

Electroreductive Acylation of Benzyl Chlorides with Acid Anhydrides.  
Stereoselective Formation of (E)-Enol Esters from Benzyl Alkyl Ketones

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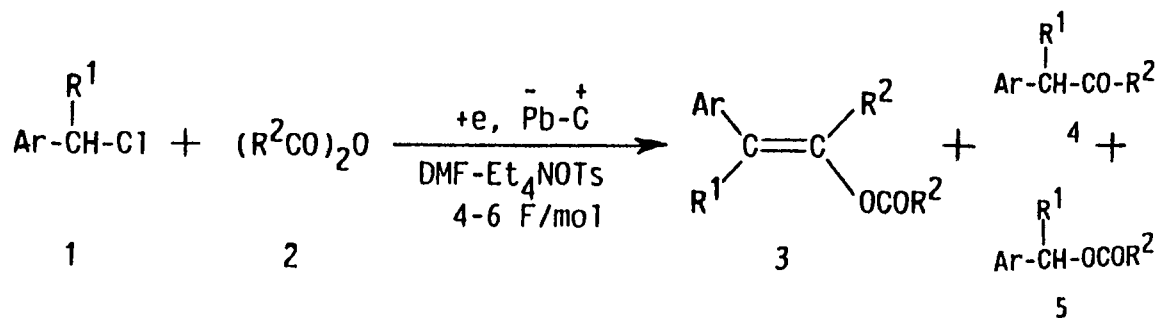
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Electroreduction of benzyl chlorides in the presence of acid anhydrides brought about stereoselective formation of (E)-enol esters of the corresponding benzyl alkyl ketones, the initial acylated products, in good to moderate yields.

Electrochemical acylation has been known as an efficient and useful method for reductive C-acylation of some of organic compounds,<sup>1)</sup> although it does not generate any acyl anions but gives the products which would be obtained from the usual chemical reactions of acyl anions.<sup>2)</sup> For example, it was found that electroreduction of benzyl chlorides and related compounds in the presence of acid chlorides resulted in the reductive C-acylation to give the corresponding benzyl alkyl ketones in moderate yields.<sup>3)</sup>

In this study, we report a unique electroreductive acylation of benzyl chlorides (1) with aliphatic acid anhydrides (2) to give the (E)-enol esters (3) of the corresponding benzyl alkyl ketones (4) as the main product in satisfactory yields. The corresponding benzyl alkyl ketones (4) and benzyl esters (5) were obtained as the by-products in small amounts.

A typical procedure is as follows: A solution of 20 g (0.067 mol) of tetraethylammonium p-toluenesulfonate in 80 ml of anhydrous N,N-dimethylformamide was placed in cathodic (64 ml) and anodic (16 ml) chambers of a divided cell separated with a cylindrical ceramic diaphragm, to which a



lead-plate cathode and a carbon-rod anode were attached. To a catholyte was added 2.53 g (0.02 mol) of benzyl chloride (1a) and 20.4 g (0.20 mol) of acetic anhydride (2a). The mixture was electrolyzed with stirring at room temperature under constant current condition (current density: 15-10 mA/cm<sup>2</sup>) until 4.0 F/mol of electricity has been charged. The usual work-up of the catholyte and the distillation of the product mixture gave 2.50 g of (E)-1-phenyl-2-acetoxypropene (3a) (yield: 71%), along with benzyl methyl ketone (4a) and benzyl acetate (5a) in 2% and 5% yields, respectively.

This electroreductive acylation was influenced by current density and the kind of cathode material, and better results were obtained at current density of 15-10 mA/cm<sup>2</sup> by employing a Pb or Sn plate for the cathode.

A variety of substituted benzyl chlorides (1a-f) were electrochemically reduced in the presence of large excess of acetic or propionic anhydride (2a,b) under similar conditions as above. The corresponding (E)-enol esters 3a-j were formed stereoselectively as the main product in satisfactory yields accompanying with formation of benzyl ketones 4a-j and esters 5a-j as the by-products in small quantities, as shown in Table 1.<sup>4)</sup>

(E)-Stereochemistry of 3a-j was determined by analysis of chemical shift of the vinyl protons ( $\delta = 6.10-6.16$  ppm (CDCl<sub>3</sub>)) in their <sup>1</sup>H-NMR spectra. The vinyl protons of their (Z)-isomers are thought to appear in higher field by 0.2-0.4 ppm than those of the (E)-isomers since those of the (E)-isomer 3a and the (Z)-isomer of 1-phenyl-2-acetoxypropene appear at  $\delta = 6.15$  and 5.80 ppm, respectively.<sup>5)</sup>

Table 1. Electroreductive Acylation of Benzyl Chlorides with Acid Anhydrides<sup>a)</sup>

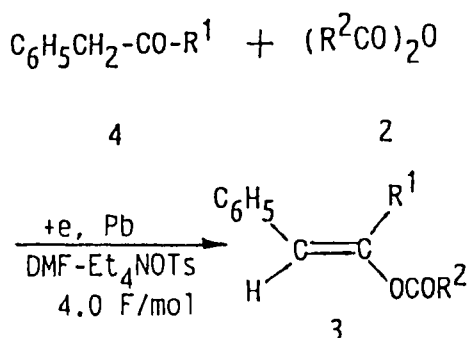
Benzyl chlorides X	R <sup>1</sup>	Acid anhydrides R <sup>2</sup>	Products / % <sup>b)</sup>		
			3 <sup>c)</sup>	4	5
H	H(1a)	CH <sub>3</sub> (2a)	71 (3a)	2 (4a)	5 (5a)
H	H(1a)	C <sub>2</sub> H <sub>5</sub> (2b)	73 (3b)	6 (4b)	6 (5b)
p-F	H(1b)	CH <sub>3</sub> (2a)	67 (3c)	7 (4c)	6 (5c)
p-F	H(1b)	C <sub>2</sub> H <sub>5</sub> (2b)	72 (3d)	9 (4d)	6 (5d)
p-Cl	H(1c)	CH <sub>3</sub> (2a)	56 (3e)	7 (4e)	8 (5e)
p-Cl	H(1c)	C <sub>2</sub> H <sub>5</sub> (2b)	63 (3f)	4 (4f)	6 (5f)
p-CH <sub>3</sub>	H(1d)	CH <sub>3</sub> (2a)	53 (3g)	10 (4g)	9 (5g)
p-CH <sub>3</sub>	H(1d)	C <sub>2</sub> H <sub>5</sub> (2b)	53 (3h)	18 (4h)	11 (5h)
p-OCH <sub>3</sub>	H(1e)	CH <sub>3</sub> (2a)	52 (3i)	12 (4i)	18 (5i)
3,4-(CH <sub>3</sub> ) <sub>2</sub>	H(1f)	C <sub>2</sub> H <sub>5</sub> (2b)	51 (3j)	11 (4j)	15 (5j)

a) Reaction conditions: cathode(Pb), current density (15 mA/cm<sup>-2</sup>). b) Based on isolated products. c) The ratio (E/Z) of the stereoisomers was analyzed by GLC technique (column: SE-30, 2 m) and was found to be more than 99/1 for 3a-j.

Initial formation of **4a-j** and their subsequent transformation to **3a-j** in this reaction were confirmed by controlled experiments.<sup>6)</sup> Thus, the electrolysis of **4a,b** with **2a,b** under the similar conditions, which gave **3a,b** in almost quantitative yields, as shown in Table 2.

Table 2. Electroreductive Acylation of Benzyl Alkyl Ketones **4** with Acid Anhydrides **2**

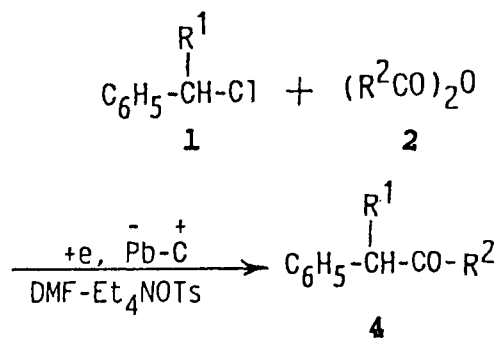
Ketone $R^1$	Anhydrides $R^2$	Products, Yield / % <b>3</b>
CH <sub>3</sub> ( <b>4a</b> )	CH <sub>3</sub> ( <b>2a</b> )	91 ( <b>3a</b> )
CH <sub>3</sub> ( <b>4a</b> )	C <sub>2</sub> H <sub>5</sub> ( <b>2b</b> )	94 ( <b>3k</b> )
C <sub>2</sub> H <sub>5</sub> ( <b>4b</b> )	CH <sub>3</sub> ( <b>2a</b> )	90 ( <b>3l</b> )
C <sub>2</sub> H <sub>5</sub> ( <b>4b</b> )	C <sub>2</sub> H <sub>5</sub> ( <b>2b</b> )	95 ( <b>3b</b> )



It may be noteworthy that the presence of an alkyl group at the  $\alpha$ -position of the starting benzyl chlorides **1** in this electroreductive acylation brought about selective formation of the ketones **4** (Table 3).

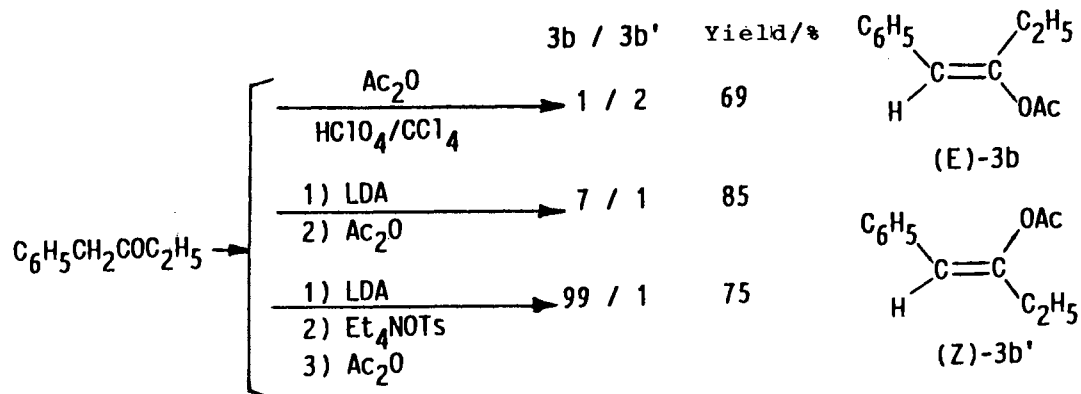
Table 3. Electroreductive Acylation of  $\alpha$ -Alkyl Benzyl Chlorides **1** with Acid Anhydrides **2**

Chlorides <b>1</b> , $R^1$	Anhydrides <b>2</b> , $R^2$	Products, Yield / % <b>4</b>
CH <sub>3</sub>	CH <sub>3</sub>	81
CH <sub>3</sub>	C <sub>2</sub> H <sub>5</sub>	88
C <sub>2</sub> H <sub>5</sub>	CH <sub>3</sub>	70
C <sub>2</sub> H <sub>5</sub>	C <sub>2</sub> H <sub>5</sub>	75
C <sub>3</sub> H <sub>7</sub>	CH <sub>3</sub>	71
C <sub>3</sub> H <sub>7</sub>	C <sub>2</sub> H <sub>5</sub>	79

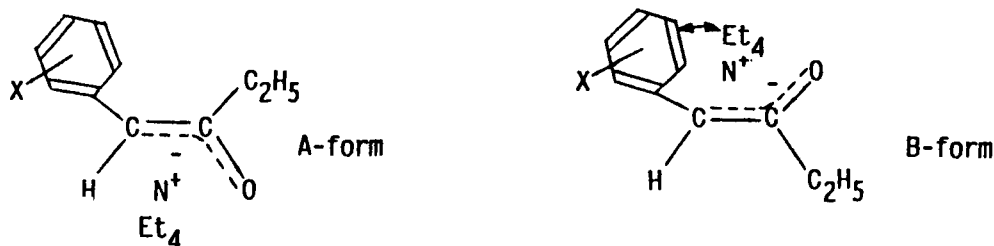


In order to explain high stereoselectivity on formation of (E)-enol esters **4** in this electrochemical acylation, conventional methods for preparation of enol acetates from ketones have been examined. An acid-catalyzed O-acylation (HClO<sub>4</sub>/Ac<sub>2</sub>O/CCl<sub>4</sub>)<sup>7)</sup> of benzyl ethyl ketone (**4b**) gave a stereoisomeric mixture of (E) and (Z)-1-phenyl-2-acetoxy-1-propene (**3b** and **3b'**) in the ratio of 1:2. On the other hand, treatment<sup>5)</sup> of **4b** with lithium diisopropyl amide(LDA) at -78 °C followed by acetylation with Ac<sub>2</sub>O led to formation of **3b** and **3b'** in the ratio of 7:1 while the (E)-enol acetate **3b** was exclusively obtained ((E)-**3b**/(Z)-**3b'** = 99:1) by addition of Et<sub>4</sub>NOTs after treatment of **4b** with LDA and subsequent acetylation with Ac<sub>2</sub>O. Furthermore, reduction potential of **1a** was -1.97 V (E<sub>p</sub> vs. SCE) and **2a** showed no reduction peak up to -2.50 V. This fact may indicate that the products **4** were initially formed by electron transfer to **1** followed by

electrophilic attack of 2 in the present electroreductive acylation.



Therefore, coordination of sterically bulky tetraethylammonium cations ( $\text{Et}_4\text{N}^+$ ) with negative charges on the oxygen and/or the benzylic carbon atoms of the anion species, possibly formed by direct electron transfer to the ketones 4 or their reactions with an electrogenerated base,<sup>8)</sup> may also make A-forms more favorably than B-forms because of steric hindrance between  $\text{Et}_4\text{N}^+$  and phenyl rings in B-forms.



#### References

- 1) For a review, see H. J. Schafer, *Angew. Chem., Int. Ed. Engl.*, **20**, 911 (1981).
- 2) For a recent leading reference on chemistry of acyl anion, see S. Murai, I. Ryu, J. Iriguchi, and N. Sonoda, *J. Am. Chem. Soc.*, **106**, 2440 (1984).
- 3) T. Shono, I. Nishiguchi, and H. Ohmizu, *Chem. Lett.*, **1977**, 1021.
- 4) Spectroscopic (NMR, MS, and IR) and/or chromatographic behaviors (GLC and TLC) of all of the products were consistent with their assigned structures.
- 5) H. O. House, L. J. Czuba, M. Gall, and H. D. Olmstead, *J. Org. Chem.*, **34**, 2324 (1969).
- 6) Yields (%) of the products 3-5 based on charged amounts of current were as follows. 1 F/mol (3:15, 4:22, 5:1), 2 F/mol (3:36, 4:48, 5:3), 3 F/mol (3:58, 4:27, 5:4).
- 7) H. O. House, M. Gall, and H. D. Olmstead, *J. Org. Chem.*, **36**, 2361 (1971).
- 8) T. Shono, S. Kashimura, and H. Nogusa, *J. Org. Chem.*, **49**, 2043 (1984).

(Received August 5, 1991)