Oxidation of Erythritol, D-Threitol, *erythro*-2,3- and *threo*-2,3-Butanediols Respectively, by Mercury(II) Acetate

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The secondary hydroxyl groups of erythritol and D-threitol undergo oxidation in a boiling methanolic solution of mercury(II) acetate to give DL- and D-glycerotetruloses. Similarly, acetoin is formed from *erythro*-2,3- and *threo*-2,3-butanediols under the mentioned reaction conditions. Differences in yields of particular α-hydroxycarbonyl compounds obtained show that the structures of the studied substances influence the rate of oxidation. The effect of subsequent dehydrating reactions to which DL- and D-glycerotetruloses respectively, are submitted upon overall course of reaction is discussed.

The preparation of keto-sugars by synthesis [1] as well as by transformation of the appropriate aldoses [2] proceeds at small yields. Mercury(II) acetate was shown to be a proper oxidizing agent for the preparation of some rare keto-sugars as *erythro*-3-pentulose [3] and D-*threo*-3-pentulose [4]. In our work [4], oxidation of pentitols and some other polyalcohols as well as oxidation of isopropyl alcohol was described to prove the assumption that the mentioned oxidations would proceed through a cyclic intermediate [3].

In the present work, the effect of *erythro*- or *threo*-configurations in the molecules of erythritol, *erythro*-2,3-butanediol, D-threitol, and *threo*-2,3-butanediol on the oxidizability of the mentioned compounds by mercury(II) acetate is studied.

Experimenta

Apparatus

Polarographic analysis was performed on a polarograph LP-60 in Kalousek vessel with a separate mercurous sulfate electrode. pH Measurements of buffers were carried out using a compensator type E 148c, Metrohm AG Herisau, Switzerland. Electrophoresis was performed on Whatman No. 1 paper within 24 hours at 1,000 volts. Power supply used was manufactured at Development Workshop, Czechoslovak Academy of Sciences, Prague. Oxidation products were separated on Whatman cellulose columns (90 × 4.5 cm) or by means of ion-exchange chromatography on columns (200 × 1 cm) of Dowex-50WX8 (100—200 mesh) (Ba^{2+}) resin. Melting points were determined on a Kofler micro hot stage.

Chemicals

Erythritol was a commercial product of Loba-Chemie, Wien, chromatographically pure, m.p. 118°C. D-Threitol prepared by reduction of D-threose with sodium borohydride [5] had m.p. 87°C after recrystallization from ethanol. D-Threose was prepared by

oxidation of D-galactose with lead tetraacetate [6]. The mixture of *erythro*-2,3- and *threo*-2,3-butanediols was prepared by reduction of diacetyl (3 g) with sodium borohydride (2 g). After removal of Na^+ ions with cation exchanger and volatile borates with boiling methanol, the mixture was separated on the named ion-exchange resin and particular fractions were assayed by paper chromatography in system S_2. *Erythro*-2,3-butanediol (620 mg) and *threo*-2,3-butanediol (710 mg) were obtained besides their mixture (615 mg) after the evaporation of fractions. Both isomers were identified by means of electrophoresis [7]. The ratio of mobility of *erythro*-2,3-butanediol to that of *threo*-2,3-butanediol was 12 : 17. As standards for the identification of oxidation products, acetoin (commercial product of Koch-Light) and L-glycerotetrulose prepared enzymatically by the action of *Acetobacter suboxydans* [8] on erythritol, were used. Chemicals used for the preparation of buffers and solvent systems were anal. grade or redistilled, respectively. Mercury(II) acetate as well as the other chemicals used were also anal. grade.

Chromatography

Descending paper chromatography was performed on Whatman No. 1 paper using the following solvent systems: acetone—*n*-butyl alcohol—water (7 : 2 : 1) (S_1); acetone—*n*-butyl alcohol—4% sodium tetraborate in water (7 : 2 : 1) (S_2); ethyl acetate—acetic acid—4% boric acid in water (9 : 1 : 1) (S_3); cyclohexanol—pyridine—water saturated with boric acid (6 : 5 : 2) on a paper impregnated with 1% boric acid solution (S_4). Erythrose ($R_e = 1$) was used as a reference for estimation of the particular spots. The spots were detected with a solution of aniline hydrogen phthalate and potassium periodate—benzidine [9].

Procedures

1 g (8.2 mmoles) of each erythritol and D-threitol and 0.5 g (5.5 mmoles) of each *erythro*-2,3- and *threo*-2,3-butanediols were oxidized by mercury(II) acetate (5.25 g, 16 mmoles and 3.7 g, 11 mmoles, respectively) in methanol (25 ml). Reactions proceeded in a flask provided with a reflux condenser at boiling point of methanol on a water bath. From the reaction medium, samples (3 ml each) were taken after 1, 4, 7, and 24 hours. The insoluble mercury(I) acetate as well as the mercury salts precipitated from the filtrate by hydrogen sulfide, were filtered off and washed with methanol. The obtained filtrate was adjusted with methanol to the final concentration 1×10^{-3} M with regard to the parent compound in a graduated vessel. In some cases, both mercury(I) and mercury(II) acetates were removed by ion exchangers not to introduce hydrogen sulfide to the reaction medium. The obtained products were determined by comparative polarographic method [10, 11].

In order to isolate the oxidation products on a preparative scale, tenfold amounts of reagents were allowed to react for 4 hours. Separation of the crude oxidation mixture from 10 g of erythritol on cellulose column (S_3) gave 0.61 g (6.1%) of DL-glycerotetrulose (R_e 1.36) and 0.28 g (2.8%) of an unstable product (R_e 1.73). The obtained DL-glycerotetrulose was further characterized by m.p. of its *o*-nitrophenylhydrazone (m.p. 234 to 236°C), by elementary analysis, and by reduction to erythritol and DL-threitol which were identified by paper chromatography (S_4).

The unstable product (R_e 1.73, S_3) was detectable by using not only aniline hydrogen phthalate but also potassium periodate—benzidine. This compound was already decomposed during the isolation giving two products. In order to identify by-products,

DL-glycerotetrulose was dehydrated with 5% acetic acid in boiling methanol during 4 hours. Reaction products were analyzed polarographically and by means of paper chromatography.

The presence of further polarographic waves belonging to addition compounds formed mainly from hydrogen sulfide and dicarbonyl compounds was proved. These waves occurred when hydrogen sulfide was used to precipitate mercury acetates. This fact was considered at the evaluation of polarograms.

Results and Discussion

Oxidation of erythritol and D-threitol gave DL-glycerotetrulose and D-glycerotetrulose, respectively. This result provides evidence for the oxidation of secondary hydroxyl groups of the studied tetritols. Yields of products obtained during oxidation of the studied substances with mercury(II) acetate are presented in Table 1. It is evident that the yields of glycerotetrulose pass through a maximum in dependence on the reaction time. Since glycerotetrulose formed in the early stage is dehydrated, the effect of dehydration causes a decrease in the above-mentioned yields. Erythritol is oxidized twice faster than D-threitol as it is evident from the obtained yields of DL-glycerotetrulose and D-glycerotetrulose, respectively.

Table 1

Oxidation of erythritol, D-threitol, *erythro*-2,3- and *threo*-2,3-butanediols respectively, by mercury(II) acetate in boiling methanol

Substance	Product	Yields [%] in dependence on the reaction time [hours]			
		1	4	7	24
erythritol	DL-glycerotetrulose	5.2	8.3	8.2	3.4
D-threitol	D-glycerotetrulose	2.5	3.7	3.8	2.5
erythro-2,3-butanediol	acetoin	9.0	20.0	25.0	33.0
threo-2,3-butanediol	acetoin	10.4	19.0	27.3	33.2

In contrast to the tetritols, the oxidation rate of *erythro*-2,3- and that of *threo*-2,3-butanediols respectively, are practically identical. Because acetoin does not undergo dehydration under these conditions, its yield increases proportionally with the reaction time. The rate of oxidation of butanediols, however, is not so much greater, as shown in Table 1, than that of tetritols because the decrease of glycerotetrulose caused by dehydration has not been taken into consideration.

In addition to acetoin, the presence of diacetyl has also been found polarographically, proving thus that the hydroxyl group of α-hydroxycarbonyl compound can be oxidized, too. The oxidizability of acetoin to diacetyl was also proved in a separate experiment. We failed, however, to prove similar oxidation of hydroxyl group in the case of glycerotetrulose because of the great amount of dehydration products (deoxytetruloses).

Experimental results obtained in the present as well as in our previous work [4] provide evidence for the preferential oxidizability of secondary alcoholic groups of

the studied compounds by mercury(II) acetate and indicate the operation of stereochemical effects on the rate of their oxidation. So far, no sufficient evidence has been found that the summary reaction of oxidation

$$\begin{array}{c} \\ \mathrm{H-C-OH} \\ \\ \end{array} + 2(\mathrm{CH_3COO})_2\mathrm{Hg} \rightarrow \begin{array}{c} | \\ \mathrm{C=O} \\ | \end{array} + (\mathrm{CH_3COO})_2\mathrm{Hg_2} + 2\mathrm{CH_3COOH}$$

proceeds through a cyclic intermediate as it was assumed by *Stoodley* [3].

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