sorption at 207 nm (ε 25,800); CD curve λ_{max} 246 nm (θ +1377, c 1.02). The high resolution mass spectrum exhibited a very weak M^+ peak.

Anal. Calcd for $C_{22}H_{26}O_7$: C, 65.66; H, 6.51; O, 27.83; mol wt, 402.1678. Found: C, 65.80; H, 6.58; O, 27.79; mol wt, 402.1682.

Subacaulin (**2a**) had mp 160–162°; $[\alpha]^{26}D$ +129.9° (c 2.1); ir bands at 3582, 3520, 1770, 1720, 1670, and 1644 cm^{-1}; CD curve λ_{max} 249 nm (θ +2226, c 0.56); it polymerized on standing. The high resolution mass spectrum exhibited a weak M^+ peak (0.4%).

Anal. Calcd for $C_{20}H_{24}O_6$: C, 66.65; H, 6.71; O, 26.64; mol wt, 360.1571. Found: C, 67.04; H, 6.85; O, 26.16; mol wt, 360.1558.

Acetylsubacaulin (**2b**).—Acetylation of 0.2 g of **2a** with 1 ml of acetic anhydride and 2 ml of pyridine overnight at room temperature followed by the usual work-up gave a gum which showed one major and two minor spots on tlc. Repeated preparative tlc resulted in homogeneous, crystalline material which had mp 154–156°; ir bands (KBr) at 1775, 1748, 1715 (split), 1662, and 1630 cm^{-1}; $[\alpha]^{26}D$ +110.6° (c 1.85).

Anal. Calcd for $C_{22}H_{26}O_7$: C, 65.66; H, 6.51; O, 27.83; mol wt, 402.1679. Found: C, 65.25; H, 6.62; O, 27.61; mol wt, 402.1686.

Tetrahydroberlandin (**3**).—A solution of 78 mg of berlandin in 20 ml of ethyl acetate was reduced catalytically with 58 mg of 5% Pd–C in an atmosphere of hydrogen for 5 hr. The filtered solution was evaporated *in vacuo*, and the residue was purified by preparative tlc and recrystallized from ethyl acetate–hexane: yield 48 mg; mp 130–132°; ir bands at 1778, 1745, 1735, and 1645 cm^{-1}.

Anal. Calcd for $C_{22}H_{30}O_7$: C, 65.01; H, 7.44; O, 27.55; mol wt, 406.1991. Found: C, 65.33; H, 7.40; O, 27.21; mol wt, 406.1991.

Tetrahydroacetylsubacaulin (**4b**).—Hydrogenation of 60 mg of **2b** in the manner described for berlandin and purification by preparative tlc gave 58 mg of a gum, ir bands at 1778, 1740, 1735, and 1650 cm^{-1}. The gum did not give a satisfactory elemental analysis, but its mass spectrum exhibited a relatively weak (1.2%) molecular ion of the correct composition. Other significant peaks in the high-mass region corresponded to the loss of C_2H_4 (1.4%), C_2H_2O (1%), C_2H_3O (1.5%), C_2H_4O (1.4%), and $C_2H_4O_2$ (14.0%); base peak $C_5H_9O^+$.

Anal. Calcd for $C_{22}H_{30}O_7$: mol wt, 406.1990. Found: mol wt, 406.1979.

Tetrahydrosubacaulin (**4a**).—Hydrogenation of 102 mg of **2a**, purification by preparative tlc, and recrystallization from ethyl acetate–hexane afforded 80 mg of **4b**, mp 165–168°, ir bands at 3500, 1770, 1735, and 1640 cm^{-1}. The mass spectrum exhibited a weak molecular ion (0.7%); the next three peaks were also weak and corresponded to M − H_2O (0.2%), M − C_5H_8O (0.6%), and M − C_5H_9O (1.0%).

Anal. Calcd for $C_{20}H_{28}O_6$: C, 65.92; H, 7.74; O, 26.34; mol wt, 364.1884. Found: C, 65.54; H, 7.72; O, 26.23; mol wt, 364.1886.

Berlandin Epoxide (**5**).—A solution of 0.1 g of **1** and 75 mg of *m*-chloroperbenzoic acid in 3 ml of chloroform was left overnight and worked up in the usual manner. Purification of the product by preparative tlc and recrystallization of the major fraction from ethyl acetate–hexane afforded 46 mg of **5**, mp 228–232° dec, ir bands at 1775, 1750, 1720, 1665, and 1640 cm^{-1}.

Anal. Calcd for $C_{22}H_{28}O_8$: C, 63.15; H, 6.28; O, 30.59. Found: C, 63.46; H, 6.28; O, 29.90.

Reaction of Berlandin with HCl.—A mixture of 102 mg of **1**, 5 ml of dioxane, and 0.2 ml of concentrated HCl was stirred at room temperature for 2 days and concentrated at reduced pressure. The residue was purified by preparative tlc. The less polar fraction (**6**) was recrystallized from ethyl acetate–hexane: yield 80 mg; mp 144–145°; ir bands at 3662, 3580, 1775, 1740, 1720, 1662, and 1642 cm^{-1}. Since the material was recovered unchanged after attempted acetylation with acetic anhydride–pyridine at room temperature, the hydroxyl group was assumed to be tertiary.

Anal. Calcd for $C_{22}H_{27}O_7Cl$: C, 60.10; H, 6.10; Cl, 8.20. Found: C, 60.58; H, 6.27; Cl, 7.96.

The more polar fraction (**7**) was recrystallized from ethyl acetate–hexane: yield 10 mg; mp 200–202°; ir bands at 3670, 3590, 3450, 1770, 1745, 1720, 1662, and 1645 cm^{-1}.

Anal. Calcd for $C_{22}H_{27}O_7Cl$: C, 60.10; H, 6.10; Cl, 8.20. Found: C, 59.97; H, 6.24; Cl, 7.93.

Registry No.—**1**, 34829-00-0; **2a**, 34837-46-2; **2b**, 34837-47-3; **3**, 34829-01-1; **4a**, 34837-48-4; **4b**, 34837-49-5; **5**, 34829-02-2; **6**, 34829-03-3; **7**, 34829-04-4.

Neighboring Group Participation in Carbohydrate Chemistry. III.[1] Neighboring Group Participation of the 6-Hydroxyl Group in a Nucleophilic Displacement of a 5-*p*-Toluenesulfonate[2a]

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The neighboring group participation of a 6-hydroxyl group in the nucleophilic displacement of a 5-*p*-tolylsulfonyl group by acetate in a model compound, 1,2-*O*-isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-α-D-glucofuranose (**3**), was investigated. The conversion of **3** into 6-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**5**) by refluxing a solution of **3** in *N*,*N*-dimethylformamide containing anhydrous potassium acetate was assumed to proceed *via* a transition state or an intermediate involving the protonated 5,6-anhydro derivative **12**. The solvent dependence of the reaction was studied. Solvolysis of **3** in *N*,*N*-dimethylformamide, in the presence and absence of $CaCO_3$, yielded 6-*O*-formyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**13**). A mechanism for this reaction, which probably involves the neighboring group participation of the hydroxyl group, is proposed.

The hydroxyl group in its un-ionized form has generally been considered to have a low driving force for neighboring group participation,[3,4] and there are only a few examples reported in the carbohydrate literature where such participation could be assumed.[5,6] However, the alkoxide anion is known[7] as a good par-

(1) Part II: M. Miljković, D. Miljković, A. Jokić, V. Andrejević, and E. A. Davidson, *J. Org. Chem.*, **36**, 3218 (1971).

(2) (a) This work was supported by Grant AM12074 from the National Institute of Arthritis and Metabolic Diseases, National Institute of Health, U. S. Public Health Service. (b) To whom all correspondence should be addressed. (c) Department of Chemistry, Faculty for Natural and Mathematical Sciences, Novi Sad, Yugoslavia.

(3) S. Winstein and E. Grunwald, *J. Amer. Chem. Soc.*, **70**, 828 (1948).

(4) L. Goodman, *Advan. Carbohyd. Chem.*, **22**, 112 (1967).

(5) B. Capon and D. Thacker, *J. Amer. Chem. Soc.*, **87**, 4200 (1965).

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(7) S. Winstein and H. J. Lucas, *ibid.*, **61**, 1576 (1939); A. A. Frost and R. G. Pearson, "Kinetics and Mechanism," 2nd ed, Wiley, New York, N. Y., 1961, p 291.

ticipating group. During our studies on the neighboring group participation of various functional groups at the C-6 carbon atom in nucleophilic displacements of a 5-*p*-toluenesulfonate,[1,8] some interesting observations regarding the participation of the C-6 hydroxyl group have been made; the results obtained are described in this manuscript.

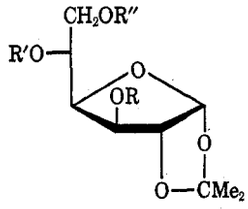
Results

As a model compound for our studies, 1,2-*O*-isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-α-D-glucofuranose (**3**) was synthesized according to the following scheme. Tosylation of 1,2-*O*-isopropylidene-6-*O*-triphenylmethyl-α-D-glucofuranose (**1**)[9] with *p*-tolylsulfonyl chloride in pyridine afforded the corresponding 3,5-di-*O*-*p*-tolylsulfonyl derivative **2** (96%), which was smoothly detritylated with hydrobromic acid in glacial acetic acid at 0° to give compound **3** (73%).

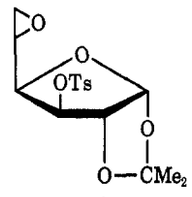
Refluxing of an acetonitrile solution of **3** with anhydrous potassium acetate for 10 days afforded three products, in addition to a small amount of starting material.

The first product (**4**), isolated in 53% yield, was identified as 5,6-anhydro-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose,[10] by comparison (ir and nmr spectra) with an authentic sample synthesized according to the procedure of Meyer and Reichstein.[10]

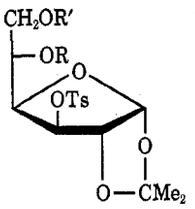
The second product (**5**) (32%) showed (ir and nmr spectra) in addition to the 1,2-*O*-isopropylidene group (two three-proton singlets at δ 1.48 and 1.30), the presence of a hydroxyl group (broad peak at 3590 cm^{-1}), one acetoxy group (1735 and 1245 cm^{-1}, C=O and CO stretch vibrations; a three-proton singlet at δ 2.05), and one *p*-tolylsulfonyl group (1192 and 1180 cm^{-1}, SO_2-symmetrical stretch vibration; three-proton singlet at δ 2.45). Since it was known from previous studies[8a,11] that the 3-*O*-*p*-tolylsulfonyl group is unreactive toward nucleophilic displacements in 1,2-*O*-isopropylidine-α-D-glucofuranose derivatives, the C-3 carbon atom was considered to be an unlikely location for the acetoxy group which was introduced during the course of the reaction. In order to determine whether the acetoxy group was on C-6 (most likely) or C-5, compound **5** was oxidized with RuO_4. The ir spectrum of the oxidation product **8** indicated the presence of two chemically nonequivalent carbonyl groups (1742 and 1732 cm^{-1}), and lacked an absorption in the region expected for a hydroxyl group. The peak at 1742 cm^{-1} was apparently the C=O stretch absorption of the acetoxy carbonyl group, whereas the peak at 1732 cm^{-1} was typical for a carbonyl group having an electron-withdrawing substituent in the α position, in this case, presumably due to an oxygen atom.[12] The nmr spectrum of compound **8** showed the absence of an aldehydic proton, thus excluding the carbonyl group from the terminal C-6 position. The significant downfield shift of resonance signals for H-4,



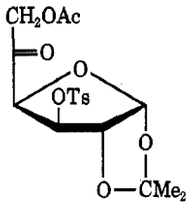
1, R = R′ = H; R″ = Ph_3C
2, R = R′ = Ts; R″ = Ph_3C
3, R = R′ = Ts; R″ = H



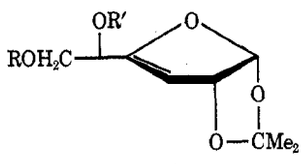
4



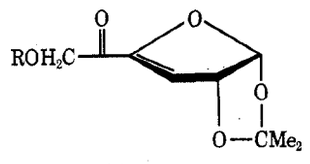
5, R = H; R′ = Ac
6, R = Ac; R′ = H
7, R = Bz; R′ = Ac
13, R = H; R′ = HCO-
14, R = Bz; R′ = HCO-



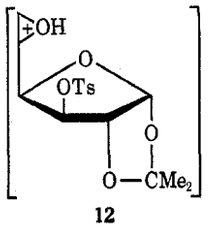
8



9, R = Ac; R′ = H
10, R = Ac; R′ = Bz



11, R = Ac



12

H-6, and H′-6 in **8** (0.5–1.0 ppm), as compared to the chemical shifts of the same protons in **5** (an unresolved multiplet at δ 3.9–4.4), the absence of the resonance signal for the H-5 proton, and the presence of an acetoxy group in the nmr spectrum of **8**, could be explained only if the structure of the oxidation product **8** were 6-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-α-D-xylohexofuran-5-ulose.[8a] This suggests that the acetyl group of the parent monoacetyl derivative **5** is attached to the C-6 carbon atom and that the correct structure for **5** is 6-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose.[8a] The above conclusions, derived from the spectroscopic data, were confirmed chemically as follows. Compound **5** could also be obtained by treatment of the 5,6-anhydro derivative **4** with anhydrous potassium acetate in refluxing *N*,*N*-dimethylformamide, and, in addition, the benzoylation of **5** with benzoyl chloride in pyridine gave the known 6-*O*-acetyl-5-*O*-benzoyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose.[8,13]

The structure of the third product (**9**) (3%) was deduced from the following observations. It was evident from the ir and nmr spectra that **9** had lost

(8) (a) M. Miljković, A. Jokić and E. A. Davidson, *Carbohyd. Res.*, **17**, 155 (1971); (b) M. A. Miljković and E. A. Davidson, *ibid.*, **13**, 444 (1970).
(9) C. T. Bishop, *Can. J. Chem.*, **35**, 61 (1957).
(10) A. S. Meyer and T. Reichstein, *Helv. Chim. Acta*, **29**, 152 (1946).
(11) M. L. Wolfrom, J. Bernsmann, and D. Horton, *J. Org. Chem.*, **27**, 4505 (1962).
(12) N. B. Colthup, L. H. Daly, and S. E. Wiberley, "Introduction to Infrared and Raman Spectroscopy," Academic Press, New York, N. Y., and London, 1964, pp 241–242, and literature cited therein.
(13) R. C. Chalk, D. H. Ball, M. A. Lintner, and L. Long, Jr., *Chem. Commun.*, 245 (1970); R. C. Chalk, D. H. Ball, and L. Long, Jr., *Carbohyd. Res.*, **20**, 151 (1971).

both *p*-tolylsulfonyl groups, and that a hydrogen-bonded hydroxyl group (3580 and 3450 cm^{-1}) was present; one acetoxy group (1732 and 1250 cm^{-1}; three-proton singlet at δ 2.03) and a trisubstituted double bond (1664 and 823 cm^{-1}; one-proton singlet at δ 5.21) were also identified. The significant downfield shift of the H-2 resonance signal in **9** (0.4–0.6 ppm), as compared to the chemical shift for H-2 in **5** (δ 4.73) could be accounted for if one assumes that the double bond, present in **9**, is located between carbon atoms **3** and **4**, since in that case H-2 would be in an allylic position and should absorb at lower magnetic field strength. Furthermore, the formation of an endocyclic (C-3–C-4) double bond would also be in accordance with our previous findings[8a] that 6-*O*-benzoyl-1,2-*O*-isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-α-D-glucofuranose eliminates the 3-*O*-*p*-tolylsulfonyl group relatively easily to give the C-3–C-4 double bond. The oxidation of **9** with MnO_2 in carbon tetrachloride at room temperature afforded **11**, the ir spectrum of which showed an acetoxy group (1742 cm^{-1}), a carbonyl group (1720 cm^{-1}), and a trisubstituted double bond (1630 and 825 cm^{-1}). The uv spectrum of **11** exhibited an absorption maximum at 266 nm (ϵ 1300), indicating conjugation of the carbonyl group with a trisubstituted double bond. A structure which would be compatible with the above spectroscopic data would be 6-*O*-acetyl-3-deoxy-1,2-*O*-isopropylidenehex-3-enefuran-5-ulose.[14] This suggests that the structure of the parent olefinic sugar **9** is 6-*O*-acetyl-3-deoxy-1,2-*O*-isopropylidene-β-L-*threo*-hex-3-enofuranose,[8a] a conclusion which was subsequently proven chemically since benzoylation of **9** yielded the known 6-*O*-acetyl-5-*O*-benzoyl-3-deoxy-1,2-*O*-isopropylidene-β-L-*threo*-hex-3-enofuranose (**10**).[8a]

Treatment of compound **3** with anhydrous potassium acetate in refluxing *N*,*N*-dimethylformamide for 50 min gave the same three products, in addition to a small amount of starting material (3%). The yield of the 5,6-anhydro derivative **4** was slightly decreased (49%) and the yield of the monohydroxy derivative **5** was unaffected (32%), whereas the yield of the olefinic sugar **9** was increased twofold (6%).

Refluxing compound **3** in pure *N*,*N*-dimethylformamide,[17] or in the presence of anhydrous $CaCO_3$, for 50 min gave, in addition to large amounts of starting material (72 and 59%, respectively), two products. The less polar fraction, isolated in very small yield (3 and 8%, respectively) was identified (ir and nmr spectra) as the 5,6-anhydro derivative **4**, whereas the more polar fraction (7 and 8%, respectively) was a new product, **13**, not previously observed. The ir spectrum of **13** showed the presence of a hydroxyl group (3600 cm^{-1}), a carbonyl (an ester group) (1720 cm^{-1}), and a *p*-tolylsulfonyl group (1191 and 1179 cm^{-1}). The nmr spectrum clearly showed the presence of only one *p*-tolylsulfonyl group (three-proton singlet at δ 2.50, Me from Ts). Except for the lack of the resonance signal for the acetate methyl group at δ 2.05, the general appearance of the nmr spectrum of **13** resembled very much that of **5**, suggesting that compound **13** may also be a 1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose derivative. This was supported by the fact that hydrolysis of **13** afforded the known 1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose[8a] (identical ir and nmr spectra with an authentic sample). Since there was a one-proton singlet at δ 8.03 in the nmr spectrum of **13**, which is typical for formate esters,[18] it was assumed that **13** might be 6-*O*-formyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose. In order to substantiate this an *N*,*N*-dimethylformamide solution of the 5,6-anhydro derivative **4** was refluxed with anhydrous sodium formate in the presence of catalytic amounts of formic acid. A product identical with **13** (ir and nmr spectra) was obtained (11%). Since it is known[8a] that the acetate anion opens the 5,6-oxirane ring in **4**, under similar experimental conditions, by attacking the less substituted 6 carbon atom, it was concluded that compound **13** must be 6-*O*-formyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose. Benzoylation of **13** with benzoyl chloride in pyridine afforded the 5-*O*-benzoyl-6-*O*-formyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**14**) (86%).

The 6-*O*-formyl derivative **13** had to be characterized as the 5-*O*-benzoyl derivative **14**, since, unlike the other C-6 acylated derivatives (6-*O*-acetyl and 6-*O*-benzoyl) of 1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose, it hydrolyzes very easily.

Discussion

The formation of 5,6-anhydro derivative **4** and 6-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**5**) on refluxing a *N*,*N*-dimethylformamide or acetonitrile solution of 1,2-*O*-isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-α-D-glucofuranose (**3**) with anhydrous potassium acetate suggests that the nucleophilic displacement of the 5-tosylate with acetate in **3** proceeds *via* the neighboring group participation of the 6-hydroxyl group. Whether this participation occurs with the 6-hydroxyl group in its un-ionized form, or in the form of an alkoxide anion, cannot be determined on the basis of the available experimental results.

The reaction of the 5,6-anhydro derivative **4** with anhydrous potassium acetate in refluxing *N*,*N*-dimethylformamide affords **5** in 12% yield, whereas refluxing an *N*,*N*-dimethylformamide solution of **4** with anhydrous potassium acetate in the presence of acetic acid affords **5** in 38% yield. Since heating of an *N*,*N*-dimethylformamide solution of **3** with anhydrous potassium acetate under reflux gives **5** in 32% yield, it is apparent that the conversion of **4** to **5** requires protonation of **4** with acetic acid either in transition state, or with the formation of **12** as an intermediate, prior to the nucleophilic opening of the 5,6-oxirane ring.

(14) The calculated absorption maxima for the above compound would be 262 nm,[15,16] which is in fair agreement with the experimentally determined value; the estimated molar extinction coefficient, ϵ 1300, is, however, lower than expected, possibly due to impurities present in the sample.

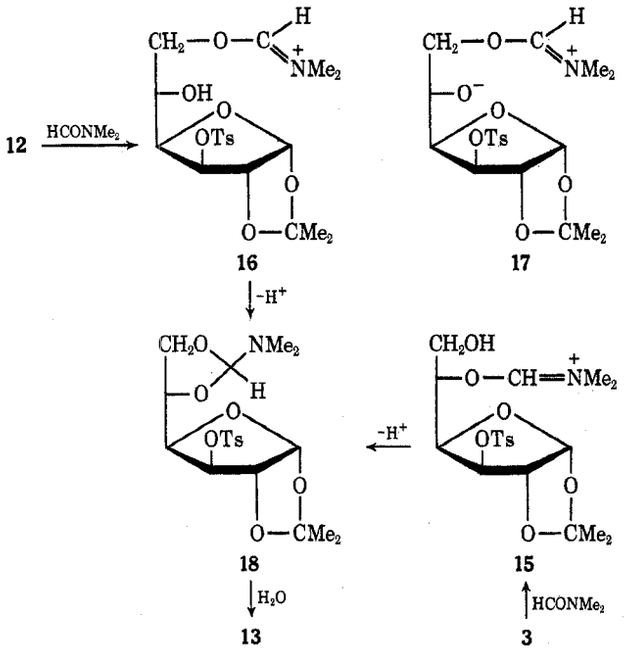
(15) R. B. Woodward, *J. Amer. Chem. Soc.*, **63**, 1123 (1941); **64**, 72, 76 (1942).

(16) L. F. Fieser and M. Fieser, "Steroids," Reinhold, New York, N. Y., 1959, p 19.

(17) *N*,*N*-Dimethylformamide used for our studies was analyzed by mass spectrometry for formic acid content. It was found that the formic acid content must be less than 0.16%, and may be zero.

(18) "High Resolution NMR Spectra Catalog," compiled by N. S. Bhacca, L. F. Johnson, and J. N. Shoolery, Varian Associates, Palo Alto, Calif., 1962, Spectrum No. 9; N. S. Bhacca and D. H. Williams, "Applications of NMR Spectroscopy in Organic Chemistry," Holden-Day, San Francisco, Calif., 1964, p 77.

The formation of 6-*O*-formyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**13**) on refluxing of **3** in pure *N*,*N*-dimethylformamide, or in the presence of $CaCO_3$, can be formulated as follows. Since it is known that *N*,*N*-dimethylformamide has considerable nucleophilic character with a partial negative charge located at the oxygen atom,[19] it is plausible to assume that *N*,*N*-dimethylformamide could either directly displace the 5-*O*-*p*-tolylsulfonyl group in **3** to give **15**,



or it could open the oxirane ring in **4** and/or the protonated oxirane ring in **12** by attacking the C-6 carbon atom to give **16** and/or **17**. All three charged intermediates (**15**, **16**, and **17**) thus obtained could be easily stabilized by cyclizing into the *N*,*N*-dimethylaminoorthoformate intermediate **18**, which on hydrolysis (on silica gel, or in the presence of water) would lose dimethylamine and give **13** as the sole product. The nucleophilic opening of the oxirane ring in **4** by *N*,*N*-dimethylformamide can be, however, excluded since it was found that the 5,6-anhydro derivative **4** does not react when refluxed in *N*,*N*-dimethylformamide with or without $CaCO_3$.

Experimental Section

General.—The silica gel used for all column chromatographies was E. Merck (Damstadt, Germany) silica gel, grain size <0.08 mm. The melting points are uncorrected. Optical rotations were determined with a Cary 60 spectropolarimeter in a 1.0-cm cell. The ir spectra were recorded with a Perkin-Elmer infrared spectrophotometer model 337, and nmr spectra with a Varian T-60 spectrometer with tetramethylsilane as the internal standard. Chemical shifts (δ) are expressed in parts per million.

1,2-*O*-Isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-6-*O*-triphenylmethyl-α-D-glucofuranose (2).—A chloroform solution (100 ml) containing *p*-toluenesulfonyl chloride (16.0 g, 84 mmol) was added to a pyridine solution (100 ml) of 1,2-*O*-isopropylidene-6-*O*-triphenylmethyl-α-D-glucofuranose (**1**) (8.0 g, 17 mmol), and the reaction was allowed to proceed for 5 days at 37°. The reaction mixture was then poured into 2 l. of ice–water and extracted with chloroform. The chloroform extract was evaporated *in vacuo* and the crude material (14.60 g) was chromatographed on silica gel (300 g). Elution with 95:5 benzene–2-propanol gave pure **2** (13.94 g, 96%): mp 82–85°; $[\alpha]^{27}D$ +193° (*c* 0.1, $CHCl_3$); ir ($CHCl_3$) 3010 (aromatic CH), 1600 (aromatic C=C), 1190 and 1180 cm^{-1} (Ts, sym SO_2 stretch); nmr ($CDCl_3$) δ 7.9–7.0 (m, 23, one trityl and two Ts groups), 5.71 (d, $J_{1,2}$ = 3.6 Hz, 1, H-1), 4.96 (d, $J_{3,4}$ = 2.8 Hz, 1, H-3), 4.81 (d, $J_{1,2}$ = 3.6 Hz, 1, H-2), *ca.* 4.81 (d, 1, H-4), *ca.* 4.58 (m, 1, H-5), 3.31 (d, $J_{5,6}$ = 4.8 Hz, 2, H-6 and H′-6), 2.45 and 2.40 (two s, 6, Me of Ts), 1.40 and 1.25 (two s, 6, Me of Ip).

Anal. Calcd for $C_{42}H_{42}O_{10}S_2$: C, 65.44; H, 5.49; S, 8.32. Found: C, 65.20; H, 5.29; S, 8.45.

1,2-*O*-Isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-α-D-glucofuranose (3).—Compound **2** (12.83 g, 16 mmol) was dissolved in glacial acetic acid (55 ml) and the resulting solution was treated with freshly prepared 40% HBr in acetic acid (5.48 g) for 45 sec. The precipitate (triphenylmethyl bromide) was removed by filtration and the filtrate was poured into 1 l. of ice–water. The emulsion was extracted with chloroform and the chloroform extract was dried over anhydrous $MgSO_4$. The crude product obtained after removal of chloroform *in vacuo* (8.80 g) was chromatographed on silica gel (300 g). Elution with 95:5 benzene–2-propanol afforded pure **3** (6.36 g, 72%) as an oil: $[\alpha]^{27}D$ −15.2° (*c* 1.0, $CHCl_3$); ir ($CHCl_3$) 3575 (broad peak, hydrogen bonded OH), 3010 (aromatic CH), 1600 (aromatic C=C), 1195 and 1183 cm^{-1} (Ts, sym SO_2 stretch); nmr ($CDCl_3$) δ 8.0–7.2 (m, 8, two Ts), 5.83 (d, $J_{1,2}$ = 3.6 Hz, 1, H-1), 5.00 (d, $J_{3,4}$ = 3.0 Hz, 1, H-3), 4.76 (d, $J_{1,2}$ = 3.6 Hz, 1, H-2), 4.8–4.6 (m, 1, H-5), 4.40 (m, $J_{3,4}$ = 3.0 and $J_{4,5}$ = 6.0 Hz, 1, H-4), *ca.* 3.8 (m, 2, H-6 and H′-6), 2.46 (s, 6, Me from Ts), 1.43 and 1.26 (two s, 6, Me from Ip).

Anal. Calcd for $C_{23}H_{28}O_{10}S_2$: C, 52.26; H, 5.34; S, 12.13. Found: C, 52.00; H, 5.33; S, 11.89.

Treatment of 1,2-*O*-isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-α-D-glucofuranose with Potassium Acetate in Acetonitrile under Reflux.—An acetonitrile solution (75 ml) containing **3** (1.80 g, 3 mmol) was treated with anhydrous potassium acetate (930 mg, 9 mmol) under reflux for 10 days. At the end of the third and sixth day, additional amounts (930 mg) of anhydrous potassium acetate were added. When the reaction was terminated, the suspension was filtered, and the filtrate was evaporated *in vacuo* to dryness. The crude product (1.50 g) was chromatographed on silica gel (100 g). Elution with 95:5 benzene–2-propanol gave as the first fraction the 5,6-anhydro derivative **4** (652 mg, 53%) as an oil: $[\alpha]^{27}D$ +81° (*c* 0.1, $CHCl_3$); ir ($CHCl_3$) 3015 (aromatic CH), 1595 (aromatic C=C), 1192 and 1180 (sym SO_2 stretch, Ts), 870 cm^{-1} (sym C–O–C stretch, monosubstituted oxirane ring); nmr ($CDCl_3$) δ 7.9–7.2 (m, 4, Ts), 5.95 (d, $J_{1,2}$ = 3.8 Hz, 1, H-1), 4.88 (d, $J_{3,4}$ = 3.0 Hz, 1, H-3), 4.62 (d, $J_{1,2}$ = 3.8 Hz, 1, H-2), 3.87 (m, $J_{3,4}$ = 3.0 and $J_{4,5}$ = 5.7 Hz, 1, H-4), 3.2–2.9 (m, 1, H-5), 2.7–2.3 (m, 2, H-6 and H′-6), 2.46 (s, 3, Me from Ts), 1.43 and 1.27 (two s, 6, Me from Ip).

Anal. Calcd for $C_{16}H_{20}O_7S$: C, 53.93; H, 5.66; S, 9.00. Found: C, 53.74; H, 5.47; S, 9.18.

The second fraction obtained was 6-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-iodofuranose (**5**) (452 mg, 32%) as an oil: $[\alpha]^{27}D$ −24.7° (*c* 1.0, $CHCl_3$); ir ($CHCl_3$) 3600 (broad peak, hydrogen bonded OH), 3010 (aromatic CH), 1735 (acetate C=O), 1600 (aromatic C=C), 1230 (acetate C–O), 1190 and 1180 cm^{-1} (sym SO_2 stretch, Ts); nmr ($CDCl_3$) δ 7.9–7.2 (m, 4, Ts), 5.95 (d, $J_{1,2}$ = 3.8 Hz, 1, H-1), 4.92 (d, $J_{3,4}$ = 3.0 Hz, 1, H-3), 4.73 (d, $J_{1,2}$ = 3.8 Hz, 1, H-2), 4.4–3.8 (m, 4, H-4, H-5, H-6 and H′-6), 2.45 (s, 3, Me from Ts) 2.05 (s, 3, Me from Ac), 1.48 and 1.30 (two s, 6, Me from Ip).

Anal. Calcd for $C_{18}H_{24}O_9S$: C, 51.92; H, 5.81; S, 7.70. Found: C, 51.86; H, 5.69; S, 7.89.

The third product (**9**) was isolated in very small amounts (28 mg, 3%). It was an oil: $[\alpha]^{27}D$ −17.5° (*c* 1.0, $CHCl_3$); ir ($CHCl_3$) 3580 (OH), 3010 (aromatic CH), 1740 (acetate C=O), 1665 (olefinic C=C stretch), 1250 (acetate C–O), 823 cm^{-1} (trisubstituted olefin, CH wag); nmr ($CDCl_3$) δ 6.01 (d, $J_{1,2}$ = 4.5 Hz, 1, H-1), 5.3–5.1 (m, 2, H-2 and H-3), 4.6–4.1 (m, 3, H-5, H-6, and H′-6), 2.02 (s, 3, Me from Ac), 1.42 (s, 6, Me from Ip).

Anal. Calcd for $C_{11}H_{16}O_6$: C, 54.09; H, 6.60. Found: C, 54.06; H, 6.54.

Treatment of 3 with Anhydrous Potassium Acetate in Refluxing *N*,*N*-Dimethylformamide.—An *N*,*N*-dimethylformamide solution (60 ml) of **3** (3.63 g, 6.8 mmol) was treated with anhydrous potassium acetate (3.63 g, 37 mmol) under reflux for 50 min.

(19) F. C. Chang and R. T. Blickenstaff, *J. Amer. Chem. Soc.*, **80**, 2906 (1958); R. A. Edington, *J. Chem. Soc.*, 3499 (1964); J. D. Albright, E. Benz, A. E. Lanziloti, and L. Goldman, *Chem. Commun.*, 413 (1965); see also ref 1.

After the solution was cooled to room temperature, water (60 ml) was added and the reaction mixture was extracted with three 200-ml portions of ether. The ethereal extract was successively washed with saturated aqueous sodium bicarbonate solution and water, and dried over anhydrous magnesium sulfate. The removal of ether *in vacuo* gave a crude product (2.540 g) which was chromatographed on silica gel. Elution with 95:5 benzene–2-propanol gave (1) 5,6-anhydro derivative **4** (1.193 g, 49%); (2) monohydroxy sugar **5** (916 mg, 32%); (3) starting material **3** (127 mg, 3%); and (4) unsaturated sugar **9** (102 mg, 6%).

6-*O*-Acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (5).—An *N*,*N*-dimethylformamide solution (10 ml) containing 5,6-anhydro compound **4** (500 mg, 1.4 mmol) and anhydrous potassium acetate (500 mg, 5.1 mmol) was heated at reflux for 50 min. The mixture was cooled to room temperature, water was added (10 ml), and the solution obtained was extracted with three 100-ml portions of ether. The combined ether extracts were washed with saturated aqueous sodium bicarbonate solution and water, and then dried over anhydrous $MgSO_4$. The crude product (525 mg), obtained after removal of ether *in vacuo*, was chromatographed on silica gel (50 g). Elution with 95:5 benzene–2-propanol gave starting material **3** (320 mg, 64%), monoacetate **5** (72 mg, 12%), and unsaturated sugar **9** (6 mg, 2%).

6-*O*-Acetyl-5-*O*-benzoyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (7).—Benzoyl chloride (0.3 ml) was added to a pyridine solution (1.0 ml) containing 6-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**5**) (100 mg, 0.24 mmol) and the reaction was allowed to proceed for 1 hr at room temperature. The reaction mixture was cooled to 0° and methanol was added. The solvents were evaporated *in vacuo* and the residue was recrystallized from ethanol. The white, crystalline product (50 mg, 40%), mp 125–126°, was identical (mixture melting point and ir spectra) with the known 6-*O*-acetyl-5-*O*-benzoyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-L-β-idofuranose (**7**).[8,13]

6-*O*-Acetyl-5-*O*-benzoyl-3-deoxy-1,2-*O*-isopropylidene-β-L-*threo*-hex-3-enofuranose (10).—Benzoyl chloride (0.1 ml) was added to a pyridine solution (1.0 ml) of compound **9** (50 mg, 0.2 mmol). After standing at room temperature for 20 min, the reaction mixture was cooled to 0° and methanol was added. The pyridine and excess of methanol were evaporated *in vacuo*, the residue was dissolved in chloroform, and the chloroform solution was washed successively with saturated aqueous sodium bicarbonate solution and water. The chloroform extract was then dried over anhydrous $MgSO_4$ and evaporated *in vacuo*. The crude product (75 mg) was chromatographed on silica gel (8 g). Elution with 3:1 hexane–acetone gave 46 mg (64%) of pure **10**, which was identical (ir and nmr spectra) with an authentic sample.[8a]

Treatment of 5,6-Anhydro Derivative 4 with Anhydrous KOAc/AcOH in Refluxing *N*,*N*-Dimethylformamide.—An *N*,*N*-dimethylformamide solution (10 ml) containing 5,6-anhydro derivative **4** (300 mg, 0.84 mmol) was treated with glacial acetic acid (60 mg, 1 mmol) and anhydrous potassium acetate (300 mg, 3 mmol). The reaction mixture was heated under reflux for 50 min and cooled to room temperature, and water (10 ml) was added. The resulting solution was extracted with three 100-ml portions of ether and the combined ethereal extract was dried over anhydrous $MgSO_4$. Ether was removed *in vacuo* and the residue (281 mg) was chromatographed on silica gel (30 g). Elution with 95:5 benzene–2-propanol afforded starting material (27 mg, 9%), 6-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**5**) (139 mg, 38%), and unsaturated sugar **9** (79 mg, 37%).

Oxidation of Unsaturated Sugar 9 with MnO_2.—The carbon tetrachloride solution (2.5 ml) of olefinic sugar **9** (50 mg, 0.2 mmol) was treated with freshly prepared MnO_2 for 24 hr at room temperature. After removal of MnO_2 by filtration, the solvent was evaporated *in vacuo* and the residue (18 mg) was chromatographed on silica gel (8 g). Elution with 95:5 benzene–2-propanol gave compound **9** (10 mg, 20%) which was homogenous by tlc (solvent systems: 95:5 benzene–2-propanol and 3:1 hexane–acetone): $[\alpha]^{27}D$ −59° (*c* 0.2, ethanol); ir ($CHCl_3$) 1750 (acetate C=O stretch), 1720 (carbonyl C=O stretch), 1635 (olefinic C=C stretch), 1240 (acetate C—O stretch), 825 cm^{-1} (trisubstituted double bond, CH wag); uv max (95% EtOH) 266 nm (ε 1300).

6-*O*-Acetyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-α-D-xylo-hexofuran-5-ulose (8).—The oxidation of compound **5** with RuO_4 was previously described.[8a] The specific rotation, not reported earlier,[8a] is $[\alpha]^{27}D$ −90° (*c* 0.6, $CHCl_3$).

Solvolysis of 1,2-*O*-Isopropylidene-3,5-di-*O*-*p*-tolylsulfonyl-α-D-glucofuranose (3) in Refluxing *N*,*N*-Dimethylformamide. A. Without $CaCO_3$.—An *N*,*N*-dimethylformamide solution (15 ml) of compound **3** (200 mg) was heated under reflux for 50 min. The reaction mixture was cooled, the solvent was removed by distillation *in vacuo*, and the crude material was chromatographed on silica gel. Elution with 95:5 benzene–2-propanol afforded, in addition to the starting material (144 mg, 72%), the 5,6-anhydro derivative **4** (4 mg, 3%) and 6-*O*-formyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (**13**) (10 mg, 6%) as an oil: ir ($CHCl_3$) 3600 (OH), 1720 (formate C=O), 1585 (aromatic C=C), 1210 (formate C–O), 1190 and 1180 cm^{-1} (sym SO_2 stretch, Ts); nmr ($CDCl_3$) δ 8.03 (s, 1, HCOO–), 7.9–7.2 (m, 4, Ts), 5.97 (d, $J_{1,2}$ = 3.8 Hz, 1, H-1), 4.93 (d, $J_{3,4}$ = 2.4 Hz, 1, H-3), 4.73 (d, $J_{1,2}$ = 3.8 Hz, 1, H-2), 4.3–4.0 (m, 4, H-4, H-5, H-6 and H′-6), 2.47 (s, 3, Me from Ts), 1.50 and 1.30 (two s, 6, Me from Ip).

B. In the Presence of $CaCO_3$.—An *N*,*N*-dimethylformamide solution (15 ml) of **3** (200 mg) was refluxed in the presence of $CaCO_3$ (200 mg) for 50 min. The reaction mixture was cooled down, $CaCO_3$ was filtered off, the filtrate was evaporated *in vacuo*, and the crude product (220 mg) was chromatographed on silica gel (15 g). Elution with 95:5 benzene–2-propanol afforded (1) the 5,6-anhydro derivative **4** (10 mg, 7%), (2) starting material (118 mg, 59%), and (3) the 6-*O*-formyl derivative **13** (12 mg, 8%).

C. In the Presence of $CaCO_3$ for 5.5 Hr.—An *N*,*N*-dimethylformamide solution (15 ml) containing compound **3** (200 mg) and $CaCO_3$ (200 mg) was refluxed for 5.5 hr. After removal of $CaCO_3$ by filtration, evaporation of the solvent *in vacuo*, and chromatography of the crude product on silica gel, compound **13** was isolated in considerably higher yield (46 mg, 30%).

Refluxing of the 5,6-Anhydro Derivative 4 in *N*,*N*-Dimethylformamide.—An *N*,*N*-dimethylformamide solution (15 ml) containing the 5,6-anhydro derivative **4** (130 mg) was heated under reflux for 5 hr, and the reaction mixture was examined by tlc. There were no detectable amounts of **13** or any other reaction product present in the mixture.

5-*O*-Benzoyl-6-*O*-formyl-1,2-*O*-isopropylidene-3-*O*-*p*-tolylsulfonyl-β-L-idofuranose (14).—To a pyridine solution (2 ml) of **13** (59 mg), benzoyl chloride (0.15 ml) was added. The reaction mixture was allowed to stand at room temperature for 1 hr, and then diluted with water. The aqueous solution was extracted with ether, and the etheral extracts were dried over anhydrous $MgSO_4$ and evaporated *in vacuo*. The oily residue (167 mg) was chromatographed on silica gel. Elution with 4:1 benzene–acetone afforded pure **14** (64 mg, 86%) as an oil: $[\alpha]^{27}D$ −11.8° (*c* 0.79, $CHCl_3$); ir ($CHCl_3$) 1725 and 1715 (formate and benzoate C=O), 1270 (benzoate C–O), 1190 and 1178 cm^{-1} (sym SO_2 stretch, Ts); nmr ($CDCl_3$) δ 8.1–7.2 (m, 10, Ph, Ts, and HCOO), 6.00 (d, $J_{1,2}$ = 4.0 Hz, 1, H-1), 5.8–5.4 (m, 1, H-5), 5.07 (d, $J_{3,4}$ = 3.2 Hz, 1, H-3), 4.80 (d, $J_{1,2}$ = 4.0 Hz, 1, H-2), 4.57 (m, $J_{3,4}$ = 3.2 and $J_{4,5}$ = 8.0 Hz, 1, H-4), 4.4–4.2 (m, 2, H-6 and H′-6), 2.47 (s, 3, Me from Ts), 1.53 and 1.30 (two s, 6, Me from Ip).

Anal. Calcd for $C_{24}H_{26}O_{10}S$: C, 56.91; H, 5.17; S, 6.33. Found: C, 57.13; H, 5.09; S, 6.49.

Registry No.—**2,** 34885-58-0; **3,** 34885-59-1; **4,** 34885-60-4; **5,** 28642-59-3; **7,** 28642-56-0; **8,** 32785-86-7; **9,** 34885-84-2; **13,** 34885-64-8; **14,** 34885-65-9.