temperatures *m/e* 645, 647 disappears and the base peak shifts to *m/e* 277 ($Ph_3PCH_3^+$), an ion not present in the original 18-mA spectrum. Fragments of *m/e* 262 (Ph_3P^+) and *m/e* 289 ($Ph_3PCH{=}CH_2^+$) also appear above 23 mA.

In summary, we conclude that field desorption mass spectrometry provides a means of characterizing mono- and bisphosphonium halides formed in synthetic sequences and may have some application in the identification of these and similar salts when they are presented as unknowns. In general, the lowest anode current at which the sample is desorbed is most likely to provide ions related to unfragmented species. However, where additional current can be applied without causing instant desorption, valuable supplementary information may be obtained. This series of related salts has also provided some further background on the behavior of molecules under field desorption conditions, information which is essential if this technique is to have wide applicability as a supplement to electron impact mass spectrometry in structure determination.

Experimental Section

All compounds used in this work were prepared and characterized by published procedures.[2] The mass spectrometer was a Varian MAT Model CH5 DF with combined FD–FI–EI source. The samples were prepared as chloroform solutions (about 1 mg in 100 μl) and transferred to a conditioned anode by dipping.[10] The anodes are 10-μ tungsten wires spot-welded on supporting posts and conditioned in a Varian apparatus in a manner similar to that described by Beckey.[11] After excess solvent had evaporated, the anode carrying the sample was introduced into the cool source (generally 80°) through a vacuum lock. When vacuum better than 10^{-6} Torr was restored, the high voltage was applied (+3 kV to anode and −7 kV to cathode) and the focusing elements adjusted using the signals from a field ion beam produced by a mixture of acetone, toluene, and 6-undecanone introduced through the reference inlet. Anode heating was increased until a steady ion beam was obtained on the total ion beam monitor and the magnet scan was then commenced. Signals were obtained from an electron multiplier set at 1.75–2 kV (gain of 10^5–10^6) and spectra were recorded at nominal resolution of 1500 on an oscillographic recorder. The mass scale was calibrated with a Varian mass marker calibrated against perfluorokerosene (EI mode) every 20 amu (±0.4 amu). After each sample, the anode current was gradually increased to its maximum value (50 mA) to clean the wire before a new sample was run.

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Registry No.—**1**, 1100-88-5; **2**, 1530-32-1; **3**, 1560-54-9; **4**, 5044-52-0; **5**, 42855-48-1; **6**, 7354-47-4; **7**, 1519-45-5; **8**, 7333-67-7; **9**, 15546-42-6; **10**, 53643-43-9.

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5-Thio-D-fructofuranose[1,2]

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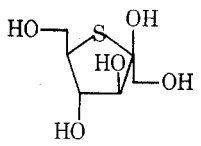
Three routes of synthesis for 5-thio-D-fructofuranose (1) are examined. Treatment of methyl 4-*O*-acetyl-1,3-*O*-benzylidene-5-*O*-tosyl-α-L-sorbopyranoside (**5**) with potassium thioacetate in DMF gives methyl 4-*O*-acetyl-5-*S*-acetyl-1,3-*O*-benzylidene-5-thio-β-D-fructopyranose (**13**). After three hydrolysis steps **1** is obtained. Alternately, **5** can be hydrolyzed to 4-*O*-acetyl-5-*O*-tosyl-α-L-sorbopyranoside (**22**). This, after acetylation with acetic acid, acetic anhydride, and sulfuric acid is treated with potassium thioacetate in DMF solution to give 1,2,3,4-tetra-*O*-acetyl-5-*S*-acetyl-5-thio-β-D-fructopyranose (**24**). Deacetylation of **24** leads to **1**. **1** is also obtained from 1,3-*O*-isopropylidene-α-L-sorbose (**25**) by selective tosylation and treatment with potassium thioacetate to give the 5-*S*-acetyl compound which is then hydrolyzed with aqueous trifluoroacetic acid and deacetylated.

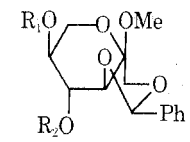
The interesting chemical and biochemical properties of thiosugars containing sulfur as the ring heteroatom have led in recent years to several examples of their preparation.[4] Such monosaccharides as 5-thio-D-glucopyranose,[4a] methyl 4-thio-D-arabinoside,[4b] 4-thio-D- and -L-ribose,[4c] and methyl 5-thio-D-xyloside[4d] have been synthesized. To provide analogs of D-fructose for metabolic examination we have prepared 6-thio-D-fructose[4e] and now 5-thio-D-fructose (**1**).

Recently Murphy[5] has found that treatment of methyl 1,3-*O*-benzylidene-4,5-di-*O*-mesyl-α-L-sorbopyranoside (**3**) with an excess of sodium benzoate or sodium azide in boiling *N,N*-dimethylformamide leads to displacement at the C-5 position to give the D-fructo sugars **9** and **10**, respectively. Treatment of 1,2-*O*-isopropylidene-3,4,5-tri-*O*-mesyl-α-L-sorbose (**11**) with sodium azide in hexamethylphosphoric triamide results in ready displacement of the mesyl group at C-5 only, to give the sugar **12** with the D-fructo configuration.[6] Armenakian, Mahmood, and Murphy[7] have found that **2** when treated with an equimolar amount of tosyl chloride in pyridine gives a good yield of the 5-substituted derivative **4** only.[8] These results suggested the synthesis of 5-thio-D-fructose (**1**) from an L-sorbose derivative.

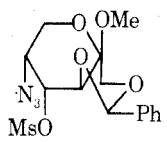
Compound **5**, prepared according to Murphy's procedure,[5,7] when heated at 100° in *N,N*-dimethylformamide in



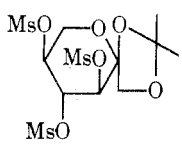
1



2, $R_1 = R_2 = H$
3, $R_1 = R_2 = Ms$
4, $R_1 = Ts$; $R_2 = H$
5, $R_1 = Ts$; $R_2 = Ac$
6, $R_1 = R_2 = Ts$
7, $R_1 = H$; $R_2 = Ts$
8, $R_1 = Ac$; $R_2 = Ts$



9, $R_3 = OBz$
10, $R_3 = N_3$



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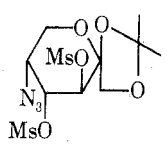


12

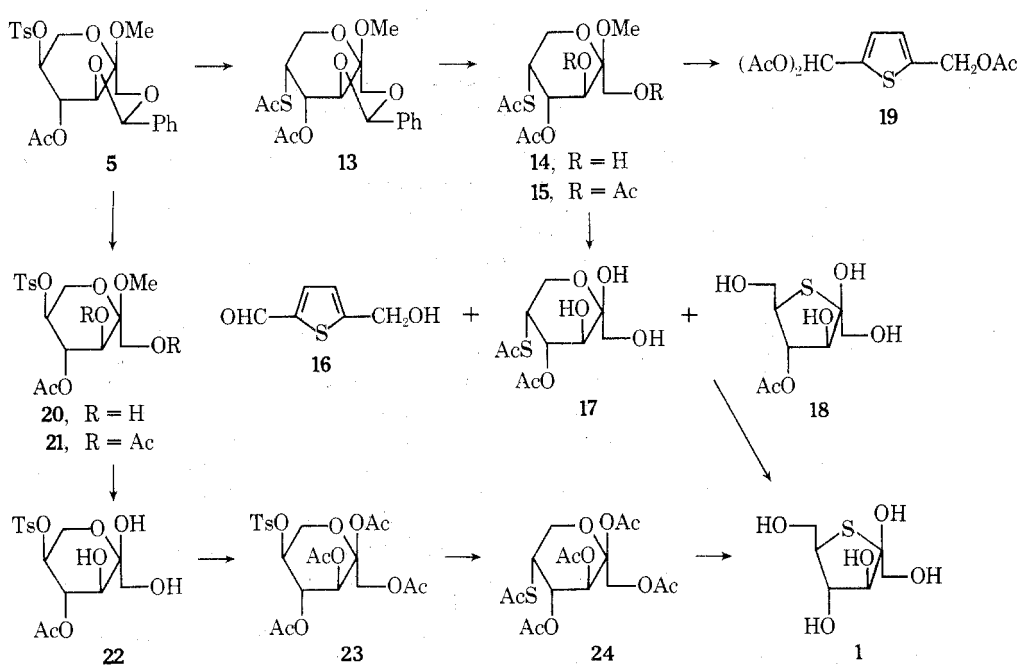
the presence of an excess of potassium thioacetate yielded methyl 4-*O*-acetyl-5-*S*-acetyl-1,3-*O*-benzylidene-5-thio-β-D-fructopyranoside (**13**). The nmr spectrum (*cf.* Experimental Section) of **13** shows signals characteristic for acetyl, thioacetyl, methoxyl, and benzylidene groups. H-3 signal at δ 4.03 is in the form of a doublet ($J_{3,4}$ = 10.9 Hz) whereas H-4 at δ 5.86 is a pair of doublets ($J_{3,4}$ = 10.9 and $J_{4,5}$ = 4.6 Hz). These data verify the β-D-fructose configuration of **13.**

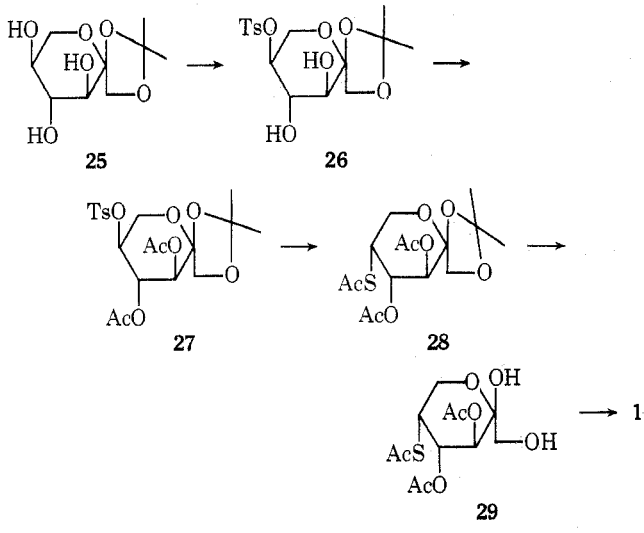
Hydrolysis of **13** with 50% aqueous acetic acid proceeds smoothly and affords the methyl 4-*O*-acetyl-5-*S*-acetyl-5-thio-β-D-fructopyranoside of **14.** Acid hydrolysis of **14** did not give a satisfactory yield of **17** or **18.** Numerous experiments using diluted acids such as sulfuric acid, hydrochloric acid, acetic acid, and ionic exchange resin IR120 (H^+) were unsuccessful. Compound **14** easily undergoes transformation into the thiophene derivative **16.** Likewise the acetolysis of **14** with acetic acid and acetic anhydride in the presence of a catalytic amount of sulfuric acid gives a mixture of several products. The major component was isolated chromatographically and identified as the triacetate **19.** Mineral acids induce formation of furan compounds from mono- and polysaccharides[9] and ketoses decompose more readily than aldoses.[10] The possibility of obtaining the more stable thiophene, higher energy of resonance than furan, makes the degradation of derivatives of 5-thio-D-fructose into **16** and **19** very easy. Treatment of **14** with trifluoroacetic acid at 25°, however, gave a mixture of three compounds which could be separated chromatographically. From their nmr spectra, the less polar (tlc) compound is the thiophene derivative **16** and the others are 4-*O*-acetyl-5-*S*-acetyl-5-thio-β-D-fructopyranose (**17**) and 4-*O*-acetyl-5-thio-β-D-fructofuranose (**18**). The nmr spectrum of **17** shows two singlets at δ 2.08 and 2.60, corresponding to *O*-acetyl and *S*-acetyl groups, and does not show an absorption due to an *O*-methyl group. The doublet of H-3 at δ 3.99 with $J_{3,4}$ = 10.4 Hz and the pair of doublets of H-4 at δ 5.48 ($J_{3,4}$ = 10.4 and $J_{4,5}$ = 4.7 Hz) indicates a fructo configuration and a pyranose ring in **17.** The nmr spectrum of **16** indicated the absence of *S*-acetyl and *O*-methyl groups. A three-proton singlet at δ 2.24 for *O*-acetyl, a doublet for H-3 at δ 4.31 ($J_{3,4}$ = 9.8 Hz), and a pair of doublets at δ 5.53 ($J_{3,4}$ = 9.8 and $J_{4,5}$ = 7.6 Hz) support a furanose ring structure for **18.** Deacetylation of **18** with sodium methoxide in methanol led to the free sugar **1.**

An alternate method was examined for the synthesis of **1** so as to avoid the necessity of hydrolyzing **14** with acid. Compound **5** can be hydrolyzed with aqueous trifluoroacetic acid to give **20.** After removing benzaldehyde, **20** was again hydrolyzed with trifluoroacetic acid. The crude product **22,** when acetylated at 0° with acetic acid and acetic anhydride in the presence of a catalytic amount of sulfuric acid, gave 1,2,3,4-tetra-*O*-acetyl-5-*O*-tosyl-α-L-sorbose **23** only. The structure of **23** was readily deduced from its nmr spectrum (*cf.* Experimental Section). Treatment of **23** with potassium thioacetate in *N,N*-dimethylformamide at 70° produces the pentaacetate **24,** which after deacetylation gives **1.**

Because the overall yield in these reactions was not satisfactory a shorter and more efficient route was worked out. 1,2-*O*-Isopropylidene-α-L-sorbose (**25**) was the starting material.

Compound **25** is readily tosylated with an equimolar amount of tosyl chloride at 0° to produce the 5-*O*-tosyl derivative **26** in 40% yield. The structure of **26** was deduced from its nmr spectrum and from the spectrum of its diacetate **27.** The nmr spectrum of **26** shows signals characteristic of isopropylidene and tosyl groups. The pair of triplets for H-5 ($J_{4,5} \simeq J_{5,6a} \simeq 9$ and $J_{5,6e} \simeq 7$ Hz) at δ 5.06 testifys that only the hydroxyl group at C-5 was substituted. Heating **27** at 80° in *N,N*-dimethylformamide in the presence of

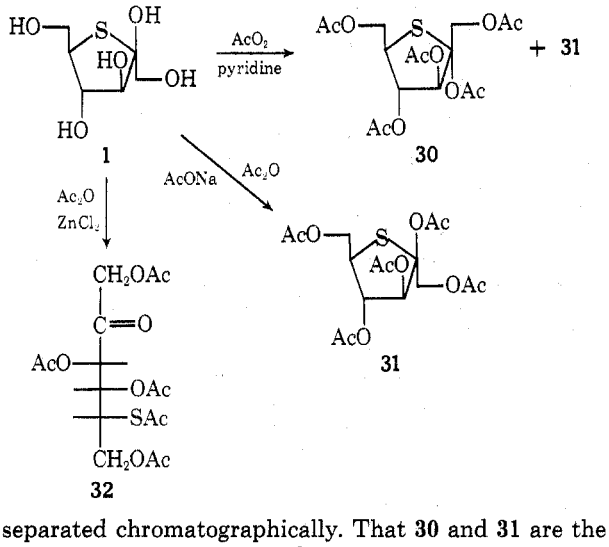




an excess of potassium thioacetate gives 3,4-di-*O*-acetyl-5-*S*-acetyl-1,2-*O*-isopropylidene-5-thio-β-D-fructopyranose (**28**) in good yield. The structure of **28** is deduced from its nmr spectrum (*cf.* Experimental Section). Triacetate **28** is easily hydrolyzed with aqueous trifluoroacetic acid and yields **29**. Deacetylation of **29** gives the free sugar **1**.

5-Thio-D-fructofuranose (**1**) is a colorless syrup, stable at 25°, and does not oxidize at a perceptable rate. The specific optical rotation in methanol is +1.4°.

Acetylation of **1** with acetic anhydride and pyridine leads to a mixture of two pentaacetates, **30** (highest R_f on tlc) and **31**, whereas acetylation in boiling acetic anhydride and sodium acetate gives **31** only. Pentaacetates **30** and **31** can



be separated chromatographically. That **30** and **31** are the anomers of 1,2,3,4,6-penta-*O*-acetyl-5-thio-D-fructofuranose is easily deduced from their ir and nmr spectra. The ir spectra of **30** and **31** show acetyl–carbonyl absorption but do not show any absorption attributable to SAc, OH, and SH groups. The nmr spectra of both compounds integrated for five OAc groups, and the coupling constants $J_{3,4}$ and $J_{4,5}$ are 6.8 and 6.7 Hz for **30**, whereas they are 7.9 and 5.8 Hz for **31**, respectively. Due to the opposition of the anomeric *O*-acetyl group it was expected that in nmr spectra the signals of H-3 and H-5 in the α-D-anomer would be shifted downfield and H-4 would be shifted upfield when compared with β-D-anomer. In the spectrum of **30** H-3 was observed at δ 6.06, H-4 at δ 5.56, and H-5 at δ 3.90, whereas the corresponding data for **31** are H-3 at δ 5.80, H-4 at δ 5.65, and H-5 at δ 3.66. Consequently we characterize **30** as α-D-anomer and **31** as β-D-anomer of 1,2,3,4,6-penta-*O*-acetyl-5-thio-D-fructofuranose. The specific optical rotation of **30** is +153.8° and that of **31** is −91.3°. These rotations are fully consistent with proposed structures.[11] Acetylation of **1** with acetic anhydride in the presence of zinc chloride leads to a mixture of three isomeric pentaacetates. The major component **32** readily crystallizes from the mixture in 25% yield. On the basis of the nmr spectra and the specific optical rotation it is recognized as 1,3,4,6-tetra-*O*-acetyl-5-*S*-acetyl-5-thioketo-D-fructose (**32**) and the two remaining compounds as **30** and **31**.

Acetylation of 5-thio-D-fructose (**1**) differs from that of natural D-fructose. D-Fructose, however, exists in the crystalline form as β-D-fructopyranose only, while in solution it occurs in an equilibrium of pyranose and furanose forms.[11,12] Our thio analog remains in the furanose form.

The acetylation of D-fructose has been the subject of numerous investigations.[11-18] Acetylation using boiling acetic anhydride and sodium acetate leads to an unidentified mixture of acetates.[13] The only crystalline product isolated after acetylating D-fructose in pyridine solution is keto-D-fructose pentaacetate in 5% yield.[14] Treatment of D-fructose with acetic anhydride and zinc chloride at 50° leads to the open chain pentaacetate,[15] whereas at 0–5° 1,3,4,5-tetra-*O*-acetyl-β-D-fructopyranose is obtained.[14] Sulfuric acid as a catalyst at 0–5° gives this same tetraacetate.[16] Perchloric acid in an acetylating mixture at 70° gives 1,2,3,4,5-penta-*O*-acetyl-β-D-fructopyranose.[17] No crystalline acetate of D-fructofuranose has been prepared. D-Fructofuranose pentaacetate (a liquid) was first synthesized using perchloric acid as the catalyst.[17,18]

5-Thio-D-fructose (**1**) is sufficiently stable in the presence of the basic catalysts such as pyridine or sodium acetate to produce the pentaacetates of the furanose form only. Production of the mixture of **30** and **31** in pyridine proves that in this solvent **1** exists as an equilibrium of α- and β-D-anomers of the furanose form. The observed specific optical rotation of **1** of −7.7° in water and +13.5° after 4 hr in pyridine strongly supports this view. In aqueous solution, **1** exists predominantly as β-D-furanose, which can be deduced from the nmr spectrum of **18** in D_2O. This shows H-3 and H-4 signals for one anomer only. There is no reason to expect that the $\alpha \rightleftarrows \beta$ equilibrium of **1** is different than that for **18**. In addition, the optical rotation of **1** is close to the value expected for β-D-fructofuranose ($[\alpha]^{25}D$ −4.58°).[19] The opening of the thioacetal ring is possible in the presence of a Lewis acid catalyst ($ZnCl_2$). The main product **32** is probably the most stable pentaacetate. The formation of pentaacetate or tetraacetate with the pyranose ring, as obtained with D-fructose, was not observed under any conditions with our thio analog. The lower stability of **1**, however, in the presence of strong acids precludes using perchloric acid or sulfuric acid as a catalyst.

Experimental Section

General Methods. Purity of products was determined by thin-layer chromatography (tlc) on silica gel G (E. Merck, Darmstadt, Germany). Components were located by spraying with 5% sulfuric acid in ethanol and heating. Column chromatography was performed on silica gel, powder 60–200 mesh (J. T. Baker Chemical Co.). Melting points were determined with a Fisher-Johns apparatus and were corrected. Optical rotations were measured on a Perkin-Elmer Model 141 polarimeter. Nuclear magnetic resonance spectra were obtained in chloroform-*d* and pyridine-d_5 solution (TMS as internal standard) or deuterium oxide (*tert*-butanyl alcohol as internal standard) with a Varian T-60A spectrometer. Ir spectra were recorded with a Perkin-Elmer Model 337 infrared spectrometer.

Methyl 4-*O*-acetyl-1,3-*O*-benzylidene-5-*O*-tosyl-α-L-sorbopyranoside (**5**) was prepared according to Murphy's procedure.[5,7] 1,2-*O*-Isopropylidene-α-L-sorbose (**25**) was obtained according to the literature procedure.[20]

A sample of the crude **4**[5] was chromatographed using 9.9:0.1

benzene–acetone mixture as eluent. In addition to **4**, the small amounts of the less polar (tlc) methyl 1,3-*O*-benzylidene-4,5-di-*O*-tosyl-α-L-sorbopyranoside (**6**) and the more polar methyl 1,3-*O*-benzylidene-4-*O*-tosyl-α-L-sorbopyranoside (**7**) were isolated.

6: mp 121–122° dec; $[\alpha]^{25}D$ −71.3° (*c* 1.54, $CHCl_3$); nmr ($CDCl_3$) δ 2.31, 2.54 (2 s, 6, CH_3 of tosyl), 3.43 (s, 3, OCH_3), 3.59 (d, 1, $J_{1,1}$ = −12.8 Hz, H-1), 3.66 (d, 1, $J_{3,4}$ = 10.1 Hz, H-3), 3.87 (t, 1, $J_{5,6a}$ = 11.0, $J_{6a,6e}$ = −11.3 Hz, H-6a), 4.32 (pd, 1, $J_{5,6e}$ = 6.2 Hz, H-6e), 4.45 (d, 1, H-1′), 4.72 (pt, 1, $J_{4,5}$ = 9.0 Hz, H-5), 5.39 (pd, 1, H-4), 5.50 (s, 1, CH of benzylidene), 7.08–8.23 (m, 13, aromatic).

Anal. Calcd for $C_{28}H_{30}S_2O_{10}$: C, 56.9; H, 5.1; S, 10.9. Found: C, 57.2; H, 5.2; S, 10.7.

7: mp 124–125° dec; $[\alpha]^{25}D$ −76.6° (*c* 1.24, $CHCl_3$); nmr ($CDCl_3$) δ 2.39 (s, 3, CH_3 of tosyl), 3.41 (s, 3, OCH_3), 3.60 (d, 1, $J_{1,1'}$ = −12.7 Hz, H-1), 3.6–4.4 (m, 3, H-5, H-6a, H-6e), 3.73 (d, 1, $J_{3,4}$ = 10.1 Hz, H-3), 4.45 (d, 1, H-1′), 5.06 (pd, 1, $J_{4,5}$ = 7.5 Hz, H-4), 5.58 (s, 1, CH of benzylidene), 7.2–8.0 (m, 9, aromatic).

Anal. Calcd for $C_{21}H_{24}SO_8$: C, 57.8; H, 5.6; S, 7.3. Found: C, 58.0; H, 5.8; S, 7.4.

Acetylation of **7** with acetic anhydride and pyridine gave **8:** mp 128–129° dec; $[\alpha]^{25}D$ −88.4° (*c* 0.98, $CHCl_3$); nmr ($CDCl_3$) δ 2.13 (s, 3, OAc), 2.37 (s, 3, CH_3 of tosyl), 3.46 (s, 3, OCH_3), 3.63 (d, 1, $J_{1,1'}$ = −12.7 Hz, H-1), ~3.7 (pd, 1, $J_{5,6a}$ = 9.2, $J_{6a,6e}$ = −11.0 Hz, H-6a), 3.76 (d, 1, $J_{3,4} \simeq$ 9.2 Hz, H-3), 4.05 (pd, 1, $J_{5,6e}$ = 6.1 Hz, H-6e), 4.47 (d, 1, H-1′), 5.23 (pt, 1, $J_{4,5} \simeq$ 9.2 Hz, H-5), 5.50 (t, 1, H-4), 5.60 (s, 1, CH of benzylidene), 7.2–8.0 (m, 9, aromatic).

Anal. Calcd for $C_{23}H_{26}SO_9$: C, 58.0; H, 5.1; S, 6.7. Found: C, 58.1; H, 5.3; S, 6.6.

Methyl 4-*O*-Acetyl-5-*S*-acetyl-1,3-*O*-benzylidene-5-thio-β-D-fructopyranoside (13). A mixture of **5** (2.0 g) and potassium thioacetate (3.0 g) in *N,N*-dimethylformamide (40 ml) was stirred and heated at 100° in a current of nitrogen for 6 hr. The reaction mixture was then poured into water (500 ml). The precipitate was filtered, washed with water, and dried. Recrystallization from isopropyl alcohol gave colorless crystals (1.2 g): mp 123–124°; $[\alpha]^{25}D$ −117.8° (*c* 1.35, $CHCl_3$); yield 75%; ν_{max} (Nujol) 1740 (*O*-acetyl) and 1680 cm^{-1} (*S*-acetyl); nmr ($CDCl_3$) δ 2.04 (s, 3, OAc), 2.45 (s, 3, SAc), 3.46 (s, 3, OCH_3), 3.71 (d, 1, $J_{1,1'}$ = −12.4 Hz, H-1), 3.80 (pd, 1, $J_{5,6e}$ = 2.0, $J_{6a,6e}$ = −13.3 Hz, H-6e), 4.03 (d, 1, $J_{3,4}$ = 10.9 Hz, H-3), ~4.4 (m, 3, H-1′, H-5, H-6a), 5.86 (pd, 1, $J_{4,5}$ = 4.6 Hz, H-4), 5.80 (s, 1, CH of benzylidene), 7.66 (m, 5, aromatic).

Anal. Calcd for $C_{18}H_{22}SO_7$: C, 56.5; H, 5.8; S, 8.4. Found: C, 56.7; H, 5.9; S, 8.2.

Methyl 4-*O*-Acetyl-5-*S*-acetyl-5-thio-β-D-fructopyranoside (14). A stirred solution of **13** (0.50 g) in 50% aqueous acetic acid (10 ml) was heated at 75° under nitrogen for 30 min. The solvents were then carefully removed under vacuum. The oily residue was crystallized from an ethyl acetate–hexane mixture and 0.23 g (60%) of **14** was obtained: mp 127–128°; $[\alpha]^{25}D$ −190.7° (*c* 1.02, $CHCl_3$); nmr ($CDCl_3$) δ 2.06 (s, 3, OAc), 2.44 (s, 3, SAc), 3.46 (s, 3, OCH_3), 3.80 (pd, 1, $J_{5,6e}$ = 2.1, $J_{6e,6a}$ = −12.3 Hz, H-6e), 3.88 (s, 2, H-1, H-1′), 4.20 (pd, 1, $J_{5,6a}$ = 4.7 Hz, H-6a), 4.26 (d, 1, $J_{3,4}$ = 10.4 Hz, H-3), ~4.3 (m, 1, H-5), 5.50 (pd, 1, $J_{4,5}$ = 4.5 Hz, H-4).

Anal. Calcd for $C_{11}H_{18}SO_7$: C, 44.9; H, 6.2; S, 10.9. Found: C, 45.1; H, 6.2; S, 11.4.

Acetate **15:** oil; $[\alpha]^{25}D$ −108.9° (*c* 1.12, $CHCl_3$); nmr ($CDCl_3$) δ 1.99, 2.12, 2.17 (3 s, 9, 3 OAc), 2.45 (s, 3, SAc), 3.44 (s, 3, OCH_3), 3.86 (pd, 1, $J_{5,6e}$ = 2.1, $J_{6e,6a}$ = −13.0, H-6e), 4.26 (s, 2, H-1, H-1′), ~4.3 (m, 2, H-5, H-6a), 5.48 (d, 1, $J_{3,4}$ = 10.7 Hz, H-3), 5.64 (pd, 1, $J_{4,5}$ = 3.6 Hz, H-4).

Anal. Calcd for $C_{15}H_{22}SO_9$: C, 47.6; H, 5.9; S, 8.5. Found: C, 48.1; H, 6.1; S, 8.1.

2-Diacetoxymethyl-5-acetoxymethylthiophene (19). To a cold mixture of acetic acid (12 ml), acetic anhydride (12 ml), and sulfuric acid (0.5 ml), 0.5 g of **14** was added. The mixture was refrigerated for 48 hr. Then 2 g of sodium acetate was added, and the solvents were carefully evaporated under pressure. To the residue 50 ml of ice and water was added, and the mixture was extracted with chloroform. The extract was washed, dried, and evaporated to dryness. The oil was chromatographed with hexane–ethyl acetate (9.5:0.5) mixture. The less polar **19** (0.1 g) was obtained: colorless oil; nmr ($CDCl_3$) δ 2.16 (s, 9, 3 OAc), 5.40 (s, 2, CH_2), 7.20 (d, 1, J = 4 Hz, H-4), 7.35 (d, 1, H-3), 8.11 (s, 1, CH).

Hydrolysis of 14. Compound **14** (7.50 g) was dissolved in 50% aqueous trifluoroacetic acid (60 ml) and kept under nitrogen for 30 hr at room temperature. The mixture was then neutralized with Amberlite IR-45. The aqueous solution was evaporated to dryness and chromatographed with chloroform–methanol (9.8:0.2, v/v) as eluent. Three fractions were isolated, the first containing 0.80 g of a mixture of **14** and **16**, the second 0.18 g of **17**, and the third 1.44 g of **18**. The first fraction was chromatographed using hexane–ethyl acetate (9:1, v/v) as eluent; 0.50 g of **14** and 0.17 g of **16** were obtained.

16: colorless oil; nmr ($CDCl_3$) δ 5.01 (s, 2, CH_2), 7.30 (d, 1, J = 3.9 Hz, H-4), 7.93 (d, 1, H-3), 10.12 (s, 1, OHC); ν_{max}^{film} 3400 (OH), 1650 cm^{-1} (C=O).

17: colorless syrup; $[\alpha]^{25}D$ −67.6° (*c* 0.52, MeOH); nmr (D_2O) δ 2.08 (s, 3, OAc), 2.60 (s, 3, SAc), 3.62 (d, 1, $J_{1,1'}$ = ~12.0 Hz, H-1), 3.80 (d, 1, H-1′), ~3.8 (m, 1, H-6a), 3.99 (d, 1, $J_{3,4}$ = 10.4 Hz, H-3), ~4.4 (m, 1, H-5), 4.54 (pd, 1, $J_{5,6e}$ = 2.1, $J_{6e,6a}$ = −12.8 Hz, H-6e), 5.48 (pd, 1, $J_{4,5}$ = 4.7 Hz, H-4).

Anal. Calcd for $C_{10}H_{16}SO_7$: C, 42.9; H, 5.8; S, 11.4. Found: C, 43.0; H, 5.8; S, 11.3.

18: colorless syrup; $[\alpha]^{25}D$ −11.6° (*c* 0.92, MeOH); nmr (D_2O) δ 2.24 (s, 3, OAc), 3.1–4.1 (m, 5, H-1, H-1′, H-5, H-6, H-6′), 4.31 (d, 1, $J_{3,4}$ = 9.8 Hz, H-3), 5.53 (pd, 1, $J_{4,5}$ = 7.6 Hz, H-4).

Anal. Calcd for $C_8H_{14}SO_6$: C, 40.3; H, 5.9; S, 13.4. Found: C, 39.6; H, 5.8; S, 13.1.

Deacetylation of **17** and **18** with sodium methoxide in methanol gave **1** as a colorless syrup; $[\alpha]^{25}D$ +1.4° (*c* 0.92, MeOH).

Anal. Calcd for $C_6H_{12}SO_5$: C, 36.7; H, 6.1; S, 16.3. Found: C, 37.0; H, 6.1; S, 16.1.

Methyl 4-*O*-Acetyl-5-*O*-tosyl-α-L-sorbopyranoside (20). A solution of **5** (40.0 g) in 90% aqueous trifluoroacetic acid (40.0 ml) was stirred at room temperature for 30 min. The solution was then diluted with 200 ml of water and then the solvents were carefully removed under vacuum. Crude **20** was crystallized from a hexane–ethyl acetate mixture: yield 95% (31.0 g); mp 129–130°; $[\alpha]^{25}D$ −72.9° (*c* 0.94, $CHCl_3$); nmr ($CDCl_3$) δ 1.89 (s, 3, OAc), 2.53 (s, 3, CH_3 of tosyl), 3.43 (s, 3, OCH_3), 3.66 (t, 1, $J_{6a,6e}$ = −11.0, $J_{6a,5}$ = 10.6 Hz, H-6a), 3.76 (d, 1, $J_{3,4}$ = 9.5 Hz, H-3), 3.84 (s, 2, H-1, H-1′), 4.03 (pd, 1, $J_{5,6e}$ = 5.6 Hz, H-6e), 4.64 (m, 1, H-5), 5.41 (t, 1, $J_{4,5}$ = ~9.5 Hz, H-4), 7.5–8.1 (m, 4, aromatic).

Anal. Calcd for $C_{16}H_{22}SO_9$: C, 49.2; H, 5.7; S, 8.2. Found: C, 49.3; H, 5.7; S, 8.3.

Acetate **21:** colorless oil; $[\alpha]^{25}D$ −24.2° (*c* 1.05, $CHCl_3$); nmr ($CDCl_3$) δ 1.78, 2.06, 2.12 (3 s, 9, 3 OAc), 2.53 (s, 3, CH_3 of tosyl), 3.43 (s, 3, OCH_3), 3.71 (t, 1, $J_{5,6a}$ = 11.6, $J_{6a,6e}$ = −11.6 Hz, H-6a), 4.10 (pd, 1, $J_{5,6e}$ = 6.2 Hz, H-6e), 4.29 (d, 1, $J_{1,1'}$ = −11.6 Hz, H-1), 4.40 (d, 1, H-1′), 4.72 (m, 1, H-5), 5.08 (d, 1, $J_{3,4}$ = 10.6 Hz, H-3), 5.64 (pd, 1, $J_{4,5}$ = 8.6 Hz, H-4), 7.5–8.2 (m, 4, aromatic).

Anal. Calcd for $C_{20}H_{26}SO_{11}$: C, 50.6; H, 5.5; S, 6.8. Found: C, 50.7; H, 5.4; S, 6.9.

1,2,3,4-Tetra-*O*-acetyl-5-*O*-tosyl-α-L-sorbopyranose (23). Compound **20** (30.0 g) was dissolved in 70% aqueous trifluoroacetic acid (50 ml) and heated at 80° for 3 hr. The solvents were then carefully removed and the oily residue (**22**) was treated with a cold solution of acetic acid (40 ml), acetic anhydride (40 ml), and sulfuric acid (2.4 ml). The mixture was then refrigerated for 24 hr. Sulfuric acid was then neutralized with sodium acetate (10.0 g). The mixture was poured over ice and extracted with chloroform. The extract was washed with sodium bicarbonate, dried, and evaporated to dryness. The crude syrup was purified chromatographically: yield 39.0% (15.0 g); colorless syrup; $[\alpha]^{25}D$ −35.2° (*c* 1.01, $CHCl_3$); nmr ($CDCl_3$) δ 1.83, 2.07, 2.11, 2.24 (4 s, 12, 4 OAc), 2.53 (s, 3, CH_3 of tosyl), 3.76 (t, 1, $J_{5,6a}$ = 11.6, $J_{6a,6e}$ = −11.6 Hz, H-6a), 4.16 (pd, 1, $J_{5,6e}$ = 6.1 Hz, H-6e), 4.65 (d, 1, $J_{1,1'}$ = −12.2, H-1), ~4.7 (m, 1, H-5), 7.81 (d, 1, H-1′), 5.30 (d, 1, $J_{3,4}$ = 10.0 Hz, H-3), 5.61 (pd, 1, $J_{4,5}$ = 8.5 Hz, H-4), 7.5–8.1 (m, 4, aromatic).

Anal. Calcd for $C_{21}H_{26}SO_{12}$: C, 50.2; H, 5.2; S, 6.4. Found: C, 50.4; H, 5.5; S, 6.6.

1,2,3,4-Tetra-*O*-acetyl-5-*S*-acetyl-5-thio-β-D-fructopyranose (24). A solution of **23** (2.9 g) and potassium thioacetate (2.9 g) in *N,N*-dimethylformamide (30 ml) was stirred and heated at 70° in a current of nitrogen for 30 hr. The reaction mixture was then poured into 500 ml of water and then extracted with ether. The extract was washed, dried, and evaporated to dryness. The crude oil was purified chromatographically using (9.5:0.5, v/v) benzene–ethyl acetate as eluent: yield 52% (1.2 g); mp 104–105° (hexane–ethyl acetate); $[\alpha]^{25}D$ −116.7° (*c* 0.87, $CHCl_3$); nmr ($CDCl_3$) δ 2.01, 2.11, 2.18, 2.24 (4 s, 12, 4 OAc), 2.47 (s, 3, SAc), 4.01 (pd, 1, $J_{5,6e}$ = 1.5, $J_{6e,6a}$ = −13.3 Hz, H-6e), ~4.4 (m, 2, H-5, H-6a), 4.64 (d, 1, $J_{1,1'}$ = −12.0 Hz, H-1), 4.82 (d, 1, H-1′), 5.53 (d, 1, $J_{3,4}$ = 10.3 Hz, H-3), 5.65 (pd, 1, $J_{4,5}$ = 3.8 Hz, H-4).

Anal. Calcd for $C_{16}H_{22}SO_{10}$: C, 47.3; H, 5.5; S, 7.9. Found: C, 47.4; H, 5.5; S, 8.0.

Deacetylation of **24** with sodium methoxide in methanol gave **1**.

1,2-*O*-Isopropylidene-5-*O*-tosyl-α-L-sorbose (26). Compound **25** (30.0 g) and tosyl chloride (27.0 g) were added to dry pyridine (200 ml), and the solution was kept at 0° for 2 days. The

reaction mixture was then poured into cold water and extracted with chloroform. The extract was dried and evaporated to dryness. The residue crystallized immediately and this mass was then cooled and stirred in absolute ether (50 ml). After further cooling, the crystalline product was removed by filtration: yield 20.0 g (39%); mp 130–131° dec (ethanol); $[\alpha]^{25}D$ −52.1° (*c* 1.11, $CHCl_3$); nmr (pyridine-d_5) δ 1.61 (s, 6, isopropylidene), 2.29 (s, 3, CH_3 of tosyl), 3.9–4.8 (m, 6, H-1, H-1′, H-3, H-4, H-6a, H-6e), 5.06 (pt, 1, $J_{4,5} \simeq J_{5,6a} \simeq 9$, $J_{5,6e} \simeq 7$ Hz, H-5), 7.5–8.4 (m, 4, aromatic).

Anal. Calcd for $C_{16}H_{22}SO_8$: C, 51.3; H, 5.9; S, 8.6. Found: C, 51.5; H, 5.9; S, 8.6.

Acetylation of **26** with acetic anhydride and pyridine give **27**: mp 109–110° dec (hexane–ethyl acetate); $[\alpha]^{25}D$ −27.5° (*c* 1.12, $CHCl_3$); nmr ($CDCl_3$) δ 1.44, 1.50 (2 s, 6, isopropylidene), 1.83, 2.10 (2 s, 6, 2 OAc), 2.53 (s, 3, CH_3 of tosyl), 4.62 (m, 4, H-1, H-1′, H-6a, H-6e), 4.73 (pt, 1, $J_{4,5} = J_{5,6a} = 9.1$, $J_{5,6e} = 7.3$ Hz, H-5), 5.10 (d, 1, $J_{3,4} = 10.1$ Hz, H-3), 5.60 (pd, 1, H-4), 7.5–8.1 (m, 4, aromatic).

Anal. Calcd for $C_{20}H_{26}SO_{10}$: C, 52.4; H, 5.7; S, 7.0. Found: C, 52.7; H, 5.8; S, 7.1.

3,4-Di-*O*-acetyl-5-*S*-acetyl-1,2-*O*-isopropylidene-5-thio-β-D-fructopyranose (28). To a solution of **27** (10.0 g) in dry *N,N*-dimethylformamide (200 ml), potassium thioacetate (10.0 g) was added, and the mixture stirred and heated at 75° for 70 hr in a current of nitrogen. The reaction mixture was then poured into cold water and the solid filtered off. Recrystallization from hexane–ethyl acetate gave 6.5 g (82%) of **28**: mp 74–75°; $[\alpha]^{25}D$ −86.7° (*c* 0.56, $CHCl_3$); nmr ($CDCl_3$) δ 1.45, 1.52 (2 s, 6), isopropylidene, 2.02, 2.15 (2 s, 6, 2 OAc), 2.45 (s, 3, SAc), 3.85 (m, 1, H-6a), 4.06 (s, 2, H-1, H-1′), 4.4 (m, 1, H-5), 4.55 (pd, 1, $J_{5,6e} = 2.1$, $J_{6a,6e} = -11.5$ Hz, H-6e), 5.32 (d, 1, $J_{3,4} = 10.8$ Hz, H-3), 5.70 (pd, 1, $J_{4,5} = 4.2$ Hz, H-4).

Anal. Calcd for $C_{15}H_{22}SO_8$: C, 49.7; H, 6.1; S, 8.9. Found: C, 49.9; H, 6.2; S, 9.1.

3,4-Di-*O*-acetyl-5-*S*-acetyl-5-thio-β-D-fructopyranose (29). A solution of **28** (6.0 g) in 90% aqueous trifluoroacetic acid (40 ml) was kept under nitrogen for 3 hr at room temperature. The solvents were then carefully removed under vacuum to give the crude product, 5.0 g (24%). After recrystallization from ethyl acetate–ethyl ether, pure **29** was obtained: mp 118–120°; $[\alpha]^{25}D$ −68.9° (*c* 0.75 $CHCl_3$).

Anal. Calcd for $C_{12}H_{18}SO_8$: C, 44.7; H, 5.6; S, 10.0. Found: C, 44.6; H, 5.8; S, 9.9.

Deacetylation of crude **29** gave **1**.

1,2,3,4,6-Penta-*O*-acetyl-5-thio-α-D-fructofuranose (30) and 1,2,3,4,6-Penta-*O*-acetyl-5-thio-β-D-fructofuranose (31). Compound **1** (0.30 g) was acetylated with acetic anhydride and pyridine. Following evaporation of the solvents, the crude mixture of pentaacetates was separated chromatographically using hexane–ethyl acetate (9:1, v/v) as eluent. 0.13 g of **30** and 0.08 g of **31** were obtained.

30: mp 107–108°; $[\alpha]^{25}D$ +153.8° (*c* 0.67, $CHCl_3$); nmr ($CDCl_3$) δ 2.15 (s, 15, 5 OAc), 3.90 (q, 1, $J_{4,5} = 6.4$, $J_{5,6} = 6.9$, $J_{5,6'} = 6.6$ Hz, H-5), 4.21 (pd, 1, $J_{6,6'} = -11.5$ Hz, H-6), 4.53 (pd, 1, H-6′), 4.61 (d, 1, $J_{1,1'} = -12.2$ Hz, H-1), 4.84 (d, 1, H-1′), 5.56 (t, 1, $J_{3,4} = 6.4$ Hz, H-4), 6.06 (d, 1, H-3).

Anal. Calcd for $C_{16}H_{22}SO_{10}$: C, 47.3; H, 5.5; S, 7.9. Found: C, 47.5; H, 5.7; S, 7.8.

31: mp 70–73°; $[\alpha]^{25}D$ −91.3° (*c* 0.87, $CHCl_3$); nmr ($CDCl_3$) δ 2.15 (s, 15, 5 OAc), 3.66 (q, 1, $J_{4,5} = 6.0$, $J_{5,6} = 7.0$, $J_{5,6'} = 6.6$ Hz, H-5), 4.20 (pd, 1, $J_{6,6'} = -11.0$ Hz, H-6), 4.46 (pd, 1, H-6′), 4.64 (d, 1, $J_{1,1'} = -12.1$ Hz, H-1), 4.77 (d, 1, H-1′), 5.65 (pd, 1, $J_{3,4} = 7.5$ Hz, H-4), 5.80 (d, 1, H-3).

Anal. Calcd for $C_{16}H_{22}SO_{10}$: C, 47.3; H, 5.5; S, 7.9. Found: C, 47.5; H, 5.7; S, 8.2.

1,2,3,4,6-Penta-*O*-acetyl-5-thio-β-D-fructofuranose (31). Compound **1** (0.60 g) was heated with acetic anhydride (7 ml) and sodium acetate (0.5 g) for 2 hr. The mixture was then poured into ice and water and extracted with ether. The extract was dried and evaporated. The crude product was purified chromatographically; yield 20% (0.25 g).

1,3,4,6-Tetra-*O*-acetyl-5-*S*-acetyl-5-thioketo-D-fructose (32). Compound **1** (0.50 g) was stirred under nitrogen at room temperature for 24 hr with acetic anhydride (5 ml) containing zinc chloride (0.05 g). The solution was then poured into ice and water and extracted with ether. The extract was dried, and evaporated to dryness. Upon treatment with ethanol (1 ml), **32** crystallizes after several hours in a 25% yield (0.20 g): mp 91–92°; $[\alpha]^{25}D$ +14.1° (*c* 0.501, $CHCl_3$); nmr ($CDCl_3$) δ 2.13, 2.16, 2.25, 2.31 (4 s, 12, 4 OAc), 2.45 (s, 3, SAc), 4.0–4.7 (m, 3, H-5, H-6, H-6′), 4.83 (d, 1, $J_{1,1'} = -18.0$ Hz, H-1), 5.11 (d, 1, H-1′), 5.83 (m, 2, H-3, H-4).

Anal. Calcd for $C_{16}H_{22}SO_{10}$: C, 47.3; H, 5.5; S, 7.9. Found: C, 47.5; H, 5.6; S, 8.0.

Registry No.—**1**, 53821-50-4; **4**, 35013-06-0; **5**, 35013-04-8; **6**, 53821-51-5; **7**, 53821-52-6; **8**, 53821-53-7; **13**, 53821-54-8; **14**, 53821-55-9; **15**, 53821-56-0; **16**, 53821-57-1; **17**, 53821-58-2; **18**, 53821-59-3; **19**, 53821-60-6; **20**, 53821-61-7; **21**, 53821-62-8; **23**, 53821-63-9; **24**, 53821-64-0; **25**, 18604-34-7; **26**, 53821-65-1; **27**, 53821-66-2; **28**, 53821-67-3; **29**, 53821-68-4; **30**, 53821-69-5; **31**, 53821-70-8; **32**, 53821-71-9; potassium thioacetate, 10387-40-3.

References and Notes

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