J. Org. Chem. 1993, 58, 5628–5631

Thiol Anions in Nucleophilic Aromatic Substitution Reactions with Activated Aryl Halides. Attack on Carbon vs Attack on Halogen

Stefano Montanari, Cristina Paradisi,* and Gianfranco Scorrano

Centro Studio Meccanismi di Reazioni Organiche del CNR, Dipartimento di Chimica Organica,
Via Marzolo 1, 35131 Padova, Italy

Received April 26, 1993[•]

The reaction of *o*-iodonitrobenzene with thiol anions (RSNa, R = Me, 2-Pr, *t*-Bu) in 2-propanol solution produces the *o*-nitrophenyl thioether and nitrobenzene in relative proportions and with rates which depend on R. The results of kinetic analysis and of D-incorporation experiments are inconsistent with a radical chain mechanism as proposed earlier for the alkoxide-promoted hydro-de-halogenation of aryl halides. The data clearly indicate the involvement of a carbanionic intermediate (the *o*-nitrophenyl anion) and are consistent with a stepwise mechanism in which the first step is nucleophilic attack on iodine to form a sulphenyl halide and the *o*-nitrophenyl anion (a *halogenophilic* reaction). In contrast, the reaction of the other *o*-halonitrobenzenes (F, Cl, Br) produces exclusively the product of alkylthio-de-halogenation according to the addition/elimination (S_NAr) mechanism. The fact that in these systems the reactivity of thiol anions results from their ability as bielectronic nucleophiles rather than as reducing agents is discussed.

Aryl halides in which the halogen substituent is *ortho* or *para* to an electron-withdrawing group are activated for nucleophilic aromatic substitutions via the addition/elimination mechanism (S_NAr).[1] The reactions of *o*- and *p*-nitroaryl halides with various anions, including alkoxide and thiolate ions, are representative examples of this mechanism.[1] Thus, the 2-propanol reaction of *o*- and *p*-chloronitrobenzene with various thiol anions RS^- (R = Me, 2-Pr, *t*-Bu, Ph) leads to the expected products of *ipso*-substitution, the *o*- and *p*-nitrophenyl thioethers, and obeys the mechanistic criteria for the S_NAr process based on kinetic orders (first kinetic order in both reagents), leaving group effect (F ≫ Cl), positional effect (lack of reactivity of the *meta* isomer), and insensitivity to the presence of radical traps.[2]

Thiol anions are notoriously powerful nucleophiles but also strong reducing agents owing to the facile $RS^- \rightarrow RS^\bullet$ transformation.[3] Thus, the chance of radical processes is always high when carrying out reactions of thiol anions with oxidants like nitrocompounds.[4] The possibility for the occurrence of nitro reduction, a process which in alkaline 2-propanol solutions involves the substrate radical anion as a reaction intermediate,[5] was therefore carefully examined in the aforementioned investigation.[2] However, with the exception of a minor component in the reactions with *t*-BuSNa, reduction did not interfere with the nucleophilic aromatic substitution on *o*- and *p*-chloronitrobenzene.[2] On the other hand, when *m*-chloronitrobenzene, a substrate not activated for the S_NAr reaction, was treated with deoxygenated 2-propanol solutions of 2-propanthiolate reduction of the nitro function occurred indeed quite readily.[2] Interestingly, the rates of nucleophilic substitution (alkylthio-de-halogenation) for *p*-chloronitrobenzene and of nitro reduction for *m*-chloronitrobenzene are very similar, the pseudo-first order rate constants for the reactions with 2-PrSNa being 2.41×10^{-4} s^{-1} and 2.25×10^{-4} s^{-1}, respectively.[2]

Additional evidence for the occurrence of radical anions in the investigated systems (RSNa/2-propanol/nitroarene) was sought in experiments involving *o*-iodonitrobenzene,[2] the radical anion of which is known to undergo rapid fragmentation to 2-nitrophenyl radical and I^-.[6] The recovery of considerable amounts of nitrobenzene from the reaction of *o*-iodonitrobenzene with 2-PrSNa[2] was consistent with the proposal that radical anions are formed in these systems: the 2-nitrophenyl radical is indeed expected to abstract an $H^\bullet$ from the good hydrogen donors 2-propanol[7] and/or ionized 2-propanethiol.[8] Indeed nitrobenzene is produced in quantitative yield from the reaction of *o*-iodonitrobenzene with 2-PrOK[9] according to the established radical chain mechanism for base-induced hydro-de-halogenation.[10] Interestingly, a significant amount of the product of *ipso*-substitution was also obtained, in addition to nitrobenzene, from the reaction of *o*-iodonitrobenzene with 2-PrSNa.[2]

In order to clarify how the product of *ipso*-substitution is formed and to define the mechanism and the scope of the reductive dehalogenation process the reactions of *o*-iodo- and *o*-bromonitrobenzene with a family of thiol anions were investigated by means of product and kinetic analysis as well as D-labeling experiments. We report in this paper experimental data which are inconsistent with

---

[•] Abstract published in *Advance ACS Abstracts*, September 1, 1993.

[1] (a) Miller, J. In *Aromatic Nucleophilic Substitution*; Eaborn, C., Chapman, N. B., Eds.; Elsevier: Amsterdam, 1968. (b) de Boer, Th. J.; Dirkx, I. P. In *The Chemistry of the Nitro and Nitroso Groups*; Feuer, H., Ed.; Interscience: New York, 1969; Part 1, Chapter 8. (c) Paradisi, C. In *Comprehensive Organic Synthesis*; Trost, B., Ed.; Pergamon Press: New York, 1991; Vol. 4, Chapter 2.1. (d) Terrier, F. *Nucleophilic Aromatic Displacement—The Influence of the Nitro Group*; H. Feuer, Ed.; VCH Publishers: New York, 1991.

[2] Montanari, S.; Paradisi, C.; Scorrano, G. *J. Org. Chem.* **1991**, *56*, 4274.

[3] Surdhar P. S.; Armstrong, D. A. *J. Phys. Chem.*, **1986**, *90*, 5915 and literature cited therein.

[4] (a) Smentowskj, F. J. *J. Am. Chem. Soc.* **1963**, *85*, 3036. (b) Hodgson, H. H.; Handley, F. W. *J. Soc. Chem. Ind., London* **1927**, *46*, 435.

[5] Paradisi, C.; Scorrano, G. Nucleophilicity. *Adv. Chem. Ser.* **1987**, *215*, 339.

[6] (a) Danen, W. C.; Kensler, T. T.; Lawless, J. G.; Marcus, M. P.; Hawley, M. D. *J. Phys. Chem.* **1969**, *73*, 4389. (b) Nelson, R. F.; Carpenter, A. K.; Seo, E. T. *J. Electrochem. Soc.* **1973**, *120*, 206. (c) Bunnett, J. F.; Mitchel, E.; Galli, C. *Tetrahedron* **1985**, *41*, 4119.

[7] (a) Adams, G. E.; Willson, R. *Trans. Faraday Soc.* **1969**, *65*, 2981. (b) Neta, P. *Adv. Phys. Org. Chem.* **1976**, *12*, 223.

[8] (a) Kornblum, N.; Carlson, S. C.; Smith, R. G. *J. Am. Chem. Soc.* **1978**, *100*, 289. (b) Davies, A. G.; Neville, A. G. *J. Chem. Soc., Perkin Trans. 2* **1992**, 171.

[9] Arca, V.; Paradisi, C.; Scorrano, G. *J. Org. Chem.* **1990**, *55*, 3617.

[10] Bunnett, J. F. *Acc. Chem. Res.* **1992**, *25*, 2.

0022-3263/93/1958-5628$04.00/0

Table I. Kinetic and Product Data for the Reaction of 2-Iodo- and 2-Bromonitrobenzene (9.4×10^{-3} M) with RSNa (9.4×10^{-2} M) in 2-Propanol at 40 °C under Ar

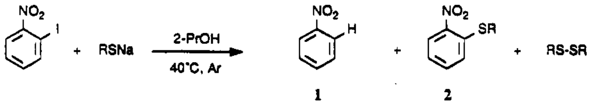
entry	2-$XC_6H_4NO_2$, X	RSNa, R	solvent	$10^4 \times k_\psi$ s^{-1}	k^H/k^D [a]	products, % yield[b]	
						$LC_6H_4NO_2$ (1)	2-$RSC_6H_4NO_2$ (2)
1	I	Me	2-PrOH	17.0		L = H: 16	64
2	I	2-Pr	2-PrOH	7.4	1.37	L = H: 40	60
3	I	2-Pr	2-PrOD	5.4		L = D: 14	81
4	I	*t*-Bu	2-PrOH	4.6	1.07	L = H: 90	10
5	I	*t*-Bu	2-PrOD	4.3		L = D: 75	20
6	I	*t*-Bu	2-PrOH/2-PrOD 50:50 v/v	–		L = H: 61.7[c] L = D: 19.3[c]	12
7	Br	2-Pr	2-PrOH	2.6			100
8	Br	*t*-Bu	2-PrOH	0.67			100

[a] Calculated as the ratio of the observed rate constants, k_ψ, in 2-PrOH and 2-PrOD, respectively. [b] Determined by quantitative GC and GC-MS analysis. [c] Calculated from the overall % yield of nitrobenzene (81% by quantitative GC analysis) and the ratio H-$C_6H_4NO_2$/D-$C_6H_4NO_2$ (3.2 by mass analysis).

the proposal that the alkylthio-promoted reduction of *o*-iodonitrobenzene proceeds via a radical chain mechanism.

Results and Discussion

The reaction of *o*-iodonitrobenzene with a 10-fold excess of RSNa (R = Me, 2-Pr, *t*-Bu) in degassed 2-propanol solutions gives two products, nitrobenzene *via* reduction of the C–I bond and the product of substitution, the *o*-nitrophenyl alkyl thioether (eq 1). The relative proportions of the two products as well as the reaction rate depend on R.



(1)

In all cases examined the decay of the substrate concentration followed a first-order exponential profile from which pseudo first-order rate constants (k_ψ) were obtained. The results of product and kinetic studies are summarized in Table I (entries 1, 2, and 4).

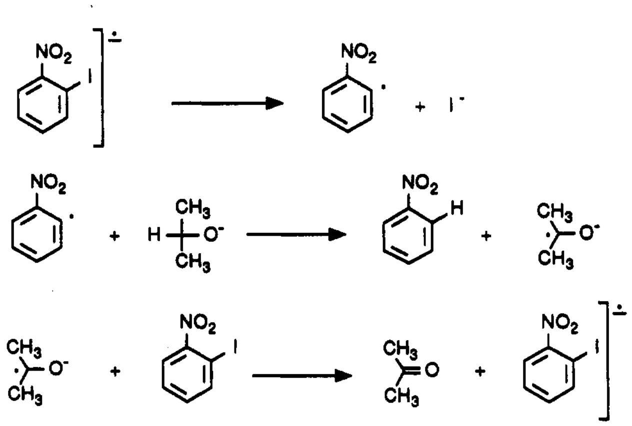
In contrast to the iodo compound, *o*-bromonitrobenzene does not undergo reduction of the carbon–halogen bond to any detectable extent (entries 7 and 8 of Table I).

The kinetic behavior of the reactions represented by eq 1 was unexpected since we had anticipated that the RS$^-$-induced reduction to nitrobenzene would proceed according to the same mechanism as proposed earlier for the alkoxide-induced reaction,[9] the radical chain hydrodehalogenation of Scheme I.[10]

Consistently with the mechanism of Scheme I, the 2-PrO$^-$ induced reaction indeed produced a characteristic concentration *vs* time plot in the shape of a sigmoid,[9] typical of a chain process involving an initiation step followed by a propagation sequence in which a product forms, specifically $(CH_3)_2CO^{\bullet -}$, which acts as chain propagator.[10] The kinetics clearly indicate that the reaction of *o*-iodonitrobenzene with thiol anions proceeds according to a different mechanism. Further evidence to substantiate the mechanistic differentiation between the RS$^-$- and the RO$^-$-induced reactions was sought in labeling experiments. When the reaction with 2-PrSNa was performed in deuterated solvent (2-propanol-OD) the recovered nitrobenzene was found by mass analysis to have the isotopic composition $C_6H_4DNO_2$, corresponding to 100%-deuterium incorporation (entry 3 of Table I). An analogous result was obtained for the reaction with *t*-BuSNa (entry 5). Control experiments indicated that no H/D exhange occurs to any detectable extent when nitrobenzene is subjected to the reaction conditions (*t*-BuSNa, 2-propanol-OD at 40 °C) for over 26 h. The D-incorporation test was also applied to the alkoxide-promoted reduction.[9] When *o*-iodonitrobenzene (0.05 M) was treated with 2-PrOK (0.5 M) in degassed 2-PrOD at 75 °C, nitrobenzene $C_6H_5NO_2$ was produced with no D-incorporation, in agreement with the proposal[9] that reduction involves, in this case, H$^\cdot$-abstraction from C_α of the alkoxide. Notably, the mechanism of the reaction with the thioanions apparently is not affected by the temperature: when the experiment reported as entry 5 in Table I was repeated at 75 °C, the recovered nitrobenzene had, as before, the composition $C_6H_4DNO_2$. These results, therefore, indicate that the RS$^-$-induced reduction of the C–I bond in *o*-iodonitrobenzene involves transfer of a hydroxylic proton and suggest the involvement of a species with carbanionic character at C-2 of the benzene ring. In view of the known ability of the NO_2 group to stabilize by inductive effect adjacent negative charges, reduction of the C–I bond can conceivably occur via the intermediacy of the *o*-nitrophenyl anion, possibly in some specifically solvated form.

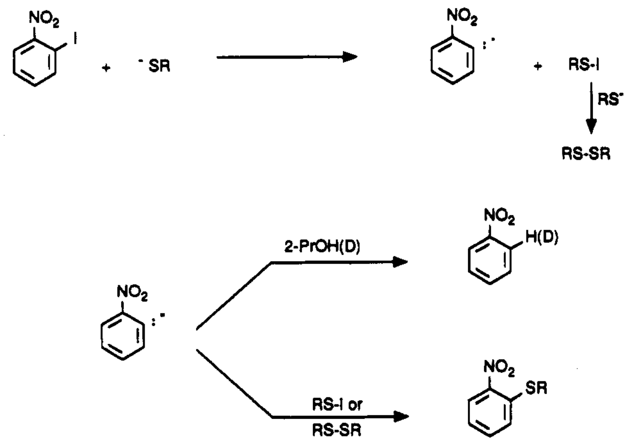
Scheme I

- initiation steps



- termination steps

Scheme II



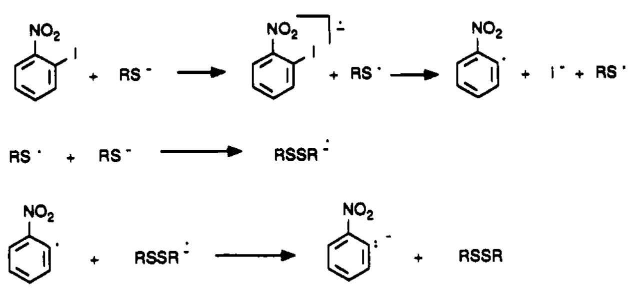
How is the carbanion formed? Since sulfur anions are capable of attacking nucleophilically a halogen substituent, I, Br, or Cl,[11a,b] the *o*-nitrophenyl anion can originate as sketched in the first part of Scheme II and, possibly, act as a common intermediate for both reaction products.

In the first step the nucleophile attacks the iodo substituent (a *halogenophilic* reaction)[11c] to produce an alkyl sulphenyl iodide and the *o*-nitrophenyl anion which undergoes proton transfer from the solvent to form nitrobenzene. In addition, "RS^+" transfer could take place[11a] via nucleophilic attack by the carbanion on the electrophilic sulfur of RSI or, possibly, of RSSR (disulfides are always observed among the products of these reactions, eq 1), produced from reaction of RSI with the thiol anion used in large excess.[12] The different proportions of reduction *vs* substitution observed with the various thiol anions (see Table I, entries 1,2, and 4) can be attributed to the different reactivity of the electrophiles RSX (X = I, SR), reasonably decreasing in the order Me > 2-Pr > *t*-Bu. Alternatively, the substitution product, **2**, could arise *via* an independent competing S_NAr reaction. Under this hypothesis, rate constants for the substitution reaction (k_{sub}) were calculated, from the rate and product data of Table I, as the product of the observed rate constants times the % yield of the substitution product ($k_{sub} = k_\psi \times \%\mathbf{2}/100$). The following values were obtained, $k_{sub} \times 10^4\ s^{-1}$ (RS^-): 0.46 (t-BuS^-), 4.4 (2-PrS^-), and 10.9 (MeS^-). These values compare reasonably well with the corresponding data for the S_NAr reaction of *o*-chloronitrobenzene, $k_{sub} \times 10^4\ s^{-1}$ (RS^-): 0.38 (t-BuS^-), 2.3 (2-PrS^-), and 7.8 (MeS^-).[2]

A radical-involving path leading to the anion was also considered. This alternative mechanism, sketched in Scheme III, consists of an electron-transfer step to form the substrate radical anion, fragmentation of this species to I^- and the *o*-nitrophenyl radical, and fast reduction of this radical to the corresponding anion.

The key step involving reduction of the *o*-nitrophenyl radical is not in disagreement with the known reduction potentials of some halo-substituted phenyl radicals which are considerably less negative than those of the corresponding neutrals.[13] However, this mechanism appears unlikely in view of the known reactivity of the *o*-nitrophenyl radical, which in 2-propanol does not undergo reduction to the anion, as discussed earlier, but rather H·-transfer from 2-propoxide.[9] Primary and secondary thiol anions are also powerful H·-donors (from C_α).[8] Thus, reduction of the presumed intermediate *o*-nitrophenyl radical should proceed also in this case *via* H·-transfer and not *via* electron transfer to the anion. Since the anion is indeed formed, the mechanism of Scheme III appears not very plausible.

Scheme III



The observed isotope effects are not in contrast with the mechanism outlined in Scheme II. The product distribution obtained in the mixed solvent (entry 6 and footnote *c*) of Table I) yields an isotope discrimination, which is a measure of the primary isotope effect, of 3.2. This rather large value could imply that the anion is sufficiently long-lived to discriminate between isotopic solvent molecules.[14,15] The solvent isotope effects on the observed rate constant, reported as k^H/k^D in Table I, are inclusive of both primary and secondary isotope effects. By dividing the primary isotope effect of 3.2 by the k^H/k^D value of 1.07, an inverse secondary isotope effect ($k^{2\text{-PrOD}}/k^{2\text{-PrOH}}$) of 2.99 is obtained for the reaction of t-BuS^-. The secondary isotope effect may be ascribed to loss of the solvation of the anion, but cannot be interpreted in greater detail since the maximum secondary isotope for the t-BuS^- anion in 2-propanol is not known (a value of 2.68 is reported for MeO^- in methanol).[16] The possibility cannot be excluded that the reaction is not stepwise and that the carbanion intermediate is not formed because of the existence of a concerted path, of lower energy, involving preassociation as discussed by Jencks.[17] This distinction, however, is beyond the focus of the present investigation since, in any case, the reaction studied is unambiguously characterized as one involving high carbanion character on C-2 of the benzene ring and in this respect it is clearly differentiated from the corresponding alkoxide promoted radical process.[9]

The reactivity scale found for the reaction of *o*-iodonitrobenzene follows qualitatively the same order as observed for the S_NAr reaction of *o*-chloronitrobenzene[2] (MeS^- > 2-PrS^-> t-BuS^-). The relative rates as a function of R are, however, significantly different for the two reactions, namely 20.3 (R = Me), 6.0 (R = 2-Pr), and 1.00 (R = *t*-Bu, taken as reference) for the reaction of the *o*-Cl compound[2] and 3.7 (R = Me), 1.6 (R = 2-Pr), and 1.00 (R = *t*-Bu, again

---

[11] (a) Grossert, J. S.; Dubey, P. K.; Elwood, T. *Can. J. Chem.* **1985**, *63*, 1263. (b) Galli, R. *J. Org. Chem.* **1987**, *52*, 5349. (c) Zefirov, N. S.; Makhon'kov, D. I. *Chem. Rev.* **1982**, *82*, 615.

[12] Capozzi, G.; Modena, G.; Pasquato, L. In *The Chemistry of Sulphenic Acids and their Derivatives*; Patai, S., Ed.; Interscience, J. Wiley & Sons: Chichester, 1990; Chapter 10.

[13] (a) Jaun, B.; Breslow, R. *J. Am. Chem. Soc.*, **1980**, *102*, 5741. (b) Andrieux, C. P.; Badoz-Lambling, J.; Combellas, C.; Lacombe, D.; Savéant, J.-M.; Thiebault, A.; Zann, D. *J. Am. Chem. Soc.*, **1987**, *109*, 1518.

[14] (a) Alexander, R.; Asomaning, W. A.; Eaborn, C.; Jenkins, I. D.; Walton, D. R. M. *J. Chem. Soc., Perkin Trans. 2* **1974**, 490. (b) Macciantelli, D.; Seconi, G.; Eaborn, C. *J. Chem. Soc., Perkin Trans. 2* **1978**, 834.

[15] Kresge, A. J.; More O'Ferrall, R. A.; Powell, M. F. In *Isotopes in Organic Chemistry. Vol. 7. Secondary and Solvent Isotope Effects*; Buncel, E., Lee, C. C., Eds.; Elsevier: Amsterdam, 1987; Chapter 4.

[16] More O'Ferrall, R. A. *J. Chem. Soc., Chem. Commun.* **1969**, 114.

[17] Thibblin, A.; Jencks, W. P. *J. Am. Chem. Soc.* **1979**, *101*, 4963.

taken as reference) for that of the *o*-I compound.[18] A much more compressed scale is obtained for the reaction of *o*-iodonitrobenzene, owing principally to the enhanced reactivity of the *t*-BuS$^-$ anion (k_ψ is 4.6×10^{-4} s^{-1} *vs* a value of 0.383×10^{-4} s^{-1} for the $\mathrm{S_NAr}$ reaction of *o*-chloronitrobenzene[2]). This behavior is consistent with the proposed attack on iodine rather than on the more sterically hindered ring carbon. Apparently this *halogenophilic* reaction is specific of the iodo compound since *o*-bromonitrobenzene gives exclusively the products of *ipso*-substitution with rates very similar to those measured for *o*-chloronitrobenzene.[2]

Precedents for the rather unusual reactivity, here reported, of activated aryl halides toward anionic nucleophiles are unknown to the best of our knowledge. A famous case of *halogenophilic* reaction on aromatic halides is the "halogen dance".[19] This reaction, however, involves substrates, like 1,3,5-tribromobenzene, which are much less activated for nucleophilic attack on ring-carbons than nitro-substituted benzenes are. An apparently related case to the one discussed here is the reaction of 2-iodobenzothiazole with aliphatic and aromatic thiol anions which gives both the products of iodine *ipso*-substitution and of reduction.[20] However, in contrast to what we find, reduction of the C–I bond is subject to acid catalysis and the reaction occurs more readily with the neutral thiols.[20]

Our studies on the reactivity of thiol anions toward halonitrobenzenes in 2-propanol emphasize the strong nucleophilic character of these species. Thus, in contrast to what was found with the 2-propoxide ion, the reaction of thiol anions with *o*- and *p*-halonitrobenzenes results from their reactivity as bielectronic nucleophiles rather than as one-electron reducing agents even, as the results of the present investigation seem to indicate, in cases when products of reduction are formed. This conclusion appears rather at odds with current trends. In the last several years an interest has developed in reexamining "established" polar mechanisms within the framework of the electron transfer theory.[21] Thus, the proposal has been advanced that, in $\mathrm{S_NAr}$ reactions, the Meisenheimer complex forms by radical coupling of the products of an initial electron transfer step between the two reactants, the nucleophile and the aromatic substrate.[22] The occurrence of such a two-step sequence taking place within the solvent cage and with no possibility of intercepting the radical intermediates is not of great significance from the point of view of differentiating radical from non-radical reaction pathways. More relevant are reports which describe some substitution reactions of activated aryl halides[23] (including *p*-halonitrobenzenes)[23a,c] with nucleophiles in terms of radical nucleophilic substitution reactions of the $\mathrm{S_{RN}2}$ type. This mechanism, characterized by a bimolecular reaction of the substrate radical anion, $\mathrm{ArX^{\bullet-}}$, with the nucleophile, $\mathrm{Y^-}$, to produce in a single step $\mathrm{ArY^{\bullet-}}$ and $\mathrm{X^-}$, is invoked to accommodate both some evidence[24] that the substrate radical anion is a reaction intermediate and the established lack of reactivity of activated aryl halide in $\mathrm{S_{RN}1}$ reactions, due to the stability of their radical anions toward fragmentation.[25] Because of the known frangibility of its radical anion,[6] *o*-iodonitrobenzene does not qualify as a substrate for an $\mathrm{S_{RN}2}$ reaction; indeed, it was the exception among nitro-substituted aryl halides as it was shown to engage in $\mathrm{S_{RN}1}$ reactions.[6c]

Experimental Section

GC analyses were performed on a Varian 3700 gas chromatograph interfaced to a Shimadzu Chromatopac C-R4A integrator, using a 2 mm (i.d.) × 1.8 m glass column packed with 3% XE 60 on Chromosorb WAW DMCS. A Hewlett-Packard 5890 GC5970 MSD system interfaced to a HP 59940A MS Chemstation was used for GC-MS analysis, with a 15-m fused silica column of polydimethylsiloxane-bonded phase. ^{1}H NMR spectra were recorded on a 200-MHz Bruker spectrometer.

Materials. Reagent grade 2-propanol was fractionally distilled from Mg turnings. 2-Propanol-OD (98% D), the commercial product of Janssen, was used as received. 2-Iodo- and 2-bromonitrobenzene (Aldrich) were recrystallized from EtOH. The RSNa salts (R = Me, 2-Pr, *t*-Bu), the products of Fluka, were used as received. The *o*-nitrophenyl thioethers **2** were prepared and purified as described earlier.[2] *n*-Hexadecane (GC standard of Carlo Erba) was used as internal standard for GC quantitative analysis.

Kinetic Determinations. The apparatus and the procedures used were as described previously.[2]

Determinations of %D Incorporation. The extent of deuterium incorporation in nitrobenzene was determined from the intensity ratio of the *m*/*z* 123 (M$^+$) and 124 (M + 1) peaks in the mass spectrum, applying the appropriate correction for the contribution due to heavy isotopes in natural abundance.

Acknowledgment. Financial support by the Ministero della Pubblica Istruzione (Fondi 40% e Fondi 60%) is gratefully acknowledged.

---

[18] The values become 1.5 (R = Me), 0.72 (R = 2-Pr), and 1.00 (R = *t*-Bu, taken as reference) if one works under the hypothesis of two competing processes, the $\mathrm{S_NAr}$ substitution and the halogenophilic reduction, and evaluates the rate constants for the latter reaction as $k_{\mathrm{red}} = k_\psi - k_{\mathrm{sub}}$. The conclusions do not change.

[19] Bunnett, J. F. *Acc. Chem. Res.* **1972**, *5*, 139.

[20] Bartoli, G.; Di Nunno, L.; Todesco, P. E. *Tetrahedron Lett.* **1968**, *19*, 2369. Bartoli, G.; Di Nunno, L.; Florio, S.; Fiorentino, M.; Todesco, P. E. *J. Chem. Soc., Perkin Trans. 2* **1976**, 1371.

[21] (a) Eberson, L.; Radner, F. *Acc. Chem. Res.* **1987**, *20*, 53. (b) Eberson, L. *Adv. Phys. Org. Chem.* **1982**, *18*, 79. (c) Pross, A. *Acc. Chem. Res.* **1985**, *18*, 212. (d) Todres, Z. V. *Tetrahedron* **1985**, *41*, 2771. (e) Bordwell, F. G.; Harrelson, J. A., Jr. *J. Org. Chem.* **1989**, *54*, 4893.

[22] Bacaloglu, R.; Blasko, A.; Bunton, C. A.; Ortega, F.; Zucco, C. *J. Am. Chem. Soc.* **1992**, *114*, 7708 and refs cited therein.

[23] (a) Denney, D. B.; Denney, D. Z. *Tetrahedron* **1991**, *47*, 6577. (b) Zhao, W.-Y.; Huang, Z.-T. *J. Chem. Soc., Perkin Trans. 2* **1991**, 1967. (c) Zhang, X.-M.; Yang, D.-L.; Liu, Y.-C. *J. Org. Chem.* **1993**, *58*, 224. (d) Marquet, J.; Jiang, Z.; Gallardo, I.; Batlle, A.; Cayón, E. *Tetrahedron Lett.* **1993**, *34*, 2801.

[24] Caution should be exercised in interpreting the decrease in the yield of substitution product at a given reaction time caused by the addition of dinitrobenzenes[23c] or of $\mathrm{Fe^{III}}$ [23b] as evidence for the involvement of radical intermediates. Oxidation or other reactions of the nucleophile, in both cases a carbanion, could interfere seriously.

[25] Bunnett, J. F. *Acc. Chem. Res.* **1978**, *11*, 413.