

ELECTROCHEMICAL PREPARATION OF ALKYNEDIAL TETRAMETHYL ACETALSJaromír HLAVATÝ^{1,*} and Miroslav POLÁŠEK²

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Tetramethyl acetals of alkynedials were prepared by anodic oxidation of corresponding alkyne-1, ω -diols (C₄ and C₆) in trimethyl orthoformate on glassy carbone anode in 80% yield. 1,1,4,4-Tetramethoxybut-2-yne (**2a**) can be prepared by this one-step procedure from but-2-yne-1,4-diol (**1a**) instead of a multistep chemical procedure starting from 2,5-dimethoxyfuran. Propargyl alcohol (**3**) can be similarly anodically oxidized in trimethyl orthoformate giving dimethyl acetal of propynal (**4**) in 85% yield.

Keywords: Anodic oxidation; Protecting groups; Electrochemistry; Alkynols; Alkynals.

Alkynedials are very reactive compounds serving as valuable synthons in organometallic chemistry and polyene synthesis. They can be employed either when generated in situ or protected as acetals. Thus, tetraethyl acetal of but-2-yne-dial was prepared from triethyl orthoformate and an acetylene bis-Grignard reagent^{1,2}. The preparation and an efficient processing of jelly acetylene bis-Grignard reagent is uneasy, providing only mild yield⁵. Gorgues³⁻⁵ described a three-step synthesis starting from acrolein. The same author⁶ prepared but-2-yne-dial after uneasy deprotection from the corresponding diacetal, 1,1,4,4-tetramethoxybut-2-yne (**2a**), by treatment of the diacetal **2a** with formic acid in dichloromethane solution in the dark. Akué-Gédu et al.⁷ recently published a large-scale synthesis of the diacetal, starting from 2,5-dimethoxy-2,5-dihydrofuran. The diacetal **2a** was prepared in three steps including bromination of the starting compound, opening of the brominated dihydrofuran intermediate and its debromination with KOH in the presence of a phase transfer agent. Hence, we decided to investigate the anodic oxidation of alkyne-1, ω -diols in anhydrous solution at low temperature. This fine electrolytic procedure could directly convert alkyne-1, ω -diols into acetals of the corresponding alkynedials in one simple step. The success of this procedure depends on the choice of the an-

ode material and the supporting electrolyte system (solvent). Wolf⁸ performed the anodic oxidation of but-2-yne-1,4-diol (**1a**) in aqueous sulfuric acid on the PbO₂ anode giving 70% yield of but-2-ynedioic acid. Propargyl alcohol (**3**) gave propiolic acid in 75% yield under similar conditions. When the same author⁸ modified the electrolytic assembly, only 15% of prop-2-yn-1-ol was obtained.

EXPERIMENTAL

Electrolytic Cell

Anodic oxidation was performed in an undivided all-glass cell at the temperature of 3 °C on the GC anode in galvanostatic way (at constant current). The cell was double-jacketed, and the temperature was controlled by the Polystat refrigerating bath (Cole Parmer). Two parallel plates of 55 × 55 mm size, made of glassy carbon (GC) served as the anode, and a GC rod between them (about 3 mm in diameter) operated as a quasi-stationary auxiliary cathode. The charge passed in the course of the electrolysis was recorded with a coulometer, constructed in the Heyrovský Institute. The cell contained 200 ml of the electrolyte, which was magnetically stirred. Nitrogen was bubbled around the auxiliary electrode. The electrolysis was controlled manually; the progress of the anodic oxidation was followed by the current drop; a simultaneous decrease in the starting substance concentration was monitored by thin layer chromatography (TLC).

1,1,4,4-Tetramethoxybut-2-yne (**2a**)

Butynediol **1a** (50 mmol, 4.3 g) and Bu₄NBF₄ (100 mmol, 33 g) were dissolved in trimethyl orthoformate (200 ml) in the electrolyte. The starting electrolytic current was about 400 mA (25 V) and the final one about 40 mA (40 V). We assumed the passage of 4 F/mol (5.36 Ah), which corresponded to withdrawing 4 electrons per molecule in the oxidation to the dialdehyde intermediate. The charge passed was higher than the theoretical one (11.3 Ah, i.e. 8.5 F/mol) due to the requested current drop and the effective depletion of the starting diol **1a**. The pale yellow neutral electrolyte was concentrated at -30 °C and 66 Pa. The viscous residue was extracted with several 30 ml portions of pentane and four 30 ml portions of diethyl ether. Combined extracts were again concentrated. Both ethereal and pentane extracts contained the same product as indicated by TLC analysis. Thus, 8.0 g of a pale yellow product was obtained. The material was distilled at 81–82.5 °C and 66 Pa, giving a colorless oil in 80% yield. Spectral data were in accord with the literature^{2,4,7}. For C₈H₁₄O₄ (174.2) calculated: 55.16% C, 8.10% H; found: 55.35% C, 8.23% H. ¹H NMR (300MHz, CDCl₃): 5.1 (s, 2 H); 3.22 (s, 12 H). ¹³C NMR (75 MHz, CDCl₃): 51.54, 112.82. MS (EI), *m/z*: 173 [M - H⁺], 167, 151, 105, 75, 59, 47. MS (CI, MeOH), *m/z*: 175 [MH⁺], 173, 133, 131, 99, 75.

1,1,6,6-Tetramethoxyhexa-2,4-diyne (**2b**)

As in the preceding procedure, hexadiynediol (**1b**; 50 mmol, 5.5 g) was dissolved in trimethyl orthoformate with the same supporting electrolyte. After the passage of 12.2 Ah (9.1 F/mol), the electrolysis was finished. The neutral yellow electrolyte was processed in the same way as in the case of butynediol **1a**. Pentane and ether extracts contained the same

product, and were again concentrated at $-30\text{ }^{\circ}\text{C}/66\text{ Pa}$. 8.5 g of the yellow product was isolated, and distilled at $89.7\text{--}91.5\text{ }^{\circ}\text{C}/66\text{ Pa}$, giving a yellow oil in 80% yield. For $\text{C}_{10}\text{H}_{14}\text{O}_4$ (198.2) calculated: 60.71% C, 7.14% H; found: 60.95% C, 7.25% H. $^1\text{H NMR}$ (300 MHz, CDCl_3): 5.05 (s, 2 H); 3.22 (s, 12 H). $^{13}\text{C NMR}$ (75 MHz, CDCl_3): 51.17, 112.49, 113.86. MS (EI), m/z : 198 [M^+], 177, 173, 133, 105, 75, 59, 45. MS (CI, MeOH), m/z : 199 [MH^+], 177, 173, 149, 133, 105, 75.

3,3-Dimethoxyprop-1-yne (**4**)

Alcohol **3** (200 mmol, 11.2 g) was dissolved in trimethyl orthoformate (200 ml) containing Bu_4NBF_4 (33 g, 100 mmol). This solution was anodically oxidized on the GC anode as described above. The starting current was 500 mA at 22.1 V. After the consumption of 19.6 Ah (the theoretical charge amounted to 10.72 Ah, i.e. 2 e per molecule), and when the starting substance was converted, the electrolysis was finished. The neutral slightly yellow electrolyte was concentrated as above. The viscous residue was extracted with several portions of pentane and then with diethyl ether. Both extracts contained the same product according to TLC, and were concentrated giving 18.1 g of a yellow oil, which was distilled at $50\text{--}51.5\text{ }^{\circ}\text{C}/66\text{ Pa}$ to give the final product **4** in 85% yield. FTIR (liquid film), ν/cm^{-1} : 2080 (vw). For $\text{C}_5\text{H}_8\text{O}_2$ (100.1) calculated: 59.98% C, 8.05% H; found: 59.80% C, 7.99% H. $^1\text{H NMR}$ (300 MHz, CDCl_3): 5.10 (s, 1 H); 4.15 (s, 6 H); 2.4 (s, 1 H). $^{13}\text{C NMR}$ (150 MHz, CDCl_3): 50.38, 51.60, 74.10, 112.84, 114.19. MS (EI), m/z (rel.%): 99 [$\text{M} - \text{H}^+$] (12), 75 (48), 59 (100), 55 (8), 47.1 (30). MS (CI, MeOH), m/z (rel.%): 101 [MH^+] (5), 99 (50), 75 (100).

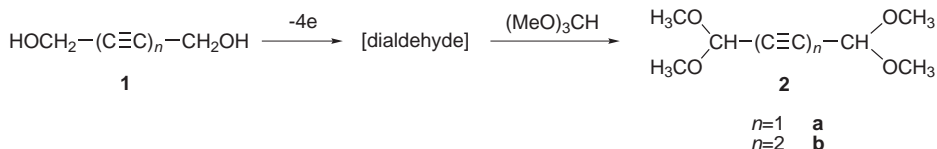
RESULTS AND DISCUSSION

We have previously observed¹⁰ that anodic oxidation of diol **1a** in methanol containing toluenesulfonic acid at $5\text{ }^{\circ}\text{C}$ in an undivided cell on a glassy carbon (GC) anode results in a mixture of dimethyl acetal and methyl acetal of but-2-yne-dial.

Orthoformates are generally used for the preparation of aldehyde acetals. We selected trimethyl orthoformate as a solvent for anodic oxidation of alkyne-1, ω -diols and a quaternary ammonium salt as an electrolyte. A glassy carbon (GC) anode was chosen as indifferent for the anodic oxidation. However, the electrolyte, suitable for the oxidation and subsequent acetalization, exhibits a low electric conductivity. For this reason and due to the required low temperature during the electrolysis, an undivided cell without a membrane was applied. We were afraid that either the reactive dialdehyde intermediate or the triple bond in the substrate structure could deteriorate due to the simultaneous cathodic reduction. The applied quasi-counter electrode technique⁹ suppresses the undesired cathodic process to minimum due to a great difference between the surface area of the large working anode and a small auxiliary cathode. The electrolyte after the electrolysis was carefully worked up at low temperature. When the starting alkyne-

1,ω-diol was consumed, the electrolysis was finished. The electrolytic procedure lasted 28–30 h for 100 mmol of alkyne-1,ω-diol.

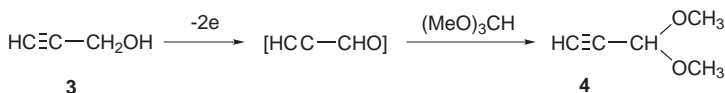
We assume that an alkynedial intermediate, primary generated in the anodic oxidation reacts subsequently with trimethyl orthoformate (Scheme 1). The reaction mechanism cannot be exactly established, since the probable intermediate but-2-ynedial is not easily accessible⁶.



SCHEME 1

We have found that the homologous propynal¹¹ undergoes fast reaction with trimethyl orthoformate at room temperature resulting in 3,3-dimethoxypropyne (Scheme 2). This reaction was evidenced by the FTIR spectra and TLC analysis. The one-pot electrolytic protocol for the preparation of tetramethoxyalkynes operates successfully giving 80% yields.

1,1,4,4-Tetramethoxybut-2-yne (**2a**) can be efficiently prepared by this simple electrolytic procedure instead of the multistep preparation⁷ published recently. The anodic oxidation of commercially available hexa-2,4-diyne-1,6-diol (**1b**) in trimethyl orthoformate gave 80% yield of 1,1,6,6-tetramethoxyhexa-2,4-diyne (**2b**) in a one-step process (Scheme 1). Similarly, propargyl alcohol (**3**) was anodically oxidized in trimethyl orthoformate, giving rise to 3,3-dimethoxyprop-1-yne (**4**) in 85% yield (Scheme 2).



SCHEME 2

CONCLUSIONS

The described anodic oxidations give access to dimethyl acetals of labile alkyne aldehydes in the yields of about 80% in a one-pot procedure, which is distinctly more advantageous in comparison with the recently published⁷ three-step chemical procedure.

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