α-Formyloxycarbonyl Compounds from the Anodic Oxidation of Enol Carbonates

Fructuoso Barba,* M. Gloria Quintanilla, and Guillermo Montero

Departamento de Química Orgánica, Universidad de Alcalá de Henares, Madrid, Spain

Received June 15, 1995[⊗]

Enol carbonates previously synthesized were anodically oxidized yielding the corresponding α-formyloxycarbonyl derivatives with participation of the DMF, used as solvent.

Anodic acetoxylation is one of the best known processes in electroorganic synthesis.[1] All the attempts to extend this reaction to formic acid have failed, and only very few examples of electrochemical formyloxylation are described in the literature. The electrochemical oxidation of formic acid in the presence of DMF produces *N*-methyl-*N*-[(formyloxy)methyl]formamide.[2] On the other hand, Simonet et al. found that when tetraalkylammonium halides are oxidized in the presence of olefins in DMF, chloroformyloxy compounds are formed the solvent being involved in the reaction.[3–5]

Enol carbonates have not been popular as starting materials in organic synthesis, but they have been employed in protection steps in synthetic routes.[6–9]

In this paper we describe the conversion of enol carbonates into α-formyloxycarbonyl compounds by an anodic oxidation process using DMF as solvent.

Results and Discussion

The oxidation of enol carbonates **1a–h** on a carbon anode in DMF/$LiClO_4$ gave the corresponding formic acid esters **2a–e** whereas **1f–h** did not oxidize. The results of the oxidation of enol carbonates are summarized in Table 1.

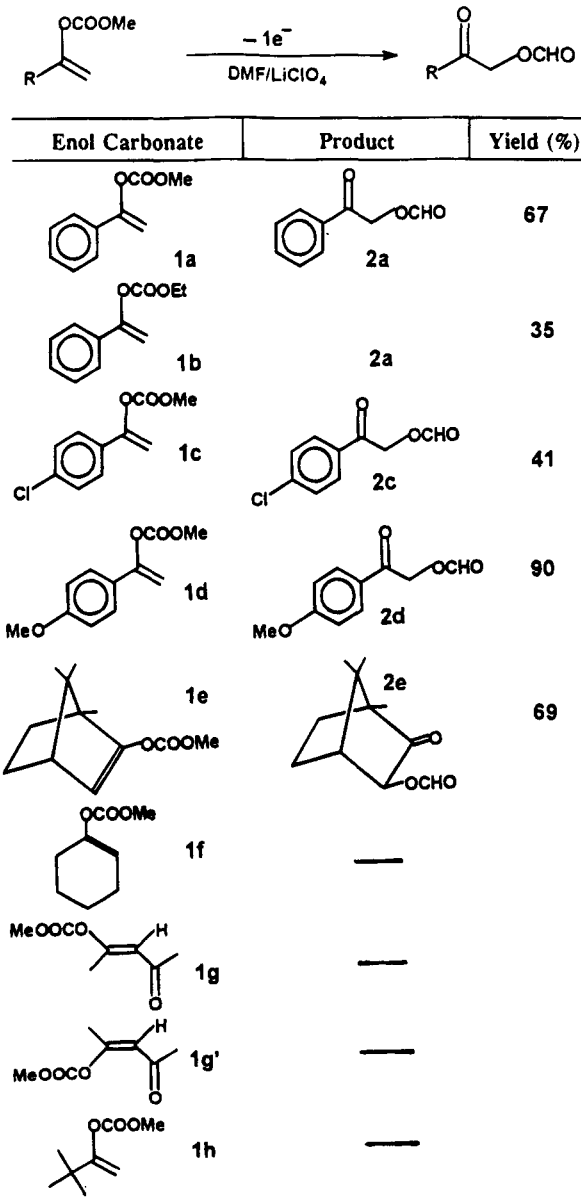
In this process the charge consumption could not be exactly measured, due to the fact that the oxidation potential of the substrate is very close to the anodic limit of the solvent-supporting electrolyte system (SSE), as it was corroborated by cyclic voltammetry.

In order to make this point clear, we arranged two similar experiments in which the passed current could be measured. The first one was performed in AcOH/$LiClO_4$ whereby the acetoxycarbonyl derivative **3a** was obtained as shown in Figure 1.

The second one was performed in CH_3CN/$LiClO_4$ giving **4a** as shown in Figure 2.

In both cases the charge consumption was only 1 F/mol unequivocally.

Table 1



In the literature[10–12] it is described that the anodic oxidation of enol acetates in AcOH/Et_4NTsO yields the acetoxy derivatives with the consumption of 2 F/mol (as shown in Figure 3) in opposition with the consumption of only 1 F/mol for the anodic oxidation of enol carbonates under the same experimental conditions (as shown in Figure 4). As it can be seen, an acetyl cation is removed in the process described by Shono et al., whereas a methoxycarbonyl radical is lost in our case.

[⊗] Abstract published in *Advance ACS Abstracts,* August 1, 1995.

(1) Lund, H.; Baizer, M. N. *Organic Electrochemistry*; Marcel Dekker: New York; 1991; pp 1080–1083.
(2) Ross, S. D.; Finkelsteink, M.; Petersen, R. C. *J. Am. Chem. Soc.* **1964**, *86*, 2745.
(3) Verniette, M.; Daremon, C.; Simonet, J. *Electrochim. Acta* **1978**, *23*, 929.
(4) Pouillen, P.; Minko, R.; Verniette, M.; Martinet, P. *Electrochim. Acta* **1979**, *24*, 1189.
(5) Pouillen, P.; Minko, R.; Verniette, M.; Martinet, P. *Electrochim. Acta* **1980**, *25*, 711.
(6) Olofson, R. A.; Schnur, R. C. *Tetrahedron Lett.* **1977**, *18*, 1571.
(7) Olofson, R. A.; Yamamoto, Y. S.; Wancowicz, D. J. *Tetrahedron Lett.* **1977**, *18*, 1563.
(8) Olofson, R. A.; Schnur, R. C.; Bunes, L.; Pepe, J. P. *Tetrahedron Lett.* **1977**, *18*, 1567.
(9) Olofson, R. A.; Pepe, J. P. *Tetrahedron Lett.* **1977**, *18*, 1575.

0022-3263/95/1960-5658$09.00/0

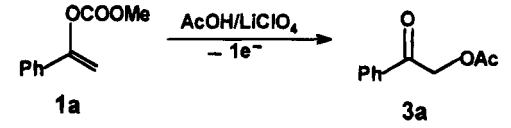


Figure 1.

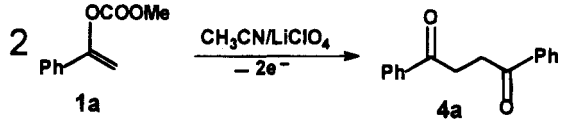


Figure 2.

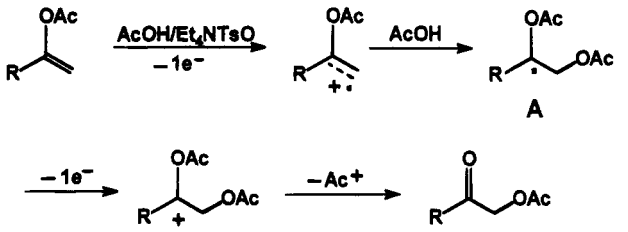


Figure 3.

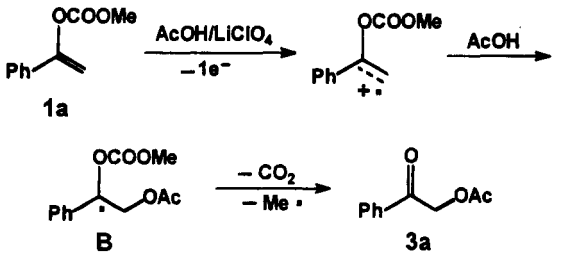


Figure 4.

This difference in behavior can be explained by the known fact that the presence of an α-alkoxy group increases the stability of the resulting radical, hence the fragmentation rate is also increased.[13] Therefore, radical B decomposes easily, whereas radical A is again oxidized to lead to the carbocation intermediate.

In the case of the anodic oxidation of **1a** in $CH_3CN/LiClO_4$ due to the fact that acetonitrile does not behave as nucleophile in Ritter type reactions in a general way, as shown by Simonet et al.,[3] the electrogenerated radical cation evolves to the dimeric product **4a**.

Taking all these results into account, we propose for our process in $DMF/LiClO_4$ the path in Figure 5.

The electrogenerated cation radical I is attacked by the DMF in a similar way as described in the literature[3-5] to give a new cation radical II which fragmentates by loss of the methoxycarbonyl radical and finally is hydrolyzed to give the formyloxycarbonyl compound.

The structures of formic acid esters **2a–e** are supported by spectroscopic data, as proven by the disappearance of the carbonate band and the appearance of a formyl band at about 1730 cm^{-1}, as well as by the presence of a strongly deshielded signal at 8 ppm, corresponding to the formate proton and by the absence of ethylenic signals.

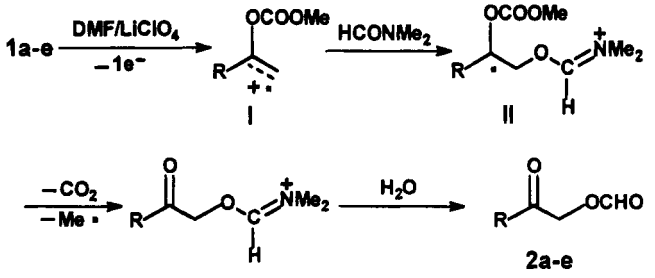


Figure 5.

Enol carbonates obtained from α-bromoacetophenone derivatives undergo the reaction both if in the 4-position there is a donor or a withdrawing substituent (**2c, 2d**). The process takes place in the same way when the methyl group from the chloroformate is substituted by an ethyl group (**1b**).

Enol carbonates derived from α-halo aliphatic ketones may undergo the reaction depending on their oxidation potential. Thus, as it can be observed, **1e** yields the corresponding **2e**, while **1f–h** cannot be oxidized because their potential is higher than the SSE.

We have recently oxidized under the same conditions the corresponding enol acetate derived from acetophenone (α-acetoxystyrene), obtaining again the corresponding formate **2a**. Therefore, we can conclude that this reaction could be considered as a general method to transform enol esters into the corresponding α-formyloxycarbonyl compounds. Again, the charge consumption could not be exactly measured, although having in mind the former considerations, the process could be assumed to involve 2 e^-.

Experimental Section

Preparation of Enol Carbonates 1a–h. The preparative experiments were carried out according to the reported method,[12] starting from the corresponding α-halo ketone. In all the cases, the ethereal extracts were chromatographed on a silica gel column as detailed below. Enol carbonates **1a, 1c,** and **1d** were described in our previous work.[14]

Ethyl 1-Phenylethenyl Carbonate (1b). The general method was followed starting from phenacyl bromide, but using ethyl chloroformate instead of methyl chloroformate. After being chromatographed in CH_2Cl_2:toluene (3:1), **1b** was obtained in 61% yield; bp 107–109 °C; IR (liquid film) 1762, 1646, 1577, 1446, 1227, 772, 698 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 192 (M^+, 17), 120 (31), 105 (100), 77 (41); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.35 (t, 3H, *J* = 7 Hz), 4.26 (q, 2H), 5.14 and 5.45 (AM system, 2H, *J* = 2.5 Hz), 7.34–7.38 (m, 3H), 7.51 (d, 2H, $J_{2,3}$ = 7.5 Hz). Anal. Calcd for $C_{11}H_{12}O_3$: C, 68.74; H, 6.29. Found: C, 68.80; H, 6.25.

Methyl 1,7,7-Trimethylbicyclo[2.2.1]hept-2-en-2-yl Carbonate (1e). The general method was followed starting from D-3-bromocamphor. After being chromatographed in CH_2Cl_2, **1e** was obtained in 61% yield; bp 222–224 °C; IR (liquid film) 2958, 2877, 1767, 1441, 1244 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 210 (M^+, 37), 182 (21), 151 (28), 123 (100), 119 (91), 95 (42), 59 (39); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 0.75 (s, 3H), 0.93 (s, 3H), 0.96 (s, 3H), 1.12 (m, 1H), 1.29 (m, 1H), 1.57 (m, 1H), 1.87 (m, 1H), 2.35 (m, 1H), 3.82 (s, 3H), 5.57 (m, 1H). Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.55; H, 8.63. Found: C, 68.50; H, 8.72.

Cyclohex-1-enyl Methyl Carbonate (1f). The general method was followed starting from 2-chlorocyclohexanone. After being chromatographed in CH_2Cl_2, **1f** was obtained in 69% yield; bp 238–240 °C; IR (liquid film) 2938, 2856,

(10) Shono, T.; Matsumura, Y.; Nakagawa, Y. *J. Am. Chem. Soc.* **1974**, *96*, 3532.
(11) Shono, T.; Masahisa, O.; Nishiguchi, I. *J. Am. Chem. Soc.* **1975**, *97*, 6144.
(12) Shono, T.; Nishiguchi, I.; Kashimura, S.; Okawa, M. *Bull. Chem. Soc. Jpn.* **1978**, *51(7)*, 2181.
(13) Nonhebel, D. C.; Walton, J. C. *Free-radical Chemistry*; Cambridge University Press: New York, 1974; p 105.
(14) Barba, F.; Quintanilla, M. G.; Montero, G. *Synthesis* **1992**, *12*, 1215.

1760, 1442, 1254 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 156 (M^+, 57), 111 (70), 97 (70), 84 (100), 59 (32); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.54−1.64 (m, 2H), 1.7−1.79 (m, 2H), 2.06−2.22 (m, 4H), 3.80 (s, 3H), 5.44−5.50 (m, 1H). Anal. Calcd for $C_8H_{12}O_3$: C, 61.52; H, 7.74. Found: C, 61.60; H, 7.70.

Methyl *cis*-1-Methyl-3-oxo-but-1-enyl Carbonate (1g). The general method was followed starting from 3-chloro-2,4-pentanedione. After being chromatographed in CH_2Cl_2:hexane (5:1), **1g** was obtained in 63% yield; bp 170−172 °C; IR (liquid film) 3005, 2962, 2855, 1766, 1702, 1633, 1441, 1264, 1163 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 158 (M^+, 22), 143 (3), 99 (100), 59 (47); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 2.21 (s, 3H), 2.34 (d, 3H, J = 0.9 Hz), 3.84 (s, 3H), 6.18 (s, 1H). Anal. Calcd for $C_7H_{10}O_4$: C, 53.16; H, 6.37. Found: C, 53.06; H, 6.40.

Methyl *trans*-1-Methyl-3-oxobut-1-enyl Carbonate (1g'). The general method was followed starting from 3-chloro-2,4-pentanedione. After being chromatographed in CH_2Cl_2:hexane (5:1), **1g'** was obtained in 36% yield; bp 174−176 °C; ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 2.06 (d, 3H, J = 0.9 Hz), 2.20 (s, 3H), 3.88 (s, 3H), 5.82 (s, 1H).

1-*tert*-Butylvinyl Methyl Carbonate (1h). The general method was followed starting from 1-bromopinacolone. After being chromatographed in CH_2Cl_2, **1h** was obtained in 75% yield; bp 142−145 °C; IR (liquid film) 2967, 2876, 1763, 1441, 1252 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 158 (M^+, 0.12), 59 (100); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.2 (s, 9H), 3.82 (s, 3H), 4.75 and 4.84 (AM system, 2H, J = 2.5 Hz). Anal. Calcd for $C_8H_{14}O_3$: C, 60.74; H, 8.92. Found: C, 60.63; H, 8.98.

General Procedure of the Anodic Oxidation of Enol Carbonates. Anode: carbon. Anolyte: lithium perchlorate (10 mmol) in DMF (dried over anhyd $MgSO_4$) (30 mL). Cathode: stainless steel. Catholyte: lithium perchlorate (5 mmol) in DMF (20 mL). Electrolysis cell: divided cell thermostated at 15 °C equipped with a magnetic stirrer containing a piece of glass tubing with a glass frit of medium porosity at one end (cathodic compartment).

Stirred with a magnetic bar and cooled with running water, a solution of **1** (5 mmol in 10 mL of DMF) was added into the anodic compartment and a potential of +1.5 V vs SCE was applied. The electrolysis was carried out using an Amel potentiostat Model 552 with an electronic integrator Amel Model 721. The anodic solution was poured over ice−water and extracted with diethyl ether (3 × 15 mL). The extract is washed with water, dried over Na_2SO_4, and evaporated to dryness under reduced pressure. In all the cases, the ethereal extracts were chromatographed on a silica gel column as detailed below. Mass spectra was obtained using a Hewlett-Packard Model 5988A spectrometer with DEI. IR spectra were obtained using a Perkin-Elmer Model 883 spectrometer. ^{1}H-NMR spectra were obtained using a 300 MHz Varian apparatus. Melting and boiling points were taken using a Büchi SMP-20 apparatus. Microanalyses were obtained using a Perkin-Elmer 240 analyzer.

2-Oxo-2-phenylethyl Formate (2a). Starting from **1a**, obtained as described in our previous work,[14] or **1b**, the general method was followed. After being chromatographed in CH_2Cl_2:petroleum ether (5:1), **2a** was obtained; bp 167−169 °C; IR (liquid film) 2942, 1731, 1700, 1597, 1448, 1168, 747, 690 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 164 (M^+, 3), 105 (100), 77 (45), 51 (13); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 5.42 (s, 2H), 7.47 (t, 2H, J = 7.5 Hz), 7.60 (t, 1H, 4-H), 7.90 (d, 2H, $J_{2,3}$ = 7.2), 8.23 (s, 1H). Anal. Calcd for $C_9H_8O_3$: C, 65.85; H, 4.91. Found: C, 65.92; H, 4.89.

2-Oxo-2-(4-chlorophenyl)ethyl Formate (2c). Starting from **1c**, obtained as described in our previous work,[14] the general method was followed. After being chromatographed in CH_2Cl_2:toluene (3:1), **2c** was obtained; mp 82−85 °C; IR (KBr) 2950, 1728, 1695, 1589, 1423, 1159, 815, 765 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 200 (M^+ + 2, 1), 198 (M^+, 2), 139 (100), 111 (43), 75 (29), 51 (8); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 5.39 (s, 2H), 7.47 (d, 2H, $J_{2,3}$ = 8.8 Hz), 7.86 (d, 2H), 8.24 (s, 1H). Anal. Calcd for $C_9H_7ClO_3$: C, 54.43; H, 3.55. Found: C, 54.30; H, 3.60.

2-Oxo-2-(4-methoxyphenyl)ethyl Formate (2d). Starting from **1d**, obtained as described in our previous work,[14] the general method was followed. After being chromatographed in CH_2Cl_2:toluene (3:1), **2d** was obtained; mp 50−52 °C; IR (KBr) 2974, 1729, 1682, 1599, 1417, 1159, 840, 633 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 194 (M^+, 3), 135 (100), 107 (13), 92 (29), 77 (45), 64 (19); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 3.88 (s, 3H), 5.39 (s, 2H), 6.96 (d, 2H, $J_{2,3}$ = 9.1 Hz), 7.90 (d, 2H), 8.25 (s, 1H). Anal. Calcd for $C_{10}H_{10}O_4$: C, 61.85; H, 5.19. Found: C, 61.67; H, 5.23.

4,7,7-Trimethyl-3-oxobicyclo[2.2.1]hept-2-yl Formate (2e). Starting from **1e**, the general method was followed. After being chromatographed in CH_2Cl_2:toluene (2:1), **2e** was obtained; bp 165−167 °C; IR (liquid film) 2963, 1756, 1732, 1258, 1164 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 196 (M^+, 16), 122 (29), 107 (39), 83 (100), 55 (41); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 0.96 (s, 9H), 1.0−2.16 (m, 4H), 2.41 (s, 1H), 4.88 (s, 1H), 8.11 (s, 1H). Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.39; H, 8.18.

Oxidation of 1a in AcOH. General procedure was followed but using AcOH as solvent. Product **3a** was isolated by chromatography on a silica gel column in CH_2Cl_2.

2-Oxo-2-phenylethyl Acetate (3a): 80% yield, thick oil; IR (liquid film) 3064, 2938, 1750, 1704, 1598, 1448, 1372, 1220, 1084, 756, 690 cm^{-1}; MS (70 eV), *m/e* (relative intensity) 178 (M^+, 1), 136 (2), 118 (7), 105 (100), 77 (50), 51 (12); ^{1}H-NMR (300 MHz, $CDCl_3$) δ (ppm) = 2.25 (s, 3H), 5.36 (s, 2H), 7.51 (t, 2H, J = 7.5 Hz), 7.63 (t, 1H), 7.93 (d, 2H, $J_{2,3}$ = 8.15), 8.23 (s, 1H). Anal. Calcd for $C_{10}H_{10}O_3$: C, 67.40; H, 5.67. Found: C, 67.21; H, 5.77.

Oxidation of 1a in CH_3CN. General procedure was followed but using CH_3CN as solvent. Product **4a** was isolated by chromatography on a silica gel column in CH_2Cl_2:toluene (3:1).

1,4-Diphenyl-1,4-butanedione (4a): 78% yield. The physical and spectroscopic data are in accordance with those described in the literature.[15]

Oxidation of α-Acetoxystyrene in DMF/$LiClO_4$. α-Acetoxystyrene was prepared by the reported method[16] and oxidized following the general procedure used in the oxidation of enol carbonates. Product **2a** was isolated by chromatography on a silica gel column in CH_2Cl_2:petroleum ether (5:1), in 65% yield.

Acknowledgment. This study was financed by the DGICYT PB94-0341.

JO9505381

(15) *Dictionary of Organic Compounds*, 5th ed.; Chapman and Hall: New York, 1982; Vol. 2, p 2301 and references cited therein.
(16) Noyce, D. S.; Pollack, R. M. *J. Am. Chem. Soc.* **1969**, 91, 119.