was then converted into ethyl 4-methylstearate in 65% yield, and the latter into 4-methyl-1-octadecanol in 58% yield.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE OHIO STATE UNIVERSITY]

Sorbityl Glycosides and 2,3,4,5,6-O-Pentamethyl Sorbitol

BY M. L. WOLFROM AND THOMAS S. GARDNER

The preparation of disaccharide sugar alcohols by the reducing action of amalgams on the reducing sugars has been unsatisfactory as the conditions employed tended to degrade the sugars and gave impure products that were difficult to crystallize. More efficient, catalytic reduction methods at high pressure and temperature were introduced by Ipatieff.[1] Improvements in equipment and technique have made it possible for several disaccharide alcohols to be so synthesized in crystalline form. Thus, lactitol,[2] cellobiotol,[3] melibiotol[4] and 6-(β-*d*-glucosido)-dulcitol[5] were obtained in the crystalline state by the reduction of the corresponding sugars, and maltitol[4,6] was prepared as an amorphous substance but characterized as a crystalline nonaacetate. Pacsu and Rich[7] used a platinum catalyst at room temperature and low pressure to reduce *keto*-turanose octaacetate to a mixture of 3-(α-*d*-glucosido)-(*levo*)[8]-sorbitol and 3-(α-*d*-glucosido)-*d*-mannitol octaacetates. The mixture was resolved by the fractional crystallization of the nonaacetates obtained on further acetylation. No attempts to crystallize the free alcohols were recorded.

In the work herein reported we wish to add another disaccharide alcohol to the above list. The high temperature and high pressure catalytic reduction of gentiobiose yielded gentiobiotol (6-(β-*d*-glucosido)-(*levo*)-sorbitol) as an amorphous material characterized as its crystalline nonaacetate. The structure of gentiobiotol was verified by its lack of Fehling reduction and by its hydrolysis to (*levo*)-sorbitol, characterized as its tribenzylidene derivative, and to *d*-glucose, identified as its diethyl mercaptal.

The methylated disaccharide alcohols and the hydrolytic products of such ethers promise to be useful in the further determination of carbohydrate structure. Levene and Kuna[3] prepared a sirupy O-nonamethyl-4-(β-*d*-glucosido)-(*levo*)-sorbitol by the methylation of cellobiotol and hydrolyzed this to the sirupy 1,2,3,5,6-O-pentamethyl-(*levo*)-sorbitol, the latter substance being described as a desirable reference compound for the study of the position of glycosidic union in a disaccharide. A derivative of this partially methylated hexitol was not recorded. In the present work we have prepared, as distilled sirups, the nonamethyl ethers of two other disaccharide alcohols, maltitol and lactitol.

We also wish to report a crystalline derivative of one of the isomeric pentamethyl ethers of (*levo*)-sorbitol. This substance is the 1-N-α-naphthylcarbamate of 2,3,4,5,6-O-pentamethyl-(*levo*)-sorbitol. This ether of sorbitol was prepared as a distilled sirup by the high pressure, high temperature, catalytic reduction of the *aldehydo*-*d*-glucose pentamethyl ether of Levene and Meyer.[9] This crystalline carbamate of a sugar structure illustrates the possible usefulness of such an ester, hitherto little used in the sugar series.[10]

Experimental

Gentiobiotol (6-(β-*d*-Glucosido)-(*levo*)-sorbitol).—The gentiobiose used in this work was prepared through the octaacetate synthesized according to the Reynolds and Evans[11] modification of the procedure of Helferich and Klein.[12] Gentiobiose methyl alcoholate (5 g., m. p. 85°) was dissolved in 100 cc. of water containing 5 g. of a nickel catalyst supported on kieselguhr. The solution was reduced in a steel shaking autoclave (American Instrument

(1) V. N. Ipatieff, *Ber.*, **45**, 3218 (1912).

(2) J. B. Senderens, *Compt. rend.*, **170**, 47 (1920); M. L. Wolfrom, W. J. Burke, K. R. Brown and R. S. Rose, Jr., THIS JOURNAL, **60**, 571 (1938).

(3) P. A. Levene and M. Kuna, *Science*, **85**, 550 (1937); *J. Biol. Chem.*, **127**, 49 (1939).

(4) M. L. Wolfrom and T. S. Gardner, THIS JOURNAL, **62**, 2553 (1940).

(5) P. A. Levene and R. S. Tipson, *J. Biol. Chem.*, **125**, 355 (1938).

(6) P. Karrer and J. Büchi, *Helv. Chim. Acta*, **20**, 86 (1937).

(7) E. Pacsu and F. V. Rich, THIS JOURNAL, **55**, 3018 (1933).

(8) This denotes the ordinary form of sorbitol, which is slightly levorotatory in aqueous solution.

(9) P. A. Levene and G. M. Meyer, *J. Biol. Chem.*, **69**, 175 (1926).

(10) M. R. Salmon and G. Powell, THIS JOURNAL, **61**, 3507 (1939); M. L. Wolfrom and D. E. Pletcher, *ibid.*, **62**, 1151 (1940).

(11) D. D. Reynolds and W. L. Evans, *ibid.*, **60**, 2559 (1938).

(12) B. Helferich and W. Klein, *Ann.*, **450**, 219 (1926).

Company) at an initial hydrogen pressure of 1810 lb. per sq. in. (123 atm.) at 35°. A maximum temperature of 150° at a pressure of 2400 lb. per sq. in. (163 atm.) was attained in one hour and was maintained for an additional four hours. The cooled mixture was filtered, heated short of boiling, and treated with hydrogen sulfide until precipitation was complete. The filtered solution was clarified further by boiling for thirty minutes with activated charcoal (1 g.), filtered hot and concentrated (37°) to a thick sirup under reduced pressure. The resultant sirup was extracted several times with boiling ethanol and the undissolved residue was placed under dioxane for several days. A stable, white, amorphous solid was thus obtained that swelled and turned brown at 90°; yield approximately 80%. Gentiobiotol purified through the crystalline acetate described below was likewise amorphous and gave the same softening point; spec. rot. −24° (25°, *c* 1, H_2O).[13] Gentiobiotol was soluble in water and methanol and was insoluble in ethanol, chloroform, dioxane and the other common organic solvents. It did not reduce boiling Fehling solution.

Anal. Calcd. for $C_{12}H_{24}O_{11}$: C, 41.84; H, 7.03. Found: C, 42.00; H, 7.20.

Gentiobiotol Nonaacetate.—One gram of gentiobiotol was acetylated with hot acetic anhydride and fused sodium acetate. The sirup obtained on pouring the cooled acetylation mixture into an excess of water was dissolved in chloroform and the extract washed free of acid. The sirup obtained after solvent removal was crystallized from hot 95% ethanol as long, distinct needles. Pure material was obtained on further recrystallizations from the same solvent; yield 1.2 g., m. p. 88–89.5°, spec. rot. −11° (26°, *c* 5, U. S. P. $CHCl_3$).

Gentiobiotol nonaacetate was soluble in hot alcohol and alcohol–water mixtures, benzene, chloroform and was somewhat soluble in boiling water.

Anal. Calcd. for $C_{12}H_{15}O_{11}(CH_3CO)_9$: C, 49.86; H, 5.86; CH_3CO, 12.45 cc. 0.1 *N* NaOH per 100 mg. Found: C, 49.80; H, 5.87; CH_3CO, 12.50 cc.

Identification of the Hydrolytic Products of Gentiobiotol.—A solution of 0.5 g. of amorphous gentiobiotol in 40 cc. of 5% hydrochloric acid was heated at reflux temperature for one hour. The hydrolyzate was evaporated to a sirup by a dry air stream overnight. The sirup was dissolved in 5 cc. of concentrated hydrochloric acid and divided into two parts. One part was treated with benzaldehyde according to the procedure of Karrer and Büchi.[6] The gelatinous product was crystallized from benzene and characterized by melting point (190–191°) and mixed melting point as tribenzylidene sorbitol, for which Karrer and Büchi record the melting point of 190–191°.

The second portion of the sirup was shaken with 2 cc. of ethyl mercaptan until solution was effected. On standing below 0° for eighteen hours and dilution with ice and water, crystals separated. The filtered product was washed with cold water and recrystallized thrice from water. The product was identified by melting point (126–127°) and mixed melting point as *d*-glucose diethyl mercaptal, for which Fischer[14] recorded the melting point of 127–128°.

O-Nonamethyl-lactitol.—O-Nonamethyl-4-(β-*d*-galactosido)-(*levo*)-sorbitol or lactitol nonamethyl ether was synthesized from lactitol[2] by methylating twice with dimethyl sulfate and sodium hydroxide according to a procedure described by West and Holden.[15] The methylation was completed by a method described by Pacsu and Trister[16] in which the alcohol was added to sodium in absolute ether and after reaction had taken place an excess of methyl iodide was added. Purification of the product gave a crude yellow sirup. Twenty-five grams of lactitol yielded 28 g. of the crude ether. The sirup was distilled in a Hickman pot still at 10^{-3} to 10^{-5} mm. with a bath temperature of 125–135°. A low boiling fraction was discarded. The main distillate consisted of a very viscous, almost colorless sirup; yield approximately 80%; spec. rot. −13.5° (25°, *c* 7, abs. $CHCl_3$), $n^{21}D$ 1.4578.

Lactitol nonamethyl ether was insoluble in water and was soluble in all of the common organic solvents.

Anal. Calcd. for $C_{12}H_{15}O_2(OCH_3)_9$: C, 53.60; H, 9.00; OCH_3, 59.36. Found: C, 53.42; H, 8.89; OCH_3, 59.14.

O-Nonamethyl-maltitol.—O-Nonamethyl-4-(α-*d*-glucosido)-(*levo*)-sorbitol or maltitol nonamethyl ether was synthesized in the same manner as described above for lactitol nonamethyl ether. Twenty-five grams of maltitol sirup[4] yielded 24 g. of crude maltitol nonamethyl ether as a yellow sirup. An almost colorless, viscous sirup was obtained in approximately 80% yield on distillation in the Hickman pot still at 10^{-3} to 10^{-5} mm. with a bath temperature of 125–135°; spec. rot. +89° (24°, *c* 8, abs. $CHCl_3$), $n^{20}D$ 1.4550.

Maltitol nonamethyl ether was insoluble in water and was soluble in all of the common organic solvents.

Anal. Calcd. for $C_{12}H_{15}O_2(OCH_3)_9$: C, 53.60; H, 9.00; OCH_3, 59.36. Found: C, 53.65; H, 9.09; OCH_3, 58.52.

2,3,4,5,6-O-Pentamethyl-(*levo*)-sorbitol.—Eighteen grams of *aldehydo*-*d*-glucose pentamethyl ether was reduced in 90 cc. of absolute ethanol containing 10 g. of a nickel catalyst supported on kieselguhr. This solution was reduced in a steel shaking autoclave (American Instrument Company) at an initial hydrogen pressure of 1600 lb. per sq. in. (109 atm.) at 35°. A maximum pressure of 2400 lb. per sq. in. (163 atm.) at 175° was attained in one hour and was held for seven hours. The cooled reduction mixture was filtered, heated to boiling and hydrogen sulfide passed in, then 3 g. of decolorizing charcoal was added and boiling continued for ten minutes. After filtration the alcohol solution was reduced to a sirup by a dry air stream; yield 14 g. The light yellow sirup was distilled in a Hickman high vacuum pot still at 10^{-3} to 10^{-5} mm. of pressure. At a 50–55° bath temperature an almost colorless sirup distilled.

2,3,4,5,6-O-Pentamethyl-(*levo*)-sorbitol was soluble in alcohol, ether, chloroform, ethyl acetate, acetic acid and other common organic solvents. In water and petroleum ether a slight opalescence was observed; $n^{21}D$ 1.4439, spec. rot. +47° (24°, *c* 5, abs. $CHCl_3$).

(13) All rotations are recorded for the D line of sodium light; 25° is the temperature and *c* is the concentration in g. per 100 cc. of soln.

(14) E. Fischer, *Ber.*, **27**, 673 (1894).

(15) E. S. West and R. F. Holden, THIS JOURNAL, **56**, 930 (1934).

(16) E. Pacsu and S. M. Trister, *ibid.*, **61**, 2442 (1939).

Anal. Calcd. for $C_6H_9O(OCH_3)_5$: C, 52.36; H, 9.58; OCH_3, 61.39. Found: C, 52.43; H, 9.24; OCH_3, 61.52.

2,3,4,5,6 - O - Pentamethyl - (*levo*) - sorbitol 1 - N - α-Naphthylcarbamate.—Four grams of 2,3,4,5,6-O-pentamethyl-(*levo*)-sorbitol was added to 3.5 g. of α-naphthyl isocyanate, shaken well and allowed to stand overnight. The general procedure used was that described by Bickel and French.[17] Crystals of the by-product, di-α-naphthyl urea, separated and the reaction solution set to a semisolid mass. Petroleum ether was added (b. p. 60–110°) and the mixture boiled and filtered rapidly in order to remove the di-α-naphthyl urea, which is not soluble in hot, high-boiling petroleum ether. On standing overnight at icebox temperature a waxy, white solid separated; yield 2 g. Further purification of the product with boiling petroleum ether was required to remove traces of the by-product. After four such treatments with petroleum ether the material crystallized in rose-shaped clusters; m. p. 71–72°. On recrystallization, performed by using a small quantity of ether as solvent, adding an excess of petroleum ether and seeding, long needles were obtained; m. p. 75–76°, spec. rot. −5° (22°, *c* 3, abs. $CHCl_3$).

The compound was soluble in ether, high-boiling petroleum ether, ethyl acetate, acetic acid and chloroform. It was practically insoluble in all other common solvents.

Anal. Calcd. for $C_{17}H_{16}O_2N(OCH_3)_5$: C, 62.73; H, 7.41; N, 3.32; OCH_3, 36.75. Found: C, 62.62; H, 7.43; N, 3.24; OCH_3, 36.75.

(17) V. T. Bickel and H. E. French, THIS JOURNAL, **48**, 747 (1926).

Summary

1. Gentiobiotol (6-(β-*d*-glucosido)-(*levo*)-sorbitol) has been synthesized as an amorphous material by the high pressure catalytic reduction of gentiobiose and characterized as its crystalline nonaacetate.

2. The structure of gentiobiotol was verified by its lack of Fehling reduction and by the characterization of its hydrolytic products, (*levo*)-sorbitol and *d*-glucose, as crystalline derivatives.

3. O - Nonamethyl - 4 - (β - *d* - galactosido)-(*levo*)-sorbitol and O-nonamethyl-4-(α-*d*-glucosido)-(*levo*)-sorbitol have been synthesized as distilled sirups by the methylation of lactitol and maltitol, respectively.

4. 2,3,4,5,6 - O - Pentamethyl - (*levo*) - sorbitol has been synthesized as a distilled sirup by the high pressure catalytic reduction of *aldehydo*-*d*-glucose pentamethyl ether and characterized as its crystalline 1-N-α-naphthylcarbamate.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE OHIO STATE UNIVERSITY]

The Preparation of Aldehydes, Ketones, and Acids by Ozone Oxidation

BY ALBERT L. HENNE AND PHILIP HILL

Oxidation with ozone can be adapted to a practical preparation of aldehydes, ketones and acids in good yields. The results of a quantitative search for the best conditions of operation are described here. All operations were carried out on half mole quantities.

The source of ozone has been described in an earlier communication.[1]

Of the three satisfactory solvents, methylene chloride was generally preferred, since (1) it permits the carrying out of the ozonization at low temperatures (solid carbon dioxide), a procedure which lessens the loss of volatile olefins in the oxygen stream, and (2) it is easily eliminated during the hydrolysis of the ozonide. Glacial acetic acid at room temperature, and ethyl acetate were also satisfactory, the latter particularly so in the ozonization of cyclic olefins, but the use of both solvents required an efficient refluxing system.

The absorption of ozone was quantitative as long as olefinic material was available.[2] This was repeatedly ascertained by weighing the ozonide after the removal of the solvent by suction. The end of the reaction was sensitively detected by odor, or by the break of a piece of rubber hose attached to the gas outlet tube.

The hydrolysis of the ozonide was carried out in an apparatus adapted from the design of Whitmore and Church.[3] These authors remove the solvent before hydrolysis, at the risk of explosions; they recommend the use of zinc dust and hydroquinone in the water, and record the violence of the hydrolysis. After many trials the following modifications were adopted. (1) A solution of the ozonide in methylene chloride was dripped into the hydrolyzing medium and the solvent was allowed to distill off through the reflux

(1) Henne, THIS JOURNAL, **51**, 2676 (1929).

(2) With dienes, one molecule of ozone was rapidly fixed but the second molecule was slow to react, and systematic titration of ozone in the effluent gases was required to find the end-point of the ozonization.

(3) Whitmore and Church, THIS JOURNAL, **54**, 3710 (1932).