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Synthesis of Dimethyl 1,2-Cycloalkanedicarboxylates by Electrochemical Cyclization of Dimethyl α,α'-Dibromoalkanedioates Using a Copper Anode

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Synopsis. The electrochemical cyclization of dimethyl α,α'-dibromoalkanedioates by making use of a platinum cathode and a copper anode in the presence of sodium iodide gave three- to six-membered dimethyl 1,2-cycloalkanedicarboxylates in good yields.

The electrochemical reductive cyclization of 1,3-dihalides has been proved to be useful for the preparation of cyclopropanes, bicyclobutanes, or spiropentanes.[1,2] The electroreductive cyclization of 1,4-dihalides has also been reported to give cyclobutane rings.[1] The preparation of higher-membered cycloalkanes by the electrochemical reduction of α,ω-dihalides, however, was not successful until we found that the electroreductive cyclization of α,ω-dibromides carrying alkoxycarbonyl groups at their terminal carbons afforded three- to seven-membered cycloalkanes.[3] We have also reported that ten-, twelve-, or fourteen-membered (*E,E*)- and (*Z,Z*)-1,5-cycloalkadienes can be prepared by the electroreductive cyclization of allylic α,ω-dibromides.[4] The preparation of substituted cyclopentanes by similar electroreductive cyclization has recently been reported.[5]

In this paper we report on the results concerning the electrochemical cyclization of α,ω-dibromides carrying alkoxycarbonyl groups at their terminal carbons. The use of a copper metal as an anode in a one-compartment cell was found to be of importance in this cyclization although the cyclization itself proceeds via reductive pathways. By using a copper anode instead of a platinum anode, much higher yields of three- to six-membered cycloalkanes could be obtained. The present work was carried out as part of our efforts to find effective carbon-carbon bond forming reactions by making use of reactive metal anodes.[6—9]

Results and Discussion

We previously reported that the electrochemical reduction of methallyl bromide gave 2,5-dimethyl-1,5-hexadiene in quantitative yield when electrolysis was carried out in the presence of one molar equivalent of sodium iodide while using a copper anode.[6] We found that this electrolysis using a reactive metal anode is also effective for the electrochemical cyclization of dimethyl α,α'-dibromoalkanedioates. The results of electrochemical cyclization of dimethyl 2,6-dibromoheptanedioate (**1c**) under various conditions are summarized in Table 1. Thus, the electrolysis of **1c** using a copper anode instead of a platinum anode gave cyclization product **2c** in 67% yield, while cyclization using a platinum anode gave only 48% yield of **2c**. We found that the addition of two molar equivalents of sodium iodide in this cyclization enhanced the yield to 85%.

Table 1. Electrochemical Cyclization of Dimethyl 2,6-Dibromoheptanedioate (**1c**) under Various Conditions[a)]

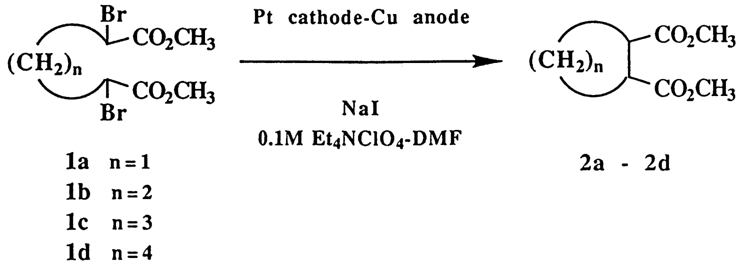
Entry	Cathode	Anode	Additive	Product (**2c**)	
				Yield/%[b)]	trans : cis
1	Pt	Pt	—	48	73:27
2	Pt	Pt	2 equiv NaI	24	56:44
3	Pt	Cu[c)]	—	67	75:25
4	Pt	Cu[d)]	2 equiv NaI	85	65:35
5	Pt	Cu–Pt[e)]	—	71	72:28
6	Pt	Cu–Pt[e)]	2 equiv NaI	47	72:28

a) Carried out according to the procedure described in the Experimental Section. b) GLC yield. c) A copper anode dissolved: 2.6 mol/mol of **1c**. d) A copper anode dissolved: 3.6 mol/mol of **1c**. e) A copper-modified platinum anode was used. The cathode and anode were alternated at 10-min intervals (0.5 Faraday/mol of **1c**). In total, an electricity of 5 Faradays per mol of **1c** was passed.

Copper equivalent to 2.6—3.6 mol per mol of **1c** was found to be dissolved into the electrolytic solution during the electrolysis using a copper anode (Table 1, Entries 3 and 4). This loss of the copper anode can be appreciably reduced by the following new procedure using a copper-modified platinum anode. This method requires only 0.64 molar equivalent of copper dissolution for the modification of the platinum anode. Furthermore, the modified copper can be recycled between the cathode and anode by alternating their polarities at constant intervals during the electrolysis. The electrolysis of **1c** by using a platinum cathode and a copper-modified platinum anode, and by alternating the polarities at 0.5 Faraday intervals gave **2c** in 71% yield along with 20% of dimethyl heptanedioate (Entry 5).

The electrolysis of dimethyl α,α'-dibromoalkanedioates (**1a**—**d**) using a platinum cathode and a copper anode in the presence of two molar equivalents of sodium iodide gave the corresponding dimethyl 1,2-cycloalkanedicarboxylates (**2a**—**d**) (Scheme 1). Table 2 summarizes the yields and isomer ratios of the cyclization products. Dimethyl esters of 1,2-cyclopropane-, cyclopentane-, and cyclohexanedicarboxylates (**2a**, **2c**, and **2d**) were obtained in isolated yields more than 70%. The formation of the four-membered ring was found to be less efficient.

The role of the sodium iodide would be to act as a nucleophile in transforming the starting α-bromo esters into the corresponding iodides, which are more reactive than the starting bromides. It has, in fact, been proved that 33% of the carbon–bromine bonds of **1d** are converted into carbon–iodine bonds when **1d** is stirred for



Scheme 1.

Table 2. Electrochemical Cyclization of Dimethyl α,α′-Dibromoalkanedioates[a)]

Dibromide	n	Product	Yield[b)] %	trans : cis
1a	1	**2a**	75 (83)	70 : 30
1a[c)]	1	**2a**	— (65)	63 : 37
1b	2	**2b**	30 (58)	70 : 30
1c	3	**2c**	71 (85)	65 : 35
1c[c)]	3	**2c**	60 (71)	72 : 28
1d	4	**2d**	77 (86)	36 : 64

a) Carried out according to the procedure described in the Experimental Section. b) Isolated yields. GLC yields are shown in the parentheses. c) Electrolysis was carried out using a platinum cathode and a copper-modified platinum anode; the cathode and anode were alternated at 10-min intervals (0.5 Faraday/mol of **1a**—**d**).

30 min at room temperature in the presence of two molar equivalents of sodium iodide.

In the electrochemical cyclization of **1d**, small amounts of dimethyl octanedioate, dimethyl 2-bromooctanedioate, and dimethyl 2-iodooctanedioate were obtained as by-products along with the major product **2d**. This result indicates that the formation of the observed cycloalkanes (**2**) involves a stabilized carbanion generated by a two-electron reduction of one of the carbon–bromine or the carbon–iodine bonds of the starting dihalides (**1**), followed by an intramolecular nucleophilic displacement of the halogen atom.

It is likely that some organocopper species formed by the electrochemical reaction of organic halides with the copper anode[10)] are precursors in the present cyclization or that the copper anode participates in the reaction by anodic dissolution,[9)] which effectively captures the halide ions generated by the electrochemical reduction of **1**.

Experimental

N,N-Dimethylforamide (DMF) was dried over molecular sieve 4A and distilled over phosphorus pentaoxide under reduced pressure. Spectral measurements and quantitative GLC analyses were carried out using our standard methods.[4)]

Preparation of Dibromo Diesters (1a—d). Starting dimethyl α,α′-dibromoalkanedioates (**1a**—**d**) were prepared in 70—90% yield from the corresponding alkanedioic acids by the method of Vogel[11)] and Shreiner.[12)] **1a**: Bp 110—113 °C (0.9 mmHg, 1 mmHg=133.322 Pa); **1b**: Mp 75—77 °C; **1c**: Bp 132—135 °C (0.7 mmHg); **1d**: Bp 149 °C (0.6 mmHg).

General Procedure for Electrolysis. A one-compartment cell (32 mm dia.) was used for the electrolysis.[4)] A mixture of dibromides **1a**—**d** (1.5 mmol) and sodium iodide (3 mmol) in 30 ml of DMF solution containing 0.1 M (1 M=1 mol dm^{-3}) tetrabutylammonium perchlorate (TBAP) was electrolyzed under a nitrogen atmosphere at a constant current of 1 A dm^{-2} using a platinum cathode and a copper anode (0.3×0.4 dm^2). The electricity passed was 5 Faradays per mol of the dibromide.

The copper-modified platinum electrode was easily prepared by the electrolysis of a DMF solution containing 0.1 M TBAP using a platinum cathode and a copper anode. When an electricity of 1 Faraday per mol of the dibromide was passed through the solution, 0.64 molar equivalent of copper were dissolved from the copper anode.

The usual work-up of the electrolyzed solution gave a product mixture which was subjected to preparative TLC (silica gel; benzene–diethyl ether 4 : 1) to give pure products.

Dimethy *trans*-1,2-Cyclopropanedicarboxylate (*trans*-2a): n_D^{25} 1.4438 (lit,[13)] n_D^{26} 1.4523); IR (neat) 1736, 1170, 1020 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.45 (m, 2H, J=5.9, 7.3, and 8.8 Hz), 2.18 (m, 2H, J=5.9 and 8.8 Hz), 3.71 (s, 6H); mass spectrum m/z 158 (M$^+$, 2), 157 (19), 127 (100), 126 (55), 99 (58), 98 (82), 59 (65), 39 (46). Anal. Calcd for $C_7H_{10}O_4$: M, 158.0579. Found: m/z 158.0561.

Dimethyl *cis*-1,2-Cyclopropanedicarboxylate (*cis*-2a): n_D^{25} 1.4455 (lit,[13)] n_D^{17} 1.4434); IR (neat) 1735, 1173, 1020 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.26 (dt, 1H, J=4.8 and 8.4 Hz), 1.69 (dt, 1H, J=4.8 and 6.6 Hz), 2.07 (dd, 2H, J=6.6 and 8.4 Hz), 3.70 (s, 6H); mass spectrum m/z 158 (M$^+$, 1), 157 (3), 127 (100), 126 (16), 99 (33), 98 (28), 59 (22), 39 (13). Anal. Calcd for $C_7H_{10}O_4$: M, 158.0579. Found: m/z 158.0592.

Dimethyl *trans*-1,2-Cyclobutanedicarboxylate (*trans*-2b): n_D^{25} 1.4422 (lit,[13)] n_D^{25} 1.4430); IR (neat) 1735, 1170 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.18 (m, 4H), 3.42 (m, 2H), 3.69 (s, 6H); mass spectrum m/z 172 (M$^+$, 3), 171 (9), 141 (55), 140 (43), 113 (77), 81 (51), 71 (49), 59 (100), 53 (68). Anal. Calcd for $C_8H_{12}O_4$: M, 172.0736. Found: m/z 172.0725.

Dimethyl *cis*-1,2-Cyclobutanedicarboxylate (*cis*-2b): n_D^{25} 1.4445 (lit,[13)] n_D^{17} 1.4453); IR (neat) 1737, 1174 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=2.27 (m, 4H), 3.41 (m, 2H), 3.68 (s, 6H); mass spectrum m/z 141 (50), 140 (26), 113 (100), 81 (62), 71 (40), 59 (47), 55 (71), 53 (69).

Dimethyl *trans*-1,2-Cyclopentanedicarboxylate (*trans*-2c): n_D^{25} 1.4501 (lit,[13)] n_D^{25} 1.4482); IR (neat) 1736, 1200, 1174 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.7—1.9 (m, 4H), 2.0—2.15 (m, 2H), 3.13 (m, 2H, J=2.2, 6.2, and 7.7 Hz), 3.70 (s, 6H); mass spectrum m/z 186 (M$^+$, 1), 155 (40), 154 (31), 126 (76), 113 (29), 95 (54), 67 (100). Anal. Calcd for $C_9H_{14}O_4$: M, 186.0892. Found: m/z 186.0894. ^{1}H NMR spectrum of ***trans*-2c** was identical to that reported previously.[14)]

Dimethyl *cis*-1,2-Cyclopentanedicarboxylate (*cis*-2c): n_D^{25} 1.4530 (lit,[13)] n_D^{17} 1.4512); IR (neat) 1735, 1195, 1170 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.8—2.1 (m, 6H), 3.05 (m, 2H, J=2.2, 5.1, and 7.3 Hz), 3.66 (s, 6H); mass spectrum m/z 186 (M$^+$, 0.4), 155 (46), 154 (32), 126 (48), 113 (45), 95 (41), 67 (100). Anal. Calcd for $C_9H_{14}O_4$: M, 186.0892. Found: m/z

186.0886. ^{1}H NMR spectrum of ***cis*-2c** was identical to that reported previously.[14,15]

Dimethyl *trans*-1,2-Cyclohexanedicarboxylate (*trans*-2d): n_D^{25} 1.4512 (lit,[13] n_D^{25} 1.4518); IR (neat) 1735, 1194, 1170, 1044 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.32 (m, 4H), 1.79 (m, 2H), 2.06 (m, 2H), 2.62 (m, 2H, J=3.0 and 11.4 Hz), 3.67 (s, 6H); mass spectrum m/z 200 (M$^+$, 0.3), 169 (30), 168 (36), 140 (51), 109 (36), 108 (26), 81 (100). Anal. Calcd for $C_{10}H_{16}O_4$: M, 200.1049. Found: m/z 200.1040.

Dimethyl *cis*-1,2-Cyclohexanedicarboxylate (*cis*-2d): n_D^{25} 1.4559 (lit,[13] n_D^{25} 1.4578); IR (neat) 1734, 1173, 1131, 1038 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=1.46 (m, 4H), 1.77 (m, 2H), 1.95—2.1 (m, 2H), 2.83 (m, 2H, J=4.0 and 8.8 Hz), 3.68 (s, 6H); mass spectrum m/z 200 (M$^+$, 0.9), 169 (29), 168 (31), 140 (72), 109 (29), 108 (48), 81 (100), 80 (48). Anal. Calcd for $C_{10}H_{16}O_4$: M, 200.1049. Found: m/z 200.1020. ^{1}H NMR spectrum of ***cis*-2d** was identical to that reported previously.[15]

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References

1) M. R. Rifi, *Org. Synth.*, Coll. Vol. 6, 153 (1988), and references cited therein; K. B. Wiberg and G. A. Epling, *Tetrahedron Lett.*, **1974**, 1119.

2) G. Gerdil, *Helv. Chim. Acta,* **53**, 2100 (1970); A. J. Fry and W. E. Britton *J. Org. Chem.*, **38**, 4016 (1973); Azizullah and J. Grimshaw, *J. Chem. Soc., Perkin Trans. 1,* **1973**, 425; T. Adachi, T. Iwasaki, M. Miyoshi, and I. Inoue, *J. Chem. Soc., Chem. Commun.,* **1977**, 248; M. Mitani, Y. Yamamoto, and K. Koyama, *ibid.,* **1983**, 1446.

3) S. Satoh, M. Itoh, and M. Tokuda, *J. Chem. Soc., Chem. Commun.,* **1978**, 481.

4) M. Tokuda, K. Satoh, and H. Suginome, *Bull. Chem. Soc. Jpn.,* **60**, 2429 (1987).

5) M. Mitani, H. Takeuchi, and K. Koyama, *Chem. Lett.,* **1986**, 2125.

6) M. Tokuda, K. Endate, and H. Suginome, *Chem. Lett.,* **1988**, 945.

7) M. Tokuda, M. Uchida, Y. Katoh, and H. Suginome, *Chem. Lett.,* **1990**, 461.

8) M. Tokuda, S. Satoh, Y. Katoh, and H. Suginome, "Electroorganic Synthesis-Festschrift in Honor of Manuel M. Baizer," ed by R. D. Little and N. Weinberg, Marcel Dekker, New York (1991), pp. 83—90.

9) For review, see: J. Chaussard, J-C. Folest, J-Y. Nedelec, J. Perichon, S. Sibille, and M. Troupel, *Synthesis,* **1990**, 369.

10) D. G. Tuck, *Pure Appl. Chem.,* **51**, 2005 (1979).

11) A. I. Vogel, *J. Chem. Soc.,* **1948**, 644.

12) R. L. Shreiner and R. E. Damschroder, *J. Am. Chem. Soc.,* **60**, 894 (1938).

13) D. S. Seigler and J. L. Bloomfield, *J. Org. Chem.,* **38**, 1375 (1973).

14) D. Wilkening and B. P. Mundy, *Synth. Commun.,* **14**, 227 (1984).

15) D. E. James and J. K. Stille, *J. Am. Chem. Soc.,* **98**, 1810 (1976).