

Selective Oxidation of 1,2-Diols by Electrochemical Method Using Organotin Compound and Bromide Ion as Mediators

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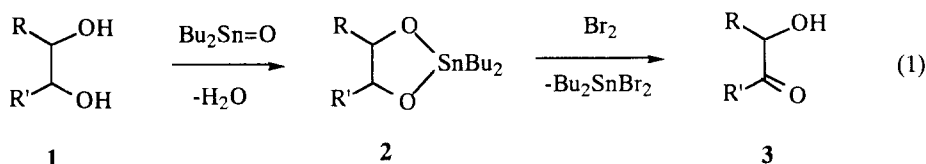
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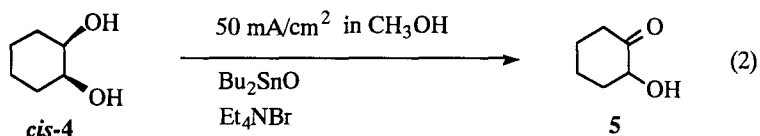
Abstract: A new electrochemical method for a selective oxidation of 1,2-diols to keto alcohols was explored. The method used dibutyltin oxide and bromide ion as mediators, and the oxidation was found to proceed effectively at 0°C under neutral conditions. Under these reaction conditions, 1,2-cyclohexanediol was selectively oxidized even in the presence of primary and secondary alcohols.
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Selective oxidation of a hydroxy group into a carbonyl group is a basic and important organic reaction. It was reported in 1974 that 1,2-diols **1** were selectively oxidized to keto alcohols **3** by transformation of the diols **1** to dibutylstannylenes **2** followed by brominolysis (eq 1),¹ and the method has been applied to fine chemistry as exemplified by the synthesis of (+)-spectinomycin² and the oxidation of unprotected sugars.^{3,4} The method, however, has some disadvantages which require improvement. Namely, dibutylstannylenes **2** have to be prepared in advance by the reaction of **1** with dibutyltin oxide prior to brominolysis. This process may be tedious and usually requires the use of more than an equimolar quantity of dibutyltin oxide, which is troublesome at the working up and is not recommended from an environmental viewpoint. Also, because of hydrogen bromide generated at the stage from **2** to **3**, the reaction system becomes sluggish and often results in low yields of products, though some devices to overcome the last problem have been presented.^{1b, 4}



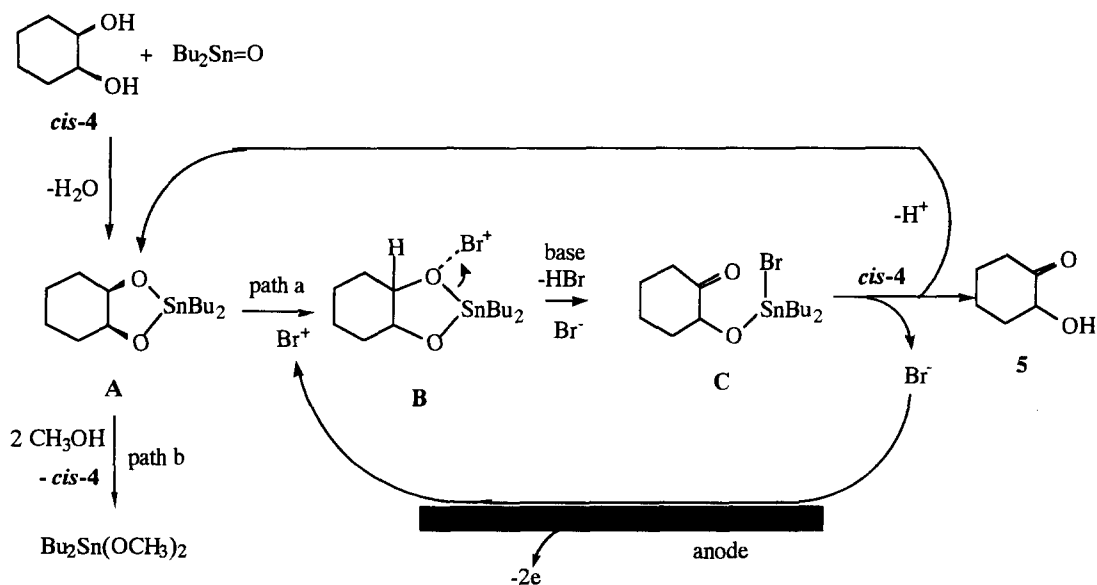
We report herein a simple and highly efficient electrochemical oxidation of 1,2-diols, which is characterized by mediation with a catalytic amount of an organotin compound and bromide ion under mild reaction conditions. *cis*-1,2-Cyclohexanediol (*cis*-**4**) was examined as a representative of 1,2-diols (eq 2).⁵ The electrolysis was carried out under various conditions to afford 2-hydroxycyclohexanone (**5**) in yields which were dependent on the reaction conditions. The results are summarized in Table 1.

A typical procedure was as follows; Heating dibutyltin oxide (0.1 mmol) in methanol (10mL) containing *cis*-4 (1mmol) for 30 min gave a homogeneous methanolic solution, which was used for electrolysis.⁶ Tetraethylammonium bromide (1mmol) as a supporting electrolyte was added to the solution, which was placed in an undivided cell equipped with a platinum anode and cathode (1cm x 2cm), and the resulting solution was subjected to constant current electrolysis (100mA) at 0°C. After passing 2.0F/mol of electricity, usual work-up gave **5** in 95% yield, which corresponded to 950% yield based on dibutyltin oxide (run 4 in Table 1).⁷



Noteworthy points of the results are as follows. 1) Dibutyltin oxide was required for efficient oxidation of *cis*-4 (run 1). 2) A considerable decrease of the yield of **5** was observed in the cases using BF_4^- in place of Br^- (run 2). 3) Use of a catalytic amount of dibutyltin oxide (0.02 to 0.1equiv. to *cis*-4) and Br^- (0.2 equiv. to *cis*-4) was enough to complete the oxidation (compare runs 4, 7, and 8). The maximum yield of **5** based on dibutyltin oxide reached 4700% (run 8). 4) The yield of **5** was largely dependent on the reaction temperature (see runs 3-6) and it was found that the electrolysis at 0°C afforded the best result (run 4). 5) Using Cl^- and I^- instead of Br^- decreased the yield of **5** (runs 9 and 10). 6) Use of bis-tributyltin oxide as an organotin compound resulted in a low yield of **5** (run 11). 7) The reaction conditions were neutral over the electrolysis.

On the basis of these facts, the following reaction mechanism can be presented, though it is still a working hypothesis (Scheme 1).⁸



Scheme 1 Working Hypothesis for Reaction Mechanism

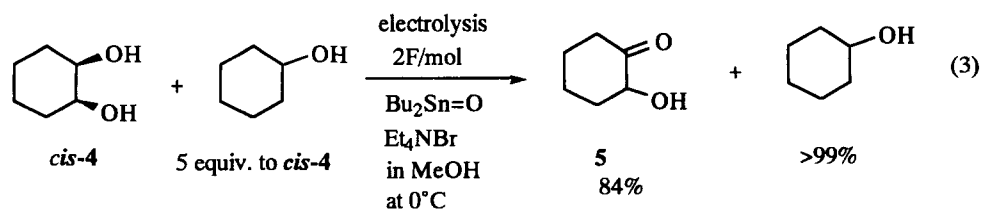
Table 1. Electrochemical Oxidation of *cis*-1,2-Cyclohexanediol (*cis*-4)^a

Run	Organotin Compound (equiv. to <i>cis</i> -4)	Supporting Electrolyte (equiv. to <i>cis</i> -4)	Temp.	Electricity F/mol	Yield (%) of 5 ^b	Yield (%) of 5 based on Organotin Compound
1	non	Et ₄ NBr (1.0)	0°C	2.0	11	-
2	Bu ₂ Sn=O (0.1)	Et ₄ NBF ₄ (1.0)	0°C	2.0	27 ^c	470
3	Bu ₂ Sn=O (0.1)	Et ₄ NBr (1.0)	-20°C	2.0	84	840
4	Bu ₂ Sn=O (0.1)	Et ₄ NBr (1.0)	0°C	2.0	95	950
5	Bu ₂ Sn=O (0.1)	Et ₄ NBr (1.0)	r. t.	2.0	58	580
6	Bu ₂ Sn=O (0.1)	Et ₄ NBr (1.0)	reflux	2.0	36	360
7	Bu ₂ Sn=O (0.05)	Et ₄ NBr (0.2)	0°C	2.0	96	1920
8	Bu ₂ Sn=O (0.02)	Et ₄ NBr (1.0)	0°C	2.8	94	4700
9	Bu ₂ Sn=O (0.1)	Et ₄ NCl (1.0)	0°C	4.0	33	330
10	Bu ₂ Sn=O (0.1)	Et ₄ NI (1.0)	0°C	4.7	10	100
11	(Bu ₃ Sn) ₂ O(0.1)	Et ₄ NBr (1.0)	0°C	2.0	63	630

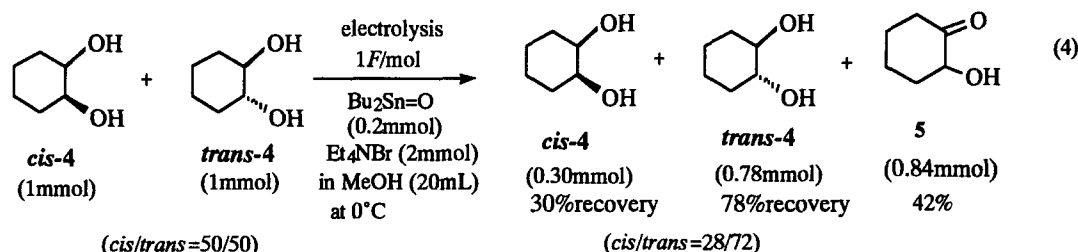
^a Electrolysis was carried out in an undivided cell equipped with platinum anode and cathode (1cm x 2cm).^b Determined by GLC.^c Significant amount of unidentified by-products was formed.

A reaction of dibutyltin oxide with *cis*-4 gives dibutylstannylene A, which is dissolved in methanol.⁵ Then, A is converted by the action of electrochemically generated Br⁺ through a transition state B (path a) to an intermediate C, which reacts with *cis*-4 to afford 5 with regeneration of A and Br⁻. High yields of 5 observed in the cases of a catalytic amount of dibutyltin oxide and Br⁻ indicate an efficient regeneration of A and Br⁺. Temperature dependence of the yields of 5 may be explained in terms of temperature dependence of the efficiencies of the formation of A and 5. Namely, at room and reflux temperatures, some of A may be decomposed in methanol (path b), and at low temperature below 0°C the rate of the transformation of A to 5 may be decelerated. The best result was obtained in the experiment carried out at 0°C.

Another remarkable point of the electrolysis was the high chemoselectivities. As shown in Table 1, *cis*-4 was efficiently oxidized even in methanol as a solvent. Also, when the electrolysis was carried out in the presence of cyclohexanol (5 equiv. to *cis*-4) in methanol as a solvent, 5 was obtained in 84% yield with a 99% recovery of cyclohexanol after 2F/mol of electricity was passed (eq 3).



The stereoselectivity observed in the oxidation of *cis*- and *trans*-4 was also interesting, though it was not so high. Namely, an electrolysis of a solution of a mixture of *cis*- and *trans*-4 (50 to 50 ratio) in methanol containing dibutyltin oxide gave **5** in 42% yield at the stage of 1F/mol of electricity with a recovery of *cis*- and *trans*-4 in a ratio of 28 to 72, suggesting that the *cis* isomer was oxidized at about three times faster than the *trans* isomer (eq 4).¹⁰



In conclusion, we developed a new electrochemical method in which both dibutyltin oxide and Br⁻ worked as efficient mediators for highly selective oxidation of 1,2-diols. Application of this new selective oxidation process to other 1,2-diols and polyols, and modification of the structure of organotin compounds for more selective oxidation are under investigation.

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References and Notes

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5. Some other 1,2-diols were also oxidized under the similar reaction conditions to the corresponding keto alcohols (the isolated yields: 87% for 4-t-butyl-1,2-cyclohexanediol; 74% for 1,2-cycloheptanediol; 33% for 1,2-cyclopentanediol; 47% for *meso*-hydrobenzoin).
6. Dibutyltin oxide was hardly dissolved in methanol at room temperature.
7. Keto alcohol **5** was easily dimerized when isolated **5** was allowed to stand at room temperature. Thus, the yields shown in Table 1 were obtained by means of GLC immediately after the electrolysis.
8. The "base" in the scheme 1 may be an electrochemically generated base⁹ or Br⁻.
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10. In order to easily determine the ratio of recovered *cis*-4/*trans*-4, the reaction mixture was benzoylated by treatment with excess benzoyl chloride in the presence of dimethylaminopyridine in methylene chloride.