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SYNTHESES WITH ANHYDRO SUGARS

PART IX*. 1,6-ANHYDRO-2,4-DI-*O*-TOLUENE-*p*-SULPHONYL-β-D-HEXOPYRANOS-3-ULOSES AND RELATED COMPOUNDS**

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ABSTRACT

P.m.r., i.r., and u.v. spectral data establish that 1,6-anhydro-2,4-di-*O*-toluene-*p*-sulphonyl-β-D-hexopyranos-3-uloses exist in chair conformations in chloroform solution. The signals for axial protons α to the carbonyl group appear at τ values that are lower than those for the corresponding equatorial protons. The i.r. and u.v. absorption frequency of the carbonyl group of the tosylated ketones is dependent on the position of the sulphonyloxy group in a manner analogous to that for α-halogeno ketones. The c.d. spectra of these compounds do not accord with predictions based on the octant rule. The tosylated ketones in chloroform solution are isomerised by the action of 5% of pyridine.

INTRODUCTION

The 2,4-di-*O*-substituted derivatives of 1,6-anhydro-β-D-hexopyranos-3-uloses[1] have potential utility in the synthesis of deoxy, amino, and branched-chain sugars. 1,6-Anhydro-2,4-di-*O*-tosyl-β-D-*ribo*-hexopyranos-3-ulose (**1**) is isomerised by the action of pyridine at room temperature to yield the *lyxo* isomer **4**. A partial isomerisation can be effected to give a mixture containing mainly the *arabino* (**2**) and *xylo* (**3**) isomers, from which **2** was isolated. The faster isomerisation of the *ribo*-ketone **1**, in comparison with the *arabino* ketone **2**, was thought to be due to steric interaction of the 1,3-diaxial sulphonyloxy groups.

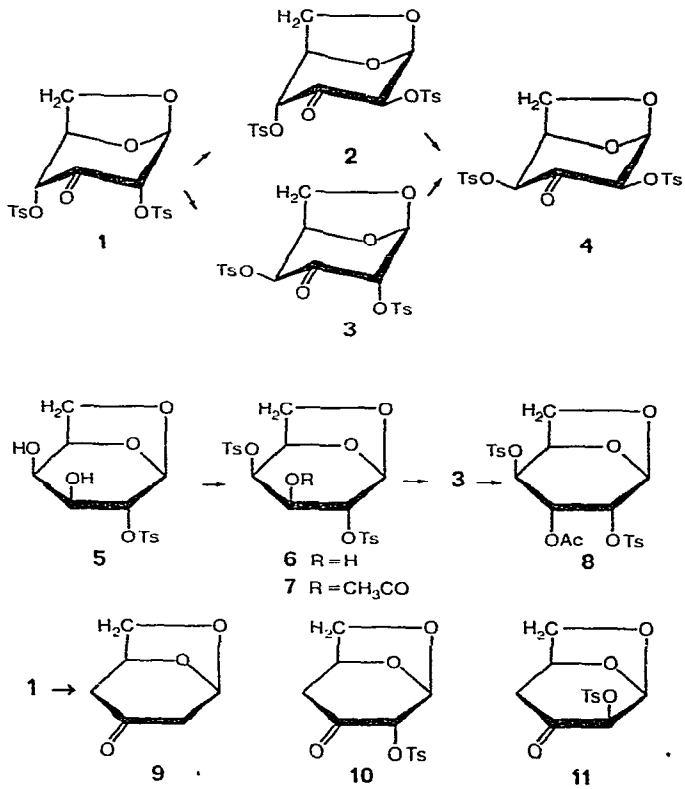
Attempted substitution of the sulphonyloxy groups in the ketones **1**–**4** with nucleophilic reagents caused isomerisation, and acetalation of the carbonyl group, and, for this reason, a detailed study of the steric situation in these compounds has been undertaken. The c.d. spectra have also been determined, in view of the discussion about the applicability of the octant rule to unsubstituted 1,6-anhydro-β-D-aldohexopyranos-2-, -3-, and -4-uloses[2].

*Part VIII: M. Černý, T. Trnka, P. Beran, and J. Pacák, *Collection Czech. Chem. Commun.*, 34 (1969) 3377.

**Dedicated to Professor F. Micheel in celebration of his 70th birthday.

RESULTS AND DISCUSSION

The series of ketones **1**, **2**, and **4** described previously[1] has been completed by the synthesis of the *xylo*-ketone **3**. Partial substitution of 1,6-anhydro-2-*O*-tosyl-β-D-galactopyranose (**5**) with toluene-*p*-sulphonyl chloride afforded the 2,4-disulphonate **6**. It is of interest to note that acetylation of 2-*O*-acetyl-1,6-anhydro-β-D-galactopyranose has been reported[3] to yield mainly the 2,3-diacetate. Oxidation of **6** with chromium trioxide in acetic acid yielded the *xylo*-ketone **3**, the structure of which was proved when isomerisation in pyridine gave the known *lyxo*-ketone **4**. Also, reduction of **6** with sodium borohydride, followed by acetylation, gave, as expected[1], 3-*O*-acetyl-1,6-anhydro-2,4-di-*O*-tosyl-β-D-gulopyranose (**8**).



A very important model compound for this study, 1,6-anhydro-2,4-dideoxy-β-D-*glycero*-hexopyranos-3-ulose (**9**) was prepared from the *ribo*-ketone **1** by reductive cleavage of the sulphonyloxy groups with Raney nickel in acetone.

P.m.r. spectra. — Table I contains the chemical shifts and coupling-constant data for the ketone sulphonates **1**–**4**. A first-order analysis of the spectra was possible. It is clear from Table I that the chemical shifts for H-1 and H-5 are practically independent of structural variation within the series **1**–**4**. The τ values for H-2a,

H-2e, H-4a, and H-4e are dependent on structure; the signals for the axial protons are shifted downfield by 0.4–0.6 p.p.m., as would be expected from the anisotropy[4] of the carbonyl group as manifested in α-halogenocycloalkanones[5–8], steroid derivatives having a cyclohexanone ring[9] (for exceptions, see Ref. 10), and unsubstituted 1,6-anhydro-β-D-hexopyranosuloses[2,11].

TABLE I

P.M.R. DATA[a] FOR THE TOSYLATED KETONES **1–4**, **10**, AND **11** AND OF THE DEOXY KETONE **9**

Compound	*H-1*	*H-2ax*	*H-2eq*	*H-4ax*	*H-4eq*	*H-5*	*H-6 endo*	*H-6 exo*
1	4.34 $J_{1,2}$ 1.5	—	5.49 $J_{1,2}$ 1.5 $J_{2,4}$ ~0	—	5.36 $J_{4,5}$ 1.5 $J_{2,4}$ ~0	5.07 $J_{4,5}$ 1.5 $J_{5,6en}$ ~1 $J_{5,6ex}$ 4.0	~6.04 $J_{6,6}$ 8.0 $J_{5,6}$ ~1	~6.16 $J_{6,6}$ 8.0 $J_{5,6}$ 4.0
2	4.35 $J_{1,2}$ 2.25	4.92 $J_{1,2}$ 2.25	—	—	5.39 $J_{4,5}$ 2.2	5.06 $J_{4,5}$ 2.2 $J_{5,6en}$ ~1.5 $J_{5,6ex}$ 5.25	6.32 $J_{6,6}$ 9.0 $J_{5,6}$ ~1.5	6.14 $J_{6,6}$ 9.0 $J_{5,6}$ 5.25
3	4.40 $J_{1,2}$ 2.0	—	5.56 $J_{1,2}$ 2.0 $J_{2,4}$ ~0	4.80 $J_{4,5}$ 5.0 $J_{4,6ex}$ ~1.0	—	5.10 $J_{4,5}$ 5.0 $J_{5,6en}$ ~0.5 $J_{5,6ex}$ 4.0	6.04 $J_{6,6}$ 9.0 $J_{5,6}$ ~0.5	6.26 $J_{6,6}$ 9.0 $J_{5,6}$ 4.0 $J_{4,6}$ ~1.0
4	4.34 $J_{1,2}$ 2.25	5.08 $J_{1,2}$ 2.25 $J_{2,4}$ ~0	—	4.94 $J_{4,5}$ 5.25 $J_{4,6ex}$ ~1.5 $J_{2,4}$ ~0	—	5.08 $J_{4,5}$ 5.25 $J_{5,6en}$ ~1 $J_{5,6ex}$ 4.0	6.02 $J_{6,6}$ 8.0 $J_{5,6}$ ~1	6.17 $J_{6,6}$ 8.0 $J_{5,6}$ 4.0 $J_{4,6}$ ~1.5
9	4.28 $J_{1,2}$ 1.7[b]	7.49 $J_{1,2}$ 1.7[b]	7.49 $J_{1,2}$ 1.7[b]	7.26 $J_{4,4}$ 16.0 $J_{4,5}$ 4.5	7.58 $J_{4,4}$ 16.0 $J_{4,5}$ ~1	5.22 $J_{4ax,5}$ 4.5 $J_{4eq,5}$ ~1	~6.22	~6.22
10	4.35 $J_{1,2}$ 2.0	—	5.72 $J_{1,2}$ 2.0	7.07 $J_{4,4}$ 16.0 $J_{4,5}$ 5.0	7.59 $J_{4,4}$ 16.0 $J_{4,5}$ 1.0	5.15 $J_{4ax,5}$ 5.0 $J_{4eq,5}$ 1.0	~6.24	~6.24
11	4.30 $J_{1,2}$ 2.2	5.14 $J_{1,2}$ 2.2	—	7.12 $J_{4,4}$ 16.0 $J_{4,5}$ 5.0	7.40 $J_{4,4}$ 16.0 $J_{4,5}$ 1.5	5.14 $J_{4ax,5}$ 5.0 $J_{4eq,5}$ 1.5	~6.16	~6.16

[a]Measurements for solutions in chloroform-*d* (internal tetramethylsilane) obtained with a Varian HA-100 instrument. The chemical shifts are expressed in τ values. Analyses are first-order. Decoupling was achieved with a Varian V 3521 A integrator-decoupler, using the frequency-sweep mode. [b]$J \approx \frac{1}{2}(J_{1,2e} + J_{1,2a})$.

Whereas the vicinal couplings $J_{1,2a}$ and $J_{1,2e}$ are of similar magnitude (1.5–2.2 Hz), the couplings $J_{4a,5}$ are greater (*ca.* 5.0 Hz) than $J_{4e,5}$ which are similar in value to the couplings $J_{1,2}$. The coupling constants in the ketone sulphonates **1–4** are very similar to those in the parent 1,6-anhydro-β-D-hexopyranoses[11] (differences

$\gtrless 1$ Hz), and we conclude that the compounds exist in a chair conformation **9a** similar to that of bicyclo[3.2.1]octan-3-one, in which the six-membered ring is partially flattened by the so-called reflex effect[12]. The dihedral angles assigned to compounds **1–4** on the basis of the Karplus equation[13] preclude the existence of boat conformations **9b**. In aqueous solution, the unsubstituted 1,6-anhydro-β-D-hexopyranosuloses, with the exception of 1,6-anhydro-β-D-*ribo*-hexopyranos-3-ulose* which exists as a dimer, also exist in chair conformations[2].

The above conclusions are supported by the p.m.r. spectral data for 1,6-anhydro-4-deoxy-2-*O*-tosyl-β-D-*erythro*-hexopyranos-3-ulose (**10**) and the corresponding *threo* derivative **11** (see Table I)[14]. The signals for the axial protons α to the carbonyl group are also shifted downfield, and the couplings $J_{4a,5}$ and $J_{4e,5}$ are very close to those for compounds **1–4**. Comparison of the parameters for the suphonylated ketones **1–4**, **10**, and **11** with those for the deoxy ketone **9** (Table I) is indicative of the chair conformation for the last compound. The protons for the methylene group at C-2 do not differ in their chemical shifts, in contrast to those at C-4. The protons H-2a, H-2e, and H-1 form an ABX system which is reduced to five lines $\nu_{H-2a} - \nu_{H-2e} = \sim 0$, and $J_{2a,2e} \gg \frac{1}{2}(J_{1,2a} - J_{1,2e})$. According to Karabatsos *et al.*[4], this situation cannot be simply explained. If the six-membered ring is deformed so that C-1–C-4 are essentially coplanar, then H-2a and H-2e have a symmetrical environment (Fig. 1). However, it is then not possible to explain readily the different chemical shift of H-4a and H-4e under the influence of the carbonyl group. This problem is being studied further.

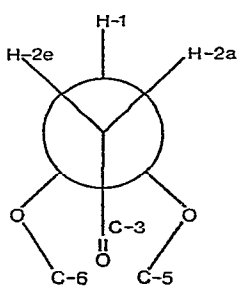
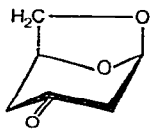


Fig. 1. The Newman projection of the deoxy ketone **9** along the C-2–C-1 bond.

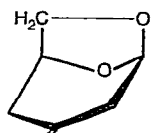
I.r. and u.v. spectra. — The existence of the sulphonylated ketones **1–4** in the chair conformation in chloroform solution was also verified by i.r. data. It has been shown[7,12,16–18] that electronegative substituents (especially halogen atoms) α to the carbonyl group shift the carbonyl band to higher frequencies. An equatorial group has a greater influence in the cyclohexane system than does an axial substituent; for chlorine, the shifts are 26–31 (equatorial) and 10–18 cm^{-1} (axial). By contrast, in the u.v. spectra of ketones ($n \rightarrow \pi^*$ transition), an axial α-chlorine atom has a greater effect than an equatorial chlorine, *viz.*, a shift of 20–30 nm to longer wavelengths[19].

*Personal communication from Professor H. Paulsen.

Since these phenomena originate in the interaction of dipoles, the toluene-*p*-sulphonyloxy group should behave in a similar manner, and this effect is documented in Table II. The *ribo*-ketone **1** has the band at lowest frequency (1757, with inflection at 1770 cm^{-1}), consistent with the presence of two axial sulphonyloxy groups (**1**), whereas the *lyxo*-ketone **4** has the highest carbonyl frequency (1771 cm^{-1}), indicative of two equatorial sulphonyloxy groups. The *arabino*-ketone **2** and the *xylo*-ketone **3** each have one axial and one equatorial sulphonyloxy group, and the absorption of the carbonyl group is intermediate in frequency between those for **1** and **4**. For **1**, the superimposed band at *ca.* 1770 cm^{-1} is probably due to the boat form **9b** (having two equatorial sulphonyloxy groups) in equilibrium with the chair conformation **9a**. On the assumption that the extinction coefficient for each band is similar, the ratio of **9a**:**9b** at 25° is *ca.* 76:24 in chloroform and *ca.* 66:34 in acetonitrile. The equilibrium **9a** $\rightleftharpoons$ **9b** was not detected for the *ribo*-ketone **1** by u.v. spectroscopy. The size of the



9a



9b

shift ν(C=O) for the change **1**→**2** or **3** is 5–7 cm^{-1}, and 7–9 cm^{-1} for **2** or **3**→**4**, which is in agreement[14] with the value of 6 cm^{-1} found for the sulphonylated ketones **10** (1745 cm^{-1}) and **11** (1751 cm^{-1}).

TABLE II

I.R., U.V., AND HEMIACETAL EQUILIBRIUM DATA FOR THE KETONES **1–4** AND **9**

Compound	$\nu_{max}^{CHCl_3}$ (*C=O*) (*cm*$^{-1}$)	$\lambda_{max}^{CHCl_3}$ (ε) (*nm*)	*Free ketone at equilibrium* (%)	
			I.r. (h)[a]	*U.v. (min)*[b]
1	1757 (1770 inflection)	323 (40)	25 ±5 (4)	27 (131)
2	1764	299 (30)	55 ±5 (40)	52 (45)
3	1762	300 (33)	75 ±5 (60)	76 (40)
4	1771	290 (23)	95	[c]
9	1730[d]	—	—	—

[a]In chloroform–absolute ethanol (9:1). [b]In chloroform–96% ethanol (9:1). [c]Measurement was precluded because of superposition of carbonyl and tosyloxy bands. [d]An increase of the frequency by 19 cm^{-1} in comparison with bicyclo[3.2.1]octan-3-one[12].

The formation of hemiacetals. — In solution in alcohols, carbonyl compounds exist in equilibrium with the hemiacetals[20–22]. The equilibrium constant for hemiacetal formation is increased by electronegative substituents α to the carbonyl group. Thus, in ethanol, 1-chloropropanone exists to the extent of 71% as the free ketone, but this percentage falls to 10% for 1,3-dichloropropanone. Monosubstituted deri-

vatives of acetone exhibit a greater degree of acetal formation as the absorption maximum of the ketone shifts to longer wavelengths. Steric influences are not important for aliphatic aldehydes[23,24] but, for alicyclic ketones, the ring size makes an important contribution[25]. Moreover, substitution with an alkyl group in the α-position in cyclohexanone and steroidal ketones suppresses hemiacetal formation[26]. Some sugar ketones[11,27–29] form hydrates, and a crystalline hemiacetal of a substituted D-*erythro*-pentofuranos-3-ulose is known[28].

In this work, hemiacetal formation of the sulphonylated ketones **1–4** in a chloroform–ethanol (9:1) mixture was followed by using i.r. spectroscopy (see Table II). It was found that an axial α-tosyloxy group promotes acetal formation, whereas an equatorial group results in inhibition. The *ribo*-ketone **1** reacts more rapidly and yields *ca.* 75% of hemiacetal, whereas the *lyxo*-ketone **4** reacts most slowly and yields less than 5% of hemiacetal. Essentially similar results were obtained when hemiacetal formation (catalysed by conc. hydrochloric acid) was followed by u.v. spectroscopy (see Table II).

The various extents of hemiacetal formation may be related to product stability. The Newman projections along the C-2–C-3 (*A*, *B*) and C-3–C-4 (*C*, *D*) bonds for the hemiacetals of ketones **1–4** are shown in Fig. 2. The steric interaction between the tosyloxy group and the acetal oxygen atoms is less in *A* and *C* than in *B* and *D* (*cf.*

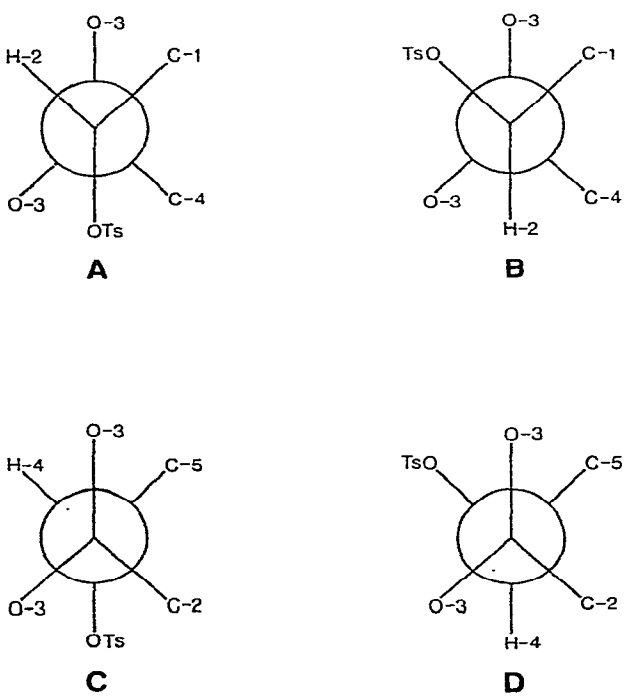


Fig. 2. The Newman projection of the hemiacetals of the tosylated ketones **1–4** along the C-2–C-3 (*A*, *B*) and C-3–C-4 (*C*, *D*) bonds.

the Reeves A^2 effect[30]). For this reason, the ease of hemiacetal formation decreases along the series *ribo*-ketone **1** (*A*, *C* interactions) > *arabino*-ketone **2** (*B*, *C*) > *xylo*-ketone **3** (*A*, *D*) > *lyxo*-ketone **4** (*B*, *D*).

The easy formation of a hemiacetal causes difficulties when the *ribo*-ketone **1** is recrystallised from ethanol. Crystallisation of the *arabino*-ketone **2** from ether–ethanol did not yield **2** as described earlier[1], but gave the ethyl hemiacetal, m.p. 125–135°, $[\alpha]_D$ −129° (chloroform). When chloroform–ether was used as crystallising solvent, the free ketone **2** was obtained.

Isomerisation. — The rate of isomerisation of the ketones **1**–**4** (see Fig. 3) at 25° in chloroform containing 5% of pyridine was followed polarimetrically, and the previously suggested scheme of isomerisation **1**→**2** and **3**→**4** was verified. It is clear from Fig. 3 that the *ribo*-ketone **1** is isomerised more quickly to the mixture **2** and **3** than the mixture is converted into **4**, and after 7–8 h, the mixture comprised **2** and **3** in the ratio 7:3. The rapid isomerisation of the *ribo*-ketone **1** is due to the interactions of the 1,3-diaxial tosyloxy groups. When one tosyloxy group is equatorial (see discussion in Refs. 1 and 14), the steric interactions are diminished and the rate of isomerisation falls. Eventually, the equilibrium is shifted completely in favour of the *lyxo*-ketone **4**.

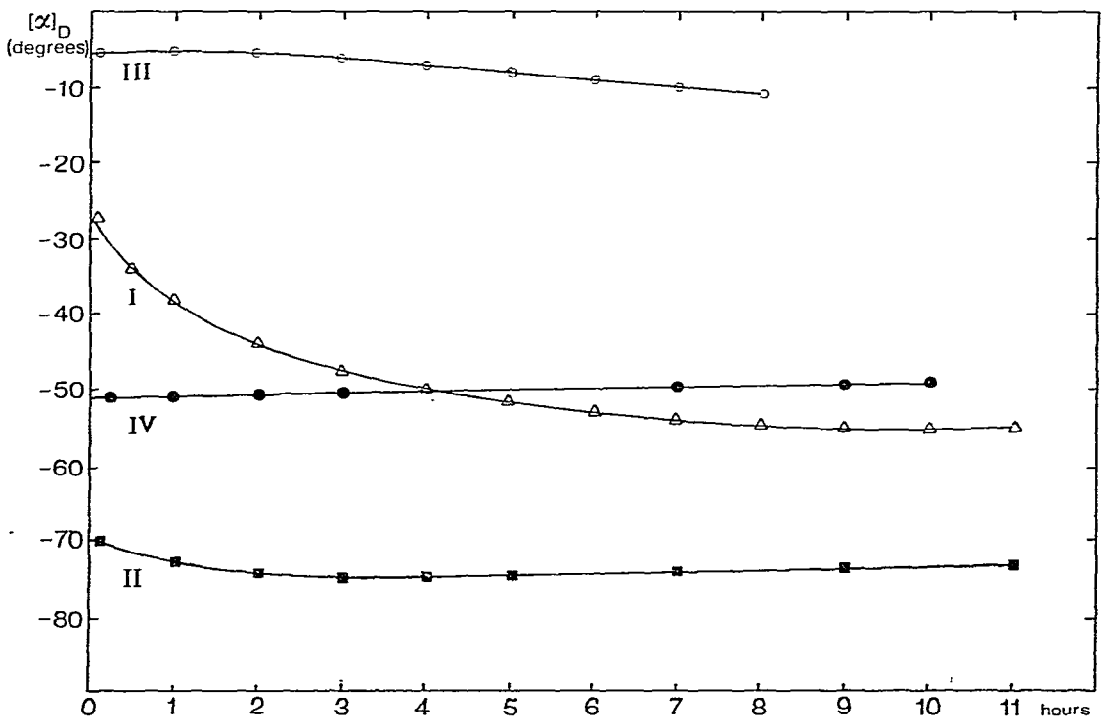


Fig. 3. Isomerisation of the tosylated ketones **1**–**4** followed polarimetrically at 25° in chloroform containing 5% of pyridine (1% solution, 1-dm pathlength); D-*ribo* (△), D-*arabino* (■), D-*xylo* (○), and D-*lyxo* (●).

C.d. spectra and optical rotation. — The availability of sugar ketones has stimulated interest in their c.d. and o.r.d. characteristics. Published data indicate that, for sugar ketones, the octant rule should be used with great caution[2,32]. In seeking further information, we have examined the ketones **1**–**4** and **9**. The data (Table III) are not easily interpreted. At first sight, they appear not to agree with the octant rule[33]. The *ribo*-ketone **1** has the most positive and the *lyxo*-ketone **4** has the most negative c.d. curve. A better coincidence with the octant rule has been found[2] for aqueous solutions of unsubstituted 1,6-anhydro-β-D-hexopyranos-3-uloses, with the exception of 1,6-anhydro-β-D-*lyxo*-hexopyranos-3-ulose, where the highest negative c.d. ($\Delta\varepsilon_{max}$ −1.03) was observed*.

TABLE III

C.D. AND $[\alpha]_D$ VALUES FOR THE KETONES **1**–**4** AND **9**

Compound	$\Delta\varepsilon$ (λ_{max}, *nm*) *p-Dioxane*	$\Delta\varepsilon$ (λ_{max}, *nm*) *Methanol*[a]	$[\alpha]_D$ (*CHCl*$_3$) (*degrees*)
1	+0.85 (300)	+0.18 (290)	−27
2	+0.24 (320)	−0.30 (299)	−75
3	−0.67 (310)	−0.27 (315)	−4.5
4	−0.73 (287)	−0.53 (285)	−51
9	−0.27 (295)	−0.32 (290)	−98

[a]These values are for comparison, since they were obtained before the hemiacetal equilibrium was established.

However, because of the tendency of sugar ketones to form hydrates and hemiacetals[11,27–29], c.d. measurements for aqueous or alcoholic solutions are of doubtful value[26], and aprotic solvents should be used. The *ribo*-ketone **1**, which quickly forms a hemiacetal, gives a considerably lower c.d. value in methanol than in *p*-dioxane (see Table III).

The negative c.d. of the model compound **9** is probably a measure of the different influence of the $-CH_2-$ and $-O-$ groups of the 1,6-anhydro ring on the carbonyl group. Both these groups are situated β to the carbonyl group and axial with respect to the tetrahydropyranone ring. Their contribution to the c.d.[35–37] and the influence of the geometry of the tetrahydropyranone ring itself[38,39] cannot be resolved at this time.

Although c.d. data for the ketones **1**–**4** cannot be used to assign structure, it is rather surprising that the $[\alpha]_D$ values for these compounds agree with predictions based on the octant rule, and that the very simple relation

$$[\alpha]_D\,\mathbf{1} + [\alpha]_D\,\mathbf{4} = [\alpha]_D\,\mathbf{2} + [\alpha]_D\,\mathbf{3}$$

is valid; this relation has been used to calculate the optical rotations of 1,6-anhydro-β-D-hexopyranoses[40].

*This property is not dependent on the nature of the substituents; thus, 1,6-anhydro-2,4-di-*O*-benzoyl-β-D-*lyxo*-hexopyranose has $\Delta\varepsilon_{max}$ −0.65 (methanol) and 1,6-anhydro-2,4-di-*O*-benzyl-β-D-*lyxo*-hexopyranose has $\Delta\varepsilon_{max}$ −0.74 (methanol)[34].

EXPERIMENTAL

Melting points were determined on a Boetius micro melting-point apparatus. Optical rotations were obtained at 22–25° by using a Bendix–Ericsson automatic polarimeter Type 143A. P.m.r. spectra were measured with a Varian HA-100 spectrometer in solutions in chloroform-*d* with tetramethylsilane as internal standard. I.r. spectra were measured with a Unicam SP 200 or a prototype Tesla spectrometer. U.v. spectra were recorded with a Unicam SP 700 spectrometer, and c.d. spectra with a Dichrograph Roussel–Jouan spectropolarimeter. All solutions were evaporated at diminished pressure and 30–40°.

*1,6-Anhydro-2-*O*-tosyl-β-*D*-galactopyranose* (**5**). — This compound was prepared from 1,6-anhydro-3,4-*O*-isopropylidene-2-*O*-tosyl-β-D-galactopyranose[41] by hydrolysis[42] with 20% acetic acid.

*1,6-Anhydro-2,4-di-*O*-tosyl-β-*D*-galactopyranose* (**6**). — A solution of compound **5** (3 g) in pyridine (15 ml) was treated at 20° with tosyl chloride (2.2 g), and the mixture was kept for 48 h at 20–25°. T.l.c. (silica gel, benzene–acetone, 9:1) then revealed the main product **6** and a very small proportion of the trisulphonate. Isolation of the product in the usual manner, followed by recrystallisation from ether–light petroleum, afforded **6** (3.2 g, 72%). Material purified by chromatography (silica gel, benzene–acetone, 9:1) had m.p. 115–117°, $[\alpha]_D$ −49° (*c* 0.8, chloroform) (Found: C, 51.20; H, 4.75; S, 13.64. $C_{20}H_{22}O_9S_2$ calc.: C, 51.05; H, 4.71; S, 13.63%).

The acetate (**7**) of compound **6** had m.p. 165–167°, $[\alpha]_D$ −19° (*c* 1.0, chloroform) (Found: C, 51.56; H, 4.84, S, 12.73. $C_{22}H_{24}O_{10}S_2$ calc.: C, 51.57; H, 4.73; S, 12.50%).

*1,6-Anhydro-2,4-di-*O*-tosyl-β-*D*-xylo-hexopyranos-3-ulose* (**3**). — To a solution of **6** (1 g) in acetic acid (10 ml), a solution of chromic trioxide (0.5 g) in water (0.75 ml) was added at 20°. The reaction mixture was stirred for 15 min, and was then diluted with chloroform (15 ml) and poured into water (40 ml). The chloroform layer was separated, the aqueous layer was extracted with chloroform, and the combined organic solutions were washed with aqueous sodium hydrogen carbonate and water, dried ($CaCl_2$), and concentrated. Crystallisation of the syrupy residue from ether yielded **3** (0.80 g, 80%), m.p. 86–89°. Recrystallisation from ether afforded material having m.p. 87–89°, $[\alpha]_D$ −4.5° (*c* 2.3, chloroform) (Found: C, 51.34; H, 4.41; S, 13.70. $C_{20}H_{20}O_9S_2$ calc.: C, 51.28; H, 4.30; S, 13.69%).

*3-*O*-Acetyl-1,6-anhydro-2,4-di-*O*-tosyl-β-*D*-gulopyranose* (**8**). — To a solution of the *xylo*-ketone **3** (0.1 g) in a mixture of chloroform (2 ml) and ethanol (0.5 ml), sodium borohydride (20 mg) was added at 20°. After 15 min, the reaction mixture was neutralised with acetic acid, the solution was then evaporated, and the residue was acetylated with acetic anhydride (1 ml) and anhydrous sodium acetate (0.1 g), in the usual manner, to give **8**. Crystallisation from ethanol gave material (0.07 g, 64%) having m.p. 195–197°, $[\alpha]_D$ +36° (*c* 0.6, chloroform) (Found: C, 51.58; H, 4.97; S, 12.39. $C_{22}H_{24}O_{10}S_2$ calc.: C, 51.57; H, 4.73; S, 12,50%).

*1,6-Anhydro-2,4-di-*O*-tosyl-β-*D*-arabino-hexopyranos-3-ulose* (**2**) *and its hemiacetal.* — This compound was prepared by a modified literature procedure[1]. A

solution of the *ribo*-ketone **1** (10 g) in chloroform (100 ml) containing 5% of pyridine was kept for 8 h at 25°. The solution was washed with dilute hydrochloric acid and water, dried ($CaCl_2$), and concentrated. Crystallisation of the residue from chloroform–ether yielded **2** (4.5 g, 45%), m.p. 115–119°. Recrystallisation afforded material having m.p. 122–124°, $[\alpha]_D$ −75° (*c* 0.8, chloroform) (Found: C, 51.37; H, 4.26; S, 13.69. $C_{20}H_{20}O_9S_2$ calc. C, 51.28; H, 4.30; S, 13.69%).

Crystallisation of **2** from ethanol gave the ethyl hemiacetal, m.p. 122–135°, $[\alpha]_D$ −129° (*c* 0.6, chloroform), previously described, and which had a weak i.r. band at 1765 cm^{-1} (C=O) and an intense, broad band at *ca.* 3560 cm^{-1} (OH).

*1,6-Anhydro-2,4-di-*O*-tosyl-β-*D*-lyxo-hexopyranos-3-ulose* (**4**). — (*a*) A solution of the *xylo*-ketone **3** (0.1 g) in pyridine (0.5 ml) was kept for 50 h at 20°. After addition of chloroform (10 ml) and dilution with water, the chloroform layer was washed with 5% hydrochloric acid and water, dried ($CaCl_2$), and evaporated. Crystallisation of the residue from ethanol gave the *lyxo*-ketone **4** (0.70 g, 70%), m.p. 141–142°, $[\alpha]_D$ −51° (*c* 0.8, chloroform).

(*b*) A similar isomerisation of the *arabino*-ketone **2** yielded 65% of **4**.

*1,6-Anhydro-2,4-dideoxy-β-*D*-glycero-hexopyranos-3-ulose* (**9**). — A solution of ketone **1** (12 g) in acetone (70 ml) was shaken with an ethanolic suspension (120 ml) of Raney nickel (T-1)[43] for 40 min. The filtered mixture was then washed with ether (3 × 20 ml), and the combined organic solutions were concentrated. The residue was extracted with boiling ether (3 × 30 ml), and the cooled and filtered ethereal solution was dried ($CaCl_2$) and evaporated. The residue was distilled to give **9** (1.5 g, 46%), b.p. 60°/0.1 Torr, $[\alpha]_D$ −98° (*c* 0.7, chloroform) (Found: C, 56.01; H, 6.22;. $C_6H_8O_3$ calc.: C, 56.25; H, 6.29%).

Hemiacetal formation of the ditosylketones **1–4**. — (*a*) The i.r. absorption of a 6% solution of each ketone in chloroform–ethanol (9:1) was measured at 20° in the region 1300–2000 cm^{-1} at a speed of 1.55 cm^{-1}/sec, using rock-salt cells and a path length of 0.208 mm. The loss of ketone was calculated from the change of the extinction for the bands at 1760 (C=O) and 1600 cm^{-1} (phenyl). The results are presented in Table II.

(*b*) To a 1.5% solution of each ketone in chloroform–96% ethanol (9:1), conc. hydrochloric acid (0.01 ml) was added for each 2 ml of solution. The time change of the extinction for the $n \rightarrow \pi^*$ transition was measured in 0.5-cm cells at 25°. The results are recorded in Table II.

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REFERENCES

1 M. ČERNÝ, L. KALVODA, AND J. PACÁK, *Collection Czech. Chem. Commun.*, 33 (1968) 1143.
2 K. HEYNS, J. WEYER, AND H. PAULSEN, *Ber.*, 100 (1967) 2317.
3 D. SHAPIRO, J. A. ACHER, AND E. S. RACHAMAN, *J. Org. Chem.*, 32 (1967) 3767.
4 G. J. KARABATSOS, G. C. SONNICHSEN, N. HSI, AND D. J. FENOGLIO, *J. Amer. Chem. Soc.*, 89 (1967) 5067.
5 A. NICKON, M. A. CASTLE, R. HARADA, C. E. BERKOFF, AND R. O. WILLIAMS, *J. Amer. Chem. Soc.*, 85 (1963) 2185.
6 K. M. WELLMAN AND F. G. BORDWELL, *Tetrahedron Lett.*, (1963) 1703.
7 R. N. MCDONALD AND T. E. TABOR, *J. Amer. Chem. Soc.*, 89 (1967) 6573.
8 Y. H. PAN AND J. B. STOTHERS, *Can. J. Chem.*, 45 (1967) 1943.
9 K. L. WILLIAMSON AND W. S. JOHNSON, *J. Amer. Chem. Soc.*, 83 (1961) 4623.
10 N. S. BHACCA, J. E. GURST, AND D. H. WILLIAMS, *J. Amer. Chem. Soc.*, 87 (1965) 302.
11 K. HEYNS AND J. WEYER, *Ann.*, 718 (1968) 224.
12 B. WAEGELL AND C. W. JEFFORD, *Bull. Soc. Chim. France*, (1964) 844.
13 M. KARPLUS, *J. Amer. Chem. Soc.*, 85 (1963) 2870.
14 M. ČERNÝ, J. STANĚK, JR., AND J. PACÁK, *Collection Czech. Chem. Commun.*, 34 (1969) 1750.
15 R. J. ABRAHAM AND H. J. BERNSTEIN, *Can. J. Chem.*, 39 (1961) 216.
16 E. J. COREY, *J. Amer. Chem. Soc.*, 75 (1953) 3297.
17 E. J. COREY AND H. J. BURKE, *J. Amer. Chem. Soc.*, 77 (1955) 5418.
18 J. PETRISSANS, S. GROMB AND J. DESCHAMPS, *Bull. Soc. Chim. France*, (1967) 4381.
19 N. J. LEONARD AND F. H. OWENS, *J. Amer. Chem. Soc.*, 80 (1958) 6039.
20 P. LE HÉNAFF, *Bull. Soc. Chim. France*, (1968) 4687.
21 W. HEROLD-KIEL, *Z. Electrochem.*, 38 (1932) 633.
22 W. HEROLD-KIEL, *Z. Electrochem.*, 39 (1933) 566.
23 P. GREENZAID, Z. LUZ, AND D. SAMUEL, *J. Amer. Chem. Soc.*, 89 (1967) 749.
24 P. LE HÉNAFF, *Compt. Rend.*, 265 C (1967) 175.
25 R. BRESLOW AND C. RYAN, *J. Amer. Chem. Soc.*, 89 (1967) 3073.
26 C. DJERASSI, L. A. MITSCHER, AND B. J. MITSCHER, *J. Amer. Chem. Soc.*, 81 (1959) 947.
27 K. HEYNS, J. LENZ, AND H. PAULSEN, *Ber.*, 95 (1962) 2964.
28 K. ONODERA, S. HIRANO, AND N. KASHIMURA, *Carbohyd. Res.*, 6 (1968) 276.
29 K. N. SLESSOR AND A. S. TRACEY, *Can. J. Chem.*, 47 (1969) 3989.
30 R. B. KELLY, *Can. J. Chem.*, 35 (1957) 149.
31 J. S. BRIMACOMBE, *Angew. Chem.*, 81 (1970) 415.
32 D. HORTON AND J. S. JEWELL, *Carbohyd. Res.*, 5 (1967) 149.
33 W. MOFFIT, R. B. WOODWARD, A. MOSKOWITZ, W. KLYNE, AND C. DJERASSI, *J. Amer. Chem. Soc.*, 83 (1961) 4013.
34 M. ČERNÝ AND J. PACÁK, unpublished results.
35 Y.-H. PAO AND D. P. SANTRY, *J. Amer. Chem. Soc.*, 88 (1966) 4157.
36 G. SNATZKE, B. EHRIG, AND H. KLEIN, *Tetrahedron*, 25 (1969) 5601.
37 G. SNATZKE AND G. ECKHARDT, *Tetrahedron*, 24 (1968) 4543.
38 G. SNATZKE, *Tetrahedron*, 21 (1965) 413.
39 G. SNATZKE, *J. Chem. Soc.*, (1965) 5002.
40 M. ČERNÝ, J. PACÁK, AND J. STANĚK, *Chem. Ind.* (London), (1966) 1559.
41 R. M. HANN AND C. S. HUDSON, *J. Amer. Chem. Soc.*, 64 (1942) 2435.
42 R. M. HANN AND C. S. HUDSON, *J. Amer. Chem. Soc.*, 68 (1946) 1867.
43 X. A. DOMINGUEZ, I. C. LOPEZ, AND R. FRANCO, *J. Org. Chem.*, 26 (1961) 1625.