22842-67-7; **35**, 22842-68-8; **36**, 22842-69-9; **37**, 22842-70-2; **42**, 22842-71-3; **43**, 22842-74-6; **45**, 22842-75-7; **46**, 3528-17-4; thiacyclohexan-4-one-3,3,5,5-d_4, 22842-37-1; 5-methyl-1,4-hexadien-3-one, 13058-38-3; 3,3-dimethyl-4-thiahexanoic acid, 22842-53-1; 3,3-dimethylacrylic acid, 541-47-9; 3-thia-7-oxo-1-octanol, 22842-72-4; 3-thia-7-oxo-1-octanol acetate, 22842-73-5.

Rearrangement Reactions of Hexose 4-*O*-Sulfonates in the Presence of Azide and Phthalimide Nucleophiles[1]

C. L. STEVENS, R. P. GLINSKI, K. G. TAYLOR, AND F. SIROKMAN

Chemistry Department, Wayne State University, Detroit, Michigan 48202

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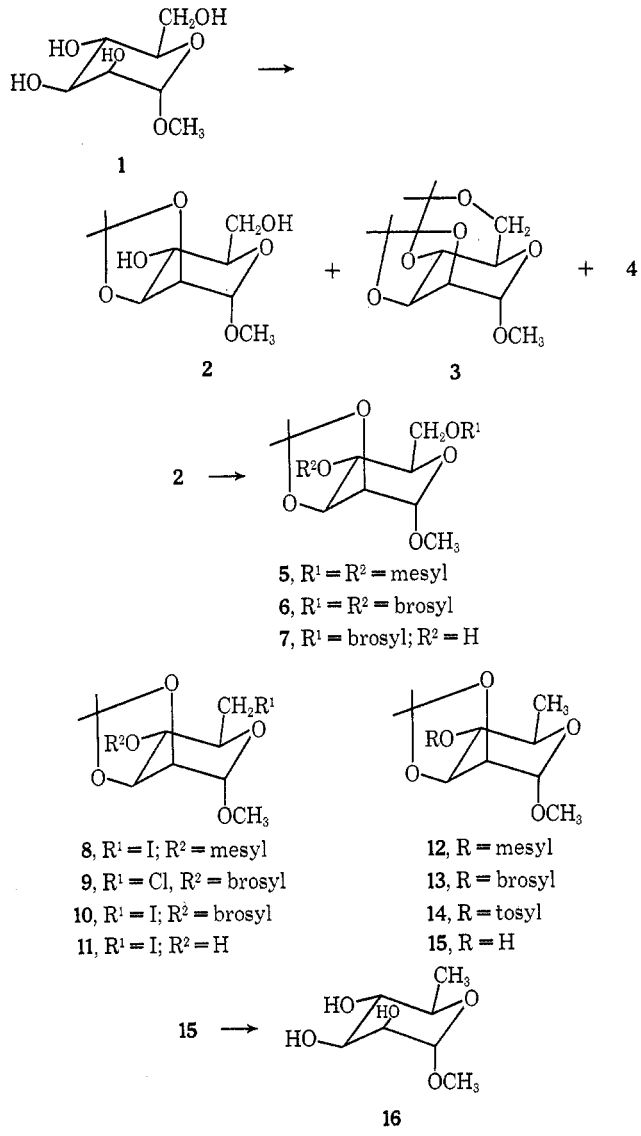
The reaction of various 4-*O*-sulfonates of methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**15**) in the presence of azide and phthalimide nucleophiles was investigated. The expected displacement product, having the α-D-talo configuration, was not detected. Instead, drastic skeletal rearrangement occurred to yield C-5-substituted derivatives of α-D-talofuranoside. The development of two high-yield routes to 4-*O*-sulfonates of compound **15** is discussed. Also, methyl 6-deoxy-α-D-mannopyranoside (**16**) was synthesized by a new route and obtained in crystalline form for the first time.

Since the appearance of our first publication[1] concerning the novel rearrangement reaction of various 4-*O*-sulfonates of methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**15**) with azide (later confirmed by others[2,3]), acetate, and phthalimide anions under conditions[4] expected to yield normal SN2 products, it was found that the tosyl ester of **15** also undergoes rearrangement in the presence of thiobenzoate ion[5] to give crystalline methyl 6-deoxy-2,3-*O*-isopropylidene-5-thiolbenzoyl-α-D-talofuranoside in 10% yield. An earlier erroneous report[6] had assigned the SN2 displacement product structure, methyl 6-deoxy-2,3-*O*-isopropylidene-4-thiobenzoyl-α-L-talopyranoside, to the enantiomer of this crystalline material. These and recent related publications,[7] which describe solvolysis reactions and anhydride formation from various sugar sulfonates by neighboring-group participation, prompt the authors to report in more detail results of the ring-contraction–rearrangement reaction in the presence of nitrogen-containing nucleophiles. The synthetic sequences used to prepare the various 4-*O*-sulfonates of methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**15**) as well as the proof of structure of these compounds will be outlined.

Two routes to compounds **12**, **13**, and **14** were developed. The first sequence was similar to that employed in earlier syntheses.[4] Thus methyl α-D-mannopyranoside (**1**) was heated in acetone under reflux in the presence of zinc chloride to afford a mixture of isopropylidene compounds, **2**, **3**, and **4**, which were separated by a combination of extraction techniques, fractional crystallization, and column chromatography.

SCHEME I



(1) A preliminary report of portions of this work has appeared earlier: C. L. Stevens, R. P. Glinski, K. G. Taylor, P. Blumbergs, and F. Sirokman, *J. Amer. Chem. Soc.*, **88**, 2073 (1966).

(2) S. Hannesian, *Chem. Commun.*, 796 (1966); S. W. Gunner, W. G. Overend, and N. R. Williams, *Carbohyd. Res.*, **4**, 498 (1967).

(3) J. Jarý, P. Novák, Z. Ksandr, and Z. Samek, *Chem. Ind.* (London), 1490 (1967); J. Jarý and P. Novák, *Collect. Czech. Chem. Commun.*, **33**, 1744 (1968). A successful SN2 displacement of methyl 6-deoxy-2,3-*O*-isopropylidene-4-*O*-mesyl-α-L-mannopyranoside with refluxing hydrazine also is described.

(4) See C. L. Stevens, P. Blumbergs, F. A. Daniher D. H. Otterbach, and K. G. Taylor, *J. Org. Chem.*, **31**, 2822 (1966), and references cited therein.

(5) C. L. Stevens, R. P. Glinski, G. E. Gutowski, and J. P. Dickerson, *Tetrahedron Lett.*, 649 (1967).

(6) L. N. Owen and P. G. Ragg, *J. Chem. Soc.*, *C*, 1291 (1966).

(7) P. W. Austin, J. G. Buchanan, and R. M. Saunders, *Chem. Commun.*, 146 (1965); P. W. Austin, J. G. Buchanan, and R. M. Saunders, *J. Chem. Soc.*, *C*, 372 (1967); P. W. Austin, J. G. Buchanan, and D. G. Large, *Chem. Commun.*, 418 (1967); N. A. Hughes, *ibid.*, 1072 (1967); J. S. Brimacombe and L. C. N. Tucker, *Carbohyd. Res.*, **5**, 36 (1967); J. S. Brimacombe and O. A. Ching, *ibid.*, **5**, 239 (1967); J. S. Brimacombe and O. A. Ching, *J. Chem. Soc.*, *C*, 1642 (1968).

The desired methyl 2,3-*O*-isopropylidene-α-D-mannopyranoside (**2**), was prepared conveniently on a several-hundred-gram scale in yields of 30–45% and had physical constants in agreement with those reported by earlier workers.[8] Compound **2** was converted into compound **12** in good yield *via* compounds **5** and **8**. (See Scheme I).

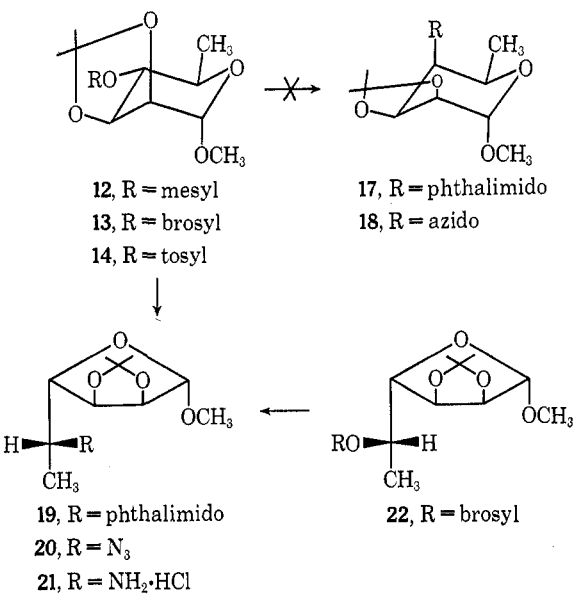
The structure of compound **12**, and consequently of compounds **13** and **14**, was established by the high yield conversions to the known (L series) methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**15**),[9] the corresponding crystalline 4-*O*-tosylate (**14**),[9,10] and methyl 6-deoxy-α-D-mannopyranoside (**16**).[11] At first, compound **16** was obtained as a homogeneous gum which resisted all attempts to be crystallized. Two other groups[12,13] have experienced similar difficulties. Methyl 6-deoxy-α-D-mannopyranoside (**16**) has since been obtained in this laboratory in crystalline form after nucleation with the crystalline L enantiomer. To the authors' knowledge, this is the first time the D enantiomer has been crystallized.

A second series of reactions involved brosylation of **2** under varied conditions to afford three different brosylate derivatives, **6**, **7**, and **9**, in excellent yields. Thus, when compound **2** was heated in a pyridine–tetrahydrofuran mixture at 63° for 4 days in the presence of brosyl chloride, an 82% yield of crystalline methyl 4-*O*-brosyl-6-chloro-6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**9**) was obtained. There is precedent for the preparation of primary chloro derivatives from primary alcohols under sulfonation conditions with various sulfonyl chlorides in the literature.[13,14]

Reaction of compound **2** in pyridine solution at room temperature for 24 hr afforded crystalline methyl 4,6-di-*O*-brosyl-2,3-*O*-isopropylidene-α-D-mannopyranoside (**6**). Compound **6** also gave **10** by a selective sodium iodide displacement of the primary 6-*O*-brosylate group. An attempted hydrogenolysis of the 6-iodo group of **10** using Raney nickel catalyst failed to afford pure **13**, however. Treatment of **2** with brosyl choride in a chloroform–pyridine mixture at room temperature afforded methyl 6-*O*-brosyl-2,3-*O*-isopropylidene-α-D-mannopyranoside (**7**) as an oil (quantitative yield), which was used without purification for a sodium iodide displacement. Thus **7** gave crystalline methyl 6-deoxy-6-iodo-2,3-*O*-isopropylidene-α-D-mannopyranoside (**11**, 89%) when heated in 2-butanone under reflux in the presence of sodium iodide. Hydrogenolysis of the 6-iodo group of **11** in methanol in the presence of palladium-on-carbon catalyst and sodium hydroxide afforded a 96% yield of **15**, identical with a sample prepared by a lithium hydride reduction of **12**.

With 4-*O*-sulfonates **12**, **13**, and **14** in hand, a number of displacement reactions with nitrogen-containing nucleophiles were attempted. Simple displacement products such as **17** and **18** were not isolated; instead, complex mixtures were formed (Scheme II); and **19** and **20**, representing both displacement and ring-contraction reactions, were isolated in low yield. Thus, for example, when methyl 6-deoxy-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (**12**) was heated in dimethylformamide under reflux in the presence of excess lithium azide for 48 hr, tlc indicated a crude five-component mixture containing methyl 5-azido-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-talofuranoside (**20**). Reduction of this mixture and hydrochloride salt formation gave methyl 5-amino-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-talofuranoside hydrochloride (**21**) in 31% yield. Similarly, methyl 4-*O*-brosyl-6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**13**) was allowed to react with potassium phthalimide in dimethylformamide at 90° for 8 hr and then at 135° for 48 hr to give an 18% yield of methyl 5,6-dideoxy-2,3-*O*-isopropylidene-5-phthalimido-α-D-talofuranoside (**19**).

SCHEME II

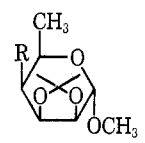


The assignment of the C-5-substituted furanoside structures to compounds **19** and **20** was verified by independent synthesis. Methyl 5-*O*-brosyl-2,3-*O*-isopropylidene-β-L-allofuranoside (**22**)[1] was converted into methyl 5-amino-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-talofuranoside hydrochloride (**21**) *via* a three-step sequence. Compound **22** was allowed to react with sodium azide in dimethylformamide at 110° (oil-bath temperature) for 1 hr to yield methyl 5-azido-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-talofuranoside (**20**). Catalytic reduction of **20** over platinum followed by hydrochloride salt formation gave crude **21** in 82% overall yield. Subsequent recrystallization afforded pure **21**, which was identical with samples prepared by the rearrangement route from 4-*O*-sulfonates of methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**15**). Reaction of **22** with potassium phthalimide in dimethylformamide under reflux for 8 hr gave compound **19**, identical in all respects with samples prepared by the rearrangement route.

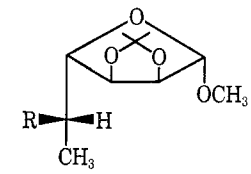
The fact that only one pure rearranged, ring-contracted product was isolated from these complex reaction mixtures, in low yield, does not preclude the possibility of the presence of the SN2 displacement products

(8) R. G. Ault, W. N. Haworth, and E. L. Hirst, *J. Chem. Soc.*, 517 (1935); R. G. Ault, W. N. Haworth, and E. L. Hirst, *ibid.*, 1012 (1935).
(9) P. A. Levene and J. Compton, *J. Amer. Chem. Soc.*, **57**, 2306 (1935).
(10) C. Fouquey, J. Polonsky, and E. Lederer, *Bull. Soc. Chim. Fr.*, 803 (1959).
(11) J. Minsaas, *Kgl. Norske Videnskab. Selskabs Forh.*, **6**, 177 (1933).
(12) W. T. Haskins, R. M. Hann, and C. S. Hudson, *J. Amer. Chem. Soc.*, **68**, 628 (1946).
(13) M. E. Evans, L. Long, Jr., and F. W. Parrish, *J. Org. Chem.*, **33**, 1074 (1968).
(14) K. Hess and R. Pfleger, *Justus Liebigs, Ann. Chem.*, **507**, 48 (1933).

(compound **24**) or the C-5 epimers of **19** and **20** (compound **25**), since analogs of these compounds were isolated from other reactions[1,3] expected to yield only SN2 products. Since the authors' original communication,[1] there have been comments in the literature[2] concerning the mechanism of the low-yield formation of rearranged ring-contracted **20** from methyl 6-deoxy-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (**12**). Whether these speculations are correct or whether the formation of **20** proceeds *via* a more complex carbonium-ion intermediate(s) need(s) further investigation, since these mechanistic interpretations account for only one product of the reaction mixture.



24, R = N_3 or phthalimido



25, R = N_3 or phthalimido

Experimental Section

Melting points were taken on a Thomas–Hoover melting point apparatus and are uncorrected. Silica gel H from Brinkman Instruments, coated on 5 × 20 cm glass plates, was used for the tlc analyses. The ethyl ether–*n*-pentane (1:1) solvent system was used in the development of the tlc plates. All compounds were detected by spraying the dried, developed plates with 6 *N* sulfuric acid and baking at 110° for 10–30 min.

Tetrahydrofuran was freshly distilled from lithium aluminum hydride before use. Pyridine was Merck reagent grade, dried over KOH pellets. Acetone was dried over anhydrous K_2CO_3, and 2-butanone was distilled from NaI. Dimethylformamide was purified by passage through a column of Merck acid-washed alumina. The petroleum ether used had bp 30–60°.

Methyl 2,3-*O*-Isopropylidene-α-D-mannopyranoside (2), Methyl 2,3:4,6-Di-*O*-isopropylidene-α-D-mannopyranoside (3) and Compound 4.—Methyl-α-D-mannopyranoside (**1**, 200 g) was converted to a mixture of isopropylidene derivatives in acetone solution using zinc chloride as catalyst. The yield of **2**,[8] mp 102–104°, was 45%. In addition to 7% diisopropylidene derivative **3**,[8] mp 67–69°, the large-scale conversion allowed the isolation of a previously unknown isomer of **2** in 0.5% yield. From the mother liquors of **2**, fractional crystallization using benzene–*n*-pentane, ethyl ether–*n*-pentane, and chloroform–*n*-pentane mixtures gave 1.25 g of the unknown **4**: mp 100–101°; $[\alpha]^{27}D$ +68.3° (*c* 1.15, CH_3OH). A mixture melting point with **2** was depressed and the infrared spectra of two compounds were very similar but not identical. Compound **4** had the formula $C_{10}H_{18}O_6$ by elemental analysis.

Anal. Calcd for $C_{10}H_{18}O_6$: C, 51.27; H, 7.75; O, 40.98. Found: C, 51.36; 51.20; H, 7.70, 7.70; O, 41.18.

Methyl 2,3-*O*-Isopropylidene-4,6-di-*O*-mesyl-α-D-mannopyranoside (5).—Methyl 2,3-*O*-isopropylidene-α-D-mannopyranoside (**2**, 17.5 g) was converted into **5** at 0° in a mixture of tetrahydrofuran (30 ml) and pyridine (30 ml) using methanesulfonyl chloride (23 ml) as the reagent. The yield of product, mp 104–106°, was 92%. Two additional recrystallizations of a small sample from ethanol yielded material melting at 105.5–106° with $[\alpha]^{25}D$ +14.7° (*c* 1.32, $CHCl_3$).

Anal. Calcd for $C_{12}H_{22}O_{10}S_2$: C, 36.90; H, 5.68; S, 16.43. Found: C, 37.14; H, 5.85; S, 16.31.

Methyl 6-Deoxy-6-iodo-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (8).—A reaction mixture of methyl 2,3-*O*-isopropylidene-4,6-di-*O*-mesyl-α-D-mannopyranoside (**5**, 26.0 g), NaI (21 g), and 2-butanone (150 ml) was mechanically stirred and heated at the reflux temperature for 12 hr. The product of selective displacement was isolated in 96% yield, mp 82–84°. Material with this melting point is sufficiently pure for further transformations. An analytical sample was prepared by sublimation (five times) at 80° (5 × 10^{-4} mm) (bath temperature): mp 84.5–85°; $[\alpha]^{28}D$ +23.9 (*c* 1.03, $CHCl_3$).

Anal. Calcd for $C_{11}H_{19}IO_7S$: C, 31.29; H, 4.54; S, 7.60. Found: C, 31.40; H, 4.64; S, 7.60.

Methyl 6-Deoxy-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (12).—Methyl 6-deoxy-6-iodo-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (**8**, 50 g) was dissolved in dioxane (150 ml) and added to a solution of 6.2 g of sodium hydroxide in 150 ml of methanol. Hydrogenation was accomplished in the presence of 10% palladium on carbon (2 g). From the reaction, **12** was isolated as heavy white needles: 31.8 g (91%); mp 126–127.5°. An analytical sample was prepared by recrystallization of small quantity from ethanol: mp 128–129.5°; $[\alpha]^{25}D$ +14.2° (*c* 1.17, $CHCl_3$).

After the authors' preliminary communication,[1] other workers[2,3] have reported similar physical constants for the L enantiomer of **12** prepared by a different route.

Anal. Calcd for $C_{11}H_{20}O_7S$: C, 44.58; H, 6.79; S, 10.81. Found: C, 44.84; H, 6.94; S, 10.58.

Methyl 6-Deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (15). A.—Methyl 6-deoxy-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (**12**, 28 g), dissolved in dry tetrahydrofuran (75 ml), was added dropwise to a stirred suspension of lithium aluminum hydride (12 g) in dry tetrahydrofuran (150 ml) heated under reflux. When the addition was complete (3 hr), the reaction was heated under reflux for an additional 16 hr. Compound **15** was isolated as a thick, light yellow oil (19.5 g, 95%), which was homogeneous by vpc analysis (2-ft 10% Carbowax, 170°). A small portion was evaporatively distilled slowly at 35° (bath temperature) (0.03 mm): $n^{21}D$ 1.4541; $[\alpha]^{27}D$ +15.2 (*c* 1.39, CH_3OH). The literature values[9] are *n* D 1.4545 and $[\alpha]^{24}D$ −11.9 (*c* 3.14, CH_3OH) for the L enantiomer of compound **15**.

B.—Methyl 6-deoxy-6-iodo-2,3-*O*-isopropylidene-α-D-mannopyranoside (**11**, 1.85 g) was dissolved in methanol (30 ml) containing NaOH (0.4 g) and hydrogenated using 10% palladium-on-charcoal catalyst (0.20 g). The reaction afforded 1.16 g (96%) of compound **15** as a colorless viscous oil. A sample was evaporatively distilled for analysis: bp 78–79° (bath temperature) (0.025 mm); $n^{20.2}D$ 1.4555; $[\alpha]^{25}D$ 14.3° (*c* 1.17, CH_3OH). The literature values[9] for the enantiomer of compound **15** are *n*D 1.4545 and $[\alpha]^{27}D$ −11.9° (*c* 1.39, CH_3OH).

Anal. Calcd for $C_{10}H_{18}O_5$: C, 55.04; H, 8.31. Found: C, 55.15; H, 8.30.

Methyl 6-Deoxy-2,3-*O*-isopropylidene-4-*O*-tosyl-α-D-mannopyranoside (14).—Compound **15** (8.66 g) and tosyl chloride (15.2 g) were dissolved in pyridine (15 ml) at 0°. The reaction was allowed to warm to room temperature over a period of 1 hr. The product was isolated after an additional 2.5 days at room temperature. Processing in the usual manner and two recrystallizations from methanol–water mixtures gave 11.3 g (76%) of compound **14**: mp 59–61°; $[\alpha]^{27}D$ −21.7° (*c* 1, CH_3OH). The literature[9,10] has reported mp 61–62°, $[\alpha]D$ −21.94° (*c* 3.03, CH_3OH), and mp 61–3°, $[\alpha]D$ −23° (*c* 3.94, CH_3OH), for the L enantiomer.

Methyl 6-Deoxy-α-D-mannopyranoside (16).—Methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (**15**, 431 mg) was dissolved in water (4 ml) and brought to pH 3 (pH paper) by the dropwise addition of 0.1 *N* hydrochloric acid. The mixture was heated at 98° (bath temperature) for 1 hr, allowed to cool to room temperature, and concentrated *in vacuo* in the presence of absolute ethanol. Seeding with crystalline material from an earlier preparation[15] induced crystallization of compound **16**. Recrystallization from an ethyl acetate–petroleum ether mixture yielded dense cubes: 320 mg (91%), mp 106–108°; $[\alpha]^{27}D$ +64.5° (*c* 1.69, H_2O). The literature has reported mp 108–109° and $[\alpha]^{27}D$ −62.3 (*c* 0.86, H_2O) for the L enantiomer[11,12] and for the D enantiomer (an amorphous solid),[12,13] $[\alpha]^{27}D$ 61° (*c* 1.0, H_2O).

Methyl 4-*O*-Brosyl-6-chloro-6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (9).—A mixture of methyl 2,3-*O*-isopropylidene-α-D-mannopyranoside (**2**, 1.0 g), anhydrous tetrahydrofuran (3 ml), pyridine (3 ml), and brosyl chloride (3.3 g) was heated in an oil bath at 63° for 4 days to afford 1.65 g (82%) of product **9** with mp 120–122°. A sample was recrystallized three times from ethanol to afford analytically pure **9**: mp 121–122°; $[\alpha]^{24}D$ −8.6 (*c* 1.38, CH_3OH); mol wt 470 (mass spectrum).

Anal. Calcd for $C_{16}H_{20}BrClO_7S$: C, 40.73; H, 4.27; S, 6.80. Found: C, 40.97; H, 4.15; S, 6.65.

(15) These seeds were obtained by nucleation of earlier preparation of **15**, as a homogeneous gum, with the crystalline L enantiomer.

Methyl 4,6-Di-*O*-brosyl-2,3-*O*-isopropylidene-α-D-mannopyranoside (6).—Methyl 2,3-*O*-isopropylidene-α-D-mannopyranoside (2, 0.450 g) was dissolved in pyridine (1 ml) and brosyl chloride (2.4 g) was added. After the mixture was allowed to stand at room temperature for 24 hr, the product 6 was isolated in quantitative yield; 1.3 g, mp 106–110°. A small portion was recrystallized twice from methanol–water mixtures to yield analytically pure 6: mp 114–115°; $[\alpha]^{25}D$ −1.4° (*c* 1, CH_3OH).

Anal. Calcd for $C_{22}H_{24}Br_2O_{10}S_2$: C, 39.30; H, 3.60; Br, 23.77; S, 9.55. Found: C, 39.55; H, 3.60; Br, 23.93; S, 9.46.

Methyl 4-*O*-Brosyl-6-deoxy-6-iodo-2,3-*O*-isopropylidene-α-D-mannopyranoside (10). A.—Methyl 4,6-di-*O*-brosyl-2,3-*O*-isopropylidene-α-D-mannopyranoside (6, 33 g) and NaI (22.4 g) were dissolved in 2-butanone and heated under reflux with stirring for 18 hr. The yield of 10 with mp 80–87° was 24.6 g (96%). One recrystallization from ethanol afforded 22 g (80%) with mp 86–88°. Two additional recrystallizations of a portion from ethanol and ethyl ether gave analytically pure 10 as white needles: mp 86–87.5°; $[\alpha]^{24}D$ +2.4° (*c* 1.0, CH_3OH). A mixture melting point of this material with compound 10 (mp 89–91°), prepared by method B, was undepressed.

Anal. Calcd for $C_{16}H_{20}BrIO_7S$: C, 34.19; H, 3.41; I, 22.58; S, 5.70. Found: C, 34.48; H, 3.66; I, 22.71; S, 5.66.

B.—Methyl 4-*O*-brosyl-6-chloro-6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (9, 5 mg) was dissolved in 2-butanone (2 ml) containing NaI (10 mg). The homogeneous solution was heated under reflux. After 3 days a gum was isolated which crystallized on standing at room temperature for 1 month: mp 90–95°. Recrystallization from ethyl ether afforded 10 with mp 89–91°.

Methyl 4-*O*-Brosyl-6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (13).—Methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (15, 2.18 g) and brosyl chloride (7.65 g) were dissolved in pyridine (4 ml) and allowed to react for 24 hr at room temperature. The resulting product, which crystallized on standing, was recrystallized to give 3 g (69%) of 13 with mp 43–45°. One additional recrystallization of a small sample from methanol afforded analytically pure 13: mp 45–46°; $[\alpha]^{26}D$ −31.4° (*c* 1.01, CH_3OH).

Anal. Calcd for $C_{16}H_{21}BrO_7S$: C, 43.96; H, 4.84; Br, 18.28; S, 7.33. Found: C, 44.23; H, 4.77; Br, 18.40; S, 7.05.

Methyl 6-*O*-Brosyl-2,3-*O*-isopropylidene-α-D-mannopyranoside (7).—Methyl 2,3-*O*-isopropylidene-α-D-mannopyranoside (2, 8.97 g) was dissolved in pyridine (36 ml) and brosyl chloride (12.77 g), dissolved in chloroform (36 ml), was added slowly. The reaction mixture was stirred for 20 hr at room temperature, after which time 17 g of 7 was isolated as an oil. Tlc analysis of the crude product indicated the presence of trace amounts of starting material 2 and dibrosylated compound 6. The oil was used in the NaI displacement reaction without purification.

Methyl 6-Deoxy-6-iodo-2,3-*O*-isopropylidene-α-D-mannopyranoside (11).—Crude methyl 6-*O*-brosyl-2,3-*O*-isopropylidene-α-D-mannopyranoside (7, 8.3 g) was dissolved in 2-butanone (200 ml) containing NaI (8.64 g). After the mixture was heated under reflux for 18 hr with vigorous stirring 5.6 g (89%) of the reaction product 11, mp 97–105°, was isolated. A small portion was recrystallized twice from an ethyl ether–*n*-pentane mixture to give analytically pure 11: mp 109–110°; $[\alpha]^{24}D$ 44.2° (*c* 1.0, CH_3OH).

Anal. Calcd for $C_{10}H_{17}IO_5$: C, 34.91; H, 4.98; I, 36.88. Found: C, 35.18; H, 5.04; I, 37.07.

Methyl 5-Amino-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-talofuranoside (21). A.—Methyl 6-deoxy-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (12, 296 mg) and lithium azide (245 mg) were dissolved in dimethylformamide (13 ml) containing 1 drop of water. The mixture was heated under reflux for 48 hr. The solution was allowed to cool to room temperature and diluted with water (100 ml). The solution was extracted with petroleum ether (five 15-ml portions). The extracts were combined, dried (Na_2SO_4), and concentrated *in vacuo* at room temperature to yield 160 mg of crude methyl 5-azido-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-talofuranoside (20). Tlc indicated the presence of at least five components. The mixture was hydrogenated over prereduced platinum oxide (40 mg) in methanol (15 ml) to afford a yellow oil. The oil was dissolved in anhydrous ethyl ether (5 ml). Dry hydrogen chloride gas was bubbled through the solution until the separation of a white powder was complete. The powder was removed by filtration, washed well with dry ethyl ether, and dried, to afford 80 mg (31.5%) of compound 21 with mp 181–182° dec. Recrystallization from an isopropanol–*n*-pentane mixture gave, in two crops, 63 mg (25%): mp 183–183.5° dec; $[\alpha]^{24}D$ +29° (*c* 1.0, CH_3OH); pK_a 8.23.

After the authors' preliminary communication,[1] other workers[3] have reported mp 186–187° and $[\alpha]^{19}D$ −24.6° (*c* 0.9, H_2O) for the L enantiomer of 21.

Anal. Calcd for $C_{10}H_{20}ClCO_4$: C, 47.34; H, 7.95; N, 5.21. Found: C, 47.56; H, 8.02; N, 5.46.

B.—Methyl 6-deoxy-2,3-*O*-isopropylidene-4-*O*-tosyl-α-D-mannopyranoside (14, 2 g) was dissolved in dimethylformamide (40 ml) containing lithium azide (0.74 g). The mixture was heated with stirring at 80° (oil bath) for 72 hr, after which time the temperature was raised to 110° for 24 hr. The isolation procedure described above gave 20 as an oil (1.2 g) having the same tlc pattern as 20 isolated from mesylate 12. One-half of the mixture (0.6 g) was hydrogenated over prereduced platinum oxide and treated with dry hydrogen chloride gas in anhydrous ethyl ether, as described in method a, to yield 317 mg (46%) of 21 with mp 172–179° dec. Two recrystallizations from an isopropanol–*n*-pentane mixture afforded 235 mg (29%) with mp 182–183° dec. A mixture melting point with hydrochloride salt 21 prepared from mesylate 12 using method A was undepressed.

C.—Methyl 5-*O*-brosyl-6-deoxy-2,3-*O*-isopropylidene-β-L-allofuranoside (22, 630 mg)[1] and sodium azide (380 mg) were heated in dimethylformamide (15 ml) containing 1 drop of water at *ca.* 110° (oil-bath temperature) for 1 hr. After isolation, the resulting oily azide was dissolved in ethanol (10 ml) and added to prereduced platinum oxide (100 mg) in ethanol (5 ml) under an atmosphere of hydrogen. During the reduction time of 12 hr, nitrogen was removed from the system several times by flushing with fresh hydrogen. The catalyst was removed by filtration and the filtrate was concentrated *in vacuo* to afford an oil. The oily amine was dissolved in dry *n*-pentane (50 ml) and anhydrous hydrogen chloride in isopropanol was added dropwise with swirling until the precipitation of hydrochloride 21 was complete. The resulting crude solid, 300 mg (82%), mp 156–161° dec, was crystallized from an ethanol–ethyl ether–*n*-pentane mixture to afford 100 mg of pure 21 with mp 181–182° dec. A mixture melting point of this material with 21 prepared according to method a (mp 181.5–182.5° dec) was undepressed, and the infrared spectra (KBr) of the two specimens were superimposable.

Methyl 5,6-Dideoxy-2,3-*O*-isopropylidene-5-phthalimido-α-D-talofuranoside (19). A.—Methyl 6-deoxy-2,3-*O*-isopropylidene-4-*O*-mesyl-α-D-mannopyranoside (12, 296 mg) was dissolved in dimethylformamide (20 ml) containing potassium phthalimide (525 mg) and was heated at 100° (oil-bath temperature) for 24 hr. Tlc indicated that there had been no reaction. The temperature was increased to 140° and held at this temperature for 4 days. Tlc analysis showed the absence of starting material 12. The reaction mixture was allowed to cool to room temperature, diluted with water (80 ml), and extracted with chloroform (three 50-ml portions). The chloroform extracts were combined and washed with 25% NaOH solution (two 10-ml portions). The chloroform layer was dried (K_2CO_3) and concentrated *in vacuo*. The resulting yellow residue (340 mg) crystallized on standing overnight. The crystals were washed with ethyl ether. The remaining colorless crystals (176 mg, mp 132–146°) were dissolved in ethanol (3 ml) and the turbid solution was filtered. The phthalimido derivative 19 crystallized as white needles from the filtrate (mp 146–149°). Two more recrystallizations from ethanol afforded 40 mg of analytically pure 19: mp 158–159°, $[\alpha]^{27}D$ 111.4° (*c* 1, CH_3OH).

Anal. Calcd for $C_{18}H_{21}NO_6$: C, 62.24; H, 6.09; N, 4.03. Found: C, 62.45; H, 6.05; N, 4.05.

B.—Methyl 4-*O*-brosyl-6-deoxy-2,3-*O*-isopropylidene-α-D-mannopyranoside (13, 300 mg) was dissolved in dimethylformamide (15 ml) containing potassium phthalimide (525 mg), and was heated at 90° (oil-bath temperature) for 8 hr and then at 135° for 48 hr. The isolation procedure described in method a gave a gum which crystallized (97 mg). Recrystallization from ethanol afforded 63 mg of 19 with mp 156–158°. A mixture melting point with the product prepared from mesylate 12 (mp 158–159°) was undepressed.

C.—Methyl 5-*O*-brosyl-6-deoxy-2,3-*O*-isopropylidene-β-L-allofuranoside (22, 100 mg)[1] was dissolved in dimethylformamide (15 ml) containing potassium phthalimide (300 mg), and the resulting solution heated under reflux for 8 hr. From the reaction mixture 89 mg of a gum was obtained. The gum crystallized

(58 mg), and after recrystallization from ethanol amounted to 24.8 mg of compound **19**: mp 158–159°; $[\alpha]^{27}D$ 108.5° (*c* 1.0, CH_3OH). This material was identical in all respects with earlier preparations from mesylate **12** and brosylate **13**.

Registry No.—**5**, 22932-29-2; **6**, 22932-30-5; **8**, 22932-31-6; **9**, 22932-32-7; **10**, 22932-33-8; **11**, 22932-34-9; **12**, 10503-85-2; **13**, 10503-86-3; **14**, 10515-99-8; **15**, 22932-38-3; **16**, 15814-59-2; **19**, 10503-88-5; **21**, 10503-87-4.

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The Photochemical Reactions of α-Ketophosphonates[1]

YOSHIRO OGATA AND HIDEO TOMIOKA

Department of Applied Chemistry, Faculty of Engineering, Nagoya University, Chikusa-ku, Nagoya, Japan

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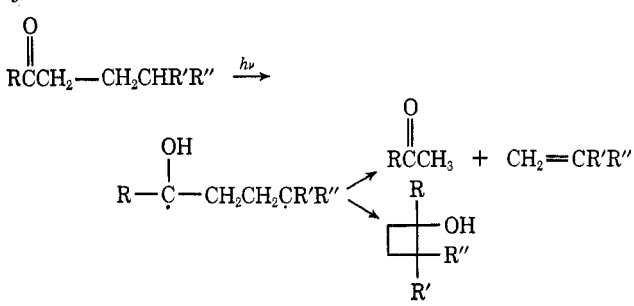
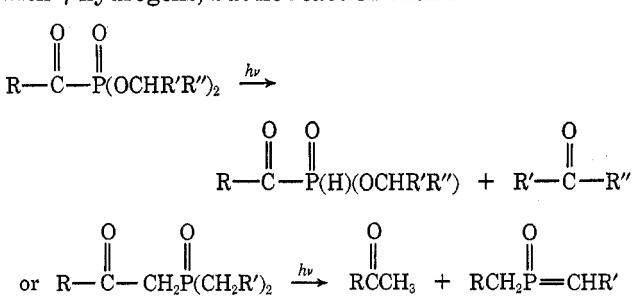
Irradiation of dialkyl α-ketophosphonates possessing tertiary γ-hydrogens (**1c–1e**) in benzene affords novel rearrangement products, *i.e.*, half-esters of β-ketophosphonates (**2c–2e**, 75–91%), together with the products derived from type I cleavage, *i.e.*, dialkyl phenylphosphonates (**3c–3e**, 2.5–4.0%). However, the similar photolysis of esters possessing primary or secondary γ hydrogens (**1a–1b**) gives much lower yields of rearrangement products (**2a–2b**, 0–21.5%) and moderately higher yields of dialkyl phenylphosphonates (**3a–3b**, 24.6–6.3%). Photoelimination and/or cyclization products are not detected. This reaction is discussed in terms of geometrical and stereoelectronic requirements for intramolecular hydrogen abstraction and type II elimination, a plausible mechanism being postulated.

The carbonyl group plays an important role as a chromophore in organic photochemical reactions. In the condensed phase the major pathway for carbonyl compounds possessing γ hydrogens is photoelimination (type II) to form olefins and smaller carbonyl compounds. This is accompanied by cyclization to form cyclobutanols.[2]



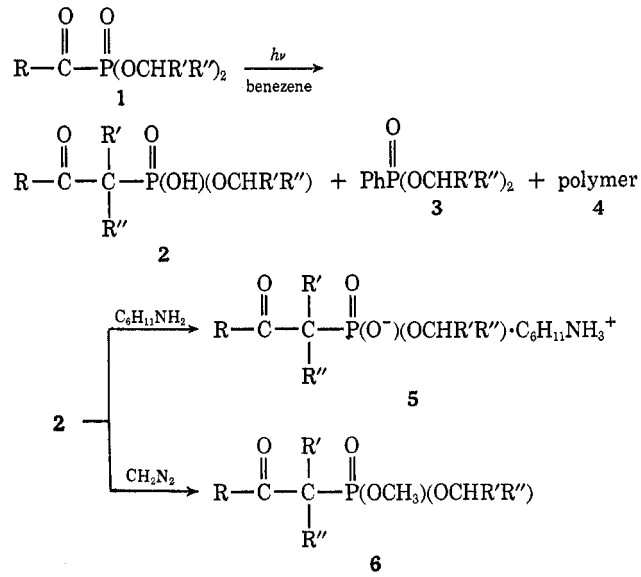
As an extension of the studies on photochemical reactions of organophosphorus compounds,[3] this photoelimination was applied[4] to ketophosphorus compounds with γ hydrogens, but no reaction such as



occurred. Instead, anomalous and interesting behavior was observed, which included a novel rearrangement instead of elimination. The present paper outlines this reaction and examines this behavior in terms of factors influencing internal hydrogen abstraction and photoelimination.

Results and Discussion

Irradiation of diisopropyl acetylphosphonate (**1c**, R = R′ = R″ = CH_3) in benzene with ultraviolet light from an unfiltered high-pressure Hg lamp in a quartz or Pyrex tube afforded viscous liquid with rapid consumption of the starting material. (For numbering of compounds, see Table II.) The infrared spectrum of the oil thus obtained showed the strong and broad band of P–OH. The addition of cyclohexylamine to the oil gave a solid (**5c**), which was identified as an isomer of **1c** by elemental analysis and titration. Chromatographic separation of the products after treatment with diazomethane gave two oily substances, which were shown to be **6c** (methyl ester of **2c**) and **3c** on



(1) Contribution No. 141.

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