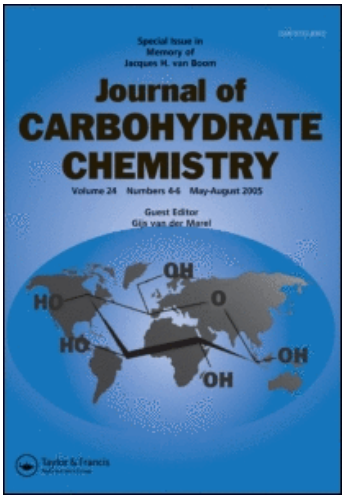

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The Isomeric Composition of D-*Xylo*-hexos-5-ulose (5-Keto-glucose) in Aqueous Solution

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THE ISOMERIC COMPOSITION OF D-*XYLO*-HEXOS-5-ULOSE (5-KETO-GLUCOSE) IN AQUEOUS SOLUTION[1]

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ABSTRACT

1,2-*O*-Isopropylidene-α-D-*xylo*-hexofuranos-5-ulose (**2**) was deprotected in aqueous acid solution to give a mixture of at least six isomeric forms and one anhydro form of the parent ketoaldohexose, D-*xylo*-hexos-5-ulose (**3**), commonly referred to as 5-keto-glucose. Structural assignment of each form was made based on high field ^{1}H and ^{13}C NMR studies of the mixture in aqueous (D_2O) solution. The dominant isomeric form of **3** was observed to have the pyranose structure *1R,5R*-D-*xylo*-hexopyranos-5-ulose (**3a**, 67 %) with the next most abundant form being an anhydro structure, *1S,5S*-1,6-anhydro-D-*xylo*-hexopyranos-5-ulose (**3c**, 18 %). Included among the other isomers were the α and β-1,4-furanose (**3d**, **3e**) and 1-aldehydrol β-5,2-furanose (**3f**) structures. The isomer present in least amount (**3g**, < 1 %) is assigned as the α-anomer of **3f**. Experimentally determined $J_{C\text{-}1,H\text{-}1}$ values were useful in support of assigned isomer structures.

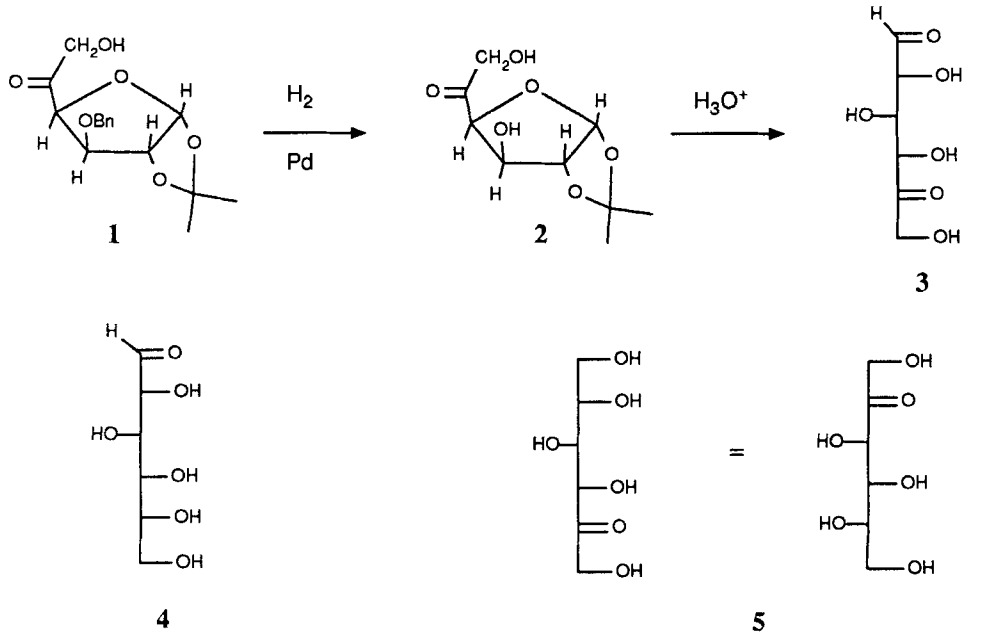
INTRODUCTION

The introduction of a keto carbonyl function into an aldohexose structure generates a ketoaldohexose, a simple sugar with two potential anomeric carbons. Consequently, aqueous (D_2O) solution high field ^{1}H and ^{13}C NMR spectra of such dicarbonyl sugars contain many more signals than do the spectra of the parent aldo- or ketohexoses. In studying the chemistry of dicarbonyl sugars, we have given particular attention to the chemistry of 5-ketoaldohexoses and some of their derivatives, and evaluated the isomeric composition of such molecules using NMR techniques.[3,4] A report from this laboratory also describes the isomeric composition of a related ketoaldohexose, "3-keto-glucose".[5]

The results presented here are from a detailed NMR study of the isomeric composition of D-*xylo*-hexos-5-ulose (**3**) in aqueous solution (D_2O). A forthcoming report will describe the results from employing the same NMR techniques to a study of the isomeric composition of D-*lyxo*-hexos-5-ulose (5-keto-mannose),[1,6] also in aqueous solution. The value of both 5-keto-glucose and 5-keto-mannose for synthetic purposes was recently demonstrated by Reitz and Baxter who used these sugars as precursors for the synthesis of biologically interesting deoxynojirimycins,[7,8] hydroxylated piperidines that serve as inhibitors of glycohydrolases. Syntheses of 1-deoxynojirimycin[7] and 1-deoxymannono-jirimycin[8] from 5-keto-glucose and 5-keto-mannose, respectively, were described by these workers. A novel synthesis and limited isomeric composition study (NMR) of structurally related L-*arabino*-hexos-5-ulose (5-keto-galactose)[9] were recently reported by Berti and coworkers.[10,11]

RESULTS AND DISCUSSION

1,2-*O*-Isopropylidene-α-D-*xylo*-hexofuranos-5-ulose (**2**), prepared from the 3-*O*-benzyl precursor (**1**) according to a literature procedure,[12] was deprotected in aqueous solution using H^+ form cation exchange resin as the acid catalyst. The water was removed from the solution by freeze-drying and the amorphous residue was dissolved in D_2O for NMR analysis.



Chemical shift and coupling constant assignments for the isomeric forms of **3** were based on data obtained from ^1H NMR spectra of **3** recorded at 400 or 360 MHz (**FIG. 1**), ^{13}C NMR spectra at 90.55 MHz (**FIG. 2**), a phase sensitive COSY plot and a ^{13}C-^1H correlated spectral plot.

In evaluating both the ^1H and ^{13}C NMR spectra of the mixture of isomeric forms of **3**, D-glucose (**4**) and L-sorbose (**5**), respectively, were considered to be appropriate aldohexose and ketohexose NMR models for **3**.

Isomers 3a and 3b - The isomeric compositions of D-glucose and L-sorbose in aqueous solutions (D_2O) as determined from ^1H NMR[13-15] and ^{13}C NMR[14,16-18] studies, are both dominated by pyranose ring structures: at 31 °C D-glucose α-P (38 %) and β-P (62 %, $^4C_1$ conformation);[13a] at 27 °C L-sorbose α-P (98 %, $^2C_5$ conformation) with α-F as a minor component.[17] Thus, one would anticipate comparable pyranose ring domination of the isomeric composition of 5-keto-glucose. At least seven anomeric proton signals are observed in the 5.0 to 6.0 ppm region of the ^1H NMR spectrum of isomeric **3** in D_2O (**FIG. 1**). Spectral data from **3** is presented in the **Table**. The dominant H-1 signal at 5.01 ppm (67 %) is a doublet with $J_{1,2}$ = 8.18 Hz (**Table**), clearly indicating an axial *H-1* corresponding to a β-(*R*)-configuration at *C-1* (isomer **3a**, **FIG. 3**) when compared to D-glucose. *H-2*, *H-3* and *H-4* of this form are also axial as seen from the correspondingly large vicinal coupling constants $J_{2,3}$ = 9.25 Hz and $J_{3,4}$ = 9.70 Hz. The ^{13}C NMR chemical shifts for *C-1* through *C-6* (**FIG. 2**) are in concert with a pyranose ring using β-D-glucopyranose ($^4C_1$) and α-L-sorbopyranose ($^2C_5$) as model ring forms. A comparison of ^{13}C NMR chemical shift values (ppm) for *C-1* - *C-3* of **3a** to *C-1* - *C-3* of β-D-GluP and for *C-4* - *C-6* of **3a** to *C-1* - *C-3* of α-L-SorP is as follows:

	C-1	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*
3a	92.96	75.67	73.49	71.51	98.44	64.8
β-D-GluP[16]	96.7	75.1	76.7			
α-L-SorP[17]				*C-3*	*C-2*	*C-1*
				71.4	98.5	64.5

There is very good chemical shift correlation between *C-4*, *C-5* and *C-6* of **3a** with the corresponding carbons of L-sorbose indicating that the *C-5* OH of **3a** is axial and that the conformation of the ring around the *C-5* carbon is dictated by the presence of the bulky hydroxymethyl group. In contrast, there is a notable difference between the chemical shifts (*ca.* 3.7 ppm) of *C-1* β-D-GluP (96.7 ppm) and *C-1* of **3a** (92.96 ppm) suggesting that the combined steric bulk of the substituents at *C-5* in **3a** restricts conformational flexibility in this isomer and slightly distorts the ring around *C-1* as

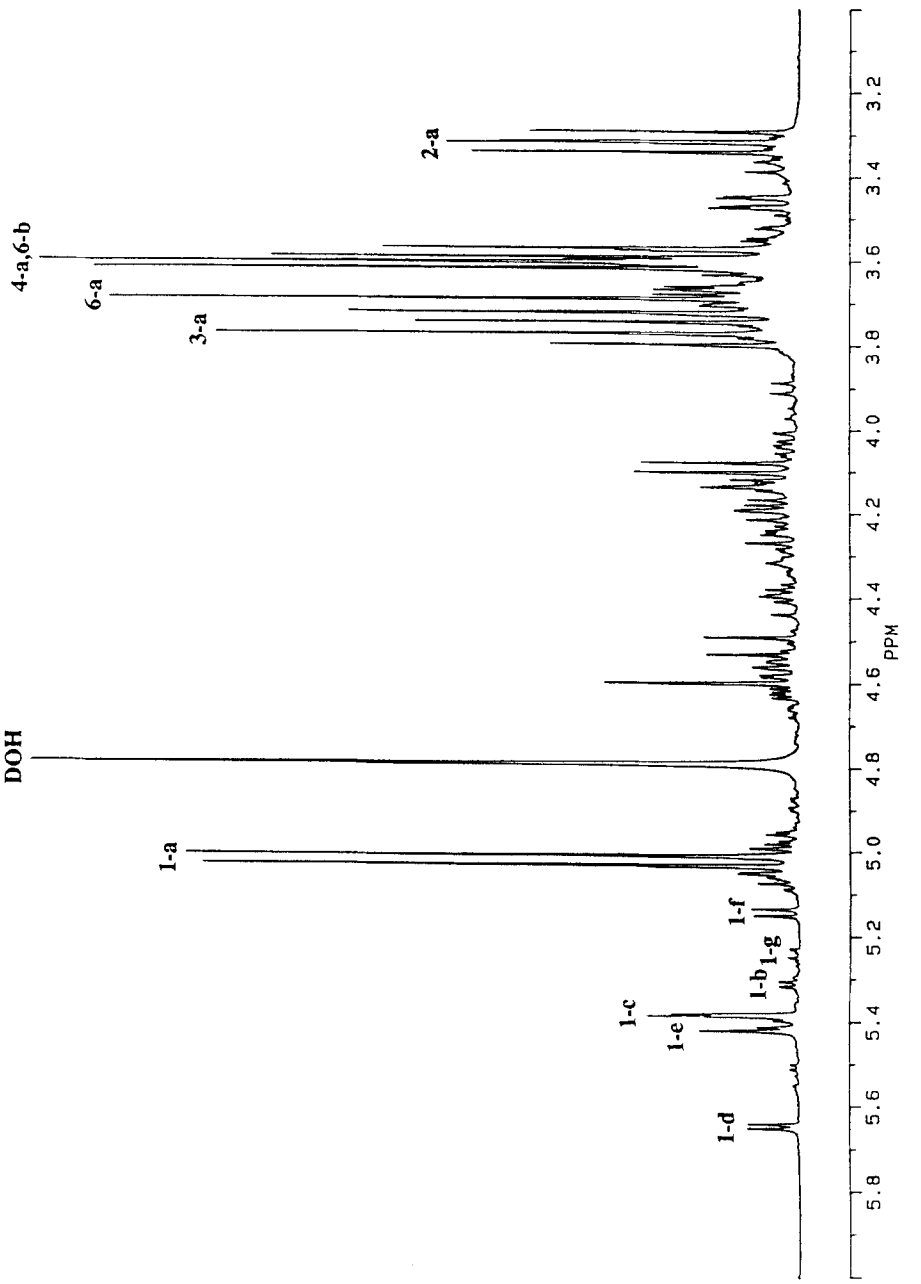


FIG. 1. Full ^{1}H NMR spectrum of **3** in D_2O at 360 MHz. Select protons (numbers) and isomers (letters) are shown.

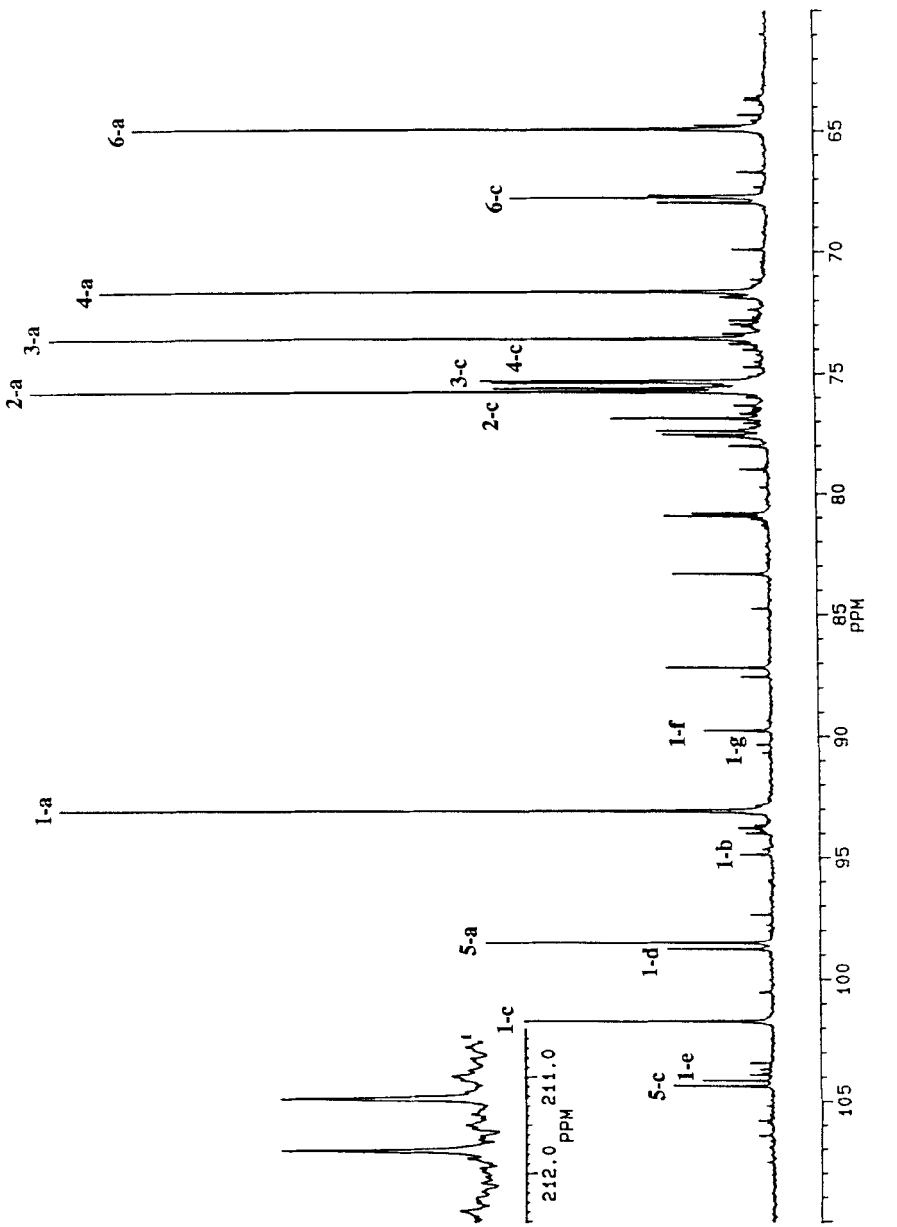
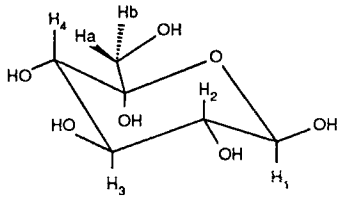


FIG. 2. Fully decoupled ^{13}C NMR spectrum of **3** in D_2O at 90.5 MHz. Select assigned carbons (numbers) and isomers (letters) are shown.

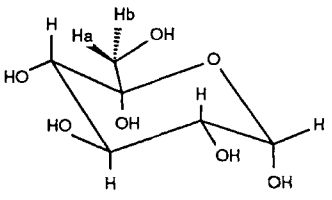
Table . Isomeric composition and NMR data from D-*xylo*-hexos-5-ulose in D_2O

		^{1}H NMR DATA (δ and J)						^{13}C NMR DATA (δ)						
Isomer	%	*H*-1	*H*-2	*H*-3	*H*-4	*H*-6a	*H*-6b	*C*-1	*C*-2	*C*-3	*C*-4	*C*-5	*C*-6	JC_1-H_1
3a	67	5.01	3.30	3.76	3.59	3.69	3.57	92.96	75.67	73.49	71.51	98.44[a]	64.80	164.4
		(8.18)	(9.25)	(9.70)		(11.8)								
3b	2	5.30	3.60					94.78	71.78					170.3
		(4.03)												
3c	18	5.37	3.61	3.60	3.70	3.41	4.07	101.63	75.56	75.33	75.25	104.32[a]	67.73	177.2
		(1.82)	(7.51)	(8.0)		H-6ex	H-6en							
					$J_{4,6ex}$ = 1.95									
3d	5	5.64	4.12	4.61	5.03	4.59	4.59	98.72	80.75	77.49	77.49	211.13[b]	67.94	172.3
		(3.66)	(2.81)	(5.13)		(broad s)					(C_4-H_4 153.57)			
		$J_{1,3}$ = 0.37												
3e	3	5.41	4.18	4.54	4.98	4.54	4.46	104.30	83.82		87.16	211.73[b]		174.3
		(0.31)	(1.34)	(5.13)		(19.2)					(C_4-H_4 149.6)			
		$J_{1,3}$ = 0.61	$J_{2,4}$ = 0.73											
3f	4	5.13	4.10	4.38	4.16			89.63						166.4
		(5.74)	(5.49)	(4.64)										
3g	1	5.23						90.26						166.4
		(7.20)												

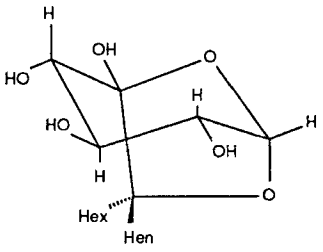
a. Quaternary carbons
b. These values may be interchanged



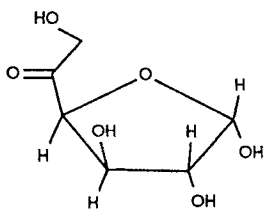
3a (67 %)



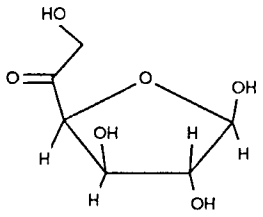
3b (2 %)



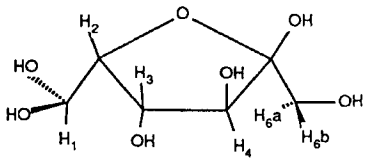
3c (18 %)



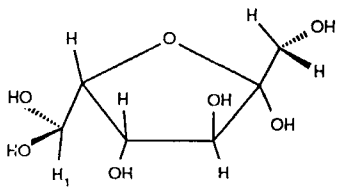
3d (5 %)



3e (3 %)



3f (4 %)



3g (1 %)

FIG. 3. Isomeric forms of **3** in deuterium oxide solution.

compared to the β-D-GluP ring. By comparison, when the *C-5* equatorial substituent is a less bulky methyl group (in 6-deoxy-5-keto glucose)[4] the difference in chemical shift between the latter ketoaldohexose and β-D-GluP is small (0.51 ppm). The presence of **3a** (*1R,5R*-D-*xylo*-hexopyranos-5-ulose) as the principal isomeric form of **3** has also been noted by Reitz and Baxter.[7]

The observed chemical shift differences between **3a** and β-D-GluP at *C-1*, *C-2* and *C-3* are also a reflection of the shielding effect of the axial hydroxyl group at *C-5* on these other carbons. An axial hydroxyl group on a pyranose or cyclitol ring carbon causes shielding of that carbon (α effect) and the β and γ carbons if they bear an axial hydrogen.[19-23] However, the chemical shift at the δ carbon is not significantly changed. Shielding of the α, β and γ carbons ranges from approximately 2.5 to 4.5 ppm.

Structure **3a** can be viewed as β-D-GluP substituted at *C-5* with an axial hydroxyl group. The presence of this group on **3a** shifts *C-3* (compared to the *C-3* of β-D-GluP) by -3.2 ppm (upfield, γ_1 effect), *C-1* by -3.7 ppm (γ_2 effect) and *C-2* by +0.57 ppm (δ effect). Relative to **3a**, the γ and δ effects from the *C-1* hydroxyl group of α-D-GluP (compared to β-D-GluP) are γ_1 (*C-3*) -2.9, γ_2 (*C-5*) -4.5 and δ (*C-4*) 0.0 ppm, respectively. The similarity of these effects from **3a** and α-D-GluP additionally supports assigning the *C-5* hydroxyl group of **3a** as axial. Interestingly, the greater γ effect from both **3a** and α-D-GluP is by way of the ring oxygen.

Myo-inositol provides a cyclitol model for the shifts observed with **3a**. Angyal and Odier compared ring carbon chemical shifts for 2,4,6/3,5-cylohexanepentol (a deoxyinositol) with those from the single axial hydroxyl substituted inositol, *myo*-inositol.[23] The γ effect at *C-4* and *C-6* of *myo*-inositol, from the *C-2* axial hydroxyl group, is -4.3 ppm; the δ effect at *C-5* is only +0.4 ppm. These values are also very close to those resulting from the influence of the *C-5* hydroxyl on **3a**.

The isomeric composition of **3** is dominated by the pyranose structure **3a** (67 %), whereas with 6-deoxy-5-keto-glucose the aldofuranose structures are the principal isomeric forms (64 %).[4] The presence of the electron withdrawing hydroxyl group at *C-6* of 5-keto-glucose makes the *C-5* carbonyl carbon more electrophilic than the *C-5* of 6-deoxy-5-keto-glucose and consequently more reactive to hemiacetal formation.

The *C-1* anomer **3b** is found in small amount (2 %) and the *C-1* equatorial proton signal (5.30 ppm) is downfield, as expected, to the *C-1* axial proton of **3a**. The $J_{1,2}$ coupling constant for **3b** (4.03 Hz) is in line with that of the α-D-GluP value ($J_{1,2}$ = 3.6 Hz).[14] The *C-1* chemical shift from **3b** (94.8 ppm) is downfield (deshielded) 1.9 ppm to that of the *C-1* on α-D-GluP (92.9 ppm).[14] Isomer **3b** has a *syn*-diaxial O/O relationship between the *C-5* and *C-1* hydroxyl groups. A similar *syn*-diaxial O/O relationship (*C-2* & *C-4*) occurs in *epi*-inositol. The presence of the *C-2, C-4 syn*-diaxial hydroxyl groups on *epi*-inositol results in deshielding of the *C-2* and *C-4* carbons (2.3 ppm) relative to the single hydroxyl bearing carbon (*C-2*) of *myo*-inositol. The deshielding at *C-1* of **3b** and *epi*-inositol is in keeping with the observation that *syn*-diaxial hydroxyl groups cause the carbons which bear them to appear further downfield than other carbons with axial hydroxyl groups.[23]

Isomer 3c - The most interesting and the second most abundant isomer in the mixture (18 %) was determined to be the bicyclic anhydro form *1S,5S*-1,6-anhydro-D-*xylo*-hexopyranos-5-ulose. An appropriate structural and NMR model for **3c** is 1,6-anhydro-β-L-idopyranose (**6a**). Like **3c**, compound **6a** is held in a rigid 6,8-dioxa-bicyclo[3.2.1.]octane structure with *C-2* to *C-4* equatorial hydroxyl groups. ^{1}H NMR data for **6a** (as the β-D-isomer) have been reported with D_2O[24] and DMSO-d_6[25] as solvent, and for the tri-*O*-acetyl derivative (**6b**) in $CDCl_3$.[25] The ^{13}C NMR spectrum of **6a** recorded in D_2O has also been reported.[16,22,26] A comparison of spectral data from **3c, 6a** and **6b** is given below.

	H-1	*H-2*	*H-3*	*H-4*	*H-6*$_{en}$	*H-6*$_{ex}$
3c	5.37	3.61	3.60	3.70	4.07	3.41
J(Hz)	1.8	7.5	8.0			
6a[24]	5.25	3.42	3.40	3.69	3.98	3.66
J(Hz)	1.9					
	1.5[25]	7.9	7.9			
6b[25]	1.7	8.2	8.8			

	C-1	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*
3c	101.6	75.56	75.33	76.25	104.32	67.73
6a[16]	101.9	74.7	74.7	71.4	75.8 65.4	

The ^{1}H and ^{13}C chemical shifts and corresponding vicinal proton couplings for *H-1* to *H-3* and *C-1* to *C-3* for **3c** and **6a** compare favorably. However, the *C-4* signal of **3c** is at a significantly lower field than *C-4* of **6a**, due to the influence of the anomeric *C-5* carbon. *C-5* of isomer **3c** is a quaternary carbon and has a chemical shift (104.32 ppm) typical of a pyranulose anomeric carbon. The anhydro *ido* compounds **6a**, **6b** and isomer **3c** all show small couplings (1.5 - 1.9 Hz) between H_{eq}-*1*, H_{ax}-*2* and large (7.9 - 8.8 Hz) between all *axial H-2, H-3* and *H-3, H-4* pairs, indicating *axial/equatorial* proton relationships.

Heyns and Meyer[24] recorded the ^{1}H NMR spectra of all eight 1,6-anhydro-β-D-hexopyranoses and observed no more than 0.2 ppm difference in the chemical shifts of the *H-6*$_{ex}$ signals. A similar observation was made by Budesinsky et al.[25] This proton is located on the top side of the bicyclic ring system and is not sensitive to change in configuration at the other ring carbons. Heyns and Meyer also observed that the H-6$_{ex}$ proton is generally at a higher field than the H-6$_{en}$ proton. In keeping with these observations, for **3c** we have assigned H_{ex} to 3.41 and H_{en} to 4.07 ppm, respectively.

Differentiation between the *H-6$_{ex}$* and *H-6$_{en}$* signals of **3c** is further supported by long range (^{4}J) coupling between *H-4* and the signal assigned to *H-6$_{ex}$*; $J_{4,6ex}$ = 1.95 Hz (**Table**). Examination of a molecular model of the rigid isomer **3c** clearly shows a planar zig-zag or "W" arrangement of *H6$_{ex}$-C6-C5-C4-H4*, an arrangement, which when observed in fully saturated systems, gives rise to effective ^{4}J coupling.[27] This structural arrangement of *H-4, H-6$_{ex}$* protons is also found in four (*galacto-, gulo-, talo- and ido-*) 1,6-anhydro-β-D-hexopyranoses as reported by Budesinsky and coworkers,[25] with these latter anhydro sugars also displaying *H-4, H-6$_{ex}$* coupling (0.8 - 1.2 Hz). Zero coupling was observed for *H-4, H-6$_{en}$* systems and for *H-4, H-6$_{ex}$* systems with an inverted stereochemistry at *C-4*.[25]

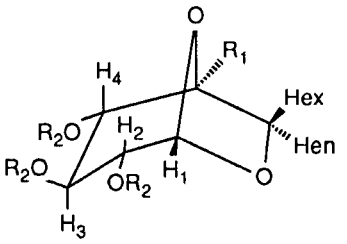
Isomers 3d and 3e - The presence of aldofuranose isomers **3d** (5 %) and **3e** (3 %) was evident from the two most deshielded anomeric signals; a doublet $J_{1,2}$ = 3.66 Hz at δ 5.64 (H-1) for 1,2-*cis*-anomer **3d** and a doublet $J_{1,2}$ = 0.31 Hz at δ 5.41 (H-1) for the 1,2-*trans* anomer **3e**. These assignments correlate well with those from the corresponding protons of the 6-deoxy-D-*xylo*-hexofuranos-5-ulose isomers **7a** and **7b**.[4] It was interesting to note that even the difference in *H-1* chemical shifts for each set of isomers (Δδ) was the same (0.09 ppm).

	3d	**7a**	**3e**	**7b**
δ (*H-1*)	5.64	5.55	5.41	5.32
$J_{1,2}$ (Hz)	3.66	3.66	0.31	0.55
Δδ	**3d** - **3e** = 0.09 ppm		**7a** - **7b** = 0.09 ppm	
δ (*C-1*)	98.72	98.31	104.30	103.95

Good proton chemical shift correlation was also found between the *H-2* to *H-4* ring protons of **3d** and **3e** (**Table**) and those of the corresponding 6-deoxy isomers **7a** and **7b**.[4] Furthermore, as shown above, the *C-1* chemical shift values of the 6-deoxy compounds **7a** and **7b** were very close to those of **3d** and **3e**, respectively.

The ^{13}C NMR spectrum of the isomeric mixture of **3** contained only two carbonyl carbon signals (211.13 and 211.73 ppm). These signals are assigned to *C-5* of the isomers **3d** and **3e**, although the assignments may be reversed. For all four of the aldofuranose rings **3d**, **3e**, **7a** and **7b**, the *C-5* free carbonyl chemical shifts fall into a narrow range, 211.06 - 211.73 ppm.

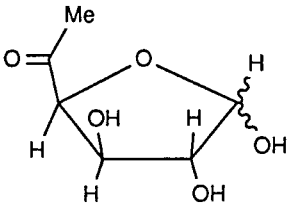
Isomers 3f and 3g - Based upon ^{13}C NMR studies it has been shown that for L-sorbose, the α-L-pyranose ring form is the principal isomer (≈ 98 %) in D_2O at room temperature whereas the next most abundant isomer (≈ 2 %) is the α-L-furanose form.[13,17,18] Therefore, one might expect to find some evidence for a ketofuranose



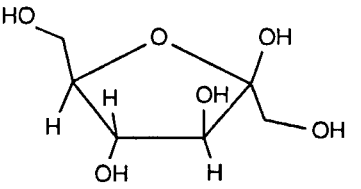
3c R_1 = OH R_2 = H

6a R_1 = H, R_2 = H

6b R_1 = H, R_2 = Ac



7a, α anomer; **7b**, β anomer



8

tautomer of **3** analogous to α-L-sorbofuranose. We have assigned to the isomer labelled **3f**, the ketofuranose structure *2R,5R*-D-*xylo*-hexo-5,2-furanos-5-ulose 1-hydrate.

A ^{13}C NMR signal at 89.63 ppm has been assigned to the hydrated aldehyde (aldehydrol) *C-1* of this isomer. The ^{13}C chemical shifts of several reported hydrated aldoses have comparable values:[14] D,L-erythrose (90.8 ppm), D,L-threose (91.1 ppm) and D,L-glyceraldehyde (91.2 ppm). The *H-1* chemical shift of **3f** (5.12 ppm) also falls within the range observed for aldehydrol *C-H* protons from a number of small saccharides (4.92-5.14 ppm).[28] These same ranges of ^1H NMR and ^{13}C NMR chemical shift and coupling constant values were found for exocyclic aldehydrol groups of the ketofuranose forms of D-*erythro*- and D-*threo*-pentos-2-uloses.[29]

While data from ^1H NMR studies is available from model compounds for isomers **3a - 3e** as described above, detailed ^1H NMR spectral data from α-L-sorbofuranose (a good model for **3f**) is lacking, presumably because this tautomer is present in such small amount in aqueous solution. However, based upon the relatively high chemical shift values from protons *H-2*, *H-3* and *H-4* of isomer **3f**, it is likely that these protons are bonded to furanose ring carbons. (See **Table** for comparison to pyranose isomers **3a - 3c** and furanose isomers **3d - 3e**.)

Although β-D-fructofuranose (**8**) is not a direct model for **3f**, a comparison of its structure and ^1H NMR data[30,31] with that of **3f** is instructive. The *C-1* branch of **3f** is *cis*

to the vicinal *C-3* OH group which presumably would make this ring a little more strained than the ring of **8** with its *C-6* branch *trans* to the vicinal OH group at *C-4*. The difference in ring conformation and ring energy might be reflected in larger chemical shift values for *H-3* and *H-4* of **3f** compared to *H-4* and *H-3* of **8**. Indeed, a modest increase in *H-3* (4.38 ppm), *H-4* (4.16 ppm) chemical shift values for isomer **3f** was observed compared to *H-4* (4.08), *H-3* (4.08 ppm) from β-D-fructofuranose (**8**).[31] However, a significant difference was noted between $J_{3,4}$ (4.64 Hz) for **3f** and $J_{4,3}$ (8.1 Hz) for **8**.[31]

Although the NMR data from isomer **3g** (≈ 1 %) are very limited, the *H-1*, *C-1* chemical shift and JC_1-H_1 values from **3g** compare favorably with those from **3f** (**Table**); 5.23 and 5.13 ppm, 90.26 and 89.63 ppm, and 166.4 and 166.4 Hz, respectively. Consequently we have assigned **3g** as the *2R,5S*-isomer of **3f**. The smaller amount of **3g** (≈ 1 %) compared to **3f** (4 %) results from the added steric strain between the *C-2* hydroxymethyl and the vicinal *C-3* hydroxyl group of **3g**.

A quaternary carbon signal at 90.61 ppm in the spectrum of **3** still remains unassigned. We can only speculate at this time that this signal is from an acyclic, hydrated aldehyde, isomeric form of **3**.

^{13}C-1, ^{1}H-1 Coupling - In the Table are listed the experimentally determined $J_{C1\text{-}H1}$ values for isomers **3a - 3g**. The magnitude of such couplings has found use in distinguishing pyranose C_1-H_{1ax} from C_1-H_{1eq} bonds. Typically ^{1}J values for C_1-H_{eq} bonds are approximately 170 Hz while ^{1}J C_1-H_{ax} values are lower and on the order of 160 Hz.[32] In contrast, ^{1}J values for *C-1, H-1* coupling of α and β-methyl aldohexofuranosides (172.0 - 175.0 Hz) and methyl aldopentofuranosides (171.0 - 174.0 Hz)[33] are higher than those of the corrsponding pyranosides. The assignments $J_{C1,H1ax}$ = 164.4 Hz for **3a**, $J_{C1,H1eq}$ = 170.3 Hz for **3b** and $J_{C1,H1eq}$ = 177.2 Hz for **3c** are consistent with the above guidelines. The particularly high C_1-H_1 value for **3c** (177.2 Hz) is due to *C-1* being a bridgehead carbon for both a five and six-membered ring of the [3.2.1] bicyclic system. The C_1-H_1 values for **3d** (172.3 Hz) and **3e** (174.3 Hz) are in the range of what would be expected for simple furanose ring structures. The remaining *C-1, H-1* couplings for the hydrated aldehyde groups of **3f** and **3g** are each 166.4 Hz, a value similar to that of the conformationally most stable isomer, **3a**. It is clear from the $J_{C\text{-}1,H\text{-}1}$ values for the isomers of **3a** (**Table**) that the magnitude of the coupling is a good indicator of pyranose *C-1* configuration and helps to distinguish furanose rings (simple and bicyclic) from pyranose rings.

EXPERIMENTAL

General Procedures. All chemicals and solvents were analytical grade and were used without further purification. Melting points were determined on a Fisher-Johns

melting point apparatus and are reported uncorrected. Infrared spectra were recorded on a Beckman Acculab 1 spectrometer or on a Nicolet IR-44 spectrometer interfaced with a Dell System 200 data station. Optical rotations were measured with a Perkin-Elmer 141 instrument at ambient temperature (22 °C). The ^1H NMR spectra for all intermediates were recorded at 300 MHz using a GE widebore spectrometer (NT series) equipped with an 1180e computer and 293c pulse programmer in $CDCl_3$. Chemical shifts (δ) are reported downfield from TMS (0.00 ppm) and chemical shift assignments were confirmed by homonuclear decoupling experiments and/or using COSY experiments. The ^1H and ^{13}C NMR spectra of **3** were recorded at 27 °C with a Bruker AM spectrometer at 360.1 and 90.55 MHz, respectively, relative to internal acetone (2.07 and 28.9 ppm). ^{13}C spectra of **3** were recorded with a relaxation time of 3.0 sec and an acquisition time of 1.5 sec. ^1H-^1H connectivities were established using a phase sensitive COSY experiment and ^1H-^{13}C connectivities using a heterocuclear (XCOORRD, Bruker) correlation experiment.

3-*O*-Benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-hexofuranos-5-ulose (1). Detritylation of 3-*O*-benzyl-1,2-*O*-isopropylidene-6-*O*-(triphenylmethyl)-α-D-*xylo*-hexofuranos-5-ulose[34] was modeled after that of Kiely and Fletcher[35] to give **1**. ^1H NMR δ 7.0 - 7.6 (m, ArH, 5 H), 6.06 (d, H-1, $J_{1,2}$ = 3.6 Hz), 4.83 (d, H-4), 4.60 (d, H-2, $J_{2,3} \cong 0$ Hz), 4.55 (m, H-6a,6b, $J_{6a,6b}$ = 11.7 Hz, $J_{6a,OH} = J_{6b,OH}$ = 5.0 Hz), 4.49 (s,$PhCH_2O$, 2H), 4.3 (d, H-3, $J_{3,4}$ = 3.6 Hz), 2.96 (ψt, OH), 1,47 and 1.33 (s, CH_3, each 3H). The mp, IR spectrum and optical rotation data matched those previously reported.[35]

1,2-*O*-Isopropylidene-α-D-*xylo*-hexofuranos-5-ulose (2). Debenzylation of **1** with hydrogen in the presence of freshly generated palladium black gave **2**.[12] ^1H NMR δ 6.07 (d, H-1, $J_{1,2}$ = 3.3 Hz), 4.78 (d, H-4, $J_{2,3}$ = 3.0 Hz), 4.60 (bs, H-3), 4.55 (d, H-2, $J_{2,3} \cong 0$ Hz), 4.54 (complex, H-6a, H-6b), 2.98, 2.52 (each bs, each OH), 1.49 and 1.34 (each s, each CH_3). The mp, IR spectrum and optical rotation data matched those previously reported.[12]

D-*Xylo*-hexos-5-ulose (3). To compound **2** (70 mg) dissolved in distilled water (3 mL) was added Dowex 50W H^+ resin (1 mL) which had been prewashed with 10% HCl, distilled water and dry methanol. The mixture was warmed at 40 °C without stirring for 40 h, the resin was removed by filtration and the water from the filtrate removed by freeze-drying. The amorphous residue was prepared for high field NMR study by repeated freeze-drying from D_2O to exchange all hydroxyl protons and the sample was finally dissolved in D_2O (0.5 mL).

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