

Studies on Electrolytic Substitution Reactions. XIII. Anodic Acyloxylation of Aromatic Substrates in Emulsion Systems with the Aid of Phase Transfer Agents

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The anodic acyloxylation of moderately activated aromatic substrates has been studied in an emulsion system. The electrolyte contained alkanecarboxylic acid and/or the corresponding sodium salt, dichloromethane, substrate, and tetrabutylammonium sulfate. Good yields of aryl carboxylates were obtained from anisole while naphthalene gave a lower yield, and *p*-xylene, durene and hexamethylbenzene very low yields of benzylic carboxylates. Predominant products from the acyloxylation of the methylbenzenes were the corresponding alcohols and aldehydes. A study of different anode materials showed that platinum is superior to graphite and lead dioxide. Addition of surfactants to the electrolyte had little or no effect on the formation of aryl alkanecarboxylates.

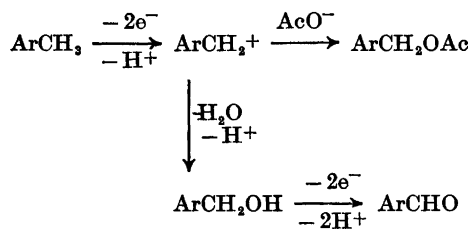
RESULTS AND DISCUSSION

The anodic acetoxylation of aromatic substrates in acetic acid/sodium acetate or tetrabutylammonium tetrafluoroborate has been extensively investigated,¹⁻⁸ and mechanistically the reaction is fairly well understood.⁹ We have earlier shown¹⁰⁻¹² that electrolysis in an emulsion system containing aqueous sodium cyanide, dichloromethane, tetrabutylammonium sulfate, and an aromatic substrate is a useful method to accomplish substitution of a ring hydrogen or an alkoxy group for a cyano group. We now report a study of the anodic acyloxylation reaction under emulsion conditions in order to investigate further the synthetic utility of this technique.

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It is well known that short-chain alkanecarboxylates, such as acetates, are poorly extracted by tetrabutylammonium ion into dichloromethane.¹³ If, however, an equivalent amount of the corresponding carboxylic acid is present the hydrogen bisalkanecarboxylate ion $[\text{RCOO}\cdots\text{H}\cdots\text{OOCR}]^-$ will be formed in a low equilibrium concentration in the aqueous phase and easily extracted into the organic phase. Using a system with the aqueous phase containing 1 M concentrations of acetic acid and sodium acetate but otherwise with the same composition as described earlier,¹⁰⁻¹² emulsion electrolysis was performed on a number of representative aromatic substrates. Table 1 shows current and material yields for the emulsion electrolyses, and these are compared with the yields obtained in the ordinary NaOAc/HOAc acetoxylation procedure.¹ The acetoxylation yields for anisole and naphthalene in emulsion are the same as the yields obtained in acetic acid/sodium acetate, although there is a slight difference in the isomer ratio for anisole.

p-Xylene, durene and hexamethylbenzene give much lower yields of acetates in the emulsion system relative to the acetic acid/acetate system. The main products are the corresponding alcohol and aldehyde, formed by the reaction between the intermediate benzylic cation and water. This reaction gives the alcohol which is further oxidized to the aldehyde (Scheme 1). We have found analogous results in the attempted cyanation of durene.⁴



Scheme 1.

The results are contrary to what one would expect according to the usual order of nucleophilicity.¹⁵ A few other examples of the same kind are known.^{9,16,17} These effects have been attributed to adsorption which in our case would mean that water is strongly adsorbed on the electrode and thus reacts preferentially with the benzyl cation formed. The results from the acetoxylation of *p*-xylene indicate that the benzylic cation formed on the route to the side-chain substituted product is more sensitive to water than the radical cation since the 2,5-dimethylphenol/2,5-dimethylphenyl acetate ratio is much lower (13/87) than the corresponding ratio (88/13) between aldehyde + alcohol and benzyl acetate.

In order to ensure that the benzylic acetates were not formed from the alcohols *via* an

ordinary esterification process, pentamethylbenzyl alcohol was treated with the solvent supporting electrolyte system at 25 °C for 24 h. No acetates were formed. This means that the benzylic acetates were formed according to the reaction in Scheme 1.

As is seen in Table 1 the current yield of the reaction is low to moderate. This is probably due to concomitant oxidation of water and/or acetate ions adsorbed on the electrode surface.⁷ In the hope of diminishing the amount of water on the anode surface by making it more hydrophobic, surfactants were added to the electrolyte. The results of these experiments are shown in Table 2. Only one experiment, acetoxylation of naphthalene in the presence of CTAB (hexadecyltrimethylammonium bromide), gave any significant changes in the yield. The anionic surfactants FC 98 (sodium perfluoroalkylsulfonate) and SAS 60 (sodium alkylsulfonate) made no significant changes in the yield of naphthyl acetate. The effects of the surfactants are too small to allow any conclusions about their possible influence on the state of the anode surface.

Table 3 shows yields of anisyl alkanecarboxylates with different alkanecarboxylic acids and/or sodium alkanecarboxylates in the aqueous

Table 1. Anodic acetoxylation of aromatic compounds. Charge passed equivalent to 1 F mol⁻¹.

Substrate	Products	Yield/%		HOAc/NaOAc ^b Material
		Emulsion system ^a Current	Material	
Anisole	Anisyl acetate	44	63 ^c	40 ^d
Naphthalene	Naphthyl acetate	18	25 ^e	22 ^{f,g}
	Binaphthyl	6	8	
<i>p</i> -Xylene	2,5-Dimethylphenyl acetate	2.8		
	4-Methylbenzyl acetate	3.6		
	4-Methylbenzaldehyde	8		
	4-Methylbenzyl alcohol	5.6		
	2,5-Dimethylphenol	0.4		
Durene	2,4,5-Trimethylbenzyl acetate	4	10	46 ^g
	2,4,5-Trimethylbenzaldehyde	15	38	
	2,4,5-Trimethylbenzyl alcohol	5	12	
	2,4,5,2',3',5',6'-Heptamethyl-diphenylmethane		1	
Hexamethylbenzene	Pentamethylbenzyl acetate	0.4	0.5	57 ^g
	Pentamethylbenzaldehyde	1	2	
	Pentamethylbenzyl alcohol	3	4	

^a Analyzed by GLC. ^b Ref. 1, isolated yields. ^c Isomer distribution *o*-52, *m*-1, *p*-47. ^d Isomer distribution ¹ *o*-86, *p*-14; *o*-67, *m*-3.5, *p*-29.1. ^e $\alpha/\beta > 19$. ^f No β -substitution found. ^g Charge equivalent to 1.5 F mol⁻¹ had been passed.

Table 2. Effect of addition of ionic surfactants to the electrolyte.

Substrate	Surfactant (amount/g)	Products	Yield/%		Isomer distribution
			Current	Material	
Anisole	CTAB ^a (0.84)	Anisyl acetate	45	67	<i>o</i> - 52, <i>m</i> - < 0.1, <i>p</i> - 48
Naphthalene	CTAB (0.84)	Naphthyl acetate	29	39	$\alpha/\beta > 19$
		Binaphthyls	4	5	
Naphthalene	FC 98 ^b (1.2)	Naphthyl acetate	22	27	$\alpha/\beta > 19$
		Binaphthyls	6	7	
Naphthalene	SAS 60 ^c (1.05)	Naphthyl acetate	19	23	$\alpha/\beta > 19$
		Binaphthyls	7	8	
Durene	CTAB (0.84)	2,4,5-Trimethyl- benzyl acetate	7	12	
		2,4,5-Trimethyl- benzaldehyde	21	34	
		2,4,5-Trimethyl- benzyl alcohol	11	19	
		2,4,5,2',3',5',6'- Heptamethyldi- phenylmethane			1

^a Hexadecyltrimethylammonium bromide. ^b Sodium perfluoroalkylsulfonate commercially available from 3M Company. ^c Hostapur SAS 60 commercial mixture of sodium alkylsulfonates 60 % in water, available from Farbwerke Hoechst A.G.

Table 3. Anodic acyloxylation of anisole.

Carboxylic acid	Carboxylate	Tetraalkyl- ammonium ion	Yield of anisyl carboxylates ^a		Isomer distribution		
			Current	Material	<i>o</i> -	<i>m</i> -	<i>p</i> -
Acetic	Acetate	TBA ^b	44	63	52	1	47
Acetic	Acetate	THA ^c	44	48	51	0.1	49
		TBA	17	24	55	0.1	45
Propionic	Propionate	TBA	50	64	49	2	49
		TBA	28	64	50		50
Valeric	Valerate	TBA	32	46	50	0.1	50
		TBA	31	51	47		53

^a All experiments with anisole gave tarry residues. ^b Tetrabutylammonium ion. ^c Tetrahexylammonium ion.

Table 4. Effect of the anode material on anodic acetoxylation of anisole. Electrolyte composition is the same as used in Table 1.

Anode	Current density/ mA cm ⁻²	Yield of anisyl acetate/%		Isomer distribution		
		Current	Material	<i>o</i> -	<i>m</i> -	<i>p</i> -
Platinum	6.25	44	63	52	1	47
Graphite	6.7	2	4 ^a	46	<0.1	54
Lead dioxide on graphite	6.7	0	0 ^b			

^a Recovered substrate 76 %. ^b Recovered substrate 96 %.

phase. Acetic acid/acetate and propionic acid/propionate give almost the same yields of the corresponding anisyl alkanecarboxylate while valeric acid/valerate gives a slightly lower yield. This is presumably due to the high solubility of valeric acid in dichloromethane which reduces complex formation in the aqueous phase and hence produces a lower degree of extraction of valerate ion. The yield of anisyl valerate is the same whether valeric acid is added or not. When the reaction is run without addition of carboxylic acid the yield of anisyl carboxylate is somewhat increased with the increasing chain-length of the alkanecarboxylate. This indicates that the extractability of the alkanecarboxylate increases from acetate to valerate.

The degree of extraction of alkanecarboxylate ions has been shown¹³ to increase with the chain-length of the tetraalkylammonium ion when tetrabutylammonium and tetrapentylammonium salts are compared. Therefore, tetrahexylammonium sulfate was used in one experiment but no change in the yield of aryl acetates in the acetoxylation of anisole was observed.

Table 4 shows the effect of different anode materials on the acetoxylation of anisole. It is obvious that platinum is the anode material of choice, as has also been found for the anodic cyanation in emulsions. It is reasonable to assume that this is due to a wetting phenomenon.

EXPERIMENTAL

General. GLC analyses were performed using either a Hewlett-Packard 5830 GLC system equipped with a 2 m × 3 mm 3 % OV 101 column or a Varian 1400 GLC equipped with a 2 m × 3 mm 5 % NPGS column and connected to a Hewlett-Packard 3380 integrator. GLC/MS analyses were performed on an LKB 9000 mass spectrometer.

Chemicals. Solvents, reagents and supporting electrolytes used in this work were commercially available reagent grade chemicals used without further purification with one exception: Tetrabutylammonium hydrogen sulfate was dissolved in dichloromethane, the solution filtered and evaporated to dryness. The residue was washed repeatedly with ether in order to remove remaining solvent from the commercial preparation.

Reference substances. *p*-Methylbenzaldehyde was purchased from Fluka AG, Buchs, Switzerland.

All acetates used have been prepared earlier in this laboratory.¹⁻³ The following substances were prepared according to well-known procedures: *o*-, *m*-, *p*-anisyl propionates,¹⁸ *o*-, *m*-, *p*-anisyl valerate,¹⁹ *p*-methylbenzyl alcohol,²⁰ 2,4,5-trimethylbenzyl alcohol,¹ pentamethylbenzyl alcohol,¹ 2,4,5-trimethylbenzaldehyde,²¹ pentamethylbenzaldehyde,²² 2,4,5,2',3',5',6'-heptamethyldiphenylmethane,²³ and binaphthyl.²⁴

General electrolysis procedure. The equipment used in this work has been described earlier.¹⁰⁻¹² The electrolyte consisted of substrate (10 mmol), aqueous alkanecarboxylic acid and/or sodium alkanecarboxylate (230 ml, 1 M in each), dichloromethane (230 ml), and tetrabutylammonium hydrogen sulfate (20 mmol), dissolved in a small amount of aqueous phase and neutralized with sodium hydroxide. A charge equivalent to 1 F mol⁻¹ was passed at a constant current of 0.50 A. When the electrolysis was started the stirrer had to be turned on for a few seconds and then turned off for 30 s and then turned on again. After this procedure the potential drop over the cell increased from initially around 4 V to around 15 V.

Work-up procedure. The phases were allowed to separate and the organic layer was evaporated to dryness. The residue was taken up in ether and washed twice with water to remove the supporting electrolyte. A suitable standard was added to the solution and the yield was determined by GLC.

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