

HYDROGEN ABSTRACTION FROM THE ISOMERIC CYMENES

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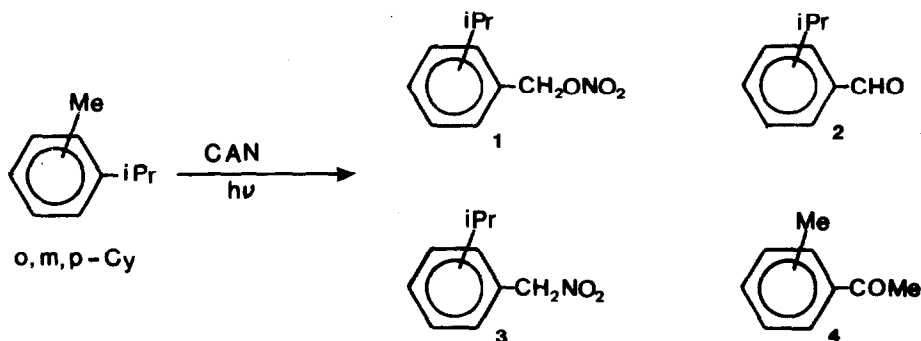
Abstract. The irradiation of cerium (IV) ammonium nitrate in the presence of ortho, meta and para cymene yields products from attack at the methyl group (the nitrates - these ones in 55 to 69% isolated yield-, the nitro derivatives, and the aldehydes) as well as at the isopropyl group (the acetophenones, not obtained from the ortho isomer), with minimal ring nitration. The formation of bibenzyls on irradiation with t-butyl peroxide of the same substrates is also studied. The mechanisms of the reactions with the NO_3^\bullet radical, a good electron acceptor, and with the alkoxy radical are contrasted and compared with photochemical hydrogen abstraction by $n\pi^*$ and, respectively, $\pi\pi^*$ excited states.

Hydrogen abstraction is one of the most common photochemical reaction, typical e.g. of the triplet state of ketones. This reaction involves either homolytic hydrogen transfer or electron transfer followed by proton transfer.¹ The role of electron transfer in the case of the photochemical α -hydrogen abstraction from alkyl aromatics has been extensively investigated by Wagner.^{2,3} A clue to the mechanism has been the intramolecular primary vs tertiary selectivity in p-cymene, homolytic cleavage being favoured at the tertiary position, in view of the lower bond dissociation energy, while the contrary selectivity obtains with the electron transfer mechanism. A similar result had been previously rationalized by Onopchenko (for metal ions oxidation) since proton loss from the radical cations requires that the C-H bond is aligned with the π orbitals, and thus is disfavoured in the predominant conformation with the isopropyl group perpendicular to the ring.⁴ According to Wagner this argument is not conclusive, because benzylic stabilization of the tertiary radical and interaction of the isopropyl group with the ortho hydrogens are opposed whatever is the mechanism, and he rather explains the observed difference on the basis of the better hyperconjugative stabilization by the methyl group of the positive charge in the radical cation, and thus of the favoured proton transfer from that position in the donor-acceptor complex.³

We recently investigated the photochemical hydrogen abstraction from the three isomeric cymenes (since the conformation of the donor is important, it was thought that *o*-Cy might behave differently) with various acceptors, viz. singlet excited 1,4-dicyanonaphthalene (DCN) and triplet trifluoroacetophenone (TFA) and benzophenone (BP) and found that indeed the geometry of the complex formed, as well as the degree of electron transfer, determine the selectivity in the abstraction.⁵ We were obviously interested in checking the applicability of this model to hydrogen abstraction by radicals, and our attention turned to the photochemical nitroxilation by cerium (IV) ammonium nitrate (CAN), a reaction demonstrated by Baclocchi to proceed via photogenerated NO_3^{\cdot} radicals and for which the intramolecular selectivity with some alkylbenzenes had been previously measured.^{6,7}

RESULTS AND DISCUSSION

The cymenes (*o*-, *m*-, and *p*-Cy) were irradiated in acetonitrile solution in the presence of CAN, and the progress of the reaction was followed by vpc and nmr. In every case, two moles of CAN were consumed for mole of cymene reacting and the detected products accounted for more than 85% of the substrate consumed, with isolated yield >70% (see below). The reaction was conveniently carried out in gram scale by irradiating a 0.04 M cymene solution in a well stirred reactor, in order to avoid deposition of a light-absorbing film of the polymeric reduced salt on the lamp well. Chromatographic separation with limited loss of the acid sensitive products was obtained by adding some triethylamine to the eluant.



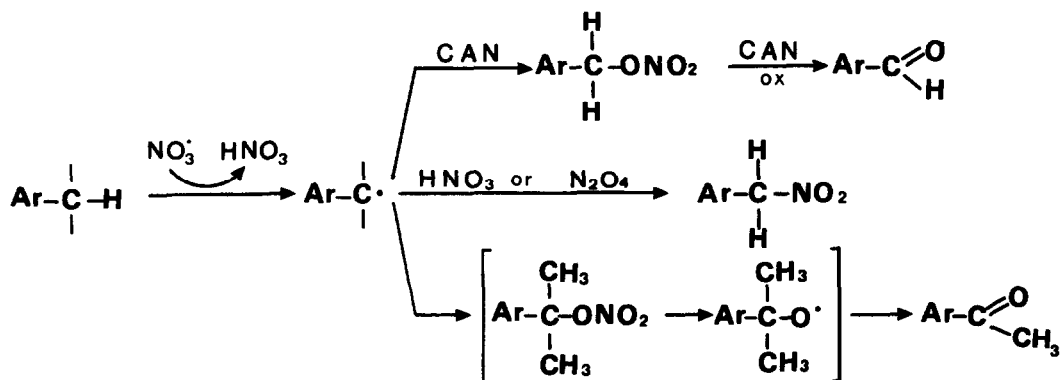
Five types of products are formed (see Table 1), viz the benzyl nitrates 1, the aldehydes 2, the nitrobenzyl derivatives 3, the acetophenones 4 (not obtained from *o*-Cy), and a small amount of ring-nitrated derivatives. These were recognized on the basis of

Table 1. Products from the irradiation of the Cymenes and CAN^a

| Substrate | Products (% Yield) |
|-----------|--|
| p-Cy | p-1(62), p-2(6), p-3(3), p-4(6), Ring-nitrated (1) |
| m-Cy | m-1(55), m-2(7), m-3(4), m-4(4), Ring-nitrated (1) |
| o-Cy | o-1(69), o-2(14), o-3(5) |

a. In acetonitrile at room temperature, isolated yield after chromatography.

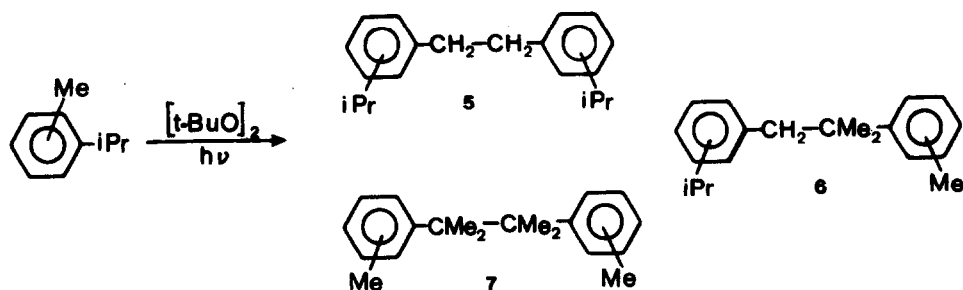
their spectroscopic and analytic properties (see Experimental). The stability of the products was checked in the case of m-Cy, and it was found that m-1, 2, and 3 do not suffer significant decomposition when separately irradiated (Pyrex-filtered light) for the time required for the reaction of m-Cy with CAN, nor are interconverted during work-up. However, irradiation of m-1 in the presence of CAN yields some m-2. Since the nitrates 1 are the main products from these reactions, it is possible that the aldehydes 2 are, at least in part, secondary products from them, but the other compounds isolated are clearly primary products. Indeed, these are the products expected from the reaction of the benzylic radical formed in the initial step. Thus, primary radicals react with CAN through a ligand-transfer reaction⁸ to yield the nitrates 1 or with N_2O_4 or HNO_3 formed as by products in the hydrogen abstraction to yield the nitro derivatives 3. The latter type of derivatives had not been previously detected in related reactions⁶⁻⁹ (their NMR spectrum is virtually superimposed to that of the nitrates), but their formation is not surprising in view of the fact that volatile products are not driven off by the slow argon flow during irradiation, nor are other potential scavengers of the benzylic radicals present.



The only isolated products which arise from attack at the iso-propyl group are the acetophenones p- and m-4. No methyl styrenes or dinitrates which could arise from them¹⁰ are detected under these conditions. Since material balance is good, it appears that at the relatively high CAN concentration used and in the absence of bases, tertiary radicals add to CAN rather than deprotonate, and the overcrowded nitrates cleave to the observed products.

Ring nitration accounts, as expected, for only a minimal part of the process.

As for intramolecular selectivity, attack at the primary position predominates largely with p- and m-Cy, and is the exclusive pathway with o-Cy. In order to clarify the basis for this selectivity, the cymenes were irradiated in the presence of t-butyl peroxide. Under this condition the bibenzyls 5-7 are formed from the statistical recombination of the benzylic radicals and the primary vs tertiary (P/T) ratio in the initial attack is determined. As it appears in Table 2, the P/T value is around 0.5 for p- and m-Cy, and is 12 with o-Cy. The corresponding P/T values for the reaction with CAN (i.e. the yield of 1+2+3 vs the yield of 4) are much higher. A different intramolecular selectivity for nitroxylation as compared to homolytic processes had been previously reported for some alkylbenzenes.^{6b} The P/T values observed in the formation of bibenzyls 5-7 by reaction with triplet BP and TFA (from ref. 5) are also reported in Table 2.



From these data, it appears that there is a close similarity between NO_3^{\cdot} and TFA^{3*} on one hand, and at $t\text{-BuO}^{\cdot}$ and BP^{3*} on the other. In the former case, electron transfer is a favoured pathway. For comparison, measured rate for electron transfer to NO_3^{\cdot} from the isomeric xylenes are in the range $1.7\text{--}5.5 \times 10^9 \text{ M}^{-1} \text{ s}^{-1}$,⁷ as expected from the known oxidizing properties of this radical.¹¹ The nitrate can be either a σ or a π -radical in matrix,¹² and it is not obvious which is its structure in solution, though a D_{3h} symmetry appears certain.¹³ Thus, though precise description is premature, there is good ground to

Table 2. Primary vs Tertiary Reactivity of the Cymenes

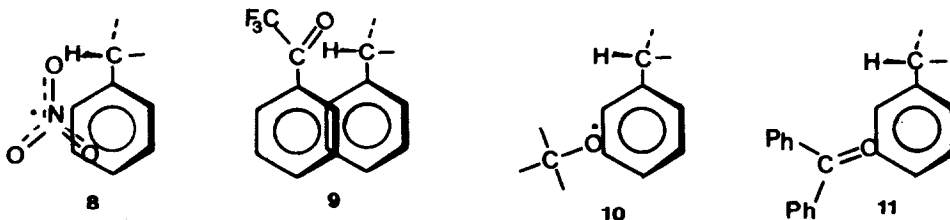
| | p-Cy | m-Cy | o-Cy |
|-------------------------------|------|------|------|
| NO_3^{\cdot} | 12 | 16 | high |
| tBuO^{\cdot} | 0,44 | 0,56 | 12 |
| $\text{CF}_3\text{COPh}^{3*}$ | 4,7 | 2,8 | 10 |
| $\text{Ph}_2\text{CO}^{3*}$ | 0,35 | 0,32 | 3.2 |

a. In acetonitrile at room temperature. Data for trifluoroacetophenone and benzophenone from ref 5.

suggest that NO_3^{\cdot} , like TFA^{3*} , forms a face to face complex with the cymenes (see formulae 8 and 9), in order to maximize the interaction between the π -orbital of the donor and the planar acceptor. Thus, the greater reactivity at the primary position results either from the better hyperconjugative stabilization of the charge by the methyl group as suggested by Wagner,³ or simply from the larger hindering exerted by the isopropyl group to the formation of such close-distance complexes. The effect is more conspicuous in the case of NO_3^{\cdot} , in view of the small dimension of the acceptor, and thus of the larger charge density in the complex.

In the latter case a localized radical (or the localized $n\pi^*$ triplet of benzophenone of marked radicalic character) approaches the cymene through a perpendicular pathway without forming a stabilized complex, and no significant charge transfer interaction (see formulae 10 and 11). Hence the observed preference for the thermodynamically easier reaction.

In the case of o-Cy, the barrier to rotation is increased with respect to the other isomers, and thus attainment of the favourable conformation (with the C-H bond parallel to the π -system) is more difficult for the isopropyl group. This precludes reaction at the isopropyl group in the former mechanism, and at any rate steric hindrance disfavours reactions also by the homolytic mechanism.



This work supports the role of the charge-transfer complexes and of their conformation in hydrogen abstraction from alkylaromatics, and suggest that, besides the long-known analogy between $n\pi^*$ excited states and alkoxy radicals, there is an analogy between planar electron-accepting radicals and $\pi\pi^*$ excited states (both triplet and singlet: the formation of benzyl-naphthalenes from the reaction of DCN with the cymenes gives a P/T value near to that observed with TFA).⁵ The intramolecular selectivity in various reactions of p-Cy, particularly in metal ions oxidation had been previously reported to give a non unequivocal indication for an electron-transfer mechanism.^{4,6,10,14} This is due at least in part to the role of subsequent steps in determining the yield of the final products. The present investigation involves relatively simple and well understood reactions, and has been carried out under mild conditions in inert medium. Therefore we feel that the product-deduced P/T ratio is near to the actual rate-ratio for primary vs tertiary hydrogen-abstraction in the initial step. Finally, the preparative value of photochemical side-chain nitroxylation by CAN is reiterated, on the basis of the fair isolated yield obtained.

EXPERIMENTAL

Materials. p-Cymene, cerium (IV) ammonium nitrate and t-butylperoxide were commercial samples. o- and m-Cymene were prepared and purified according to literature procedures. Spectrophotometric grade acetonitrile was used as received.

Photochemical Nitroxylation. A solution of 7 g (12.8 mM) $\text{Ce}(\text{NH}_4)_2(\text{NO}_3)_6$ and of 0.86 g (6.4 mM) cymene in 170 mL acetonitrile was flushed with argon for 15 min. and then irradiated by means of a Pyrex-filtered, 125 W medium-pressure mercury arc at 17°C. After 40 min the orange colour had disappeared and a white precipitate had formed. The solvent was evaporated and the residue treated with water and diethyl ether. The organic layer was dried and chromatographed on a silica gel column (20 g, 230-400 mesh) eluting with cyclohexane-ethyl acetate mixtures of increasing polarity, all containing 1% triethylamine. V.p.c. analysis of the reaction mixture was carried out on a wide bore (0.5 mm, 10 m length) phenyl-methyl polysiloxane (Hewlett-Packard HP17) column, at temperatures from 150 to 250°C.

Photochemical Reaction with t-Butylperoxide. A solution of 55 mg t-butylperoxide and 250 mg cymene in 3 mL acetonitrile was flushed with argon for 10 min and then irradiated by means

of three external phosphor-coated lamps (20 W, center of emission 320 nm) at 30°C. After 1 h the solution was analyzed on a capillary (25 m length) methylsilicone (Hewlett-Packard HP1) column, at temperatures from 160 to 250°C. The amount of bibenzyl formed was of 5-6 mg for p- and m-Cy, of 3 mg for o-Cy (measured against authentic samples).

Characterization of the photo-products. The products from the photochemical nitroxylation were separated as above and recognized on the basis of elementary analysis and/or exact-mass determination and of spectroscopic measurements. Key features are gathered in Table 3 (notice, e.g., the typical IR absorptions for compounds 1 and 3). The bibenzyl 5-7 were compared with the samples previously obtained.⁵

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Table 3. NMR and IR Data for Products 1-4.

| | iPr | NMR, δ in CDCl_3 | | | CHO | IR, neat, cm^{-1} |
|-----|------------|----------------------------------|---------------|----------|------|----------------------------|
| | | Me | CH_2 | aromatic | | |
| p-1 | 2.9, 1.25 | | 5.4 | 7.3 | | 1630, 1280 |
| p-2 | 3, 1.25 | | | 7.3-7.9 | 10 | 1690, 1600 |
| p-3 | 2.9, 1.25 | | 5.35 | 7.3 | | 1550, 1280 |
| p-4 | | 2.55, 2.4 | | 7.2-7.9 | | 1677, 1605 |
| m-1 | 2.95, 1.25 | | 5.4 | 7.3 | | 1630, 1280 |
| m-2 | 2.95, 1.27 | | | 7.2-7.8 | 10 | 1690, 1630 |
| m-3 | 2.95, 1.25 | | 5.4 | 7.3 | | 1550, 1280 |
| m-4 | | 2.6, 2.45 | | 7.2-7.8 | | 1680, 1600 |
| o-1 | 3.15, 1.25 | | 5.55 | 7.2-7.6 | | 1630, 1280 |
| o-2 | 4, 1.27 | | | 7.3-7.9 | 10.4 | 1690, 1600 |
| o-3 | 3.2, 1.25 | | 5.55 | 7.25-7.5 | | 1550, 1280 |

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