Studies on Electrolytic Substitution Reactions. VIII.[1] The Effect of Anode Material on Anodic Acetoxylation; Synthesis of 2,4,6-Trimethylphenol

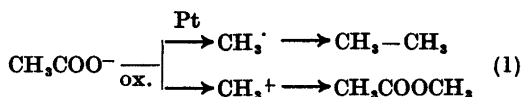LENNART EBERSON AND KLAS NYBERG*

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Anodic oxidation of mesitylene in acetic acid containing acetate ion produces 2,4,6-trimethylphenyl acetate and 3,5-dimethylbenzyl acetate as the major products. The effect of anode material on the ratio of nuclear to side-chain acetates and the current yield of products has been studied for eleven different anode materials. The highest ratios were obtained on graphite based anodes. A considerable variation in the current yield was also observed. The highest yields were obtained with a rhodium (57 %) and an AUC graphite anode from Union Carbide (56 %). The latter anode material was used in a large-scale oxidation of mesitylene, 2,4,6-trimethylphenol being isolated after hydrolysis of the acetate in 40 % yield.

Electrochemical oxidations are generally carried out using only a few types of anode materials. Platinum is the most widely used due to its stability under anodic polarization. It can therefore be used repeatedly without loss of metal. The vast amount of knowledge of anodic reaction mechanism gathered by electroanalytical techniques is predominantly based on the use of platinum as the anode. Graphite, in various forms, is of great practical importance as an anode material, since the much lower cost compared to that of platinum and other noble metals makes it attractive for large-scale synthesis.
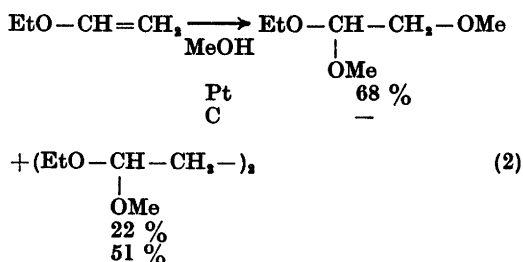
In selecting a suitable anode material for synthetic reactions it is important to know whether a specific reaction will follow the same path independent of anode material. Empirically, it is known that drastic changes may occur by substituting graphite for platinum. Thus, the Kolbe reaction, *i.e.* discharge of a carboxylate anion, leads to radical derived products (1 e-transfer) at a platinum anode [2] and carbonium ion derived products (2 e-transfer) at a graphite anode.[3] This is exemplified for the oxidation of acetic acid in eqn. 1. In a more recent investigation it was shown that radical

$$CH_3COO^- \xrightarrow[\text{ox.}]{Pt} \begin{cases} \rightarrow CH_3^\cdot \longrightarrow CH_3-CH_3 \\ \rightarrow CH_3^+ \longrightarrow CH_3COOCH_3 \end{cases} \quad (1)$$

derived products could be obtained on special carbon anodes, such as vitreous carbon and baked carbon, the yields being similar to those obtained with platinum.[4]

Another interesting change in the product distribution takes place in the oxidation of ethyl vinyl ether in methanol (eqn. 2).[5,6]

$$EtO-CH=CH_2 \xrightarrow[\substack{Pt \\ C}]{MeOH} EtO-CH-CH_2-OMe$$
$$\substack{| \\ OMe \\ 68\%}$$

$$+ (EtO-CH-CH_2-)_2 \quad (2)$$
$$\substack{| \\ OMe \\ 22\% \\ 51\%}$$

Similar drastic changes in the product yields occur in the anodic alkoxylation of N-methylamides, the substitution product being formed at a platinum anode but not at a graphite anode.[7] In the formyloxylation of N,N-dimethylformamide a high yield of N-formyloxy-

methyl-N-methylformamide is obtained at a platinum anode,[8] whereas a zero yield was experienced at a graphite anode.[9]

In this work anodic oxidation of mesitylene in acetic acid containing sodium acetate has been investigated at different anode materials with regard to the ratio of isomeric acetates and the yield of the products. This reaction has previously been studied from a mechanistic point of view, and is believed to follow the usual ECE type mechanism.[10]

RESULTS

Anodic oxidation of mesitylene in acetic acid containing sodium acetate resulted in the formation of 2,4,6-trimethylphenyl acetate (I) and 3,5-dimethylbenzyl acetate (II) as the major products (eqn. 3). The reaction was run at different anode materials until 0.2 F/mol of mesitylene

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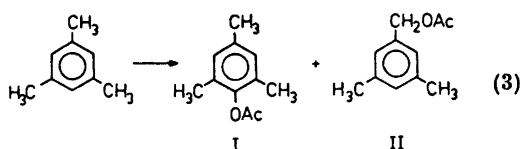
had passed. As usual in this type of study conversions were kept low in order to avoid further oxidation of the products formed.[11] The ratio of I to II and the yield of the products were determined by GLC. In order to ensure that similar reaction conditions prevail at the different materials the reaction was run at a

Table 1. Anodic acetoxylation of mesitylene (0.2 M) in acetic acid-sodium acetate (1 M) at constant current density ($i_d = 10$ mA/cm^2).

Anode	Ratio I to II	Product yield (%)
Gold	3.6	23
Platinum	4.4	19
Palladium	4.9	13
Rhodium	7.6	57
Platinum on graphite	14	38
Lead dioxide on graphite	9.6	37
Magnetite	10	22
Boron carbide	22	27
Carbon cloth	23	34
Glassy carbon	21	35
AUC graphite	23	56

constant current density of 10 mA/cm^2. The results are presented in Table 1. The variation in the ratio for the nuclear to side-chain acetates is surprisingly large, changing by a factor of six in going from the gold anode to the carbon based anodes. The product yields are also affected by the change in anode material, AUC quality graphite (Union Carbide) being the most favorable choice. Accordingly, a large-scale (1 mol of substrate) experiment was carried out using a slightly modified version of the concentric capillary gap cell previously described.[12,13] A solution of mesitylene, acetic acid, and potassium acetate (potassium acetate gives a better conductivity than sodium acetate) was electrolyzed at a constant current of 20 A. The product mixture was then hydrolyzed giving pure 2,4,6-trimethylphenol in 40 % yield.

In similar experiments with toluene as the substrate we have also experienced drastic changes. When a mixture of toluene, acetic acid and Bu$_4$NBF$_4$ was electrolyzed at either a platinum or a graphite anode, the major product was benzyl acetate, the yield being slightly higher (20 *vs.* 33 %) in the latter case.[14] On the other hand, when sodium acetate was used as the supporting electrolyte instead of Bu$_4$NBF$_4$, cresyl acetates were the major products at the platinum anode whereas no acetoxy derivatives of toluene were formed at all on graphite. The major anode process was oxidation of acetate ion with eventual formation of methyl acetate.[15] It thus seems as if the order of oxidation potentials for toluene and acetate ion is different on platinum and graphite anodes.

We do not at present wish to speculate in detail about the possible mode(s) of influence of the anode material upon the product distribution in anodic acetoxylation. Our synthetic goal, to optimize the reaction with respect to the yield of nuclear acetate, has been achieved to a reasonable extent. However, we would like to draw attention to the suggestion by Brennan and Brettle [4] that the *actual* current density at a porous electrode like graphite might be much lower than at a metallic surface like bright platinum and thus the prevailing concentration profiles near the anode surface might be significantly different in the two cases. This would certainly affect the relative concentrations of acetate ion and cation radical at the electrified interface.

EXPERIMENTAL

Anode materials. Gold, platinum, palladium, and rhodium were purchased from Engelhard Industries, USA, magnetite from KemaNord, Sweden, boron carbide (Norbide) from Norton Co, Worchester, Mass., USA, glassy carbon from Vitreous Carbon Ltd, England, carbon cloth and AUC graphite from Union Carbide Sweden. AUC graphite was plated with platinum by Degussa, Schwäbisch Gmund, Germany. Lead dioxide was plated on graphite according to a published procedure.[16]

Electrolysis conditions. A solution of mesitylene (0.01 mol) and acetic acid (50 ml) containing sodium acetate (0.05 mol) was electrolyzed at room temperature between the anode and a platinum cathode under stirring. The current was controlled by a Radiak 2 A/60 V instrument to give a constant current density of 10 mA/cm^2 (the electrode area was measured as the geometric area; in the case of the carbon cloth anode this value is of course uncertain due to difficulties in measuring the anode area). When 0.2 F/mol of mesitylene had passed, the electrolysis was stopped. Acetic acid was removed by evaporation *in vacuo*. The residue was treated with water and extracted with ether. The ether solution was washed with sodium bicarbonate solution and water and dried over anhydrous sodium sulfate. After filtration the ether solution was analyzed by GLC (Perkin-Elmer Model 880 in connection with Perkin-Elmer Integrator D 26 on a 2 m × 0.3 cm 5 % NPGS on Chromosorb P column). The isomer ratio and the product yield was calculated against a calibrated solution of authentic samples using an internal standard (pentamethylbenzene).

Synthesis of 2,4,6-trimethylphenol. A solution of mesitylene (1.0 mol) in acetic acid (1 l) containing potassium acetate (1.0 mol) was electrolyzed in the concentric capillary gap cell at a constant current of 20 A and an applied voltage of 20 V at a temperature of 25 °C until 2 F/mol of mesitylene had passed. After removal of acetic acid by evaporation *in vacuo* the residue was treated with water and extracted with ether. The ether solution was washed with sodium bicarbonate solution and water and dried over anhydrous sodium sulfate. After filtration and evaporation of the ether *in vacuo* the residue was hydrolyzed with a solution of potassium hydroxide in ethanol and water by boiling overnight. Most of the ethanol was removed by evaporation *in vacuo* and the residue extracted once with ether. The aqueous solution was cooled in an ice-bath and neutralized with dilute hydrochloric acid. The white precipitate was filtered off, washed with cold water and dried, giving pure (by GLC) 2,4,6-trimethylphenol (55.3 g; 40 % yield) identical with an authentic sample.

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