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Note

Confirmation of the structure of tetra-*O*-(*tert*-butyldimethylsilyl)-D-glucono-1,4-lactone formed by silylation of D-glucono-1,5-lactone

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Abstract

The structure of tetra-*O*-(*tert*-butyldimethylsilyl)-D-glucono-1,4-lactone made by the silylation of D-glucono-1,5-lactone has been confirmed by single-crystal *X*-ray analysis. © 2002 Elsevier Science Ltd. All rights reserved.

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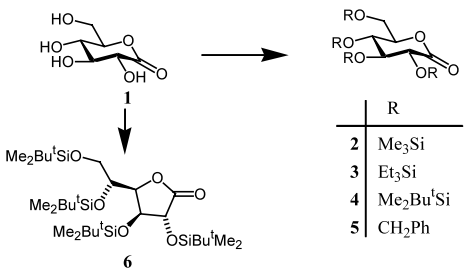
Carbohydrates and their suitably protected derivatives have been widely utilized as chiral synthons for the construction of enantiomerically pure compounds.[1–4] During investigation of the addition reactions of organometallics to protected D-glucono-1,5-lactones **2**–**5** (Scheme 1), it was noticed that the structure of tetra-*O*-(*tert*-butyldimethylsilyl)-D-glucono-1,5-lactone (**4**) prepared by a literature[5] method was not compatible with its infrared stretching frequency at 1786 cm^{-1}.[6] The isomeric structure, tetra-*O*-(*tert*-butyldimethylsilyl)-D-glucono-1,4-lactone (**6**) appeared more plausible for this compound. In a recent communication, Lin[7] has described the use of ^{13}C NMR spectroscopy to corroborate the structures of compounds **4** and **6**, and in this note we describe our investigations that led to the confirmation of the γ-lactone structure of **6** by single-crystal X-ray analysis.



Scheme 1. Silylation of D-glucono-1,5-lactone (**1**).

Tetra-*O*-(trimethylsilyl)-D-glucono-1,5-lactone (**2**) has an IR absorption at 1755 cm^{-1} that is comparable to the corresponding tetra-*O*-(benzyl)-D-glucono-1,5-lactone (**5**) (1756 cm^{-1}).[8,9] However, the sterically more congested tetra-*O*-(triethylsilyl)-D-glucono-1,5-lactone (**3**) shows an absorption at a higher wave number (1769 cm^{-1}).[10] The enhancement in the stretching frequency of this gluconolactone is evidently due to the additional ring strain caused by steric compression. We examined two literature methods for the preparation of the very bulky tetra-*O*-(*tert*-butyldimethylsilyl)-D-gluconolactone from D-glucono-1,5-lactone (**1**). The crystalline compound (mp 100 °C) obtained by silylation (Bu^tMe_2SiCl, DMF) using imidazole as the HCl scavenger showed an IR absorption at 1786 cm^{-1}.[5] This carbonyl stretching frequency is more in line with that expected of the isomeric D-glucono-1,4-lactone (**6**) rather than of **4**.[6] We were unable to reproduce the silylation of D-glucono-1,5-lactone (**1**) by the second

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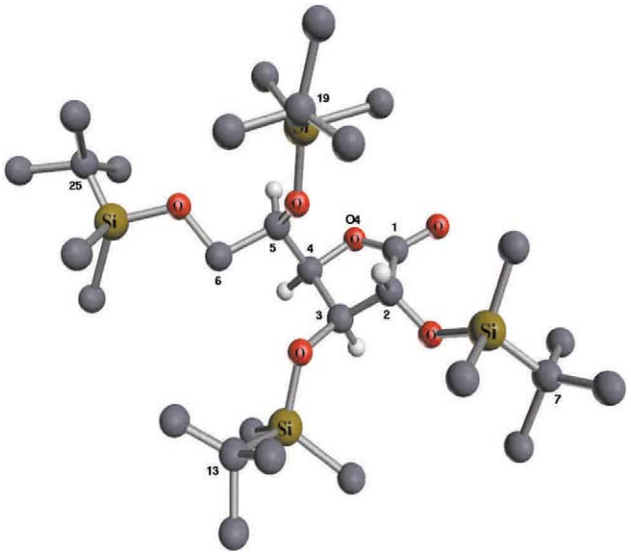

Fig. 1. Molecular structure of tetra-*O*-(*tert*-butyldimethylsilyl)-D-glucono-1,4-lactone (**6**).

method (4-dimethylaminopyridine, Bu^{t}Me$_2$SiCl, 2,6-lutidine).[11] Rather, in our hands, a mixture of the tetrasilylated and partially silylated products was formed. The IR absorption of this mixture showed a strong absorption at 1790 cm^{-1}, again suggesting the presence D-glucono-1,4-lactones. We have confirmed the isomeric D-glucono-1,4-lactone structure **6** for this compound by single-crystal X-ray analysis (Fig. 1).

Analysis and least-square refinements clearly revealed the 1,4-lactone ring of **6** and its substituents extending to the four silicon atoms, but the methyl positions of the *tert*-butyl groups were poorly defined due to considerable rotameric disorder about all four Si–C(Me)$_3$ bonds. Only the 'major' rotameric positions of the methyl groups are shown in the drawing (Fig. 1). The γ-lactone adopts an envelope conformation for the trans–cis configuration of substituents at C-2, C-3 and C-4. With C-3 as the envelope flap, these substituents are pseudoequatorial, equatorial and axial, respectively. Unit cell data: $a = 15.512(9)$, $b = 21.408(9)$, $c = 12.578(5)$ Å, $P2_12_12_1$, $Z = 4$, $R = 0.12$ for 969 intensities with $I > 3\sigma(I)$ (Enraf–Nonius CAD4 diffractometer, $\lambda = 1.5418$ Å, $T = -33$ °C) (Table 1).

There is no evidence for the formation of any other crystalline products in this batch, since an X-ray powder diffraction pattern simulated from the refined atomic parameters is in excellent agreement with the experimental pattern observed from 'bulk' samples (Fig. 2). Bulk recrystallized product therefore is crystallographically homogeneous and has this same γ-lactone crystal structure **6**.

In conclusion, we have confirmed the structure of the tetra-*O*-(*tert*-butyldimethylsilyl)-D-glucono-1,4-lactone (**6**).[5] The steric compression due to trans diequatorial interactions in the six-membered lactone **4** apparently favors formation of the thermodynamically more stable five-membered lactone **6**. The silylation[7] of the D-glucono-1,5-lactone (**1**) with the very reactive *tert*-butyldimethylsilyltrifluoromethane sulfonate in DMF is probably under kinetic control to produce the unrearranged δ-lactone (**4**).

1. Experimental

General methods.—For NMR spectra, a Bruker DRX 400 MHz spectrometer was used with Me$_4$Si as the internal standard. IR spectra were taken on a JASCO FT-IR-410 instrument. The optical rotation was determined with a Perkin–Elmer model 241 polarimeter in $CHCl_3$ solution at 20 °C.

Table 1
Crystallographic data and details of the refinement for tetra-*O*-(*tert*-butyldimethylsilyl)-1,4-furanone (**6**)

Temperature (°C)	−33 (240 K)
Solvent	95% EtOH
a (Å)	15.512(9)
b (Å)	21.408(9)
c (Å)	12.578(5)
V (Å^3)	4177(6)
Crystal system,	orthorhombic
Space group	$P2_12_12_1$
d_{calcd} (g cm^{-3})	1.010 (at −33 °C (240 K))
Formula	$C_{30}H_{66}O_6Si_4$
f_w	635.20
Z	4
Habit	colorless rods
Crystal size (mm)	0.8 × 0.3 × 0.2
μ (cm^{-1})	15.8
Instrument	CAD4/Nonius FR591 X-ray generator
λ (Å)	1.5418
2θmax (°)	94
Index ranges	$0 \le h \le 14$, $0 \le k \le 20$, $0 \le l \le 11$
Refinement method	full-matrix least-squares on F
N_{ref} [a]	2159
N_{uni} [b]	2159
N_{obs} [c]	969
N_{var} [d]	181
ERRWT [e]	4.64
R	0.122
R_w	0.139
$R_{enantiomer}$	0.122
$R_{w\ enantiomer}$	0.139

[a] Total number of measured reflections within (2θ)max.
[b] Total number of symmetry-independent measured reflections.
[c] Total number of 'observed' reflections with $I \ge 3\sigma(I)$ used in least-squares refinement.
[d] Number of variables in least-squares refinements.
[e] Error in an observation of unit weight.

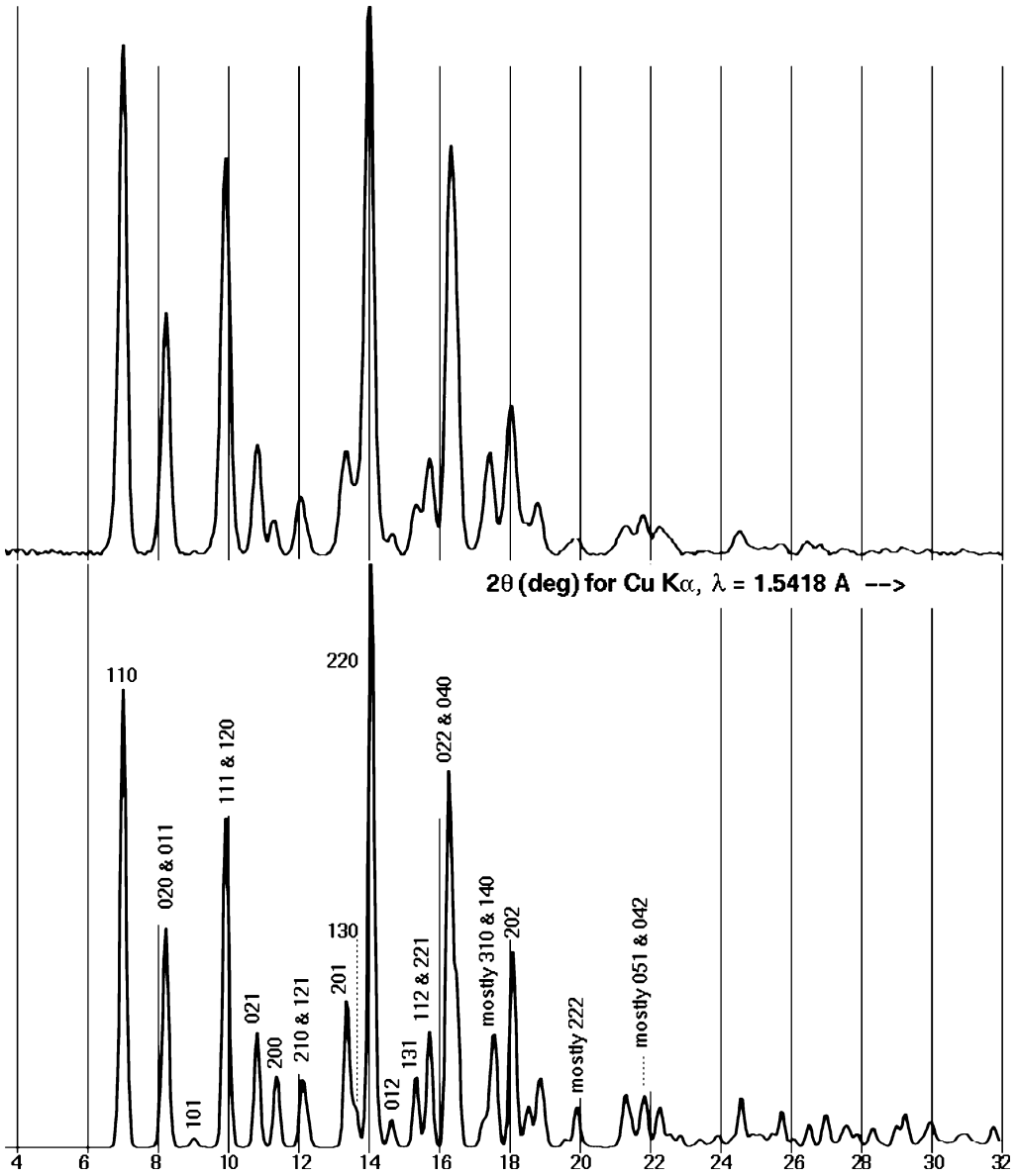

Fig. 2. Simulated (bottom) and observed (top) powder X-ray diffraction patterns of tetra-*O*-(*tert*-butyldimethylsilyl)-D-glucono-1,4-lactone (**6**).

X-ray crystallography.—X-ray data were measured on a Nonius CAD4 kappa geometry diffractometer at − 33 °C. The structure was solved by direct-methods with the SIR88 program[12] and refined using full-matrix least-squares method in the MOLEN package,[13] with isotropic displacement coefficients for most non-hydrogen atoms. Silicon atoms were refined anisotropically. Hydrogen atoms were introduced in idealized positions and assigned isotropic temperature factors, 1.2 times the equivalent isotropic temperature factor of the adjacent C atom. Their scattering was included in the structure factor calculations but no hydrogen parameters were varied.

Tetra-O-*(*tert-*butyldimethylsilyl)*-D-*glucono-1,4-lactone* (**6**).—A mixture of D-glucono-1,5-lactone (**1**, 5.0 g, 28.1 mmol)], imidazole (15.29 g, 225 mmol), and *tert*-butylchlorodimethylsilane (25.38 g, 168.4 mmol) in DMF (25 mL) was heated at 45 °C in an oil bath. After 24 h, the reaction mixture was dissolved in heptane (400 mL) and washed with water (4 × 600 mL). The heptane solution was dried over $MgSO_4$, filtered, and evaporated on a rotary evaporator. The residue was dissolved in *tert*-butyl methyl ether (100 mL) and stirred with K_2CO_3 overnight. The mixture was filtered, and the solvent was evaporated under vacuum to give 17.76 g of crude product (yield 76%); IR (CH_2Cl_2 film) 1786

cm^{-1}. The crude product was crystallized twice from MeOH to give 7.2 g (yield 31%) of D-glucono-1,4-lactone (**6**) as a colorless solid: mp 99–100 °C (lit.[5] mp 99.5–100 °C); $[\alpha]_D^{20}$ +33.5° (*c* 1, $CHCl_3$), lit.[5] +17.2°; IR[14] (KBr) 1787 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 0.07 (s, 6 H, 2 × CH_3), 0.08 (s, 3 H, CH_3), 0.12 (s, 3 H, CH_3), 0.13 (s, 6 H, 2 × CH_3), 0.16 (s, 3 H, CH_3), 0.20 (s, 3 H, CH_3), 0.9 (s, 9 H, *t*-Bu), 0.91 (s, 9 H, *t*-Bu), 0.93 (s, 9 H, *t*-Bu), 0.95 (s, 9 H, *t*-Bu), 3.63–3.67 (dd, 1 H, $J_{5,6a}$ 5.5, $J_{6a,b}$ 10.1 Hz, H-6a), 3.92–3.96 (dd, 1 H, $J_{5,6b}$ 6.6, $J_{6a,b}$ 10.1 Hz), 4.02–4.06 (m, 1 H, H-5), 4.43–4.46 (dd, 1 H, $J_{2,3}$ 7.0, $J_{3,4}$ 7.0 Hz, H-3), 4.57–4.61 (m, 2 H, H-2,4). ^{13}C NMR (100 MHz, $CDCl_3$): δ −5.4, −4.9, −4.6, −4.5, 17.8, 17.7, 18.1, 18.2, 25.6, 25.7, 25.8, 63.8, 73.8, 74.4, 76.3, 78.7, 174.0. Anal. Calcd for $C_{30}H_{66}O_6Si_4$: C, 56.7; H, 10.5. Found: C, 56.51; H, 10.48.

2. Supplementary material

Full crystallographic details, excluding structure features, have been deposited (accession no. CCDC 164592) with the Cambridge Crystallographic Data Centre. These data may be obtained free of charge, on request from The Director, CCDC, 12 Union Road, Cambridge CB21EZ, UK (Tel.: +44-1223-336408; fax: +44-1223-336033; e-mail: deposit @ccdc.cam.ac.uk or www:http://www.ccdc.cam.ac.uk).

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