γ tripartite hypothesis (Shallenberger & Acree, 1967; Kier, 1972) is currently the most widely accepted explanation for sweetness. However, the location of the AH,B,γ glucophore in many classes of high intensity sweeteners is still far from defined (Mathlouthi *et al.*, 1993; Suami *et al.*, 1994). Our studies are aimed at trying to locate this tripartite glucophore and the determination of the sweet conformation of the intensely sweet halodeoxy sucrose sweeteners. As part of this programme, the low-temperature crystal structure of the title compound, (I), has been determined.



(I)

The absolute configuration of (I) has been confidently determined by refinement of the absolute structure parameter and is shown in Fig. 1. The bond lengths and angles exhibit normal values and generally agree with those of sucrose (Brown & Levy, 1963, 1973; Hanson *et al.*, 1973) and 3-*O*-acetyl-1,4,6-trichloro-1,4,6-trideoxy-β-D-tagatofuranosyl 2,3,6-tri-*O*-acetyl-4-chloro-4-deoxy-α-D-galactopyranoside (Lee *et al.*, 1999). The torsion angles (Table 1) about the anomeric O1 atom are also very similar to those in sucrose (Brown & Levy, 1973). The acetoxymethyl and hydroxymethyl groups of the two sugar moieties all have the *gauche–gauche* conformation. In sucrose, however, the hydroxymethyl substituents at C5 and C5′ (equivalent to C5 and C10 in Fig. 1) are *gauche–gauche*, while that at C2′ (equivalent to C7 in Fig. 1) is *trans–gauche* (Brown & Levy, 1973). These *gauche–gauche* conformations in compound (I) position the respective acetoxy and hydroxy groups so as to avoid possible *peri* interactions, namely O6 with Cl4, O11 with I9, and O12 with both O8 and O10. Interestingly, in 3-*O*-acetyl-1,4,6-trichloro-1,4,6-trideoxy-β-D-tagatofuranosyl 2,3,6-tri-*O*-acetyl-4-chloro-4-deoxy-α-D-galactopyranoside (Lee *et al.*, 1999), the C5-hydroxymethyl substituent adopts a *gauche–trans* conformation. Since the pyranosyl ring in this latter sugar is the *galacto* isomer, the *gauche–trans* conformation positions the O atom bonded to C6 *anti* to Cl4.

The glucopyranosyl ring in compound (I) adopts the $^4C_1$ chair conformation. The puckering parameters (Cremer & Pople, 1975) are: Q = 0.592 (3) Å, q_2 = 0.020 (2) Å, q_3 = 0.592 (3) Å, φ_2 = 174 (8)° and θ = 1.7 (2)°. The puckering amplitudes ($q_3 >> q_2$) of the pyranose ring describe a very slightly distorted chair. Indeed, the total puckering amplitude (Q) is only slightly lower than that of the ideal cyclohexane chair [0.63 Å for d(C—C) = 1.54 Å]. The magnitude of the distortion is significantly smaller than in sucrose (θ = 5.2°; Cremer & Pople, 1975) and both peracylated 1,4,6-trichloro-1,4,6-trideoxy-β-D-fructofuranosyl 4-chloro-4-deoxy-α-D-galactopyranoside and 1,4,6-trichloro-1,4,6-trideoxy-β-D-tagatofuranosyl 4-chloro-4-deoxy-α-D-galactopyranoside [θ = 4.7 (5) and 5.0 (3)°, respectively; Lee *et al.*, 1999], but comparable with that of sucralose (θ = 1.9°; Kanters *et al.*, 1988). With φ_2 being close to 180°, the distortion is towards the inverted boat $B_{3,0}$ conformation, which is very close to the conformational distortion found in sucrose.

The furanoid ring in compound (I) has a $^4T_3$ twist conformation [θ = 277.1 (3)°], which is the same as in sucrose (Rohrer, 1972) and 3-*O*-acetyl-1,4,6-trichloro-1,4,6-trideoxy-β-D-fructofuranosyl 2,3,6-tri-*O*-acetyl-4-chloro-4-deoxy-α-D-galactopyranoside (Lee *et al.*, 1999). The twist is on C8 and C9, with these atoms being 0.205 (6) and −0.479 (6) Å, respectively, from the plane defined by C7, C10 and O10.

It is now generally believed that the AH,B unit of the Shallenberger and Acree–Kier AH,B,γ glucophore (Shallenberger & Acree, 1967; Kier, 1972) spans the two sugar rings of sucrose (Mathlouthi *et al.*, 1993). From molecular mechanics and dynamics studies, Hooft *et al.* (1993) suggested that the sweet conformation of the sweet chlorinated sucroses should have values for the torsion angles defined by Φ(C1—O1—C7—O10) and Ψ(C7—O1—C1—O5) of 75 and 95°, respectively. In (I), these torsion angles are −42.5 (3) and 104.7 (2)°, respectively, which are very similar to those of sucrose [−44.75 (11) and 107.82 (10)°, respectively; Brown & Levy, 1973] and two reported chlorinated sucrose analogues, namely

3-*O*-acetyl-1,4,6-trichloro-1,4,6-trideoxy-β-D-fructofuranosyl 2,3,6-tri-*O*-acetyl-4-chloro-4-deoxy-α-D-galactopyranoside [Φ = −25.1 (5)° and Ψ = 99.5 (4)°] and 3-*O*-acetyl-1,4,6-trichloro-1,4,6-trideoxy-β-D-tagatofuranosyl 2,3,6-tri-*O*-acetyl-4-chloro-4-deoxy-α-D-galactopyranoside [Φ = −48.0 (3)° and Ψ = 113.1 (2)°] (Lee *et al.*, 1999), but are very different from those of another chlorinated sucrose analogue, *viz*. sucralose [Φ = −162.2 (2)° and Ψ = 91.4 (2)°; Kanters *et al.*, 1988].

The hydroxy group at O12, which is part of the hydroxymethyl group adjacent to the bridging O atom, is involved in bifurcated hydrogen bonds. One is a weak intramolecular interaction with the ring O atom of the furanoid ring, forming

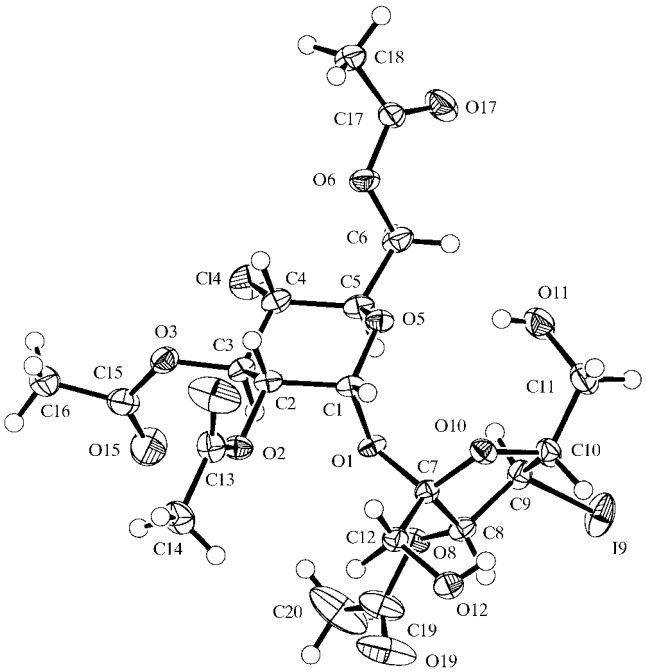


Figure 1
View of the molecule of (I) showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 50% probability level. H atoms are represented by circles of arbitrary size.

a five-membered loop with a graph-set motif of *S*(5) (Bernstein *et al.*, 1995), while the other interaction is a stronger intermolecular hydrogen bond with the carbonyl O atom of the acetoxymethyl substituent at C5 of the glucopyranosyl ring of a neighbouring molecule (Table 2). These interactions link the molecules into infinite one-dimensional chains which run parallel to the [100] direction and have a graph-set motif of *C*(10). The hydroxy group at O11 participates in an intramolecular hydrogen bond with the ring O atom of the glucopyranosyl ring. This results in the formation of a nine-membered loop with a graph-set motif of *S*(9).

Experimental

A solution of 3-*O*-acetyl-4-deoxy-4-iodo-1,6-di-*O*-trityl-β-D-fructofuranosyl 2,3,6-tri-*O*-acetyl-α-D-galactopyranoside (0.7 g) (Muhammad Sofian & Lee, 2001) in dry CH_2Cl_2/pyridine (15:1, 32 ml) was treated with trifluoromethane sulfonic anhydride (0.2 ml) at 195 K for 15 min and then at 273 K for 2 h. The reaction mixture was worked up in the usual way and treated with LiCl (0.15 g) in acetone to give, after flash chromatography (ether/hexane, 1:1), 3-*O*-acetyl-4-deoxy-4-iodo-1,6-di-*O*-trityl-β-D-fructofuranosyl 2,3,6-tri-*O*-acetyl-4-chloro-4-deoxy-α-D-glucopyranoside (0.5 g, 70%), m.p. 366–368 K; $[\alpha]_D$ +34.9° (*c* 0.57, $CHCl_3$); ^{1}H NMR ($CDCl_3$, δ, p.p.m.): 1.62, 1.94, 1.96, 2.07 (4 × *s*, 12H, 4 × CH_3), 3.06–3.19 (2 × *d*, 2H, $J_{1'a,1'b}$ = 9.7 Hz, H1′*a*,*b*), 3.3–3.4 (*m*, 2H, H6′*a*,*b*), 3.69 (*t*, 1H, $J_{3,4} = J_{4,5}$ = 10.1 Hz, H4), 4.1–4.3 (*m*, 5H, H4′, 5, 5′, 6*a*,*b*), 4.54 (*dd*, 1H, $J_{1,2}$ = 3.8, $J_{2,3}$ = 10.1 Hz, H2), 5.27 (*t*, 1H, $J_{2,3} = J_{3,4}$ = 10.1 Hz, H3), 5.60 (*d*, 1H, $J_{1,2}$ = 3.8 Hz, H1), 5.92 (*d*, 1H, $J_{3',4'}$ = 9.7 Hz, H3′) and 7.1–7.4 (*m*, 30H, Ar-H); ^{13}C NMR: δ 170.3, 169.5, 169.4, 169.1 (*C*OCH$_3$), 143.6, 143.5 (*C*Ph$_3$), 128.8, 128.7, 127.8, 127.1 (Ar-*C*), 103.9 (C2′), 88.6 (C1), 83.8 (C5′), 80.1 (C3′), 71.3, 70.4, 70.3 (C2, C3, C5), 65.0, 63.2, 62.2 (C1′, C6, C6′), 55.4 (C4), 21.0, 20.6, 20.5, 20.3 (CO*C*H$_3$) and 18.4 (C4′); HRMS–ESI (positive mode), calculated for $[M + Na]^+$: 1145.2352:1147.2322; found: 1145.2370:1147.2375 (3:1). The above 4-chloro-4′-iodo derivative (0.42 g, 0.37 mmol) was dissolved in ice-cold CH_2Cl_2/AcOH (1:1, 10 ml) and treated with concentrated HCl (0.080 ml) at room temperature for 30 min to give, after flash chromatography (ethyl acetate/hexane, 1:1), the title compound, (I) (0.18 g, 75%), m.p. 386–387 K; $[\alpha]_D$ +5.92° (*c* 0.76, $CHCl_3$); ^{1}H NMR ($CDCl_3$, δ, p.p.m., the assignments employ the crystallographic atom numbering used in Fig. 1): 1.99, 2.03, 2.06, 2.20 (4 × *s*, 12H, 4 × CH_3), 3.45–3.90 (*m*, 5H, H4, 12*a*,*b*, 11*a*,*b*), 4.17–4.44 (*m*, 5H, H9, 5, 10, 6*a*,*b*), 4.75 (*dd*, 1H, $J_{1,2}$ = 3.5, $J_{2,3}$ = 10.2 Hz, H2), 5.40 (*d*, 1H, $J_{8,9}$ = 10.4 Hz, H8), 5.41 (*t*, 1H, $J_{2,3} = J_{3,4}$ = 10.2 Hz, H3) and 5.58 (*d*, 1H, $J_{1,2}$ = 3.5 Hz, H1); ^{13}C NMR: δ 170.7, 170.4, 170.1, 169.5 (*C*OCH$_3$), 104.3 (C7), 89.5 (C1), 85.4 (C10), 80.5 (C8), 71.1, 70.8, 70.5 (C2, 3, 5), 64.3, 62.2, 58.7 (C12, 6, 11), 54.9 (C4), 20.7, 20.6, 20.5, 20.4 (CO*C*H$_3$) and 16.2 (C9); HRMS–ESI (positive mode), calculated for $[M + Na]^+$: 661.0161:663.0131; found: 661.0164:663.0105 (3:1). Suitable crystals were obtained by very slow evaporation of a solution of compound (I) in chloroform.

Crystal data

$C_{20}H_{28}ClIO_{13}$
M_r = 638.77
Orthorhombic, $P2_12_12_1$
a = 8.8407 (1) Å
b = 10.5562 (1) Å
c = 28.2974 (4) Å
V = 2640.83 (5) Å^3
Z = 4
D_x = 1.607 Mg m^{-3}
Mo *Kα* radiation
Cell parameters from 39 653 reflections
θ = 2.0–30.0°
μ = 1.38 mm^{-1}
T = 160 (1) K
Prism, colourless
0.35 × 0.22 × 0.20 mm

Data collection

Nonius KappaCCD diffractometer
φ and ω scans with κ offsets
Absorption correction: multi-scan (Blessing, 1995)
T_{min} = 0.679, T_{max} = 0.786
27 635 measured reflections
7621 independent reflections
6659 reflections with $I > 2\sigma(I)$
R_{int} = 0.044
θ_{max} = 30.0°
h = −12 → 12
k = −14 → 14
l = −38 → 39

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)]$ = 0.035
$wR(F^2)$ = 0.076
S = 1.03
7621 reflections
323 parameters
H-atom parameters constrained
$w = 1/[\sigma^2(F_o^2) + (0.0193P)^2 + 2.6788P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max}$ = 0.001
$\Delta\rho_{max}$ = 1.99 e Å^{-3}
$\Delta\rho_{min}$ = −1.23 e Å^{-3}
Extinction correction: *SHELXL*97
Extinction coefficient: 0.0015 (4)
Absolute structure: Flack (1983), 3319 Friedel pairs
Flack parameter = −0.021 (14)

Table 1
Selected geometric parameters (Å, °).

O1—C1	1.413 (3)	O5—C5	1.442 (3)
O1—C7	1.426 (3)	O10—C7	1.416 (3)
O5—C1	1.420 (3)	O10—C10	1.453 (3)
C1—O1—C7	117.35 (18)		
C7—O1—C1—O5	104.7 (2)	C1—O1—C7—C8	−156.28 (19)
C7—O1—C1—C2	−135.5 (2)	O10—C10—C11—O11	−64.4 (3)
C17—O6—C6—C5	−179.2 (2)	C9—C10—C11—O11	50.9 (4)
O5—C5—C6—O6	−71.8 (3)	O10—C7—C12—O12	−58.3 (3)
C4—C5—C6—O6	48.5 (3)	O1—C7—C12—O12	−179.6 (2)
C1—O1—C7—O10	−42.5 (3)	C8—C7—C12—O12	59.4 (3)
C1—O1—C7—C12	76.3 (3)		

Table 2
Hydrogen-bonding geometry (Å, °).

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
O11—H11···O5	0.84	2.25	2.964 (3)	143
O12—H12···O10	0.84	2.38	2.773 (2)	109
O12—H12···O17^{i}	0.84	2.16	2.952 (3)	158

Symmetry code: (i) $\frac{1}{2}+x, \frac{1}{2}-y, -z$.

The methyl and hydroxy H atoms were constrained to an ideal geometry (0.98 and 0.84 Å, respectively), with U_{iso}(H) = 1.5U_{eq}(parent atom), but were allowed to rotate freely about the C—C and C—O bonds. All other H atoms were placed in geometrically idealized positions (C—H = 0.99–1.00 Å) and constrained to ride on their parent atoms, with U_{iso}(H) = 1.2U_{eq}(C). The determined absolute structure agreed with that expected for a natural sucrose derivative. The largest and the most negative peaks of residual electron density were within 0.9 Å of the I atom.

Data collection: *COLLECT* (Nonius, 2000); cell refinement: *DENZO-SMN* (Otwinowski & Minor, 1997); data reduction: *DENZO-SMN* and *SCALEPACK* (Otwinowski & Minor, 1997); program(s) used to solve structure: *SIR*92 (Altomare *et al.*, 1994); program(s) used to refine structure: *SHELXL*97 (Sheldrick, 1997); molecular graphics: *ORTEP*II (Johnson, 1976); software used to prepare material for publication: *SHELXL*97.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: SK1489). Services for accessing these data are described at the back of the journal.

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