

Associates 206 and 500 instruments.

(2*RS*,3*RS*)- and (2*SR*,3*RS*)-Methyl 2-Methyl-3-hydroxy-3-phenylbutyrate (**1e** and **1t**). To a solution of diisopropylamine (5 g, 0.05 mol) in anhydrous Et₂O (100 mL) at -78 °C was added with stirring a solution of BuLi (0.05 mol) in hexane (20 mL). The resulting mixture was stirred at -78 °C for 15 min. A solution of methyl propionate (4.4 g, 0.05 mol) in Et₂O (20 mL) was added rapidly with stirring. After 20 min of additional stirring at -78 °C, a solution of acetophenone (6.0 g, 0.05 mol) in Et₂O (25 mL) was added, and the mixture was stirred for 15 min. A 10% HCl solution (35 mL) was added, and the mixture was allowed to warm to room temperature. The organic layer was separated, washed with water, dried (MgSO₄), and evaporated under reduced pressure. The liquid so obtained was distilled in a Kugelrohr apparatus to yield 5.3 g (51%) of pure **1** as a 1:1 mixture of **1e** and **1t**: bp 55 °C (air-bath temperature; 0.025 mmHg); IR (neat) 3505, 1715, 1448, 1350, 1205, 1070, 765, 700 cm⁻¹. Anal. Calcd for C₁₂H₁₆O₃: C, 69.21; H, 7.74. Found: C, 69.02; H, 7.96.

The two diastereoisomers were separated by preparative HPLC with 1:19 EtOAc-hexane as the eluent. Pure samples of the less polar (assigned **1t**, solid, mp 52-54 °C) and the more polar (assigned **1e**, liquid) isomers were obtained.

(2*RS*,3*RS*)- and (2*SR*,3*RS*)-Ethyl 2-Propyl-3-hydroxy-3-phenylbutyrate (**2e** and **2t**). To a solution of LDA (0.11 mol), prepared as above, in anhydrous Et₂O (200 mL) at -78 °C was added with stirring a solution of ethyl valerate (13.0 g, 0.1 mol) in Et₂O (40 mL) over a period of about 2 min. The mixture was stirred at -78 °C for 20 min. A solution of acetophenone (12.0 g, 0.1 mol) in Et₂O (50 mL) was added, and the mixture was stirred at -78 °C for 15 min. The workup as in the case of **1** afforded a liquid which was distilled in a Kugelrohr apparatus to yield 12.4 g (50%) of pure **2** as a 1:1 mixture of **2e** and **2t**: bp 80 °C (air-bath temperature; 0.05 mmHg); IR (neat) 3500, 1710, 1445, 1375, 1345, 1185, 1028, 712, 700 cm⁻¹. Anal. Calcd for C₁₅H₂₂O₃: C, 71.97; H, 8.86. Found: C, 72.01; H, 8.99.

The two diastereoisomers were separated by preparative HPLC with 1.5% EtOAc in hexane as the eluent. Pure samples of the less polar (assigned **2t**) and the more polar (assigned **2e**) isomers both as liquids were obtained. The IR spectra of the two isomers in CCl₄ are slightly different. The OH in **2t** absorbs at 3520 cm⁻¹ whereas that of **2e** absorbs at 3500 cm⁻¹. Some other small differences exist mainly in the fingerprint area.

(2*RS*,3*RS*)- and (2*SR*,3*RS*)-Ethyl 2-(2-Propyl)-3-hydroxy-3-phenylbutyrate (**3e** and **3t**). To a solution of LDA (0.05 mol), prepared as above, in anhydrous Et₂O (100 mL) at -78 °C, was added with stirring a solution of ethyl 3-methylbutyrate (6.5 g, 0.05 mol) over a period of about 2 min. The mixture was stirred at -78 °C for 20 min. A solution of acetophenone (6.0 g, 0.05 mol) in Et₂O (25 mL) was added, and the mixture was stirred at -78 °C for 15 min. The workup as in the case of **1** afforded a liquid which was distilled in a Kugelrohr apparatus to yield 6.8 g (54%) of pure **3** as a 1:1 mixture of **3e** and **3t**: bp 65-70 °C (air-bath temperature; 0.025 mmHg); IR (neat) 3495, 1708, 1448, 1380, 1190, 1028, 762, 698 cm⁻¹. Anal. Calcd for C₁₅H₂₂O₃: C, 71.97; H, 8.86. Found: C, 72.06; H, 8.88.

The two diastereoisomers were separated by preparative HPLC with 2.5% EtOAc in hexane as the eluent. Pure samples of the less polar (assigned **3t**, a solid; mp 37-39 °C) and the more polar (assigned **3e**, liquid) isomers were obtained.

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Registry No. **1e**, 14366-99-5; **1t**, 14366-98-4; **2e**, 83633-71-0; **2t**, 83633-72-1; **3e**, 83633-73-2; **3t**, 83633-74-3; diisopropylamine, 75-31-0; butyllithium, 109-72-8; lithium diisopropylamide, 4111-54-0; methyl propionate, 554-12-1; ethyl valerate, 539-82-2; ethyl 3-methylbutyrate, 108-64-5; acetophenone, 98-86-2.

Structure and Selectivity in Anodic and Metal Ion Oxidations of Polyalkylbenzenes^{1a}

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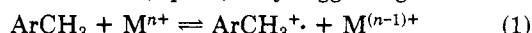
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Positional selectivity and the partition deuterium isotope effect (k_H/k_D) have been determined in the chemical [with cerium(IV) ammonium nitrate (CAN), cobalt(III) acetate, and *N*-bromosuccinimide (NBS)] and electrochemical side-chain oxidation of alkyl aromatics by using 5-*R*-hemimellitenes ($R = H, t\text{-Bu}$) and 1,3-dimethyl-2-(trideuteriomethyl)-5-*tert*-butylbenzene as the substrates. Considering also the already available data for isodurene, it has been found that the positional selectivity is strongly influenced by the substrate structure in the anodic and CAN-promoted oxidations, both reactions exhibiting a very similar pattern. In contrast, Co(OAc)₃ selectivities do not correlate with those of the anodic oxidation but with the selectivities of the side-chain bromination promoted by NBS. These results have been interpreted by suggesting that, as in the anodic oxidations, CAN-induced reactions involve first the formation of a radical cation intermediate which then loses a proton to give a benzylic free radical in the selectivity-determining step. The data for Co^{III} would instead suggest a mechanism involving a hydrogen atom transfer, but this conclusion cannot yet be considered definitive. No simple correlation exists between selectivity data and the k_H/k_D values.

A recent study has shown that the isomeric product distribution (intramolecular selectivity) in the side-chain oxidation of isodurene and *p*-ethyltoluene by metal ion (Ce^{IV}, Co^{III}, Mn^{III}) reagents is strongly influenced by the nature of the metal.² This result has been accommodated to what is at present the more generally accepted mech-

anism for the reactions of alkyl aromatic compounds with one-electron oxidants (eq 1-3)^{3,4} by suggesting that in the



B = conjugate base of the solvent or ligand of the metal ion

(1) (a) Part 8 of the series "Oxidation of Aromatic Compounds by Metal Ions". Part 7: Baciocchi, E.; Rol, C.; Mandolini, L. *J. Am. Chem. Soc.* 1980, 102, 7597. (b) Università di Perugia. (c) University of Lund.

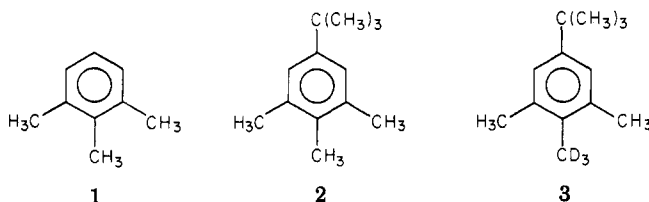
(2) Baciocchi, E.; Mandolini, L.; Rol, C. *J. Org. Chem.* 1980, 45, 3906.

product-determining step, eq 2, the proton-abstracting species can be different, its structure closely depending on the nature of the metal. However, the possibility that the different selectivities observed are due to the operation of different mechanisms in the reactions of the various ions cannot be excluded. For example, the conversion of the substrate into the benzyl radical could occur in a single step,^{5,6} with the hydrogen being transferred to one of the ligands of the metal.^{6,7} Indeed, it has to be recognized that quite convincing evidence in favor of the radical cation mechanism for reactions promoted by one-electron oxidants is available for the reactions of Ce^{IV} and Ag^{II} only.^{4,7a,8}

To get further insight into this problem, we considered useful to extend our knowledge of the role of the metal in these oxidations by also investigating the influence that the nature of the metal exerts upon (a) the dependence of the intramolecular selectivity on the substrate structure and (b) the deuterium isotope effect on the product distribution. The influence of the substrate structure on the selectivity should be related, probably more closely than the selectivity itself, to the reaction mechanism, whereas the deuterium isotope effect on the product distribution should indicate to what extent changes in selectivity reflect changes in the degree of C-H bond breaking in the transition state of the product-determining step.

Moreover, it was considered of interest to extend the investigation to the corresponding electrochemically promoted process. Interesting mechanistic information can be obtained by this comparison since anodic oxidation of a neutral substrate certainly involves a radical cation, at least when the supporting electrolyte is a difficultly oxidizable species, e.g., tetrabutylammonium tetrafluoroborate.

In this paper we report a study of the isomeric products distribution in the oxidation of hemimellitene (1), 5-



tert-butylhemimellitene (2), and 1,3-dimethyl-2-(tri-deuteriomethyl)-5-*tert*-butylbenzene (3). The oxidations were performed in acetic acid at 60 °C by cerium(IV) ammonium nitrate (CAN), cobalt(III) acetate, and anodically, either in the presence of tetrabutylammonium tetrafluoroborate or potassium acetate. In the case of compound 1 some anodic oxidations have also been carried out in the presence of nitrate ion. For purposes of comparison with a known radical mechanism, the product

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(6) Ebersson, L.; Wistrand, L. G. *Acta Chem. Scand., Ser. B* **1980**, *B34*, 349.

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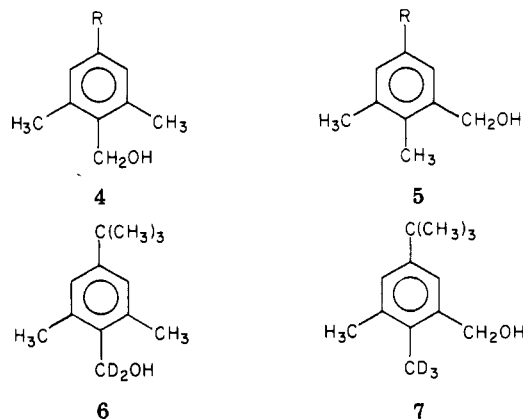
distribution was also determined at the same temperature for the side-chain bromination of isodurene and compounds 1 and 2 with *N*-bromosuccinimide (NBS), a reaction which certainly takes place by direct hydrogen atom transfer.⁹

Results

The oxidation reactions promoted by $\text{Co}(\text{OAc})_3$ and CAN were carried out under nitrogen in acetic acid at 60 °C by using stoichiometric amounts of the reactants. With $\text{Co}(\text{OAc})_3$ the products are mainly benzylic acetates accompanied by small amounts of carbonyl compounds (1-5%). With CAN, benzylic acetates and nitrates are formed, again accompanied by small amounts of carbonyl compounds. With both oxidants experiments in the presence of AcOK (1 and 0.1 M, respectively) have also been carried out. While no significant changes in the products distribution have been observed by using $\text{Co}(\text{OAc})_3$ and this salt as oxidizing system, with CAN/AcOK side-chain substitution products were obtained only when the experiment was carried out under heterogeneous conditions (undissolved CAN). If a solution of AcOK and the aromatic compound in AcOH is mixed with a solution of CAN in AcOH, no reaction occurs, whereas significant changes in the UV spectrum are observed. It is likely that the dissolved CAN exchanges NO_3^- ligands with AcO^- ligands, forming a much less reactive species.¹⁰ Interestingly, in the CAN-promoted oxidation of hemimellitene in the presence of AcOK, a small amount (ca. 3%) of nuclear acetoxylation product was detected.

The anodic oxidations were carried out in acetic acid at 60 °C and 5 mA/cm² on a Pt anode up to a conversion of 1.8 F/mol by using either Bu_4NBF_4 or AcOK as the supporting electrolyte. Formation of benzyl acetates was observed in both cases, but in the presence of AcOK significant amounts of products of nuclear acetoxylation were also formed. The anodic oxidation of 1 was also brought about in the presence of nitrate ions. In this case a mixture of benzylic acetates and nitrates was obtained.

In all the cases examined the isomeric distribution of side-chain oxidized products was determined by reducing the reaction product with LiAlH_4 in order to convert benzylic acetates and nitrates and carbonyl compounds into the corresponding benzyl alcohols [4 (R = H) and 5



(R = H) from 1, 4 (R = *t*-Bu) and 5 (R = *t*-Bu) from 2, and 6 and 7 from 3] which were analyzed by VPC. Control

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(10) Preliminary results indicate that $\text{Ce}(\text{OAc})_4$ reacts with hexamethylbenzene ca. 500-fold more slowly than CAN.

(11) Baciocchi, E.; Mandolini, L.; Rol, C. *J. Org. Chem.* **1977**, *42*, 3682.

(12) Ebersson, L.; Oberrauch, E. *Acta Chem. Scand., Ser. B* **1979**, *B33*, 343.

Table I. Distribution of Isomeric Alcohols^a Obtained (See Text) in Some Metal and Anode (Pt) Oxidations of 1-3 in Acetic Acid at 60 °C

oxidant	added salt	1		2		3	
		4 (R = H)	5 (R = H)	4 (R = <i>t</i> -Bu)	5 (R = <i>t</i> -Bu)	6	7
Co(OAc) ₃	AcOK (1 M)	44 ^b	56 ^b	71	29	27	73
Co(OAc) ₃		43	57	72	28		
CAN		63 ^b	37 ^b	92	8	79	21
CAN	AcOK (0.1 M)	62 ^c	38 ^c	93	7		
anode ^{d,e}	AcOK (0.5 M)	51	49	79	21	68	32
anode ^d	Bu ₄ NBF ₄ (0.1 M)	60 ^f	40 ^f	89	11	53	47
anode ^d	LiNO ₃ (0.5 M)	58	42				
NBS ^g		61	39	76 ^f	24 ^f		

^a In mole percent. The error in the reported percentages, as the average deviation from at least two experiments, is $\pm 1\%$ unless otherwise indicated. ^b In the CAN and Co(OAc)₃ oxidations of hemimellitene it has been observed that isomeric distributions are independent of degree of conversion. ^c Products of nuclear acetoxylation (3%) were also observed. ^d Conversion 1.8 F mol⁻¹. ^e In this reaction, products of nuclear acetoxylation (42%, 23%, and 30%^f with 1, 2, and 3, respectively) were also observed. ^f The error is ± 2 . ^g In CCl₄ in the presence of AIBN.

Table II. Reactivity Ratios of Nonequivalent α -Hydrogen Atoms in Some Metal Ion and Anode (Pt) Oxidations of 1, 2, and Isodurene in Acetic Acid at 60 °C

oxidant	added salt	$k_{2\text{CH}_3}/k_{1\text{CH}_3}$		
		1	2	isodurene
Co(OAc) ₃	AcOK (1 M)	1.57 \pm 0.07	4.9 \pm 0.2	4.7 \pm 0.2 ^a
Co(OAc) ₃		1.51 \pm 0.06	5.1 \pm 0.2	
CAN		3.4 \pm 0.1	24 \pm 2	55 \pm 4 ^a
CAN	AcOK (0.1 M)	3.3 \pm 0.1	26 \pm 2	
anode ^b	AcOK (0.5 M)	2.1 \pm 0.1	7.5 \pm 0.5	16 \pm 1 ^c
anode ^b	Bu ₄ NBF ₄ (0.1 M)	3.0 \pm 0.2	16 \pm 1	37 \pm 2 ^c
NBS ^d		3.1 \pm 0.1	6.3 \pm 0.6	5.4 \pm 0.3

^a See ref 2. ^b Conversion 1.8 F mol⁻¹. ^c See ref 12. ^d In CCl₄, in the presence of AIBN.

experiments in this and earlier work² have shown that this procedure does not modify the isomeric distribution of side-chain-substituted products.

The reactions of 1-3 with NBS were carried out at 60°C in CCl₄ in the presence of azobis(isobutyronitrile) (AIBN). The benzyl bromides formed were then converted into the benzyl alcohols by reaction with sodium hydroxide in aqueous acetone.

The isomeric distributions are reported in Table I. From these data the reactivity ratios (statistically corrected) of nonequivalent benzylic C-H bonds concerning the reactions of compounds 1 and 2 ($k_{2\text{CH}_3}/k_{1\text{CH}_3}$) have been calculated and are presented in Table II, together with those already available for the corresponding reactions of isodurene.

In Table III are reported values of the deuterium isotope effect ($k_{\text{H}}/k_{\text{D}}$) in the product-determining step of the oxidation of 2, calculated by comparing the isomeric distributions observed in the reactions of this compound with those of the reactions of its deuterated counterpart (3).

Discussion

The data in Table II clearly show that the $k_{2\text{CH}_3}/k_{1\text{CH}_3}$ reactivity ratio is somewhat influenced by the structure of the substrate, namely, by the nature of the 5-substituent, as well as by the nature of the oxidizing system. However, in spite of significant differences in the values of selectivity, it is evident from the data of Table II that anodic and CAN-promoted oxidations exhibit a very similar trend with respect to the structural effects on selectivity. Accordingly, we observe that in anodic and CAN-promoted oxidations the $k_{2\text{CH}_3}/k_{1\text{CH}_3}$ ratio strongly increases on going from 5-H to 5-*t*-Bu and from the latter to 5-CH₃.

In contrast, with cobaltic acetate the selectivity slightly increases by replacing 5-H with 5-*t*-Bu, and no further increase is observed when 5-*t*-Bu is replaced by 5-CH₃. A situation very similar to that of Co^{III} is found in the reaction with NBS. The difference in the selectivity trends

Table III. Deuterium Isotope Effect ($k_{\text{H}}/k_{\text{D}}$) in the Product-Determining Step for Some Metal and Anode (Pt) Oxidations of 5-*tert*-Butylhemimellitene in Acetic Acid at 60 °C

oxidant	supporting electrolyte	$k_{\text{H}}/k_{\text{D}}$ ^a
Co(OAc) ₃		6.7
CAN		3.2
anode	AcOK (0.5 M)	1.8
anode	Bu ₄ NBF ₄ (0.1 M)	7.2

^a The average error is ± 5 -7%.

between CAN and anodic oxidations on one side and the reactions promoted by cobaltic acetate and NBS on the other side is significant and well outside experimental errors.

That CAN and anodic oxidations respond analogously to changes in the nature of the 5-substituent is further demonstrated by the linear relationships existing between $\log(k_{2\text{CH}_3}/k_{1\text{CH}_3})$ values of the three processes. These plots are displayed in Figure 1. In contrast, data for Co^{III} oxidation do not correlate with data for anodic oxidation (Figure 1) but with those for the side-chain bromination induced by NBS.

Since there is no doubt that anodic oxidation in AcOH-Bu₄NBF₄ occurs by a mechanism involving the formation of a radical cation intermediate, the above observation strengthens earlier conclusions⁴ that such an intermediate is also formed in the CAN-promoted oxidation of alkyl aromatic compounds. Probably the above results have also a bearing on the problem of the direct vs. indirect mechanism of anodic oxidation in the presence of AcOK.¹³ Accordingly, the correlation between selectivity data of this oxidation with those of anodic oxidation in the presence of Bu₄NBF₄ suggests a direct mechanism also for the former reaction.

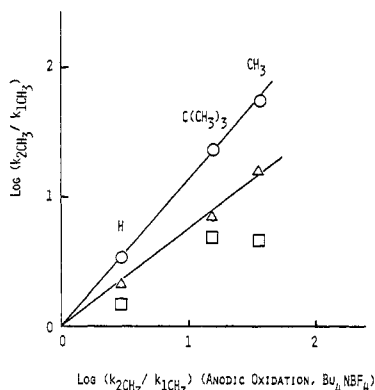


Figure 1. Selectivity data ($\log k_{2\text{CH}_3}/k_{1\text{CH}_3}$) for oxidations of 5-substituted 1,2,3-trimethylbenzenes promoted by CAN (O), $\text{Co}(\text{OAc})_3$ (\square), and anodically in the presence of AcOK (Δ) vs. selectivity data for the corresponding anodic oxidations in the presence of Bu_4NBF_4 .

The mechanism of Co^{III} -promoted oxidations of alkylaromatic compounds has been the subject of controversy. An electron transfer mechanism has been first proposed by Heiba and coworkers^{3c} and later supported by other workers.^{2,3d-f} Recently, however, this proposal has been challenged, and it has been suggested that a hydrogen atom transfer mechanism from the substrate to the salt is more probable.^{5,6} The problem has been summarized and discussed by Kochi.^{7b}

In this context the observation that structural effects on selectivity of Co^{III} -promoted oxidations are significantly different from those of anodic oxidations and similar to those of one free radical reaction¹⁴ would appear more in line with the suggestion of a hydrogen atom transfer mechanism for the reactions of cobaltic acetate. However, in view of the fact that only three substituents have been examined, we feel that this conclusion cannot yet be considered definitive, even though a recent application of the Marcus theory to the kinetic data for the oxidation of alkylbenzenes by cobaltic acetate has suggested that an electron-transfer mechanism is not feasible with this system.^{8,15} Further work is clearly needed to clarify the oxidation mechanisms of Co^{III} complexes.

With all substrates anodic acetoxylation in AcOH-AcOK is slightly less selective than in $\text{AcOH-Bu}_4\text{NBF}_4$. This observation is probably to be ascribed to the higher basicity of AcO^- with respect to AcOH , as a stronger base is expected to react with the radical cation (eq 2) less selectively than a weaker base. With a stronger base a lower degree of proton transfer in the transition state is expected, and, accordingly, the values of the deuterium isotope effect are smaller in AcOH-AcOK than in $\text{AcOH-Bu}_4\text{NBF}_4$. In the latter case the $k_{\text{H}}/k_{\text{D}}$ value suggests a nearly symmetrical transition state.

Unlike anodic oxidations, the presence of added AcOK does not significantly influence the $k_{2\text{CH}_3}/k_{1\text{CH}_3}$ ratio in the reactions induced by CAN. This observation supports previous suggestions that in these oxidations the radical cation is closely associated to its counterion,² the latter acting as the proton-abstracting species. Another possibility is that external AcO^- cannot compete with solvent attack. The radical cation is formed in a solvation shell

of AcOH molecules which collapses before reaction with external nucleophiles. In this regard it is interesting to note that the proton loss reaction from radical cations of methylbenzenes has been shown to occur in a strongly acidic medium with a rate which is pH independent.¹⁶

In the presence of AcOK some nuclear acetoxylation induced by CAN is observed, and this indicates that, with respect to a ring attack, AcO^- appears much more effective than the radical cation counterion. The very high propensity of AcO^- to attack the ring position of a radical cation is also shown by the observation that nuclear anodic acetoxylation is possible *only* in the presence of this base.¹⁷

The low $k_{\text{H}}/k_{\text{D}}$ value observed in the CAN-promoted oxidations suggests an asymmetric transition state also for step 2 of these reactions. The proton should be, in this case, more than 50% transferred to the base, as the opposite situation has been suggested for the anodic oxidations in AcOH-AcOK which exhibit a much smaller selectivity than that of the oxidations by CAN. It would thus appear that the transition state for the deprotonation step resembles the structure of the radical cation in the anodic oxidations in AcOH-AcOK and that of the benzylic free radical in the CAN-induced reactions.

However, this conclusion should be considered with much caution since such a straightforward comparison of $k_{\text{H}}/k_{\text{D}}$ values could be invalid if, as it is possible, structurally unrelated bases are actually involved in the deprotonation steps of CAN-promoted and electrochemical oxidations.¹⁸ Moreover, it would be quite difficult to reconcile the high selectivity observed in the reactions with CAN with a step 2 characterized by a transition state closely resembling the free radical.

A complicating factor with respect to the interpretation of the isotope effect and selectivity data could arise if the product- (and selectivity) determining step would not be the deprotonation step, as is generally believed and as we ourselves have assumed in the previous discussion, but a step subsequent to it. That this possibility exists has been shown by recent detailed studies¹⁹⁻²¹ on the deprotonation of anodically generated radical cations. Evidence has been obtained²⁰ that at least under acidic conditions a series of equilibria (eq 4-6) has to be considered. If the depro-



tonation step is reversible, the product-determining step becomes the reaction of the carbocation with the nucleophile (eq 6), and the selectivity would reflect the relative stabilities of isomeric carbocations formed in eq 5.

However, another consequence of a reversible deprotonation step should be the observation of hydrogen isotope exchange between a deuterated substrate and the solvent. Thus, when **3** is oxidized in AcOH , a substantial decrease in the deuterium content of the alcohol **6** should be observed. Since no such decrease was found in the electrochemical and CAN-promoted oxidations of **3**, we can

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(19) Berek, J.; Ahlberg, E.; Parker, V. D. *Acta Chem. Scand., Ser. B* **1980**, *B34*, 85.

(20) Schmid Baumberger, R.; Parker, V. D. *Acta Chem. Scand., Ser. B* **1980**, *B34*, 537.

(21) Parker, V. D. *Acta Chem. Scand., Ser. B* **1981**, *35*, 123.

(14) Certainly, with other free radicals selectivity values might be different than with NBS. However, we wish only to emphasize the point that one reaction certainly of free radical type actually exhibits structural effects on selectivity similar to those of the reaction with Co^{III} .

(15) Interestingly, the same study has shown that an electron-transfer mechanism is feasible in the reactions with CAN, in line with our conclusions.

reasonably exclude the reversibility of the deprotonation step for our reactions.

On the other hand, it should be noted that our systems do not meet the conditions favoring the reversibility of the deprotonation step: presence of a high concentration of strong acid and/or a very weakly nucleophilic species.

Experimental Section

^1H NMR spectra were taken on a JEOL JNM-C60ML spectrometer with Me_4Si as an internal standard. VPC analyses were performed on a GI Fractovap (C. Erba) chromatograph. Mass spectra were obtained on a Varian Mat 311 A spectrometer at 70 eV. All melting points are uncorrected.

Materials. Ceric ammonium nitrate $[(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6]$; Merck, 99% pure] was dried at 85 °C for 1 h. Solutions of cobaltic acetate in acetic acid were prepared by oxidation of cobaltous acetate (Erba, 99% pure) with ozone.²² The conversion of Co^{II} into Co^{III} was determined by iodometric titration to be $99 \pm 1\%$. *N*-Bromosuccinimide (Erba, 99% pure) was recrystallized from hot water, 2,2'-Azobis(isobutyronitrile) (Merck, 98% pure) was recrystallized from 50% aqueous ethanol. Hemimellitene (1, Backer, 98% pure) and 3,4,5-trimethylphenol (Aldrich) were commercial samples and were used as received. 2,4,6-Trimethylbenzyl alcohol, 2,3,5-trimethylbenzyl alcohol, 3,4,5-trimethylbenzyl alcohol, 2,6-dimethylbenzyl alcohol (4, R = H), and 2,3-dimethylbenzyl alcohol (5, R = H) were available from previous investigations.^{2,11} Isodurene was synthesized according to a known procedure.²³

1,3-Dimethyl-2-(trideuteriomethyl)-5-*tert*-butylbenzene (3) was prepared by the reaction of the Grignard reagent derived from 1,3-dimethyl-2-bromo-5-*tert*-butylbenzene with dimethyl- d_6 sulfate.²³ The crude product was distilled, and the fraction collected at 98–110 °C was purified by preparative VPC on a 2-m column packed with SE-30 (10%) operating at 130 °C. A solid, more than 99.8% pure by VPC, was obtained: mp 32–33 °C (lit.²⁴ mp 30–32 °C); NMR (CDCl_3) δ 6.8 (s, 2 H), 2.3 (s, 6 H), 1.35 (s, 9 H); mass spectrum, m/e 179 (M^+), 164, 136, 124.

Chemical Oxidations. The procedures used for oxidation with CAN and cobaltic acetate have been described.²

Bromination with NBS. Typically, the aromatic hydrocarbon (10 mmol) was reacted with NBS (3 mmol) in dry CCl_4 at 60 °C under nitrogen in the presence of AIBN (40 mg) for 20 h. The workup was as previously reported.⁹

Anodic Oxidations. The anodic experiments were performed in a jacketed microcell equipped with two parallel Pt foils (3 mm apart and each with 2-cm² effective electrode area) as electrodes. The cell contents was kept at 60.0 ± 0.2 °C by passing the vapor from a refluxing ethanol–acetone mixture through the jacket. An appropriate amount of the hydrocarbon (ca. 0.2 M) was dissolved in glacial acetic acid/supporting electrolyte (5.0 mL; see Table I). After thermal equilibration had been attained, the solution was electrolyzed at a constant current of 5.0 mA cm⁻² until 1.8 F mol⁻¹ of charge had been passed (AMEL 552 potentiostat, operated in the constant-current mode, in conjunction with a home-built coulometer). The reaction mixture was worked up by slowly pipetting it into a separating funnel containing saturated hydrogen carbonate solution (200 mL) covered by diethyl ether (20 mL). After three extractions with diethyl ether, the combined extracts were dried (magnesium sulfate) and concentrated by distilling off the ether through a 25-cm Vigreux column.

Determination of Isomeric Distributions. The isomeric distribution in the chemical and anodic oxidation (and in the NBS bromination) was determined by reducing (or hydrolyzing) the reaction products to the corresponding benzylic alcohols which were analyzed by VPC, according to a procedure previously described.² In the anodic and CAN-promoted oxidation of 3 the mass and NMR spectra of the benzylic alcohol 6 showed that this compound had not undergone any deuterium loss.

In the anodic oxidation of 1 and 2 and in the CAN-induced oxidation of 1, in the presence of AcOK, the reduced material showed more peaks (two in the case of 1 and one in the case of 2) than those corresponding to the expected benzylic alcohols. The two products observed in the reactions of 1 exhibited a mass spectrum (m/e 136 [M^+], 118) in accord with the structure of isomeric trimethylphenols. Moreover, one of them showed the same VPC retention time as 3,4,5-trimethylphenol. Similarly, the additional product from 2 showed a mass spectrum (m/e 192 [M^+], 177) in accord with the structure of 2,3,4-trimethyl-6-*tert*-butylphenol. Presumably these phenols derive from the reduction of ring-acetoxyated products.

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Registry No. 1, 526-73-8; 2, 98-23-7; 3, 83333-57-7; CAN, 16774-21-3; NBS, 128-08-5; $\text{Co}(\text{OAc})_3$, 917-69-1; D_2 , 7782-39-0.

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