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The solvent-free thermal dehydration of hexitols on zeolites☆

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Dedicated to Professor Zygfryd Smiatacz on the occasion of the jubilee of his scientific career.

Abstract

Dehydration of galactitol, D-glucitol and D-mannitol at high temperature in the presence of molecular sieves without solvent under an argon atmosphere is described. Cyclodehydration products with retention or inversion of the configuration at asymmetric carbon atoms, were observed. Reaction of galactitol yielded racemic 1,4-anhydrogalactitol in a first step and then racemic 1,4:3,6-dianhydroiditol. Complete analytical separations of exhaustively *O*-acetylated reaction products were achieved by GC and structures were assigned using co-injection with standards.

Keywords: Hexitols; Galactitol, D-Glucitol; D-Mannitol; Thermal dehydration; Zeolites; Molecular sieves

1. Introduction

Alditols, monoanhydroalditols, dianhydroalditols and their derivatives are commonly prepared from carbohydrates.[2–5] Alditol cyclodehydration is the most usual method for anhydroalditol syntheses. This approach requires treatment with strong mineral acids (sulfuric acid,[6–8] hydrochloric acid[9,10]), hydrogen fluoride in the presence of catalytic amounts of formic or acetic acid,[11] or ion-exchange resins.[6,12] For example, the reaction of pentitols with concentrated hydrochloric acid in a sealed ampoule affords cyclic products with retained or inverted configuration of C-2 or C-4 as well as chlorodeoxy and dichlorodideoxy derivatives of pentitols and anhydropentitols.[9] Heating of hexitols in a 5% aqueous sulfuric acid solution[13] affords 1,4-, 3,6-, 1,5-, 2,6- and 1,6-anhydrohexitols with retained configuration as well as 2,5-anhydrohexitols with inverted configuration at C-2 or C-5. 1,5:2,6-, 1,4:2,6-, 1,5:3,6- and 1,4:3,6-Dianhydrohexitols were also observed. More than a century has elapsed since Fauconnier[14] in 1884 described 1,4:3,6-dianhydro-D-mannitol as the first member of the last above mentioned group of dianhydroalditols. Since then, a flood of experimental work—nearly one thousand[5]—appeared in the chemical literature as a result of intensive investigations on all possible isomers of 1,4;3,6-dianhydroalditols and their derivatives. According to molecular models, 1,4:3,6-dianhydrohexitols have two nearly planar 3,4-fused five-membered rings in a 'V' configuration. Because of the C_2 symmetry of 1,4:3,6-dianhydro-D- or -L-iditol, its ^{1}H NMR and ^{13}C NMR spectra[15,16] are simpler compared with less symmetrical anhydroalditols.

Extending our recent studies,[1] we now describe a zeolites catalyzed solvent-free thermal dehydration of galactitol, D-glucitol and D-mannitol under an argon atmosphere.

☆ Part 2 in the series: Thermal dehydration of polyhydroxy alcohols. For Part 1, see Ref. 1.

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Table 1
GC Retention times and relative percentages [a] of compounds **1a**–**8a** in the exhaustively *O*-acetylated mixture formed after heating of galactitol in the presence of 3 Å zeolites (1:0.4, w/w) at different temperature and time

Compound	RT (min)	260 °C	270 °C	280 °C	290 °C			
		2 h	2 h	2 h	1 h	2 h	4 h	6 h
1a	20.98	72.8	48.2	9.5	7.8	1.3	1.0	-
2a	17.25	23.7	42.4	68.2	68.1	57.0	54.8	47.6
3a	12.62	–	–	0.8	1.0	5.3	5.1	9.3
4a	17.05	0.8	2.0	3.2	3.4	2.2	1.8	0.6
5a	17.19	1.2	2.3	5.1	5.2	5.6	5.6	3.8
6a	11.07	–	–	0.3	0.4	1.7	2.4	5.0
7a	11.33	–	–	1.8	2.0	15.9	15.7	27.1
8a	18.90	1.4	3.5	6.4	6.8	6.5	6.0	5.7

[a] Concentrations were calculated from GC peak areas.

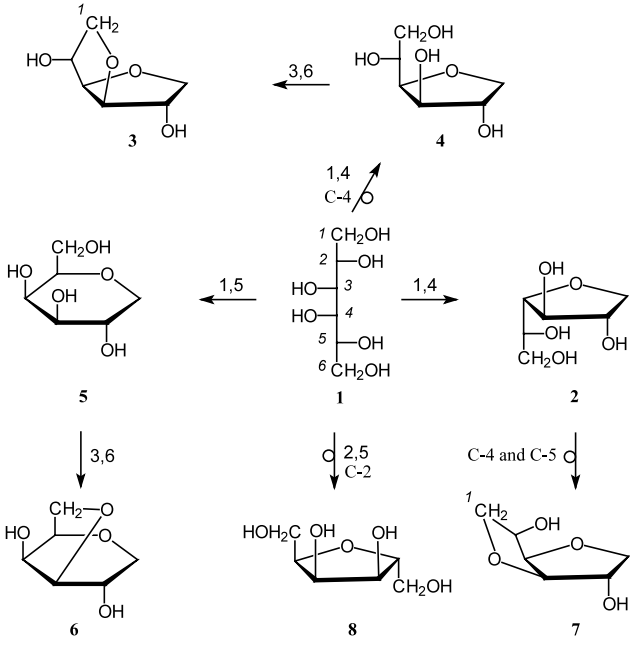
2. Results and discussion

Dehydration of galactitol (**1**) in the presence of 3 Å zeolites requires a temperature above 260 °C. Brief heating (1 h) at 290 °C or longer heating at 280 °C lead to 1,4-anhydro-D,L-galactitol (**2**) as the main product which after purification by column chromatography and recrystallization from 1,4-dioxane, was obtained in 40% yield. Its physical properties were in good agreement with literature data.[17] Longer time heating of galactitol at 290 °C (4–6 h) gave, apart from **2**, 1,4:3,6-dianhydro-D,L-glucitol (**3**), 1,4-anhydro-D,L-glucitol (**4**) and 1,5-anhydro-D,L-galactitol (**5**) which were characterized by GC analysis as their exhaustively *O*-acetylated derivatives. GC–MS analysis with CI and EI ionization techniques allowed identification of three additional compounds in the acetylated mixture, 2,4-di-*O*-acetyl-1,5:3,6-dianhydro-D,L-galactitol[18] (**6a**[†]) [*m*/*z* 43 (100%); *m*/*z* 69 (40%), *m*/*z* 102 (20%); *m*/*z* 110 (15%) and *m*/*z* 170 (10%)], 2,5-di-*O*-acetyl-1,4:3,6-dianhydro-D,L-iditol (**7a**) [*m*/*z* 43 (100%); *m*/*z* 69 (40%); *m*/*z* 110 (55%); *m*/*z* 127 (15%) and *m*/*z* 170 (5%) identical with an authentic sample] and 1,3,4,6-tetra-*O*-acetyl-2,5-anhydro-D-altritol[19] (**8a**) [*m*/*z* 43 (100%); *m*/*z* 97 (30%); *m*/*z* 110 (40%); *m*/*z* 139 (35%); *m*/*z* 152 (20%) and *m*/*z* 259 (15%)]. Their concentrations were determined from GC peak areas of their per-*O*-acetylated derivatives and are presented in Table 1.

Based on these results, we propose the mechanism in Scheme 1 for the formation of the products obtained after dehydration of galactitol in the presence of 3 Å zeolites (Scheme 1).

In a first step of the reaction, three monoanhydrohexitols **2**, **4** and **5** are formed. They subsequently undergo dehydration into dianhydrohexitols **3**, **6** and **7**. Due to the unfavorable arrangement of appropriate hydroxyl groups, compound **8** cannot form a dianhydrohexitol and its concentration in the used conditions remains constant (Table 1).

Formation of dianhydrohexitols from galactitol is not described in the literature. Of interest is the formation of **7** during heating of galactitol. 1,4:3,6-Dianhydro-D- and -L-iditol are well known as dehydration products of D- or L-iditol in acidic aqueous solution.[20] Because galactitol is cheaper than D- or L-iditol, it was of interest to find conditions for obtaining 1,4:3,6-dianhydro-D,L-iditol on a preparative scale. Prolongation of the reaction time was not productive and we decided to use additional amounts of zeolites. The results are presented in Table 2.



Scheme 1. Dehydration pathways for galactitol (**1**).

[†] Letter 'a' refers to per-*O*-acetylated derivatives.

Table 2
Composition of exhaustively *O*-acetylated mixture formed after dehydration of galactitol for 4 h at 290 °C with various amounts of 3 Å zeolites (galactitol: zeolites, w/w)

Compound	Concentration (%) of products [a]		
	0.4:1	1:1	5:3
1a	1.0	–	-
2a	54.8	12.4	10.5
3a	5.1	21.1	21.0
4a	1.8	Trace	Trace
5a	5.6	0.8	0.4
6a	2.4	9.1	9.1
7a	15.7	46.1	49.6
8a	6.0	1.4	1.3

[a] Concentrations were calculated from GC peak areas.

Table 3
Crystal data and structure refinement for compound **7a**

Empirical formula	$C_{10}H_{16}O_6$
Formula weight	232.21
Temperature (K)	293(2)
Wavelength (Å)	0.71073
Crystal system	monoclinic
Space group	$C2/c$
Unit cell dimensions	
a (Å)	16.911(4)
b (Å)	5.327(1)
c (Å)	13.132(3)
β (°)	117.06(2)
Volume (Å^3)	1053.5(4)
Z	4
D_{calcd} (M gm^{-3})	1.451
Absorption coefficient (mm^{-1})	0.121
$F(000)$	488
Crystal size (mm)	$0.15 \times 0.3 \times 0.4$
Θ Range for data collection (°)	2.71-30.08
Limiting indices	$-21 \le h \le 21$, $0 \le k \le 7$, $0 \le l \le 17$
Reflections collected/unique	1530/1502 [$R_{int} = 0.0193$]
Completeness to $\theta = 30.08$	96.6%
Refinement method	Full-matrix least-squares on F^2
Data/restraints/parameters	1502/0/73
Goodness-of-fit on F^2	1.015
Final R indices [$I > 2\sigma(I)$]	$R_1 = 0.0402$, $wR_2 = 0.1167$
R indices (all data)	$R_1 = 0.0642$, $wR_2 = 0.1027$
Largest diff. peak and hole (e Å^{-3})	0.324 and −0.210

Although **7** was obtained in almost 50% yield, we were not able to isolate it from the reaction mixture, due to contamination with 1,4;3,6-dianhydro-D,L-glucitol (**3**). To avoid this interference, we decided to prepare **7** in two steps. We obtained pure 1,4-anhydro-D,L-galactitol (**2**) first, which was used as a substrate for further dehydration to obtain **7**. Dehydration of **2** in the presence of 3 Å zeolites resulted in three products **3**, **6** and **7**. The main product **7** (racemic mixture) was isolated in 37% yield from the reaction mixture by column chromatography. Its ^{1}H and ^{13}C NMR spectra indicated a high symmetry (C_2 axis). Lack of coupling between H-2 and H-3 indicate their respective trans orientation. The structure of **7** was unambiguously proven by X-ray analysis as its per-*O*-acetyl derivative (**7a**, racemate, Table 3, Fig. 1).

The formation of **7** from **2** requires inversion of configuration at C-4 and C-5 atoms. A possible mechanism for this reaction (starting from the D-enantiomer) is presented in Scheme 2.

We assume the formation of unsaturated derivatives during the reaction with generation of four diastereoisomers, i.e. 1,4-anhydro-D-glucitol, -L-iditol, -D-galactitol and -L-talitol. The first two of them are transformed into **3** and **7**, respectively, and the two other cannot undergo the 3,6-cyclodehydration due to steric reasons. The expected 1,4-anhydro-D-talitol was not found in the reaction mixture.

Among the products of D-glucitol (**9**) dehydration, 1,4:3,6-dianhydro-D-glucitol (**3**), 1,4-, 3,6-, 1,5-, 2,6-anhydro-D-glucitols (**4**, **10**, **11**, **13**) and 2,5-anhydrohexitols (**12** and **14**) with inverted configuration at C-2 or C-5 were identified (Scheme 3) and quantified (Table 4).

Compounds **3** and **4** were isolated from the post-reaction mixture by HPLC as their per-*O*-acetyl derivatives and their identification was based on their NMR spectra and physical properties which were in accordance with literature data.[15] Coupling constants $J_{2,3}$ 0.0 Hz, $J_{3,4}$ 4.4 Hz and $J_{4,5}$ 5.0 Hz confirm the gluco configuration of compound **3**. The large difference in coupling constant $J_{4,5}$ for compounds **3** and **4** (5.0 and

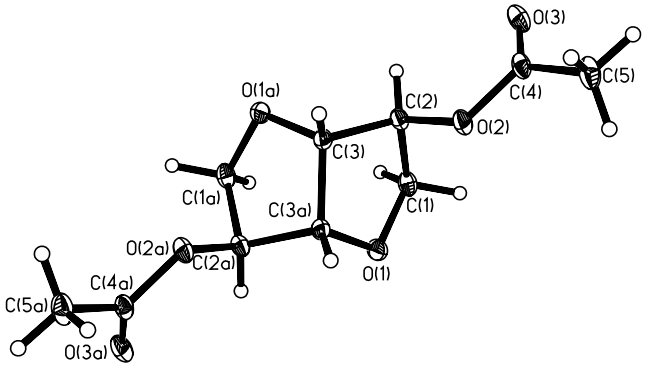
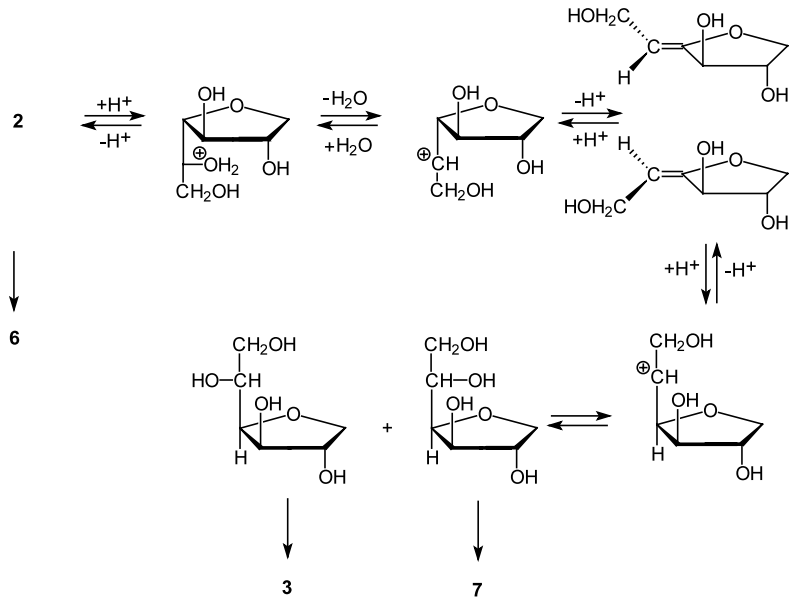


Fig. 1. ORTEP III® drawing of **7a** showing 50% probability displacement for ellipsoids.



Scheme 2. A possible dehydration mechanism of 1,4-anhydrogalactitol leading to 1,4:3,6-dianhydroiditol (**7**) (1,4-anhydro-D-galactitol was taken as an example).

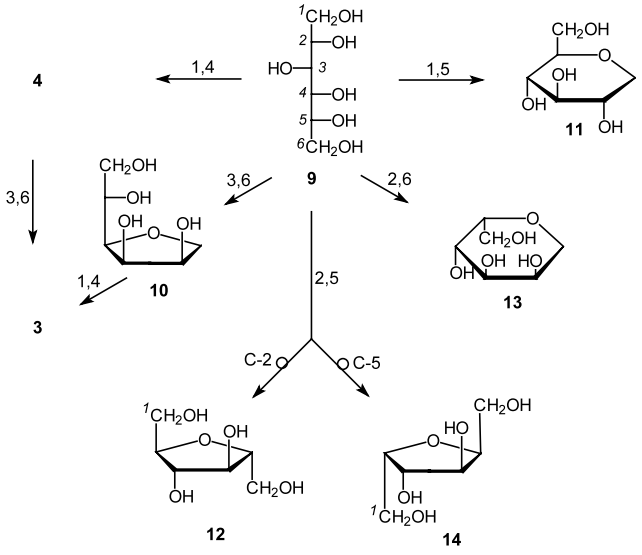
9.2 Hz) can be explained by the presence of the second ring in **3** which stiffens its structure. The rest of the components of the mixture after dehydration of D-glucitol in the presence of zeolites were identified by GC analyses and co-injection with authentic compounds. Additional GC–MS analyses of exhaustively *O*-acetylated derivatives with CI and EI techniques allowed identification of 2,6-andydro-D-glucitol as 1,3,4,6-tetra-*O*-acetate (**13a**) [major ions: *m*/*z* 170 (100%), *m*/*z* 97 (70%), *m*/*z* 110 (40%), *m*/*z* 115 (40%) identical with the fragmentation of per-*O*-acetyl-1,5-anhydro-D-glucitol] and 1,2,4,5-tetra-*O*-acetyl-3,6-anhydro-D-glucitol (**10a**) [major ions: *m*/*z* 84 (100%), *m*/*z* 115 (100%), *m*/*z* 110 (70%), *m*/*z* 187 (50%) identical with the fragmentation of per-*O*-acetyl-1,4-anhydro-D-glucitol]. Dehydration of **9** at 260–280 °C leads to the formation of a complex mixture. Heating at 290 °C for 2 h lead **3** as the major product. This compound was isolated from the mixture by column chromatography in 45% yield. Compound **3** is the final product and **4** and **10** are by-products which are transformed into **3** when the mixture is heated for longer time. At temperature above 290 °C dehydration is very fast but the sample undergoes decomposition.

Dehydration of D-mannitol (**15**) leads to the formation of a five-component mixture (Scheme 4).

These were separated and quantified by HPLC (Table 5) and identified by NMR analyses. Additionally, all compounds were identified by co-injection with authentic compounds in GC as their *O*-acetylated derivatives.

Because of symmetry of the 1,4:3,6-dianhydro-D-mannitol molecule (**16**) (C_2 axis), the ^{1}H and ^{13}C NMR spectra are simplified. A coupling constant $J_{2,3}$ 5,6 Hz indicates the cis configuration of H-2 and H-3. All NMR data, except $J_{3,4}$ are in good accordance with the literature.[15] For the same reason, protons H-3 and H-4 are chemically and magnetically equivalent and coupling is not observed.

The structure of 1,5-anhydro-D-mannitol (**18**) was determined based on its NMR spectra. Large coupling constants $J_{3,4}$ and $J_{4,5}$ (10 Hz) indicate their trans orientation, respectively. Thus, small coupling constant $J_{2,3}$ 3.4 Hz indicates an equatorial position of H-2. All these data confirm the *manno* configuration and a conformation $^4C_1$ for **18**.

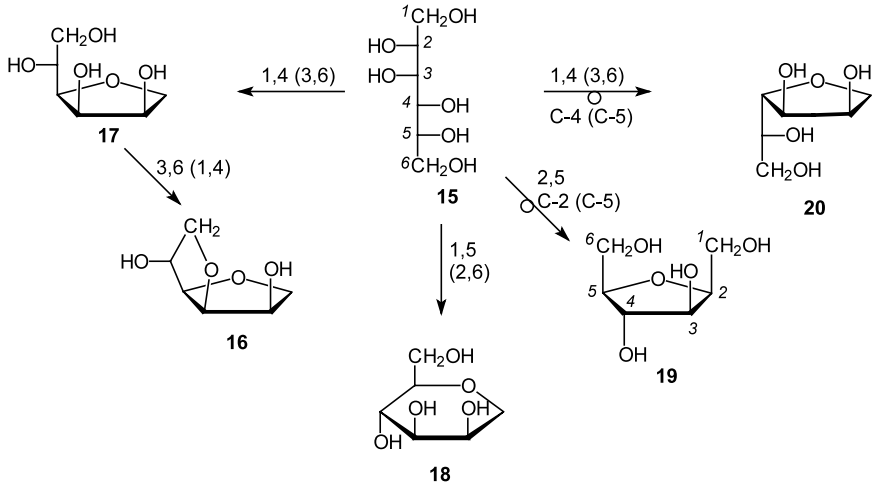


Scheme 3. Major products formed after dehydration of D-glucitol (**9**).

Table 4
GC Retention times and relative percentages [a] of compounds **3a**, **4a**, **9a**–**14a** in the exhaustively *O*-acetylated mixture after heating of D-glucitol in the presence of 3 Å zeolites at different temperatures and times

Compound	RT (min)	260 °C	270 °C	280 °C			290 °C			300 °C
		2 h	2 h	1 h	2 h	3 h	1 h	2 h	3 h	1 h
3a	12.62	4.6	28.6	4.4	37.8	50.1	48.2	72.0	80.7	54.8
10a	16.88	2.5	5.6	-	5.0	5.4	6.7	3.4	1.7	5.5
4a	17.05	8.0	15.6	2.0	13.1	11.6	11.7	3.5	0.8	7.4
11a	17.61	2.0	4.5	5.9	4.5	4.7	6.3	4.6	3.4	6.0
12a	18.31	0.7	2.2	0.7	2.9	2.1	2.5	3.2	3.6	3.3
13a	18.52	0.6	1.6	0.5	1.4	1.4	1.7	1.5	1.4	1.4
14a	18.84	2.3	6.0	2.4	5.1	5.4	7.6	5.1	3.0	6.9
9a	22.40	68.9	20.4	74.8	15.6	11.5	1.9	–	–	1.9

[a] Concentrations were calculated from GC peak areas.



Scheme 4. Major products formed after dehydration of D-mannitol (**15**).

Table 5
GC Retention times and relative percentages [a] of compounds **15a**–**20a** in the exhaustively *O*-acetylated mixture after heating of D-mannitol in the presence of 3 Å zeolites at different temperatures and times

Compound	RT (min)	260 °C	270 °C	280 °C	290 °C			
		2 h	2 h	2 h	1 h	2 h	4 h	6 h
16a	12.70	1.1	3.8	11.1	11.1	20.1	28.7	Decomposition
17a	17.72	1.2	5.9	6.0	6.5	4.0	2.2	
18a	17.83	0.6	6.0	9.9	10.0	11.4	11.2	
19a	18.10	1.7	18.8	34.3	34.1	41.2	42.0	
20a	18.76	0.8	7.2	11.7	13.6	14.3	13.6	
15a	20.56	89.6	57.6	27.0	20.8	4.1	–	

[a] Concentrations were calculated from GC peak areas.

The structure of 2,5-anhydroglucitol (**19**) was based on the following coupling constants: $J_{2,3}$ 3.9 Hz (cis), $J_{3,4}$ 1.5 Hz (trans) and $J_{4,5}$ 3.4 Hz (cis). A large NOE effect for protons H-4 and H-6 indicates that they are on the same ring side. Similar NOE effects for H-2 and H-5, and H-3 and H-5, respectively, indicate that they are placed on the opposite side of the ring to H-4.

NOE values for protons H-2, H-3 and H-5 in 1,4-anhydro-D-talitol (**20**) indicate that they are placed on the same side of the ring and this was confirmed by irradiation of H-5.

Because of the symmetry of D-mannitol, its dehydration results in a smaller number of products than D-glucitol. 1,4- or 3,6-Cyclization leads to **16** whereas 1,5- and 2,6-cyclization yield **18**. 2,5-Anhydro ring formation with change of configuration at C-2 or C-5 gives the same product—2,5-anhydro-D-glucitol (**19**), which is the major product in all reaction conditions. 1,5-Anhydro-D-mannitol (**18**) with the six-memberd ring is formed in much less concentration. The smallest concentration of 1,4-anhydro-D-mannitol (**17**) could be a result of its fast transformation into the dianhydro compound **16**. Compound **20** is not able to undergo further dehydration due to unfavourable disposition of the appropriate hydroxyl groups.

3. Experimental

General methods.—Commercial galactitol (Aldrich Chemical Co) and molecular sieves type 3 Å (Polish Chemical Co, Gliwice) were used. All reactions were conducted under normal pressure of dry argon. Wood's alloy as a heating medium was used. Molecular sieves type 3 Å were desiccated before use at 250 °C for 5 h. Evaporation was performed under reduced pressure. All reactions were monitored by thin-layer chromatography (TLC) on Kieselgel 60 F_{254} Silica Gel plates (E. Merck, 0.20 mm thickness). The spots were detected by spraying with 5% ethanolic H_2SO_4 and charring. Column chromatography was carried out with Kieselgel 60 Silica Gel (E. Merck, smaller than 200 mesh). GC separation of per-*O*-acetylated derivatives of all compounds was carried out using a VEGA 6180 (Carlo Erba) Gas Chromatograph equipped with DB 23 fused silica capillary column (60 m × 0.258 mm I.D.) and flame ionization detector (FID). Hydrogen was used as a carrier gas. The running conditions were: initial temperature 140 °C, increase 4 °C/min. to 160 °C, 6 °C/min to 200 °C, 8 °C/min to 240 °C, final hold 10 min, detector temperature 260 °C.

All crystallographic measurements were carried out on a KM-4 diffractometer with graphite monochromated Mo Kα radiation, and $\theta/2\theta$ scans. The unit cell parameters were determined from least squares refinement based on the setting angles of 80 reflections. The stability of conditions was controlled by three control measurements every 200 reflections. The structures were solved by direct methods using the SHELXS (1990) program[21] from the SHELX-97 package[22] (Sheldrick, 1997). Anisotropic displacement coefficients were applied to all non-hydrogen atoms, and hydrogen atoms were refined without any constraints with individual isotropic temperature factors. Structure refinement was performed using the SHELXL program. A summary of crystallographic data, data collection and structure refinement are presented in Table 3. A view of **7** is presented in Fig. 1.[23,24] ^1H and ^{13}C NMR spectra were recorded at 25 °C with a Varian Mercury spectrometer at 400 and 100 MHz, respectively, with Me_4Si as internal standard. Assignments were based on homonuclear decoupling experiments, and homo- and heteronuclear correlation. Optical rotations were measured with a JASCO J-20 polarimeter. Elementary analyses were made with a Carlo Erba apparatus.

Dehydration of galactitol.—Galactitol (1.05 g) and type 3 Å molecular sieves (0.5 g) were placed in a quartz apparatus, which was purged with argon for 30 min. Then, the reaction mixtures were heated under an argon atmosphere, respectively, at 260, 270 or 280 °C for 2 h and at 290 °C for 4 h or at 290 °C for 1, 2, 4 or 6 h. After cooling to rt, the crude reaction mixtures were dissolved in hot MeOH, and TLC analyses were made in 3:2:1 Et_2O–$CHCl_3$–MeOH. A small portion of each product mixture was concentrated under a nitrogen stream to a thick syrup and exhaustively *O*-acetylated with Ac_2O in the presence of a catalytic amounts of anhyd NaOAc during 1 h at 100 °C, after which the per-*O*-acetylated products were analysed by GC and GC–MS. The results are reported in Table 1.

Dehydration of D-*glucitol.*—D-Glucitol (1.0 g) and type 3 Å molecular sieves (0.4 g) were placed in a quartz apparatus, which was purged with argon for 30 min. Then the reaction mixtures were heated under an argon atmosphere at 260, 270 °C for 2 h, at 280 °C and at 290 °C for 1, 2 or 3 h or at 300 °C for 1 h. After cooling to rt the crude post-reaction mixtures were dissolved in hot MeOH, and TLC analyses were made in 3:2:1 Et_2O–$CHCl_3$–MeOH. A small portion of each product mixture was concentrated under a nitrogen stream to a thick syrup and exhaustively *O*-acetylated with Ac_2O in the presence of catalytic amounts of anhyd NaOAc over 1 h at 100 °C, after which the per-*O*-acetylated products were analyzed by GC and HPLC.

Dehydration of D-*mannitol.*—D-Mannitol (1.4 g) and type 3 Å molecular sieves (0.6 g) were placed in a quartz apparatus, which was purged with argon for 30 min. Then the reaction mixtures were heated under an argon atmosphere at 260, 270 and 280 °C for 2 h, at 290 °C for 1, 2, 4 or 6 h. After cooling to rt, the crude post-reaction mixtures were dissolved in hot MeOH, and TLC analyses were made in a solvent mixture of 3:2:1 Et_2O–$CHCl_3$–MeOH. A small portion of each product mixture was concentrated under a nitrogen stream to a thick syrup and exhaustively *O*-acetylated with Ac_2O in the presence of catalytic amounts of anhyd NaOAc over 1 h at 100 °C, after which the per-*O*-acetylated products were analyzed by GC and HPLC.

1,4-Anhydro-D,L-*galactitol* (**2**).—Galactitol (9.71 g) and molecular sieves 3 Å (3.89 g) were heated under an argon atmosphere at 290 °C for 1 h. After cooling, the reaction mixture was dissolved in MeOH and purified with charcoal. After separation by column chromatography (3:2:1, EtOAc–$CHCl_3$–MeOH) the syrupy product was crystallized from 1,4-dioxane; 3.052 g (40%), mp 58–62 °C, $[\alpha]_D$ 0° (*c* 0.78, H_2O); ^{1}H NMR (D_2O): δ 4.26 (m, 1 H, $J_{2,3}$ 2.8 Hz, H-2); δ 4.15 (dd, 1 H, H-3); δ 4.02 (dd, 1 H, $J_{1,1'}$ 10 Hz, $J_{1,2}$ 2.8 Hz, H-1); δ 3.86 (m, 2 H, $J_{5,6}$ 7.2 Hz, $J_{5,6'}$ 4.6 Hz, H-1′ and H-5); δ 3.77 (dd, 1 H, $J_{4,5}$ 4.6 Hz, H-4); δ 3.73 (dd, 1 H, $J_{6,6'}$ 11.4 Hz, H-6); δ 3.65 (dd, 1 H, H-6′). ^{13}C NMR (D_2O): δ 85.75, C-4; δ 79.23, C-3; δ 77.84, C-2; δ 73.70, C-1; δ 72.32, C-5; δ 63.87, C-6. Anal. Calcd for $C_6H_{12}O_5$: C, 43.90; H, 7.31. Found: C, 43.82; H, 7.47.

1,4:3,6-Dianhydro-D-*glucitol* (**10**).—Glucitol (1.02 g) and molecular sieves 3 Å (0.42 g) were heated under an argon atmosphere at 290 °C for 1 h. After cooling, the reaction mixture was dissolved in MeOH and purified with charcoal. The product, after separation by column chromatography (3:2:1, Et_2O–$CHCl_3$–MeOH), was crystalline (0.356 g, 45%), mp 60–63 °C, $[\alpha]_D$ +44.8 ° (*c* 0.78, H_2O), ^{1}H NMR ($CDCl_3$) of per-*O*-acetyl derivative: δ 3.80 (1 H, dd, $J_{5,6}$ 5.4 Hz, H-6), δ 3.95 (1 H, dd, $J_{5,6'}$ 6.2 Hz, $J_{6,6'}$ 9.4 Hz, H-6), δ 4.00 (2 H, m, H-1, H-1′), δ 4.49 (1 H, d, $J_{3,4}$ 4.4 Hz, H-3), δ 4.83 (1 H, dd, $J_{4,5}$ 5.0 Hz, H-4), δ 5.19 (1 H, m, $J_{2,3}$ 0.0, H-2); ^{13}C NMR ($CDCl_3$): δ 70.42 C-6, δ 73.69 C-1, δ 74.15 C-5, δ 78.28 C-2, δ 80.93 C-4, δ 86.09 C-3.

Dehydration of 1,4-anhydro-D,L-*galactitol*.—1,4-Anhydro-D,L-galactitol and type 3 Å molecular sieves were placed in a quartz apparatus, which was purged with argon for 30 min. Then the reaction mixture was heated under an argon atmosphere at 290 °C for 4 h. After cooling to rt, the crude reaction mixture was dissolved in hot MeOH, and TLC analysis was made in 3:2:1 Et_2O–$CHCl_3$–MeOH. A small portion of the product mixture was concentrated under a nitrogen stream to a thick syrup and exhaustively *O*-acetylated with Ac_2O in the presence of catalytic amounts of anhyd NaOAc over 1 h at 100 °C, the per-*O*-acetylated products were then analyzed by GC and GC–MS. The results are reported in Table 2.

1,4:3,6-Dianhydro-D,L-*iditol* (**7**).—1,4-Anhydro-D,L-galactitol (4.110 g) and molecular sieves 3 Å (4.090 g) were heated under an argon atmosphere at 290 °C for 4 h. After cooling, the reaction mixture was dissolved in MeOH and purified with charcoal. After separation by column chromatography (3:2:1, Et_2O: $CHCl_3$: MeOH) the title compound was obtained as a solid oil (1.38 g 37%); mp 73–77 °C, ^{1}H NMR (D_2O): δ 4.65 (s, 2 H, H-3, H-4); δ 4.36 (d, 2 H, H-2, H-5); δ 3.90 (d, 2 H, $J_{1,1'}$ 10.4 Hz, H-1, H-6); δ 3.84 (dd, 2 H, $J_{6,6'}$ 10.4 Hz, H-1′, H-6′); ^{13}C NMR (D_2O): δ 87.55 (2 C, C-3, C-4); 75.86 (2 C, C-2, C-5); δ 74.92 (2 C, C-1, C-6). Anal. Calcd for $C_6H_{10}O_4$: C, 49.3; H, 6.85. Found: C, 49.48; H, 6.87.

2,5-Di-O-*acetyl-1,4:3,6-dianhydro*-D,L-*iditol* (**7a**).—1,4:3,6-Dianhydro-D,L-iditol (0.18 g) was dissolved in a mixture of pyridine (2 mL) and acetic anhydride (0.8 mL) and left at rt for 24 h. The mixture was poured into ice water and extracted with $CHCl_3$ chloroform. The organic layer was washed with water and dried with $MgSO_4$. After concentration, the residue was crystallized from EtOH yielding **7a** (0.20 g, 70%); mp 69–71 °C, ^{1}H NMR ($CDCl_3$): δ 5.04 (dd, 2 H, H-2, H-5); δ 4.53 (s, 2 H, H-3, H-4); δ 4.00 (dd, 2 H, $J_{1,1'}$ 11.2 Hz, $J_{1,2}$ 1.6 Hz, $J_{1',2}$ 3.8 Hz, H-1, H-6; δ 3.58 (dd, 2 H, H-1′, H-6′); δ 2.08 (s, 6 H, C**H**$_3$) ^{13}C NMR ($CDCl_3$): δ 169.88 (2 C, C = O); δ 85.62 (2 C, C-3, C-4); δ 77.86 (2 C, C-2, C-5); δ 72.81 (2 C, C-1, C-6); δ 21.23 (2 C, **C**H_3). Anal. Calcd for $C_{10}H_{14}O_6$: C, 52.17; H, 6.09. Found: C, 52.37; H, 6.19.

4. Supplementary material

Full crystallographic details, excluding structural features, have been deposited (deposition no. CCDC 174418) with the Cambridge Crystallographic Data Centre. These data may be obtained, on request, from The Director, CCDC, 12 Union Road, Cambridge, CB2 1EZ, 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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References

1. Kurszewska M.; Skorupa E.; Kasprzykowska R.; Sowiński P.; Wiśniewski A. *Carbohydr. Res.* **2000**, *326*, 241–249.
2. Wiggins L. F. *Adv. Carbohydr. Chem.* **1950**, *5*, 191–228.
3. Mills J. A. *Adv. Carbohydr. Chem.* **1955**, *10*, 1–53.
4. Soltzberg S. *Adv. Carbohydr. Chem. Biochem.* **1970**, *25*, 229–283.
5. Stoss P.; Hemmer R. *Adv. Carbohydr. Chem. Biochem.* **1991**, *49*, 93–173.
6. Klosterman H.; Smith F. *J. Am. Chem. Soc.* **1952**, *74*, 5336–5339.
7. Haines A. H.; Wells A. G. *Carbohydr. Res.* **1973**, *27*, 261–264.
8. Bock K.; Pedersen C.; Thøgersen H. *Acta Chem. Scand.* **1981**, *B35*, 441–449.
9. Wiśniewski A.; Sokołowski J.; Szafranek J. *J. Carbohydr. Chem.* **1983**, *2*, 293–304.
10. Koerner T. A. W., Jr.; Voll R. J.; Younathan E. S. *Carbohydr. Res.* **1977**, *59*, 403–416.

11. Defaye J.; Gadelle A.; Pedersen C. *Carbohydr. Res.* **1990**, *205*, 191–202.
12. Otey F. H.; Mehltretter C. L. *J. Org. Chem.* **1961**, *26*, 1673.
13. Wiśniewski A.; Skorupowa E.; Sokołowski J. *J. Carbohydr. Chem.* **1991**, *10*, 77–90.
14. Fauconnier A. *Bull. Soc. Chim. Fr.* **1884**, *41*, 119–125.
15. Hopton F. J.; Thomas G. H. S. *Can. J. Chem.* **1969**, *47*, 2395–2401.
16. Sohár P.; Medgyes G.; Kuszmann J. *Org. Magn. Res.* **1978**, *11*, 357–359.
17. Vidra I.; Simon K.; Institoris I. L.; Csoregh I.; Czugler M. *Carbohydr. Res.* **1982**, *111*, 4157.
18. Wiśniewski A.; Skorupowa E.; Sokołowski J.; Różański L.; Glód D.; Descotes G. *J. Carbohydr. Chem.* **1989**, *8*, 73–83.
19. Szafranek J.; Wiśniewski A. *J. Chromatogr.* **1978**, *161*, 213–221.
20. Wiśniewski A.; Skorupowa E.; Sokołowski J. *J. Carbohydr. Chem.* **1991**, *10*, 77–90.
21. Sheldrick G. M. *Acta Crystallogr., Sect. A* **1990**, *46*, 467–473.
22. Sheldrick, G. M. SHELXL-97. Program for the Refinement of Crystal Structures. University of Göttingen, Germany, 1997.
23. Johnson, C. K. ORTEP II. Report ORNL-5138. Oak Ridge National Laboratory, Tennessee, USA, 1976.
24. Motherwell S.; Clegg S. PLUTO-78. Program for Drawing Crystal and Molecular Structure. University of Cambridge, UK, 1978.