Radical Anions from 4-Nitrobenzyl Compounds

Sir:

We now report, for the first time, approximate lifetimes for the radical anions formed by one-electron reduction of 4-nitrobenzyl derivatives, along with reduction potentials.[1]

Data for 4-nitrotoluene are in agreement with previous reports,[2] but previous studies on other derivatives have either used two-electrode systems[3-5] or have had goals different from those we have achieved.[6,7] We have used three-electrode polarography for accurate determination of the reduction potentials and cyclic voltammetry (especially single scan) to obtain direct information on the stability ot the radical anion intermediates.

Polarographic reduction potentials (Table I) were measured in the usual manner.[8]

Table I. Electrochemical Properties of 4-Nitrobenzyl Compounds[a,b]

Compound	$E_{1/2}$	$E_{3/4} - E_{1/4}$	$(E_p)^a - (E_p)^c$	n	Radical anion decomposition rate constant, $\sec^{-1}$ [d]
4-Nitrotoluene	−1.50	0.055	0.060	0.91	Stable
4-Nitrobenzyl fluoride	−1.40	0.065	0.065	0.90	*Ca.* 0.01
4-Nitrobenzyl chloride	−1.15	0.065		0.88	10–20
4-Nitrobenzyl thiocyanate	−1.09	0.065		0.82	7–8
4-Nitrobenzyl cyanide	−1.41	0.055		0.94	0.1
4-Nitrobenzyl-[e] bromide	−0.95				At least >100

[a] Studied with a dropping mercury electrode (polarography) in a three-electrode system. All compounds were purified and checked by one or more analytical criterion. [b] Reference electrode Ag\|AgClO$_4$ (0.01 *M*) in acetonitrile containing 0.1 *M* tetra-*n*-butylammonium perchlorate. [c] From cyclic voltammetry carried out with three-electrode system; hanging mercury drop electrode, Hewlett-Packard Model 3375 wave generator, Tektronix Model RM564 storage oscilloscope, H-type cell with Luggin capillary bridge to reference compartment, Heath Co. polarographic apparatus; single-scan triangular waves were taken from the HP-3375 by means of a simple flip-flop circuit. [d] Through cyclic voltammetry as indicated in L. W. Marple, *et al.*, *J. Electrochem. Soc.*, **107**, 437 (1960), or through comparison of the heights of the reduction wave and the oxidation wave observed after its reversal. [e] A prewave (adsorption?) is seen at −0.70 V, making difficult the study of the radical anion.

Cyclic voltammetric studies[10,11] were carried out in two ways, using multiple scans for those cases in which the radical anion was moderately stable, and single scans (which yielded much clearer results) for others. Decomposition of the radical anion yielded mostly 4,4′-dinitrodibenzyl along with some 4-nitrotoluene.[6] It was then possible to determine electrochemically how much of the radical anion decomposed (see eq 2) in the time that the voltage was swept from the reduction potential for the 4-nitrobenzyl derivative to that of the reduction potential of the product ($E_{1/2}$ − 1.50 V). Approximate rate constants[12] for the rate of decomposition of the radical anions are listed in Table I.

The reactions of 4-nitrobenzyl derivatives under consideration can be written in two steps (eq 1 and 2),

$$\mathrm{NBX} \xrightarrow{e^-} \mathrm{NBX}\cdot^- \qquad (1)$$

$$\begin{array}{l} \mathrm{NBX}\cdot^- \longrightarrow \mathrm{NB}\cdot + \mathrm{X}^- \\ \qquad\qquad\quad \mathrm{NB}\cdot \longrightarrow (\mathrm{NB})_2 + \mathrm{NBH} \end{array} \qquad (2)$$

the first being the reduction, and the second the decomposition of the radical anion. The large effect of substituents not directly bonded to the aromatic ring on the reduction potential is interesting. The reduction potential for $NO_2C_6H_5CH_2X$ falls from −1.50 (H) through −1.41 (CN), −1.40 (F), −1.15 (Cl), −1.09 (SCN), to −0.95 (Br). A major portion of the change can be ascribed to the decomposition of the radical anion (*e.g.*, expected $\Delta E_{1/2}$ (F → Cl) ~0.12, actual +0.25; (F → SCN) ~0.12, actual +0.31), and the remainder can be accounted for by interaction of the π^* orbital holding the electron with the σ^* orbital of the CH_2–X bond in the fashion postulated by Traylor, *et al.*,[13] in σ–π interactions. The rates of decomposition of the radical anions roughly parallel

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(1) The rates of the electron-transfer reaction between 1-ethyl-4-carbomethoxypyridinyl radical and 4-nitrobenzyl chloride have been reported by E. M. Kosower and M. Mohammad, *J. Amer. Chem. Soc.*, **90**, 3271 (1968).

(2) A. H. Maki, and D. H. Geske, *ibid.*, **83**, 1852 (1961); D. H. Geske, *et al.*, *ibid.*, **86**, 987 (1964).

(3) J. Grimshaw and J. S. Ramsay, *J. Chem. Soc. B*, 60 (1968).

(4) Klopman, *Helv. Chim. Acta*, **44**, 1908 (1961).

(5) C. Perrin, *Progr. Phys. Org. Chem.*, **3**, 165 (1955).

(6) J. G. Lawless, D. E. Bartak, and M. D. Hawley, *J. Amer. Chem. Soc.*, **91**, 7121 (1969).

(7) W. M. Gulick, Jr., and D. H. Geske, *ibid.*, **88**, 2928 (1966), have noted the instability of the radical anion of a 4-nitrobenzyl diphenyl phosphate.

(8) Measured with a dropping mercury electrode using a three-electrode system in CH_3CN (0.1 *M* tetra-*n*-butylammonium perchlorate, TBAP) in the absence of oxygen against a silver\|silver perchlorate (0.01 *M* + 0.1 *M* TBAP) reference electrode in CH_3CN. The criterion for reversibility ($E_{3/4} - E_{1/4}$ = 0.056 V)[9] was met for all compounds except 4-nitrobenzyl bromide

(9) L. Meites, "Polarographic Technique," Wiley-Interscience, New York, N. Y., 1965.

(10) Using a hanging mercury drop electrode. The criterion for reversibility (E_p(cathodic) − E_p(anodic) = 0.056 V)[11] for one-electron processes (n = 1) was applicable only in the case of 4-nitrotoluene and 4-nitrobenzyl fluoride.

(11) P. Delahay, "New Instrumental Methods in Electrochemistry," Interscience, New York, N. Y., 1954. See also R. N. Adams, "Electrochemistry at Solid Electrodes," Marcel Dekker, New York, N. Y., 1969, p 145.

(12) The scan in which the peak for the product was about one-half of that for the starting material was chosen to calculate the time for the half-life of decomposition, given directly from the sweep rate and the separation measured on an oscilloscope. Diffusion of electroactive material would alter the composition of the solution at the electrode, but we do not believe that the magnitude of the estimated rate constants would be changed greatly. Changes in the concentration level of the benzyl derivatives did not alter the observed phenomena. Rate constants for the fluoride and cyanide were evaluated by a comparison of the reduction wave with that of the reoxidation of the radical anion.

(13) W. Hanstein, H. J. Berwin, and T. G. Traylor, *J. Amer. Chem. Soc.*, **92**, 829 (1970).

the carbon–X bond energies,[14] with solvation differences making a smaller but unknown contribution.

Opinions on the nature of the reduction step for benzyl halides have been mixed,[16–21] some regarding the anion as a transition state, others treating it as an intermediate. The 4-nitrobenzyl chloride radical anion has been proposed as an intermediate in many chemical reactions,[16–22] and reported to have a half-life for decomposition of about 30 msec.[23,24] The present work verifies previous indications about the half-life of the 4-nitrobenzyl chloride radical anion, demonstrates that many 4-nitrobenzyl derivatives will behave in the same way, and proves beyond doubt the stability of such intermediates. Reactions which proceed through such intermediates must be carefully considered in light of the lifetimes for such anions.[25]

A full report on these anions will be submitted in due course.

(14) Using data for isopropyl halides,[15] rate constants for the decomposition of 4-nitrobenzyl bromide and 4-nitrobenzyl iodide radical anions can be estimated as 10^3 and 10^5 sec^{-1}, respectively. If the transition state for radical anion decomposition occurs at a degree of bond weakening which is a constant fraction of the total bond energy, the rate difference between the 4-nitrobenzyl fluoride radical anion decomposition and that for the chloride (transition state energy difference *ca.* 4.5 kcal/mol) can be used to estimate that the transition state is reached at approximately 20% bond breaking.

(15) S. W. Benson, *J. Chem. Educ.*, 42, 507 (1965), gives the following bond energies (kcal/mol): fluoride, 105; chloride, 81; bromide, 68; and iodide, 53.

(16) G. A. Russell and W. C. Danen, *J. Amer. Chem. Soc.*, 90, 347 (1968), were unable to detect 4-nitrobenzyl chloride radical anion under the same conditions successfully used for the 3-nitrobenzyl chloride radical anion.

(17) A. Streitwieser and C. Perrin, *ibid.*, **86**, 4938 (1964).

(18) F. H. Covitz, *ibid.*, **89**, 5403 (1967).

(19) J. W. Sease, F. G. Burton, and S. L. Nickol, *ibid.*, 90, 2595 (1968).

(20) L. W. Marple, L. E. I. Hummelstedt, and L. B. Rogers, *J. Electrochem. Soc.*, 107, 437 (1960).

(21) F. L. Lambert, *J. Org. Chem.*, 31, 4184 (1966).

(22) N. Kornblum, *et al.*, *J. Amer. Chem. Soc.*, **90**, 6219 (1968).

(23) W. A. Waters and L. Kolker, *Proc. Chem. Soc. London*, 55 (1963).

(24) G. L. Closs, University of Chicago, personal communication.

(25) M. Mohammad and E. M. Kosower, *J. Amer. Chem. Soc.*, in press.

(26) On leave from Institute of Chemistry, University of Islamabad, Pakistan.

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Selective Reduction of Aliphatic Ketones and Aldehydes to Hydrocarbons with Sodium Cyanoborohydride and *p*-Toluenesulfonyl Hydrazide in Dimethylformamide–Sulfolane

Sir:

The reductive deoxygenation of carbonyl functions is of considerable importance in the area of molecular synthesis principally because carbonyl intermediates often occupy a central position in the building of complex structures but eventually must be removed after serving their synthetic purpose. Consequently, a number of procedures have been devised for converting ketones and aldehydes directly[1] or indirectly[2] to the corresponding hydrocarbon. However, the classical procedures which are employed often suffer from nongenerality, experimental difficulties, and/or a lack of selectivity in effecting the desired carbonyl reduction without altering other portions of the molecule. For example, while various Wolff–Kishner modifications have found considerable utility for deoxygenations, the high concentration of base and relatively vigorous conditions[1] preclude the presence of several other functional groups such as ester, amide, halogen, and nitro.[3] Recently, Caglioti and coworkers[4] have established that reduction of *p*-toluenesulfonylhydrazones with sodium borohydride in refluxing methanol or dioxane effects conversion to the corresponding hydrocarbon in reasonable yields (*i.e.*, 30–80%) in many cases. However, alkene side products are also produced with some substrates[5] and the selectivity of sodium borohydride is not high at the required reduction temperatures.[6] The mechanism suggested involves initial reduction to the tosylhydrazine followed by elimination of *p*-toluenesulfinic acid and subsequent decomposition of the diimide intermediate to the hydrocarbon.[5]

The very mild reducing ability of cyanoborohydride toward most functional groups with the exception of imminium ions[7] suggested the attractive possibility of utilizing this reagent in an acidic medium to selectively convert tosylhydrazones to hydrocarbons. We wish to report that, indeed, such reductions are conveniently accomplished using sodium cyanoborohydride in a 1:1 mixture of *N*,*N*-dimethylformamide and sulfolane[8] containing *p*-toluenesulfonic acid at 100–105°.

Experimentation established that a fourfold molar excess of $NaBH_3CN$ was suitable, in most cases, for

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(1) A recent critical review containing 170 references concerning methods for deoxygenation of carbonyl compounds and a comparison of their effectiveness is provided by W. Reusch in "Reduction," R. L. Augustine, Ed., Marcel Dekker, New York, N. Y., 1968, pp 171–211. For the direct conversion of aromatic acids to hydrocarbons, see R. A. Benkeser, K. M. Foley, J. M. Gaul, and G. S. Li, *J. Amer. Chem. Soc.*, 92, 3232 (1970).

(2) A common indirect method of conversion of carbonyl derivatives, including esters and acids, involves lithium aluminum hydride reduction to an alcohol followed by conversion to the tosylate or halide and displacement using a metal hydride, usually lithium aluminum hydride [see, for example, L. S. Trevoy and W. G. Brown, *ibid.*, 71, 1675 (1949); G. Buchi, W. Hofheinz, and J. Paukstelis, *ibid.*, **88**, 4113 (1966)]. More recently, sodium borohydride in polar aprotic solvents has proven effective for selective conversion of the halides or tosylates to hydrocarbons; see R. O. Hutchins, D. Hoke, J. Keogh, and D. Koharski, *Tetrahedron Lett.*, 3495 (1969); H. M. Bell, C. W. Vanderslice, and A. Spehar, *J. Org. Chem.*, 34, 3923 (1969); E. J. Corey, H. A. Kirst, and J. A. Katzenellenbogen, *J. Amer. Chem. Soc.*, 92, 6314 (1970).

(3) Huang-Minlon, *ibid.*, **70**, 2802 (1948).

(4) L. Caglioti, *Tetrahedron*, 22, 487 (1966); L. Caglioti and P. Grasselli, *Chem. Ind.* (*London*), 153 (1964).

(5) M. Fischer, Z. Pelah, D. H. Williams, and C. Djerassi, *Chem. Ber.*, **98**, 3236 (1965).

(6) Caglioti (ref 4) reports concomitant reduction of acetoxy groups when steroidal ketone tosylhydrazones are deoxygenated with sodium borohydride in methanol and/or dioxane at reflux temperatures. Reduction of esters by borohydride in methanol has also been observed by others; see, for example, M. S. Brown and H. Rapoport, *J. Org. Chem.*, 28, 3261 (1963). Aromatic nitro groups also would probably not survive borohydride treatment in refluxing methanol or dioxane; see H. J. Shine and H. E. Mallory, *ibid.*, 27, 2390 (1962); R. O. Hutchins, D. W. Lamson, L. Rua, C. Milewski, and B. Maryanoff, *ibid.*, in press.

(7) R. F. Borch and H. Durst, *J. Amer. Chem. Soc.*, **91**, 3996 (1969), have recently reported an excellent procedure for the reductive amination of aldehydes and ketones using lithium cyanoborohydride and amines in acidic methanol. The success of the method depends on the relatively rapid reduction of imminium ions over carbonyls by cyanoborohydride and on the stability of the reagent toward acid. See also M. M. Kreevoy and J. E. C. Hutchins, *ibid.*, **91**, 4330 (1969).

(8) Several other solvent systems including dimethylformamide, sulfolane, dimethyl sulfoxide, and hexamethylphosphoramide were also tried, with less success.