

Crystal structures of methyl 6-*O*-acyl- α -D-galactopyranosides

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Abstract

The crystal structures of methyl 6-*O*-n-octanoyl- α -D-galactopyranoside (**1**) and methyl 6-*O*-n-decanoyl- α -D-galactopyranoside (**2**) were investigated by X-ray analysis. Anhydrous crystals obtained from methanol solution by slow evaporation are monoclinic, and the space group is $P2_1$ with $Z = 2$. The cell dimensions are as follows, **1**: $a = 5.774(1)$, $b = 8.013(1)$, $c = 19.183(1)$ Å, $\beta = 98.50(1)^\circ$; **2**: $a = 5.762(1)$, $b = 8.003(1)$, $c = 21.227(2)$ Å, $\beta = 93.93(1)^\circ$. The galactopyranoside ring is nearly in a 4C_1 chair conformation but slightly distorted to twist boat and the alkyl chain is in all-*trans* conformation. In these crystals, molecules are arranged in a bilayer structure with interdigitated alkyl chains. The hydrogen bonding linkages between sugar moieties, which are found only between the layers, form an infinite chain through the crystal. **1** and **2** show higher melting points than those of corresponding β -D-glucopyranosides. The results indicate the important role of the sugar in the crystal.

Keywords: X-ray; Glycosurfactant; Nonionic surfactant; Acylglycoside

1. Introduction

Surfactants which have saccharide components as the hydrophilic part have become important materials as protein solubilizers [1], but the solubility of the glycosurfactants depends on the structure of sugar moieties, for example, *N*-octanoyl-*N*-methylglucamide

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[2] is highly soluble, but *N*-octyl-gluconamide [3] is difficult to dissolve in water at room temperature. Müller-Fahrnow et al. [4] have suggested from the X-ray structure that the hydrogen bond involving the sugar moiety of *N*-octanoyl-*N*-methylglucamide is weaker than that of *N*-octyl-gluconamide [5]. Dorset et al. [6] have reported *n*-octyl β -D-glucopyranoside anomers which exhibit different crystal packing and thermodynamic property. The structures of *n*-octyl α -D-glucopyranoside (5) and *n*-decyl α -D-glucopyranoside (6) have been reported [7,8]. However, the details of the crystal packing were still unclear because of the lack of structural knowledge of octyl β -D-glucopyranoside.

In this report, we deal with the crystal structures of methyl 6-*O*-*n*-octanoyl- α -D-galactopyranoside (1) and methyl 6-*O*-*n*-decanoyl- α -D-galactopyranoside (2). The physicochemical properties of some methyl *O*-acyl-D-glycopyranosides have been reported, where the position of esterification influences the surface tension and area/molecule in surface layers of aqueous solutions [9]. Melting points of methyl 6-*O*-*n*-decanoylglycosides have a wide range between 59 and 137°C — the lowest and highest temperature observed for the α -D-glucopyranoside and α -D-galactopyranoside derivative, respectively [10]. Previously, we have determined the crystal structures of methyl 6-*O*-*n*-octanoyl- β -D-glucopyranoside (3) and methyl 6-*O*-*n*-decanoyl- β -D-glucopyranoside (4) with mp of 88 and 91°C, respectively [11].

2. Experimental

Compounds 1 and 2 were prepared by the esterification of methyl α -D-galactopyranoside with methyl octanoate and methyl decanoate, respectively, by lipase [12,13]. They were recrystallized several times from methanol. Large crystals of 1 and 2 were obtained by slow evaporation of methanol solutions. A crystal was cut into a suitable size ($0.5 \times 0.5 \times 0.1$ mm for 1 and $0.5 \times 0.4 \times 0.1$ mm for 2) for X-ray measurements. Lattice constants and intensity data were measured at room temperature on an Enraf–Nonius CAD4 diffractometer. The crystal data and summary of experimental details are listed in Table 1. An empirical absorption correction was made by using the program incorporated in the CAD4 structure determination package. No extinction correction was applied. Reflections with $|F_o| > 3\sigma(|F_o|)$ were considered as observed and used for the structure analysis. The structures were determined by direct methods using the program Xtal 3.0 [14] and were refined by the least-squares method. The quantity of minimization was $\sum w(|F_c| - |F_o|)^2$ with $w = \sigma(F)^{-1}$. Since the bond angles and lengths involving the atoms C-13, C-14, and C15 in 1, and C-13, C-14, C-15, C-16 and C-17 in 2 did not converge with reasonable geometry in the refinement, these bond angles and lengths were restrained to conventional values. The hydrogen atoms on alkyl-chain and pyranose-ring carbons were located partly on a difference Fourier map. Other hydrogen atoms attached to methylene and methine groups were calculated and included in least-squares refinement. The coordinates and isotropic thermal factors of hydrogen atoms were fixed in the refinement. The refinement converged at *R* values of 0.077 and 0.094 for 1 and 2, respectively. The hydroxyl hydrogen atoms could not be located on the difference Fourier map even at the last stage. Maximum values of positive and negative electron densities in the difference Fourier map were 0.5 and $-0.4 \text{ e}\text{\AA}^{-3}$, respectively for 1 and 0.6 and $-0.4 \text{ e}\text{\AA}^{-3}$, respectively for 2.

3. Results and discussion

The molecular structures and crystal packings of **1** and **2** are shown in Figs 1 and 2, and the atomic coordinates are listed in Table 2. The crystal packings of the two structures are basically identical despite the difference in the alkyl chain length. The pyranoside rings are in 4C_1 chair conformation [15] (Fig. 1) but slightly distorted to a twist boat with puckering parameters [15] as follows: **1**, $\theta = 2.4^\circ$, $\phi_2 = 60.7^\circ$, $Q = 0.579$ Å; **2**, $\theta = 3.3^\circ$, $\phi_2 = 43.7^\circ$, $Q = 0.562$ Å. Each carbon atom of the alkyl chains in **1** and **2** has a larger thermal factor than those of **3** and **4** ($U_{eq} = 10.8(5) \sim 21(1)$, $11.9(6) \sim$

Table 1
Crystal data and summary of experimental details for **1** and **2**

	1	2
Molecular formula	C ₁₅ H ₂₈ O ₇	C ₁₇ H ₃₂ O ₇
Molecular weight	320.4	348.4
mp (°C)	140	139
$[\alpha]_D^{20}$ (°) (c 1.0, DMSO)	122.5	110.7 108.4 (ref. [10])
Crystal system	Monoclinic	Monoclinic
Space group	$P2_1$	$P2_1$
Z	2	2
Lattice constant		
<i>a</i> (Å)	5.774(1)	5.762(1)
<i>b</i> (Å)	8.013(1)	8.003(1)
<i>c</i> (Å)	19.183(1)	21.227(2)
β (°)	98.50(1)	93.93(1)
Cell volume (Å ³)	877.8(1)	976.6(1)
D_c	1.212	1.185
F(0 0 0)	348	380
Radiation	Cu K α (40 kV, 20 mA)	
μ (cm ⁻¹)	9.13	8.66
Number of reflections for the determination of lattice constants	25	23
2θ range (°)	$40 \leq \theta \leq 50$	
Number of measured reflections	2094	2457
Number of unique reflections	2094	2457
Number of observed reflections ($ F_o > 3\sigma(F_o)$)	1778	1994
Index range for data collection	$0 \leq h \leq 6$ $0 \leq k \leq 9$ $-23 \leq l \leq 23$	$0 \leq h \leq 7$ $0 \leq k \leq 9$ $-26 \leq l \leq 26$
2θ range (°)	$1 \leq 2\theta \leq 150$	
Scan mode	$\omega/2\theta$	
$\Delta\omega$	$0.80 + 0.15 \times \tan \theta$	
Scan speed (°/min)	4	
R factor	0.077	0.094
wR	0.081	0.100
S	0.885	1.107
Number of parameters refined	200	218

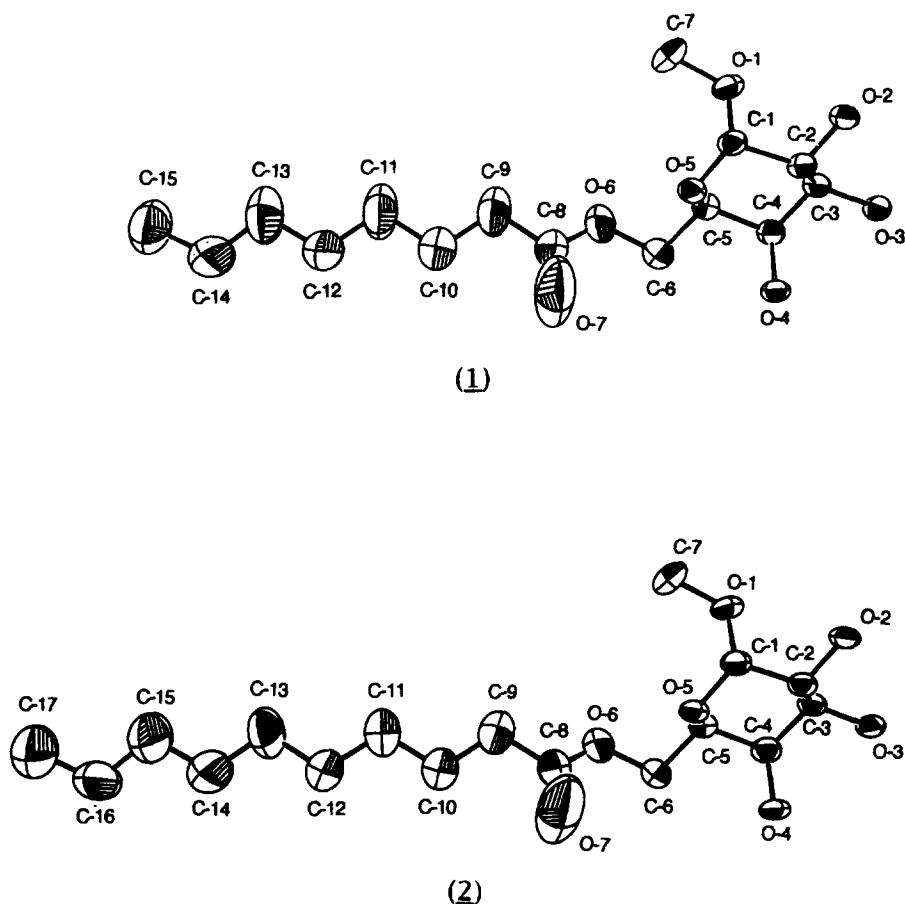


Fig. 1. Structure (ORTEP drawing) and atomic numbering for 1 and 2. Thermal ellipsoids are drawn at 50% probability.

22(1), 7(1) ~ 10(1) [11], 6.9(5) ~ 9.5(6) [11] $10^{-2}/\text{\AA}^2$ for 1, 2, 3, and 4, respectively). The torsion angle of each α -galactoside derivative in C-5–C-6–O-6–C-6 located at the bonding domain between sugar and alkyl chain is remarkably different from that of β -glucoside, and the values are -129 , -131 , 71 and 71° for 1, 2, 3 and 4, respectively. The carbonyl oxygen of the ester group has a large thermal factor, suggesting the possibility of disorder not resolved on the electron density map.

The molecules are arranged in a bilayer structure with the alkyl chains packed interdigitally. Similar packings are observed in 3, 4, [11] *n*-octyl α -D-glucopyranoside (5) [7,16] and *n*-decyl α -D-glucopyranoside (6) [8]. The area occupied by a sugar moiety in the layer can be roughly estimated as the area of the *ac* plane of the unit cell (46.2, 46.1, 57.2, 56.8, 39.1 [7] and 39.3 [8] \AA^2 in 1, 2, 3, 4, 5 and 6, respectively) and is affected by the types of sugar moiety. The alkyl chain is not normal to the layer of sugar moieties but makes angles of 32, 32, 47, 47, 26, 26° in 1, 2, 3, 4, 5 and 6, respectively.

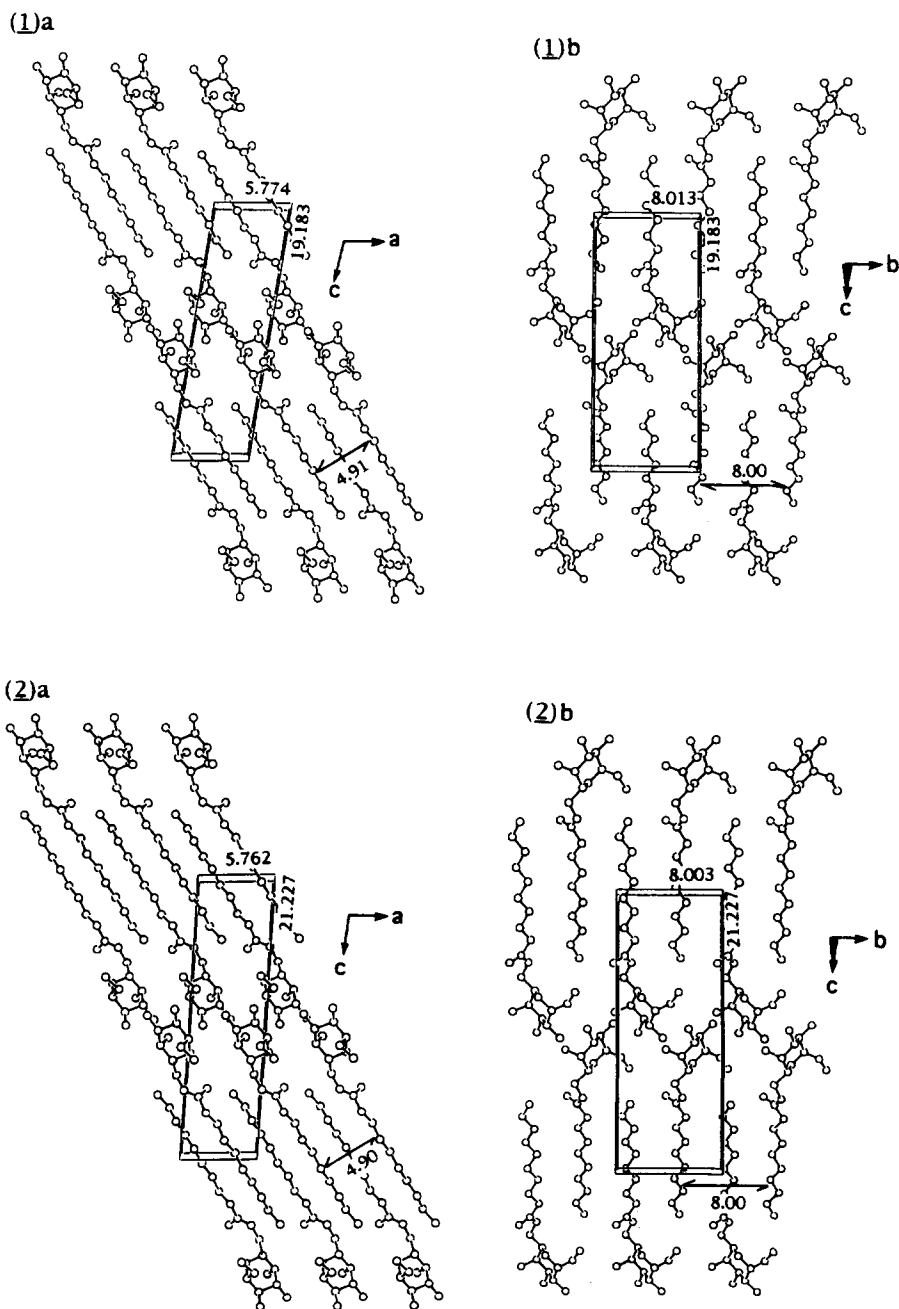


Fig. 2. Crystal structures of 1 and 2, viewed along (a) the *b* and (b) the *a* axes.

To construct an interdigitated structure, the area occupied by the sugar moiety should be twice as large as that of the cross-section of the alkyl chain. However, the cross-sectional area of two alkyl chains, which is estimated on a plane normal to the alkyl chain

Table 2
Atomic coordinate and equivalent thermal parameters of 1 and 2

Molecule	Atom	x/a	y/b	z/c	U_{eq}^a
1	C-1	0.962(1)	0.7967(7)	0.4167(3)	3.9(2)
	C-2	1.144(1)	0.7399(8)	0.4782(3)	3.4(2)
	C-3	1.368(1)	0.6852(7)	0.4518(3)	3.4(2)
	C-4	1.317(1)	0.5540(8)	0.3954(3)	3.7(2)
	C-5	1.130(1)	0.6226(8)	0.3366(3)	4.4(2)
	C-6	1.059(2)	0.491(1)	0.2805(4)	6.1(3)
	C-7	0.857(2)	1.027(1)	0.3428(4)	7.3(3)
	C-8	0.726(2)	0.504(3)	0.1945(7)	10.0(4)
	C-9	0.599(2)	0.603(1)	0.1323(6)	14.2(6)
	C-10	0.436(2)	0.502(1)	0.0841(5)	10.8(5)
	C-11	0.310(2)	0.600(1)	0.0213(5)	12.1(6)
	C-12	0.163(3)	0.493(1)	−0.0312(6)	13.4(6)
	C-13	0.013(2)	0.586(1)	−0.0897(5)	12.2(6)
	C-14	−0.109(3)	0.469(1)	−0.1443(7)	21(1)
	C-15	−0.279(2)	0.549(2)	−0.2007(5)	12.7(6)
	O-1	1.0392(8)	0.9450(5)	0.3895(2)	4.8(2)
	O-2	1.1870(7)	0.8687(5)	0.5305(2)	3.7(1)
	O-3	1.5326(7)	0.6240(5)	0.5080(2)	3.9(1)
	O-4	1.2382(7)	0.3990(5)	0.4224(2)	3.8(1)
	O-5	0.9228(7)	0.6677(5)	0.3655(2)	4.2(1)
	O-6	0.921(1)	0.5706(8)	0.2210(3)	8.5(2)
	O-7	0.642(2)	0.393(2)	0.2251(6)	25.3(8)
2	C-1	0.017(1)	0.854(1)	0.5735(4)	4.6(3)
	C-2	−0.150(1)	0.797(1)	0.5198(4)	3.7(2)
	C-3	−0.381(1)	0.7417(9)	0.5434(4)	3.9(2)
	C-4	−0.347(1)	0.613(1)	0.5945(4)	4.2(2)
	C-5	−0.175(7)	0.681(1)	0.6463(4)	4.7(3)
	C-6	−0.119(1)	0.550(1)	0.6976(4)	6.8(4)
	C-7	0.107(1)	1.082(12)	0.6413(5)	8.3(4)
	C-8	0.189(2)	0.565(2)	0.7749(7)	11.1(6)
	C-9	0.299(3)	0.663(1)	0.8301(7)	14.1(7)
	C-10	0.460(2)	0.564(1)	0.8724(6)	11.9(6)
	C-11	0.560(3)	0.661(1)	0.9293(6)	12.6(7)
	C-12	0.710(3)	0.559(1)	0.9751(7)	13.9(7)
	C-13	0.826(3)	0.660(1)	1.0307(6)	12.3(7)
	C-14	0.957(4)	0.553(1)	1.0785(7)	14.9(9)
	C-15	1.090(3)	0.646(1)	1.1305(5)	12.9(7)
	C-16	1.192(4)	0.528(1)	1.1797(7)	22(1)
	C-17	1.358(3)	0.608(2)	1.2277(6)	14.2(8)
	O-1	−0.070(1)	1.0026(6)	0.5992(3)	5.4(2)
	O-2	−0.1794(8)	0.9251(6)	0.4729(2)	4.0(2)
	O-3	−0.5310(9)	0.6815(7)	0.4932(3)	4.4(2)
	O-4	−0.2581(9)	0.4546(6)	0.5698(3)	4.5(2)
	O-5	0.0422(9)	0.7232(6)	0.6216(3)	4.6(2)
	O-6	0.022(12)	0.6261(9)	0.7513(3)	9.4(3)
	O-7	0.9723(6)	0.1424(10)	0.1895(3)	27(1)

^a $U_{eq} = \sum_i \sum_j U_{ij} a_i^* a_j^* a_i a_j$.

Table 3
Intermolecular O–O distances less than 3.2 Å

O–O	Distance (Å)	
	1	2
O-2–O-3 (A)	2.776(6) <i>a</i> ^a	2.771(7) <i>c</i>
O-3–O-4 (B)	2.805(6) <i>a</i>	2.796(7) <i>c</i>
O-4–O-2 (C)	2.750(6) <i>b</i>	2.747(7) <i>d</i>

^a The symmetry coordinates are represented by the following; *a*: $(-x+3, 1/2+y, -z+1)$; *b*: $(-x+2, -1/2+y, -z+1)$; *c*: $(-x-1, 1/2+y, -z+1)$; *d*: $(-x, -1/2+y, -z+1)$.

(39.2, 39.2, 39.0, 38.4, 35.2 and 35.3 Å² in 1, 2, 3, 4, 5 and 6, respectively), is smaller than the corresponding area of the sugar residue. This difference is compensated by the inclination of the alkyl chains to increase the occupied area.

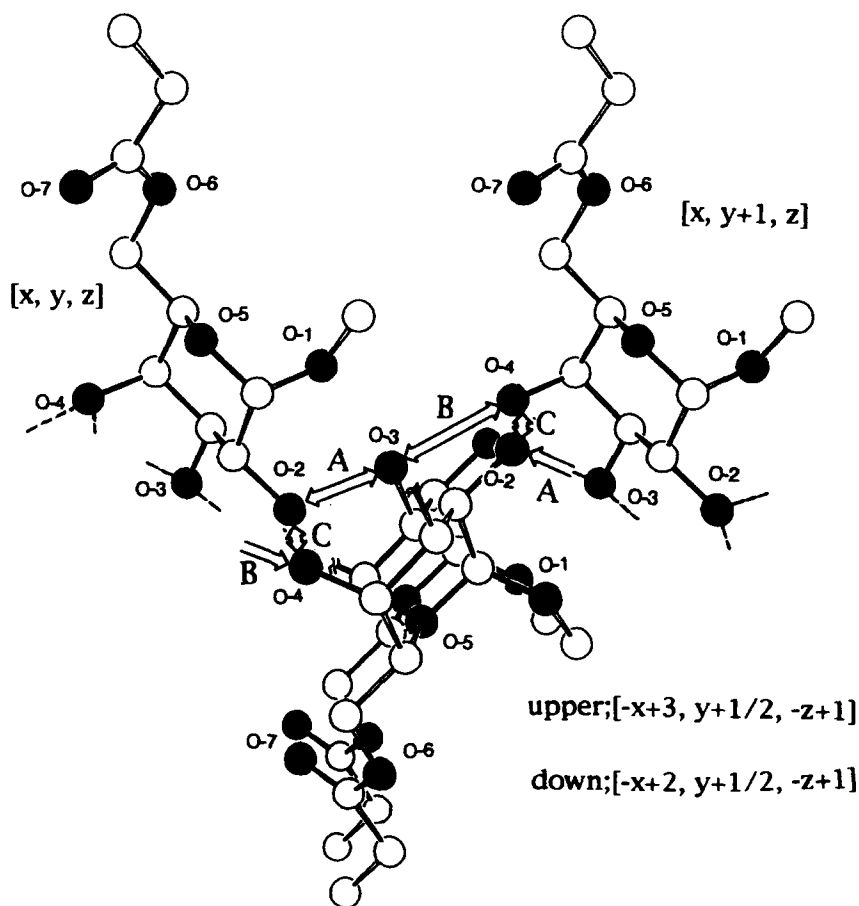


Fig. 3. Hydrogen bonds formed between the sugar moieties viewed along the *b* axis. Bands represent the linear hydrogen bond chain, O-2–(A)–O-3–(B)–O-4–(C)–O-2.

The alkyl chains lie parallel to each other in **5** [7] and **6** [8], but adjacent perpendicularly in **3** and **4** [11]. The alkyl chains in **5** and **6** occupy a slightly smaller cross-sectional area than those of **1**, **2**, **3** and **4** (19.6, 19.6, 19.5, 19.3, 17.6 and 17.6 Å² for **1**, **2**, **3**, **4**, **5** and **6**, respectively).

Hydrogen bonds are observed only between layers (Table 3). Similar hydrogen bonds are formed in **3** and **4** [11], while in **5** [7] and **6** [8] hydrogen bonds are formed not only between the layers but also within the layers. These intermolecular hydrogen bonds form an infinite linear hydrogen bond chain, –O–2–O–3–O–4–O–2– (Fig. 3), which contributes to the stability of the bilayer structure. In contrast, only a finite hydrogen bond chain, –O–4–O–3–O–2–O–5, was observed in the structures of **3** and **4** [11]. The infinite hydrogen bond chain is energetically more favorable than the finite chain [17]. Bene et al. [18] reported that each hydrogen bond energy estimated by ab initio MO calculations was increased by the amount of water in sequentially bonded H₂O polymers.

The crystals of α -galactoside derivatives are more stable than those of β -glucoside for heating. The mps which transform directly from crystal to isotropic phase are 140, 139, 88 and 91°C for **1**, **2**, **3** and **4**, respectively. The arrangement of sugar moiety which has different hydrogen bonding state is more important to stabilize the crystals of the α -galactoside derivative than their alkyl chain, since the mps of those are affected by the type of sugar, not by the increasing alkyl chain length by which the mp was decreased.

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