Cyclic Sulfite and Sulfate Esters of Polymethylene Glycols

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The preparation and characterization of carefully purified cyclic sulfite and sulfate esters of α,ω-dihydroxyethane, -propane, -butane, and -pentane are reported. The pentamethylene cyclic sulfite and cyclic sulfate esters have not been previously described in the literature. Two of the cyclic sulfate esters were prepared by a method previously not applied to the oxidation of cyclic sulfites—i.e., by means of ethyl chlorosulfonate at elevated temperatures.

A CONSIDERABLE number of publications have appeared in recent years on the synthesis and properties of cyclic sulfite and sulfate esters derived from dihydroxyalkanes. Discrepancies in the reported physical properties of some of these compounds due to the presence of various impurities in the reported preparations have now been resolved by the preparation of highly purified samples of these cyclic sulfites and sulfates. We have been able to synthesize, in addition, the C_5 analog of these esters. The syntheses employed used either existing procedures or minor modifications of existing procedures, with the exception of the ethyl chlorosulfonate oxidation of a cyclic sulfite to a cyclic sulfate.

EXPERIMENTAL

Purification of 1,3-Dihydroxypropane (I), 1,4-Dihydroxybutane (II), and 1,5-Dihydroxypentane (III). Solid dibenzoate derivatives of I and II were prepared and recrystallized from petroleum ether to a constant melting point. The bis(*p*-nitrobenzoate) of III was prepared and recrystallized to a constant melting point from benzene–absolute ethanol. These derivatives were hydrolyzed in isopropyl alcohol-KOH and the resulting dihydroxy compounds were fractionally distilled. The physical properties of these glycols are reported in Table I.

Purification of Other Reagents. Thionyl chloride (Fisher Scientific) was distilled through a 1-meter, helix-packed column at a high reflux ratio. The material was clear and colorless [b.p. 76.0–76.1° C (754 mm)].

Pyridine (Baker's analyzed) was refluxed over lump barium oxide for 3 hours, filtered, then refluxed over phosphorus pentoxide for 3 hours, and fractionally distilled (b.p. 114–16°).

Dioxane (Matheson, Coleman and Bell) was purified according to the method of Fieser (*10*) and distilled from a 50% dispersion of sodium hydride in mineral oil (Metal Hydrides, Inc.).

Chloroform (Mallinckrodt) was refluxed over phosphorus pentoxide for 12 hours and distilled the same day it was to be used (*20*).

1,1,2,2-Tetrachloroethane (Fisher Scientific) was refluxed over phosphorus pentoxide for 12 hours and distilled through a 1-meter helix-packed column (b.p. 144–46°). The compound was then passed through a 4-inch column of alumina (Woelm, almost neutral) prior to use.

Ethyl chlorosulfonate (Eastman) was fractionally distilled prior to use [b.p. 82° (70 mm)].

Carbon tetrachloride (Mallinckrodt) was shaken with alumina (Woelm, almost neutral) and filtered prior to use.

Deuterochloroform (Merck and Co., Ltd.) was used without purification.

Ethylene sulfite (Fluka, Inc.) was fractionally distilled prior to use [b.p. 72–74° (20 mm)].

Preparation of α,ω-Cyclic Sulfites. The same general procedure was employed in the preparation of each of the cyclic sulfites. This procedure is an adaptation of those reported by a number of investigators (*5, 6, 9, 15, 21, 26*). A three-necked flask of appropriate size was fitted with two dropping funnels and a condenser. Approximately 1 liter of chloroform per mole of glycol was placed in the flask together with a magnetic stirring bar. In one of the dropping funnels were placed the glycol, pyridine (2 moles per mole of glycol), and sufficient chloroform to bring the glycol to a ca. 2*M* solution. In the case of the 1,5-dihydroxypentane, dioxane also was added to obtain a homogeneous solution. To the other funnel were added thionyl chloride (1.1 moles per mole of glycol) and sufficient chloroform to make the solution ca. 2*M*. The system was placed under a nitrogen atmosphere and protected from moisture by a Drierite drying tube placed on the condenser. The chloroform was brought to reflux, with stirring, and the solutions in the dropping funnels were added dropwise simultaneously over a period of ca. 1 hour per mole of glycol. The mixture was refluxed an additional 30 minutes, cooled to room temperature, and washed three times with a saturated aqueous solution of sodium chloride. The aqueous phases were washed two times with chloroform. The chloroform solutions were combined and dried first over anhydrous sodium sulfate and then over Linde sieves (4A) for 12 hours. The solution was then filtered and the solvent was removed in vacuo. The resulting oil was fractionally

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Table I. Physical Properties of α,ω-Glycols[a]

	M.P., ° C[b]	B.P., ° C	n_D^{25}
Propane	58–59, [57–59][c]	111 (11 mm), [113 (15 mm)][d]	1.4382, [1.4385][e]
Butane	82–82.5, [81–82][c]	122 (10 mm), [127 (20 mm)][f]	1.4452, [1.4445][g]
Pentane	104–05, [104–05][c]	133–34 (11.5 mm), [118–20 (6 mm)][h]	1.4494, [1.4484][i]

[a] Bracketed values previously reported in literature. [b] Uncorrected m.p. of solid derivatives. [c] (*12*). [d] (*7*). [e] (*24*). [f] (*4*). [g] (*1*). [h] (*14*). (*8*).

distilled in vacuo. In the preparation of the pentamethylene cyclic sulfite, a large amount of nonvolatile liquid material and a nonvolatile white solid were obtained in addition to the desired product. The solid was recrystallized from chloroform-petroleum ether, yielding white crystals (m.p. 144.5–45.5°). The C, H, and S analyses of the solid were consistent with the empirical formula $C_5H_{10}O_3S$. The structure of this nonvolatile solid was not pursued.

Analytical samples of the cyclic sulfites were obtained by careful fractional distillation through a 60-cm Piros-Glover column. These samples were shown to be 99.9% pure by GLPC area measurements. Physical properties of the purified samples are given in Table II. The C, H, and S analyses (Micro-Tech Laboratories, Skokie, Ill.) were consistent with the reported structures.

Preparation of α,ω-Cyclic Sulfates. METHOD A. A calcium permanganate (Carus Chemical Co.) oxidation of the corresponding cyclic sulfite in glacial acetic acid was conducted according to the method of Garner and Lucas (*11*).

METHOD B. A three-necked flask of appropriate size was fitted with a dropping funnel and a condenser. The apparatus was maintained in a nitrogen atmosphere and protected from moisture by placing Drierite drying tubes at appropriate locations. A 2*M* solution of the cyclic sulfite in 1,1,2,2-tetrachloroethane was placed in the flask and brought to reflux with stirring. To the refluxing solution was added ethyl chlorosulfonate (2 moles per mole of sulfite) at the rate of 0.3 mole per hour. The solution was allowed to reflux for an additional hour and cooled to room temperature. The solvent and excess ethyl chlorosulfonate were removed in vacuo and the remaining brown oil was transferred to a distillation flask. The oil was fractionally distilled to dryness at either 0.5 or 2.5 mm. This distillation seemed to involve a pyrolytic decomposition as well. The distillate was dissolved in chloroform and the solution cooled to −78°. The solid material that separated was removed by filtration. The solid was then recrystallized from an appropriate solvent to constant melting point and dried over Linde sieves (13×).

Table II. Physical Properties and Yields of α,ω-Cyclic Sulfites[d]

	B.P., ° C[b]	n_D^{25}	Yield, %
Ethane	72–73 (20 mm), [80 (35 mm)][c]	1.4441 [1.4443][c]	
Propane	90–91 (38 mm), [90–91 (38 mm)][d]	1.4516 [1.4498][d]	73
Butane	86 (9 mm), [90.5–91 (13 mm)][e]	1.4671 [1.4631][c]	74
Pentane	92 (11 mm)	1.4729	23

[a] Bracketed values previously reported in literature. [b] Uncorrected. [c] (*26*). [d] (*9*). [e] (*19*).

The cyclic sulfates are all white crystalline solids; their physical properties are summarized in Table III. The C, H, and S analyses (Micro-Tech Laboratories, Skokie, Ill.) are consistent with the reported structures.

Physical Data. The infrared spectra were taken on a Perkin-Elmer 21 infrared spectrophotometer. The sulfite spectra were taken on the neat liquids between sodium chloride plates and the sulfate spectra were taken on Nujol and Fluorolube mulls. The reported sulfate spectra are corrected for the Nujol or Fluorolube absorption bands. The infrared spectra are given in Figure 1.

The NMR spectra were obtained on a Varian 4300-B NMR spectrometer operating at 56 MHz and were cal-

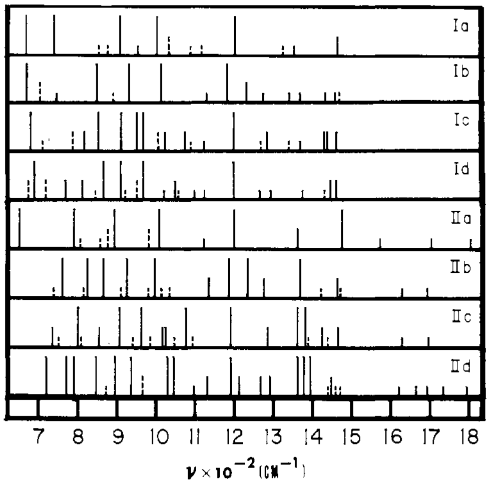

Figure 1. Infrared absorption frequencies of cyclic sulfite and sulfate esters

Height of lines proportional to intensity of absorption. Broken lines represent shoulders on neighboring bands. I indicates a cyclic sulfite and II a cyclic sulfate. Ethylene given by *a*, trimethylene by *b*, tetramethylene by *c*, and pentamethylene by *d*

Table III. Physical Properties and Yields of α,ω-Cyclic Sulfates

	M.P., ° C[a]	% Yield	Oxidation Method	Mol. Wt.[b]
Ethane	95–97 (chloroform), [97.3–97.5][c]	90	B	109, [124]
Propane	60.5–61.5 (benzene–petroleum ether), [61–2][d]	67	B	
Butane	44–45 (anhyd. ether), [44–5][e]	71	A	140, [152]
Pentane	40–41.5 (anhyd. ether)	58	A	165, [166]

[a] Uncorrected; crystallization solvent given in parentheses; bracketed values previously reported. [b] Cryoscopically determined with DL-camphor (m.p. 173°–75°) as solvent, using molal freezing point lowering constant of 50 (*22*). Reported values were determined by extrapolation to 0 weight % from four experimentally determined points (1, 2, 6, and 10%). Bracketed values are calculated mol. wt. [c] (*13*). [d] (*6*). [e] (*19*).

ibrated with audio side bands. The chemical shifts given are the result of averaging three upfield and three downfield scans. The spectra of the sulfites were obtained on 20 volume % solutions in carbon tetrachloride. The spectra of the sulfates were obtained on 10 weight % solutions in deuterochloroform. All spectra were obtained on carefully degassed samples. Tetramethylsilane was employed as internal standard.

The GLPC data were obtained on a 16-foot analytical column packed with 0.5 weight % Dow Corning 710 silicone oil on 80- to 100-mesh glass beads (3M Co.).

DISCUSSION

The procedures given above were the ones that proved most satisfactory after investigation of a large number of different approaches. The method used in the preparation of the cyclic sulfites was sufficiently general to allow the synthesis of the pentamethylene cyclic sulfite, but it could not be extended to the hexamethylene or decamethylene compounds.

The calcium permanganate oxidation was attempted on the ethylene and trimethylene cyclic sulfites, but the yields were poorer than with the ethyl chlorosulfonate oxidation (*13*). The former procedure gave high yields in the oxidation of tetramethylene and pentamethylene cyclic sulfites, probably due to the greater hydrolytic stability of these compounds and their corresponding cyclic sulfates.

The alkyl chlorosulfonate oxidation has been applied to the conversion of dialkyl sulfites to dialkyl sulfates (*3, 16, 17, 18, 25*)—i.e., $R_2SO_3 + RSO_3Cl \rightarrow R_2SO_4$ + other products, where all alkyl groups are the same. This is the first reported instance of the use of this method in the oxidation of a cyclic sulfite to a cyclic sulfate. Experiments also were conducted with methyl and 2-chloroethyl chlorosulfonates in place of ethyl chlorosulfonate, but these did not give appreciably better yields.

Baker and Field have shown by cryoscopic measurements that the ethylene and trimethylene cyclic sulfates are monomeric (*2*). Our cryoscopic measurements on the ethylene cyclic sulfate are in agreement with their results. Cryoscopic measurements on the tetramethylene and pentamethylene cyclic sulfates indicate that these compounds are also monomeric (Table III).

The logarithms of the GLPC retention times of the cyclic sulfites are a linear function of the number of methylene groups in the molecule. This indicates that the cyclic sulfites are members of a homologous series (*23*). The two different oxidation procedures would not be expected to result in rearrangements. On the basis of the demonstrated monomeric character of the cyclic sulfates, it is assumed that the cyclic sulfites are monomeric as well.

The NMR spectrum of the trimethylene cyclic sulfite is a very complex one, with four absorption regions whose mid-points are at δ ca. 1.7, 2.5, 3.8, and 4.9. The other two cyclic sulfites have two sets of absorptions: one centered at δ ca. 4, corresponding to the methylene groups adjacent to the sulfite oxygens, and another at δ ca. 1.9, corresponding to the other methylene groups. The NMR spectra of the cyclic sulfates are much simpler than those of the corresponding sulfites because of the symmetry of the tetrahedral sulfate group. The sulfate esters have two regions of absorption each: one centered at δ ca. 4.5 $(\text{—O—CH}_2\text{—})$ and the other at δ ca. 2.1 $[\text{—C—(CH}_2)_n\text{—C—}]$.

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