Nitroaromatic Compounds for Selective Photochemical Hydroxylation

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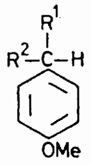
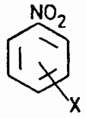
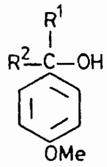
Summary Photoexcited nitrobenzene derivatives are shown efficiently to hydroxylate electron-rich aromatic substrates at the benzylic position.

RECENT investigations on the photochemical reduction[1–3] and nucleophilic substitution[1,2,4] of nitroaromatic compounds have demonstrated that both these transformations may be induced by electron transfer processes,[5] as nitroaromatic compounds have pronounced electron affinities. It thus occurred to us that photoexcited nitroaromatic compounds might well be employed for the oxidation of electron rich substrates, that may function as electron and proton donors simultaneously. This expectation was realized when photoexcited nitrobenzene and nitrobenzene derivatives were found selectively to oxidize anisole derivatives at benzylic positions.

Irradiation of 0·2 M nitrobenzene (**2a**), *o*-dinitrobenzene (**2b**), or *p*-dinitrobenzene (**2c**) in the presence of *p*-cyclohexylanisole (**1a**) (0·2 M) in acetonitrile or benzene (medium-pressure mercury lamp, Pyrex filter) afforded the corresponding benzylic alcohol (**3a**), which was isolated by chromatography of the crude reaction mixture on silica gel. *p*-Propylanisole (**1b**), *p*-methoxytoluene (**1c**), and methoxytetralin (**5**) were also oxidized to the corresponding alcohols [(**3b**), (**3c**), and (**6**), respectively] and ketones [(**4a**), (**4b**), and (**7**), respectively] upon irradiation with the nitrobenzenes (**2**). Poor electron donors such as cyclohexylbenzene or *p*-acetoxycyclohexylbenzene reacted only very slowly. The detailed reaction conditions, chemical yields, and quantum yields are summarized in the Table.


(**1**)
a; $R^1R^2 = -[CH_2]_5$
b; $R^1 = Et, R^2 = H$
c; $R^1 = R^2 = H$


(**2**)
a; X = H
b; X = NO_2-*o*
c; X = NO_2-*p*


(**3**)
a; $R^1R^2 = -[CH_2]_5$
b; $R^1 = Et, R^2 = H$
c; $R^1 = R^2 = H$


(**4**)
a; R = Et
b; R = H

CIDNP studies[6] provided direct evidence for the intermediacy of a radical pair in this process. Irradiation of *p*-methoxytoluene (**1c**) (0·2 M) and *o*-dinitrobenzene (**2b**) (0·2 M) in CD_3CN solution at 283 K gave rise to a net E-effect for the benzylic protons, $MeOC_6H_4Me$, and a net A-effect for the aromatic protons, $MeOC_6\mathit{H}_4Me$, in the starting material (**1c**), but a net A-effect for the benzylic protons, $MeOC_6H_4C\mathit{H}_2OH$, in the alcohol (**3c**), accompanied by a weak E-effect for the aromatic protons in *o*-dinitrobenzene (**2b**).‡ Assuming that the triplet state of dinitrobenzene (**2b**) is the precursor of the radical pair, the net A-effect $\Gamma_{\mathrm{net}} = \mu \cdot \epsilon \cdot \Delta g \cdot A_1 = + \cdot + \cdot - \cdot - = +$, for the benzylic protons in the alcohol (**3c**) suggests that (**3c**) is preferentially formed by recombination within the original cage. The net E-effect for the benzylic protons in the starting material (**1c**) indicates the occurrence of a reversible hydrogen transfer between the nitroaromatic compound

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† The measurements were carried out on a Bruker HFX-10 Mc spectrometer, equipped with an optical irradiation probe. Light from a 2500 Hanovia mercury-xenon lamp was passed through a quartz water cell and led to the sample through a 5 mm o.d., 50 cm long quartz light guide.

‡ In some cases E polarization of the methoxy protons of the substrates could also be observed.

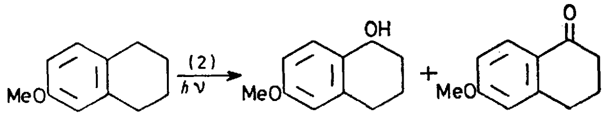
TABLE

Substrate (0·2 M)	Nitroaromatic compound (0·2 M)	Solvent additive	Photoproducts (chemical yield)[a]			Relative quantum yield for consumption of substrate[b]
			Alcohol	Ketone/aldehyde	Adduct[c]	
(1a)	**(2a)**	MeCN	**(3a)**(13)			
(1a)	**(2b)**	”	**(3a)**(65)			1·0
(1a)	**(2b)**	MeCN–2 M Pr^iOH				<0·12
(1a)	**(2b)**	MeCN–1 M H_2SO_4				<0·10
(1a)	**(2b)**	C_6H_6	**(3a)**(65)			0·75
(1a)	**(2c)**	MeCN	**(3a)**(74)			
(1b)	**(2a)**	”	**(3b)**(10)	**(4a)**(10)	(10)	
(1b)	**(2c)**	”	**(3b)**(15)	**(4a)**(10)		
(1c)	**(2b)**	”	**(3c)**(10)	**(4b)**(25)		
(1c)	**(2c)**	”	**(3c)**(10)	**(4b)**(25)		
(5)	**(2a)**	”	**(6)**(20)	**(7)**(25)		
(5)	**(2b)**	”	**(6)**(20)	**(7)**(55)	**(15)**	
(5)	**(2c)**	”	**(6)**(17)	**(7)**(17)	**(20)**	
Cyclohexylbenzene	**(2b)**	”				0·15
p-Acetoxycyclohexylbenzene	**(2b)**	”				<0·10

[a] All products were identified by comparison with authentic samples. The yields given are of isolated compounds relative to consumed starting material. The yields of the ketonic products relative to the alcoholic products increase upon prolonged irradiation. [b] The irradiations were performed on a merry-go-round apparatus; excitation wavelength 313 nm; the solutions were saturated with Argon prior to irradiation. The conversion of the substrates was determined by g.l.c. analysis (Carbowax 20M 10%, on Chromosorb P, 1/8 in × 3 ft; 150 °C). [c] These compounds are addition products of the reduced nitroaromatic components and the substrates; their detailed structures have not yet been established.

and the anisole derivative (**1c**) outside the original cage ($\Gamma_{\text{net}} = \mu\cdot\epsilon\cdot\Delta g\cdot A_i = +\cdot-\cdot-\cdot- = -$).

Analogous CIDNP effects were also observed upon irradiation of *o*-dinitrobenzene (**2b**) in the presence of methoxybenzene derivatives (**1a**) or (**1b**), and methoxytetralin (**5**), while no effects were observed upon irradiation in the presence of toluene, cyclohexylbenzene, or tetralin, which are poor electron donors and do not undergo photo-oxidation (Table).

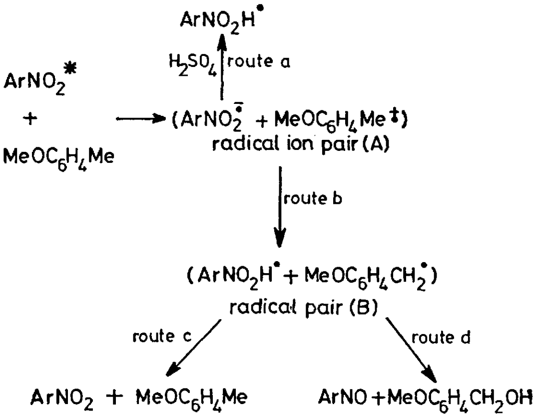


(5) (6) (7)

+ Adduct

The concurrent quenching of both photoreaction and CIDNP effects upon addition of either Pr^iOH or H_2SO_4 confirmed that both phenomena are related processes. The efficiency of the photoreaction was thus drastically reduced in the presence of 2 M Pr^iOH (Table), as were all the polarizations. In the presence of 1% H_2SO_4, the photo-oxidation was entirely quenched as were the polarizations of the substrate (**1c**), while the CIDNP effect of the nitroaromatic component was substantially enhanced.

The quenching with Pr^iOH, a chemical triplet quencher of nitrobenzene,[3a] suggests the involvement of nitrobenzene triplets in the photo-oxidation, while its restriction to electron-rich substrates indicates the occurrence of an electron transfer§ step. The intermediacy of radical ions (A) (Scheme) is confirmed by the effect of acid which quenches the photo-oxidation, while enhancing the CIDNP effect of the nitroaromaticc omponent.¶ The latter observation is attributed to protonation of the intermediate radical anion $ArNO_2^{\cdot-}$ by the acid to give the radical $ArNO_2H^{\cdot}$



SCHEME

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§ Electron transfer to excited nitrobenzene in acetonitrile is only slightly endothermic, whereas transfer to excited dinitrobenzene is exothermic and is thus energetically feasible.

¶ Protonation of either methoxybenzenes or nitrobenzenes in 0·1 M H_2SO_4 is negligible and cannot therefore account for the observed quenching. H_0 of 0·1 M aqueous H_2SO_4 is +0·83 (M.A. Paul and F. A. Long, *Chem. Rev.*, 1957, **57**, 1) the pK_a's of $C_6H_6OMe^+$ and $PhNO_2H^+$ are −6·5 (J. L. Longridge and F. A. Long, *J. Amer. Chem. Soc.*, 1967, **89**, 1292) and −11·3 (J. C. D. Brand, *J. Chem. Soc.*, 1950, 997), respectively. Ignoring solvent effects, the fraction of protonated anisole would be *ca.* 10^{-7} and of protonated nitrobenzene *ca.* 10^{-12}. Since excitation of nitrobenzene to either a n–π^* or π–π^* triplet would not enhance the electron density around the nitro-group, triplet nitrobenzene would not be a stronger base than ground state nitrobenzene and will therefore not undergo significant protonation.

(Scheme, route a), which undergoes degenerate hydrogen transfer.[7] In the absence of acid the radical anion $ArNO_2^{\cdot-}$ is protonated by the radical cation $MeOC_6H_4Me^{\cdot+}$ to give the radical pair (B) (Scheme). The latter may either collapse to the photoproducts (route d),** or regenerate the starting materials (*via* hydrogen transfer, route c), as indicated by the observed polarizations of the product (enhanced absorption, A) and the substrate (emission, E).

This nitrobenzene induced photo-oxidation reaction thus represents a mild hydroxylation method that may well be expanded to other electron-rich substrates and may find application in the field of natural product chemistry and related areas.

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** Preliminary labelling experiments using oxygen-18 labelled nitrobenzene *vs.* oxygen-18 labelled molecular oxygen established that there is a competition between oxygen incorporation in the products from the nitroaromatic chromophore and molecular oxygen.

[1] D. O. Doepp, *Topics Current Chem.*, 1975, **55**, 49.

[2] H. A. Morrison in 'The Chemistry of the Nitro and Nitroso group,' part I, ed. H. Feuer, Ch. 4, Interscience, New York, 1969.

[3] (a) R. Hurley and A. C. Testa, *J. Amer. Chem. Soc.*, 1966, **88**, 4330; (b) 1968, **90**, 7044; J. A. Barltrop and N. J. Bunce, *J. Chem. Soc. (C)*, 1968, 1467; J. W. Weller and G. A. Hamilton, *Chem. Comm.*, 1970, 1390; D. Doepp, *ibid.*, 1968, 1284; A. Patchornik, B. Amit, and R. B. Woodward, *J. Amer. Chem. Soc.*, 1970, **92**, 6333; U. Zehavi and A. Patchornik, *J. Org. Chem.*, 1972, **37**, 2281; D. Doepp and K. H. Sailer, *Chem. Ber.*, 1975, **108**, 3483; M. Takami, T. Matsuura, and I. Saito, *Tetrahedron Letters*, 1974, 661.

[4] E. Havinga, R. O. DeJongh, and M. E. Kronenberg, *Helv. Chim. Acta*, 1967, **50**, 2550; R. L. Letsinger and R. R. Hautala, *Tetrahedron Letters*, 1969, 4205; K. E. Steller and R. L. Letsinger, *J. Org. Chem.*, 1970, **35**, 308; J. Cornelisse, *Pure Appl. Chem.*, 1975, **41**, (4), 433, and references therein.

[5] G. P. DeGunst and E. Havinga, *Tetrahedron*, 1973, **29**, 2167; G. C. Wubbels, J. W. Jordan, and N. S. Mills, *J. Amer. Chem. Soc.*, 1973, **95**, 1281; A. Cu and A. C. Testa, *ibid.*, 1974, **96**, 1963; A. N. Frolov, N. A. Kutznetsova, A. V. Eltsov, and I. N. Rtishchev, *J. Org. Chem. (U.S.S.R.)*, 1973, **9**, 988.

[6] R. Kaptein, *Chem. Comm.*, 1971, 732.

[7] Since the presence of acid prevents back dissociation of the radical to the radical anion ($ArNO_2H^{\cdot} \nrightarrow ArNO^{\cdot-} + H^+$), the nuclear polarization of the nitroaromatic species is higher in the presence of acid than in its absence: K. A. Muszkat, *Chem. Phys. Letters*, 1977, **49**, 583.