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A Novel Anodic Substitution Reaction: Oxidative Displacement of Fluorine by an Acetoxy Group

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Summary Anodic oxidation of 2- and 4-fluoroanisole in a potassium acetate-acetic acid solution produces 2- and 4-acetoxyanisole, respectively, *via* a non-conventional reaction path.

ANODIC substitution reactions are commonly represented by equation (1)

$$R-E + Nu^{-} \rightarrow R-Nu + E^{+} + 2e \tag{1}$$

where Nu⁻ is the nucleophile, and E⁺ the electrophile, generally a proton or an alkoxonium ion.¹ Almost all examples of this reaction are classified as *ECEC* reactions (*E*: electron transfer step, *C*: chemical step).¹

We now report a novel anodic substitution reaction, unusual from the mechanistic point of view. When 4fluoroanisole (1) was oxidized at a controlled anode potential (1.5 V vs. S.C.E.) at a Pt anode in an undivided cell in 0.5M KOAc-HOAc the major product was 4-acetoxyanisole (2)[†] and only traces of the expected substitution products (2- and/or 3-acetoxy-4-fluoroanisole) were observed. No reaction took place in the absence of current. A high current yield of (2) was obtained at low conversion (70-80%) based on a one-electron process when <0.5 F mol⁻¹ of substrate had passed). The yield gradually decreased on prolonged electrolysis (40% after a passage of 1 F mol⁻¹), probably owing to further oxidation of (2).[‡] Coulometry at constant potential gave an *n* value of 1. On single sweep voltammetry an *n* value of 2 was calculated.§ Anodic oxidation of (1) in the absence of acetate ion (Bu₄NBF₄-HOAc) produced neither (2) nor any other aryl acetates.² 2-Fluoroanisole behaved similarly on anodic oxidation in 0.5M KOAc-HOAc yielding 2-acetoxyanisole. On the other hand anodic oxidation of 3-fluoroanisole, 4-bromoanisole, and 4-chloroanisole, respectively, in the same medium yielded normal substitution products (displacement of hydrogen by an acetoxy group) and only traces of acetoxyanisoles were detected.

Our observation that a 2- or 4-fluorosubstituent in anisole changes the usual product pattern in anodic acetoxylation is not consistent with the common *ECEC* reaction sequence in anodic substitution, since this would require a loss of F^+ from (5) in equation (2); that is extremely unlikely from an energetic point of view. A reaction mechanism must take into account the fact that 4-bromoand 4-chloro-anisole yield normal substitution products.

† All products were satisfactorily identified by comparison with authentic samples or by spectroscopic methods.

 \ddagger The voltammetric peak potential of (2) is ca. 0.1 V lower than that of (1).

§ This value was determined in MeCN-HOAc (4:1) containing 0.17M NaOAc and 0.07M LiClO₄.

A reaction path involving a loss of fluorine radicals from either (3) or (4) [reactions (2)—(4)]

$$\begin{array}{ccc} \operatorname{Ar-F} & \longrightarrow [\operatorname{Ar-F^{+}}] & \longrightarrow [\operatorname{F-Ar-OAc}]^{\bullet} & \longrightarrow [\operatorname{ArOAc}\ \mathrm{F}]^{+} & (2) \\ & -\operatorname{c} & & \operatorname{AcO^{-}} & -\operatorname{c} & \\ & & (3) & & (4) & & (5) \end{array}$$

Ar = 2- or 4-anisyl

$$(4) \rightarrow [Ar-OAc]^+ + F^- \tag{3}$$

$$(5) \rightarrow [\operatorname{Ar-OAc}]^{2+} + F^{-}$$

$$(6)$$

$$(4)$$

(yielding HF by hydrogen abstraction from a surrounding molecule or ion) might be energetically feasible, since the heat of formation of HF in a homolytic reaction is considerably higher than that of either HCl or HBr. However, several observations contradict such a radical pathway. A loss of a fluorine radical from (3) would yield an anisyl

cation that should yield (2) independently of acetate ions. The result obtained from the oxidation of (1) in the absence of acetate ions is inconsistent with that. A loss of a fluorine radical from (4) would yield (2). However, the voltammetric n value of 2 is not consistent with such a reaction path. We have not been able to detect any products resulting from radical reactions.³¶

We are left with the assumption that at some intermediary stage in the formation of (2) a fluoride ion is lost as shown in equations (3) and (4). This idea seems attractive since the fluoride ion (as in KF) is strongly solvated in acetic acid.⁴ The different n values obtained by coulometry and voltammetry give an indication that an intermediate (formed after two E steps), e.g. (6), is oxidizing the starting material.

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¶ It has been shown that acetoxyl radicals are not intermediates in the formation of acetoxyaromatic compounds during the electrolysis of a mixture of acetate ion and an aromatic compound in acetic acid.

 ¹ For a review, see: L. Eberson and K. Nyberg, Adv. Phys. Org. Chem., 1976, 12, 1.
 ² L. Eberson, J. Amer. Chem. Soc., 1976, 89, 4669; Traces of biaryl derivatives were detected. The major products are probably oligomers and polymers, cf. ref. 2.

³ For a review, see: L. Eberson and K. Nyberg, Accounts Chem. Res., 1973, 6, 106. ⁴ J. Emsley, J. Chem. Soc. (A), 1971, 2511.