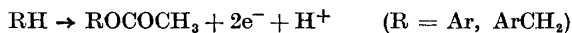# Anodic Acetoxylation of Mesitylene in Acetic Acid Containing Nitrate Ions

KLAS NYBERG

*Division of Organic Chemistry, Chemical Centre, University of Lund,
P.O.Box 740, S-220 07 Lund 7, Sweden*

The mechanism of anodic acetoxylation of mesitylene in acetic acid using tetraalkylammonium nitrates as supporting electrolytes has been investigated. It is concluded that the products are formed by two paths. Discharge of nitrate ions and oxidation of mesitylene occur at the same time. The supporting electrolyte seems to have a specific effect on the product composition. Durene and hexamethylbenzene have also been briefly investigated. The latter is oxidized at potentials lower than required for nitrate ions. Therefore discharge of these do not occur at any appreciable rate in this case.

The mechanism of anodic acetoxylation of aromatic compounds has been intensively studied in recent years.[1-4] In acetic acid containing acetate ions the products are phenyl acetates and benzylacetates. By voltammetric and product studies it has been shown that the primary reaction is oxidation of the aromatic compound followed by reaction between the aromatic positive ion and acetate ion or acetic acid. In the absence of acetate ions only benzylacetates are formed.[4] The overall reaction represents a two electron transfer.

$$RH \rightarrow ROCOCH_3 + 2e^- + H^+ \qquad (R = Ar, ArCH_2)$$

Ross and coworkers have recently shown that anodic acetoxylation of toluene and mesitylene in acetic acid containing tetramethylammonium nitrate produces benzylacetates and benzylnitrates as the major products.[5] On the basis of their results they suggested the reaction mechanism shown in Scheme 1.

The following observations are in support of this mechanism. The voltammetric curve for acetic acid/tetramethylammonium nitrate is not changed on addition of mesitylene. This indicates that no oxidation of mesitylene occurs at potentials lower than required for oxidation of acetic acid/tetramethylammonium nitrate. Ross *et al.* also detected bibenzyl from toluene and 3,5,3',5'-

Scheme 1
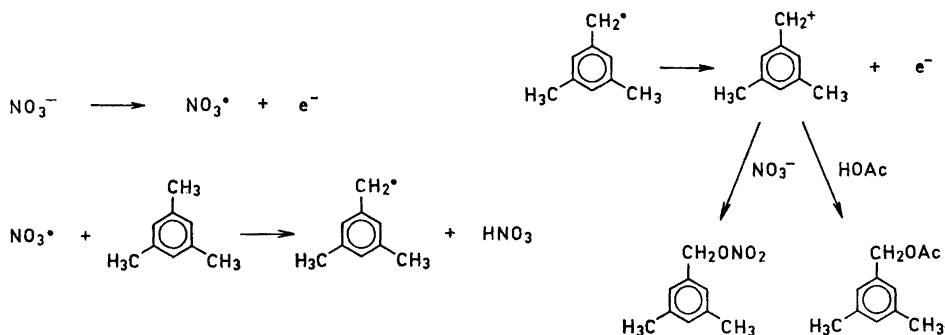
tetramethylbibenzyl form mesitylene. These products must be formed by dimerization of benzyl radicals.

It has been shown that anodic cyanation of aromatic compounds does not involve cyano radicals, although voltammetric studies show that cyanide ions are oxidized at potentials much lower than required for oxidizing the aromatics.[6,7] Thus voltammetric studies might give useful information about electrode processes but product studies are necessary in order to distinguish between different reaction paths.

The present work is a study of anodic acetoxylation of mesitylene in acetic acid containing nitrate ions. It was hoped that by varying the composition of the supporting electrolyte and by carrying out the electrolyses at low conversion it would be possible to distinguish between possible reaction paths and to see if and to what degree discharge of nitrate ion was of importance. Mesitylene was chosen because its oxidation potential in acetic acid is about the same as that of nitrate ion.[3,5] Two other substrates, durene and hexamethylbenzene, were also briefly examined.

RESULTS

The electrolytic oxidations were carried out using controlled potential conditions between two platinum electrodes. A silver/silver ion reference electrode was used (0.01 M AgNO$_3$, 0.2 M (CH$_3$)/NNO$_3$ in HOAc).

Seven products were detected from the experiments with mesitylene. These were aldehyde I, nuclear acetate II, side-chain acetate III, side-chain nitrate IV, bibenzyl V, diphenyl methane VI and a hydroxyacetate VII (Scheme 2). The first four were synthesized independently, while V—VII were identified with GLC in combination with mass spectrometry. The mass spectrum of V shows a small parent ion and a base peak at m/e 119. The mass spectrum of VI shows the parent ion as base peak and also a large abundance of m/e 132. The latter fragment is typical for diphenyl methanes.[8] The hydroxyacetate VII shows a small parent ion and large abundance for m/e 176 and 134. These correspond to loss of water and acetic acid, respectively. In the following only products I—IV will be considered in detail, since the formation

Scheme 2
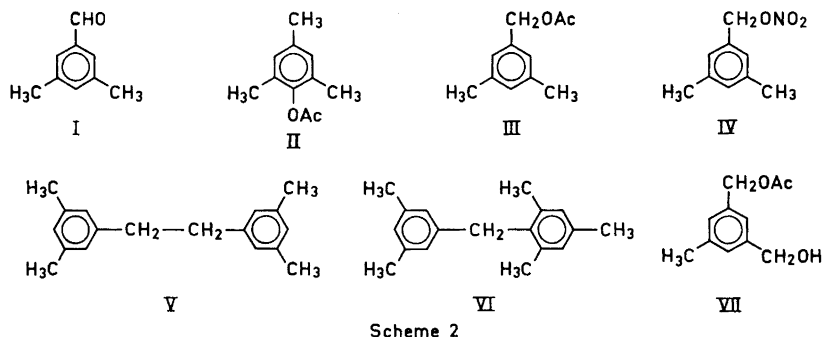
of V—VII was found to vary considerably and was not always reproducible. Sometimes only VII was formed in addition to I—IV. They were also formed in small amounts compared to I—IV.

For complete oxidation of a substrate 2 equivalents of charge per mole of substrate are necessary for a two electron oxidation. This will in the following be referred to as 100 % conversion.

The electrolytic oxidation of mesitylene in acetic acid containing tetramethylammonium nitrate was carried out at an anode potential of 1.80 V. At certain intervals samples were withdrawn. These were analyzed by GLC and the distribution of I—IV was calculated. The results are shown in Table 1. In Fig. 1 they are graphically represented. The product distribution is plotted as a function of percentage conversion. It is clearly seen that the distribution is different below and above 10 % conversion. Both I and II are initially formed in large amounts, while III and IV show the opposite trend. It is also of interest to note that at high conversions IV slowly decreases, while I increases.

Table 1. Anodic oxidation of mesitylene (0.01 mole) in acetic acid (50 ml) containing tetramethylammonium nitrate (0.02 mole). Anode potential 1.80 V. (*vs.* Ag/0.01 M Ag$^+$)

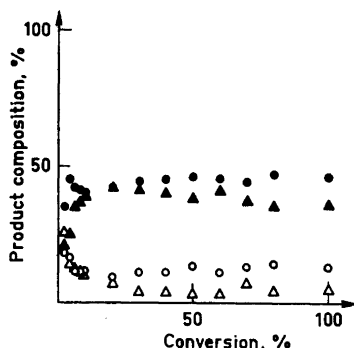| Conversion (in %)	Product distribution (in %)			
	I	II	III	IV
2	18	26	35	21
4	16	14	45	25
6	11	12	42	35
8	11	11	41	37
10	11	10	40	39
20	9	7	42	42
30	11	4	44	41
40	11	4	45	40
50	13	3	46	38
60	11	3	45	41
70	13	6	44	37
80	14	4	47	35
100	13	5	46	36

Fig. 1. Plot of product composition *vs.* percentage conversion for anodic oxidation of mesitylene (0.01 mole) in acetic acid (50 ml) containing tetramethylammonium nitrate (0.02 mole) at 1.80 V (*vs.* Ag/0.01 M Ag$^+$). O, 3,5-dimethylbenzaldehyde; △ 2,4,6-trimethylphenylacetate; ● 3,5-dimethylbenzylacetate; ▲ 3,5-dimethylbenzylnitrate.

The results from oxidation of mesitylene in acetic acid with different tetraalkylammonium nitrates are summarized in Table 2. One experiment is also included with added acetic anhydride. This shows a slight decrease in I and an increase in IV. However, no significant difference in the product

Table 2. Anodic oxidation of mesitylene (0.01 mole) in acetic acid (50 ml) with different tetraalkylammonium nitrates, R$_4$NNO$_3$, (0.01 mole). Anode potential 1.80 V. (*vs.* Ag/Ag$^+$). 10 % conversion.

| R | Product distribution (in %) | | | |
	I	II	III	IV
Me	18	4	50	28
Et	15	3	67	15
Bu	17	5	55	23
Me [a]	8	5	54	33
Me [b]	6.5	—	46.5	47

[a] 1.5 % acetic anhydride added. Anode potential 1.89 V. (*vs.* SCE)
[b] Data from Ref. 5 (these were obtained at 100 % conversion).

distribution is obtained by changing the alkyl group in the ammonium salt. The current yield was also constant just above 20 %. The last figures in the table, obtained by Ross and coworkers, show about the same amount of III and IV. But it should be pointed out that their conditions were different. They used higher concentration of nitrate ions.

In the anodic oxidation of mesitylene in acetic acid containing sodium acetate nuclear substitution dominates over side-chain substitution, while in acetic acid containing nitrate ions the opposite is observed. Therefore, it was of interest to study the product distribution when both sodium acetate and tetramethylammonium nitrate were present in acetic acid. The results are shown in Table 3. Only small amounts of nitrate are necessary to change the distribution from mainly nuclear substitution to side-chain substitution. The

Table 3. Anodic oxidation of mesitylene (0.01 mole) in acetic acid (50 ml) with mixtures of sodium acetate and tetramethylammonium nitrate at 10 % conversion.

Anode potential [a]	Mole Me$_4$NNO$_3$	Mole NaOAc	Product distribution (in %)			
			I	II	III	IV
1.80	—	0.02	0.4	81.6	18.0	—
1.80 [b]	0.0001	0.01	32	30	30	8
1.80	0.001	0.01	7	18	56	19
1.50	0.005	0.01	4	8	70	18
1.35	0.01	0.005	9	6	63	22
1.80	0.01	—	18	4	50	28
1.80 [c]	0.005	0.005	23	19	48	10

[a] *vs.* Ag/Ag$^+$
[b] 5 % conversion
[c] Bu$_4$NNO$_3$ and Bu$_4$NOAc

last figures are interesting. Using equal amounts of acetate ions and nitrate ions with the same cation surprisingly large amounts of I and II were obtained. The current yields in these experiments also remained rather constant, although they increased slightly when nitrate ions were present in the reaction mixture.

No change in product distribution was observed when electrolysis of mesitylene in acetic acid/tetramethylammonium nitrate was carried out at different anode potentials, and no change occurred when a small amount of nitric acid was added in order to suppress acetate ion formation at the cathode.

Anodic oxidation of durene (0.02 mole) in acetic acid (50 ml) containing tetramethylammonium nitrate (0.02 mole) was carried out at an anode potential of 1.65 V (*vs.* the saturated calomel electrode) until 10 % conversion. The products were found to be 2,4,5-trimethylbenzaldehyde (10 %), 2,4,5-tri-methylbenzylacetate (63 %), 2,4,5-trimethylbenzyl nitrate (14 %) and a mixture of 2,4,5,2',4',5'-hexamethylbibenzyl and 2,4,5,2',3',5',6'-heptamethyl-diphenyl methane (13 %). The current yield was 55 %. The presence of the bibenzyl is worth noting.

The product distribution from anodic oxidation of hexamethylbenzene (0.005 mole) in acetic acid (50 ml) containing tetramethylammonium nitrate (0.01 mole) could not be determined, since pentamethylbenzyl nitrate was not stable in the gas chromatograph. However, it could be established that the nitrate and the corresponding acetate were formed. The reaction was carried out at 1.05 V until 20 % conversion.

Current-voltage curves were recorded for the three substrates. Fig. 2 shows that addition of mesitylene or durene to the base solution moves the curve towards more positive potentials at constant current. With hexamethylbenzene (Fig. 3) this is not the case. The curve shows that hexamethylbenzene is oxidized at much lower potential than the base solution.
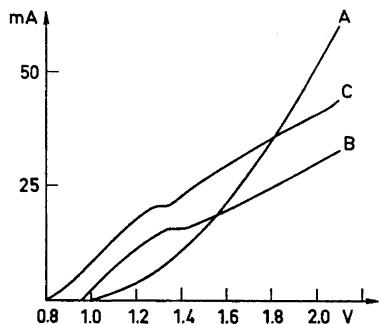
Fig. 2. Anodic voltammetry in acetic acid (50 ml) containing tetramethylammonium nitrate (0.01 mole). A: base solution; B: mesitylene (0.01 mole); C: durene (0.01 mole).
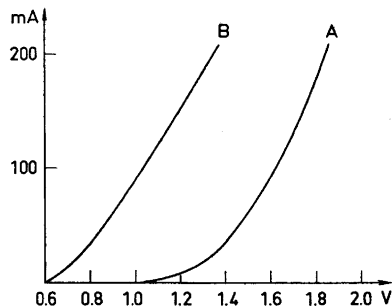
Fig. 3. Anodic voltammetry of hexamethyl-benzene (0.005 mole) in acetic acid (50 ml) containing tetramethylammonium nitrate (0.01 mole). A: base solution; B: hexa-methylbenzene.

DISCUSSION

The mechanism suggested by Ross and coworkers cannot explain the formation of II, the nuclear substituted acetate. Although it is formed in minor amounts, it must be a product of another reaction path. It has earlier been pointed out that mesitylene is oxidized in the same potential region as nitrate ions. Therefore a cation resulting from oxidation of mesitylene could explain the formation of II. The same intermediate has been suggested for anodic acetoxylation in acetic acid/sodium acetate.[3,4] III and IV are certainly formed from the reaction between the 3,5-dimethylbenzyl cations and acetic acid and nitrate ions, respectively. However, the cation does not have to be formed *via* the nitrate radical route exclusively. If mesitylene is oxidized to a cation radical or di-cation, this intermediate could be transformed to a benzyl cation. In order to explain the formation of products I—IV two reaction paths have to be considered: (1) Oxidation of a nitrate ion to nitrate radical. The latter abstracts a hydrogen from mesitylene and a benzyl radical is formed, which is oxidized to a cation; (2) Oxidation of mesitylene to a cation radical or di-cation. While (1) can explain the formation of I, III, and IV, path (2) includes also II. A third possibility is two competing reactions.

First, the formation of I under various conditions will be discussed. In most experiments I accounts for more than 10 % of the products. From Table 1 it is seen that at low conversions there is a higher yield of I than at higher conversions. Now it is known that benzyl alcohols are oxidized at anode potentials lower than required for oxidation of the parent hydrocarbons.[9-12] It is also very difficult to obtain real anhydrous acetic acid. Water, present in small amounts in the reaction mixture, would be a nucleophile to compete with nitrate ions and acetic acid for reaction with a cation. An aldehyde could therefore be formed by oxidation of the corresponding alcohol, which is formed by reaction between the cation and water. This would explain the higher degree of formation of I at low conversions. After the water is consumed, III and

IV would be favoured. From Table 2 it is seen that addition of acetic anhydride gives a lower value of I. The nominally anhydrous acetic acid was obtained by freezing out analytical grade acetic acid twice. It was noted that if acetic acid that was frozen out only once was used, the relative amount of I increased. However, this is probably not the only explanation. From Table 1 it is seen that at high conversions I is slightly increased and IV actually decreases. There is a possibility that IV could decompose and give I. Pure IV on standing is converted to I to some extent. There might also be a reason for the high degree of formation that for the moment cannot be satisfactorily explained. If water is present the formation of I seems natural, but a study of the results in Table 3 shows that when sodium acetate is the only supporting electrolyte less than 1 % of I is formed and in this experiment the water concentration was the same as in the other experiments.

Eberson [4] found that anodic acetoxylation results in side-chain substitution when sodium acetate is absent. Therefore it is surprising that nuclear substitution occurs with tetramethylammonium nitrate as supporting electrolyte. The yield of II is not high, but it is significant that it is present. The formation of II is certainly an evidence that reaction (2) is operating. The mechanism of nuclear acetoxylation has been discussed by several groups, and it is well documented that initial oxidation of the aromatic compound is responsible for the formation of phenylacetates.[1-4] From Table 1 it is interesting to note the large amounts of II at low conversions. This might be associated with a specific effect of the nitrate ion. From Table 3 the influence of the nitrate ion is also obvious. Only small amounts are necessary in order to make side-chain substitution the predominant reaction. The result from the last experiment in Table 3, using tetrabutylammonium nitrate and acetate, shows more nuclear substitution than experiments with about equal amounts of tetramethylammonium nitrate and sodium acetate. This is a more representative example of the effect of the nitrate ion, since the acetate and the nitrate ions have the same counter ion.

The formation of the side-chain substituted products, III and IV, certainly result from reaction between 3,5-dimethylbenzyl cation and acetic acid and nitrate ion, respectively.[5] Ross and coworkers pointed out that IV could be transformed into III by acetolysis, even if this is a slow reaction under the electrolysis conditions.[5]

The results presented show that the products formed in anodic oxidation of mesitylene in acetic acid containing nitrate ions cannot be satisfactorily explained by reaction path (1). But on the other hand (2) likewise does not explain all the results. The formation of I in unexpectedly high yield and the presence of II must be explained in other terms. The nature of the supporting electrolyte might be an important factor. It has been shown that there is a strong effect by the supporting electrolyte in anodic oxidation of hexamethylbenzene in mixtures of acetonitrile and acetic acid.[13]

The current-voltage curves show that nitrate ions are oxidized in the same region as mesitylene and durene. The shift towards higher anode potentials on addition of these substrates might be due to filming on the anode surface. Although durene is easier to oxidize than mesitylene, discharge of nitrate ions during electrolysis of durene cannot be avoided. The fact that there is a

bibenzyl derivative formed in this case indicates that reaction path (1) does occur. Anodic acetoxylation of hexamethylbenzene in the presence of nitrate ions does not seem to involve discharge of nitrate ions, which is seen from the current-voltage curve.

The results indicate that discharge of nitrate ions is still important when oxidation of the aromatic substrate takes place in the same potential region as that of nitrate ions. A similar interpretation has recently been reached by Ross and coworkers.[14] Therefore reaction paths (1) and (2) probably take place simultaneously as the primary reactions. A full explanation of the results must, however, await further studies, since the secondary reactions, *i.e.* reactions that take place under the influence of the electrolyte, are not yet fully understood.

EXPERIMENTAL

Materials. Analytical grade acetic acid was frozen out twice before use. Mesitylene, durene, hexamethylbenzene, and sodium acetate (anhydrous) were commerical reagent grade materials. Tetraalkylammonium nitrates were prepared by neutralizing the appropriate tetraalkylammonium hydroxide with nitric acid, the water was removed *in vacuo* and the nitrates were recrystallized and dried.[5,15] Tetrabutylammonium acetate was prepared from equivalent amounts of tetrabutylammonium tetrafluoroborate in acetic acid and sodium acetate in acetic acid. Sodium tetrafluoroborate precipitated and was filtered off. The acetic acid solution containing tetrabutylammonium acetate was then used directly in the electrolysis. 3,5-Dimethylbenzaldehyde,[16] 2,4,6-trimethylphenylacetate,[17] 3,5-dimethylbenzylnitrate,[5] pentamethylbenzylacetate[3] were prepared according to published methods. 3,5-Dimethylbenzylacetate was prepared by treating the corresponding alcohol[18] with acetic anhydride and pyridine. The identification of V, VI, and VII has already been discussed. 2,4,5-Trimethylbenzylacetate and 2,4,5,2′,3′,5′,6′-heptamethyldiphenyl methane were prepared by anodic oxidation of durene in acetic acid/tetrabutylammonium tetrafluoroborate and in methylene chloride/tetrabutylammonium tetrafluoroborate, respectively. These methods will be described elsewhere. 2,4,5-Trimethylbenzaldehyde, 2,4,5-trimethylbenzylnitrate, and 2,4,5,2′,4′,5′-hexamethylbibenzyl were identified on basis of their mass spectra. The nitrate could also be converted to the corresponding acetate by treatment with boiling acetic acid/sodium acetate. Pentamethylbenzylnitrate was kindly provided by Dr. Sidney Ross.

Electrolysis experiments. The cell consisted of a jacketed 60 ml vessel, equipped with a cylindrical platinum anode (surface area 50 cm²) and a platinum foil electrode. The reference electrode was an $Ag/0.01$ M Ag^+ electrode. The anode potential was controlled by means of the Model 557 potentiostat from Amel, Milan, Italy. The amount of charge passed through the electrolyte was measured by an Amel Model 558 integrator. The cell temperature was maintained at 30°.

After each electrolysis the reaction mixture was pured onto water. The organic material was taken up in ether. The ether phase was washed with dilute sodium bicarbonate solution, with water and dried over anhydrous sodium sulphate. The dried ether solution was then analyzed by GLC (Perkin-Elmer 880 gas chromatograph, equipped with the Model D 24 integrator) on a $2 m \times 0.3$ cm 5 % NPGS on Chromosorb W column. In determining the current yields pentamethylbenzene (for mesitylene) and hexamethylbenzene (for durene) were used as internal standards. The products were identified by comparison with authentic samples and by mass spectra (recorded on the LKB 9000 Mass Spectrometer in combination with GLC).

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