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).

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(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

(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.

Table I. Reduction of Ketones and Aldehydes to Hydrocarbons with Sodium Cyanoborohydride and *p*-Toluenesulfonyl Hydrazide in Dimethylformamide–Sulfolane at 100–105°

Entry	Carbonyl compound[a]	Time, hr	Product	% yield[b] (isolated)
1	$CH_3(CH_2)_8C{=}NNHTs(CH_3)$	3.5	$CH_3(CH_2)_9CH_3$	95
2	Cholestan-3-one tosylhydrazone	1.0	Cholestane	93
3	*N*-Benzylpiperidone 4-tosylhydrazone	4.0	*N*-Benzylpiperidone	79
4	$CH_3(CH_2)_8COCH_3$	4.0	$CH_3(CH_2)_9CH_3$	91 (86)
5	Cholestan-3-one	2.0	Cholestane	98 (88)
6	4-*tert*-Butylcyclohexanone	3.0	*tert*-Butylcyclohexane	77
7	$CH_3(CH_2)_9CHO$	4.0	$CH_3(CH_2)_9CH_3$	66
8	$CH_3CO(CH_2)_3CO_2(CH_2)_7CH_3$	2.0	$CH_3(CH_2)_4CO_2(CH_2)_7CH_3$	87 (80)
9	$CH_3CO(CH_2)_2CO_2(CH_2)_9CH_3$[c]	2.0	$CH_3(CH_2)_3CO_2(CH_2)_9CH_3$	80
10	$CH_3(CH_2)_2COCH_2CO_2(CH_2)_7CH_3$	2.0	$CH_3(CH_2)_4CO_2(CH_2)_7CH_3$	62
11	$CH_3COCH_2CO_2(CH_2)_9CH_3$	4.0	$CH_3(CH_2)_2CO_2(CH_2)CH_3$	65
12	$CH_3CO(CH_2)_3CO_2(CH_2)_6CN$	2.0	$CH_3(CH_2)_4CO_2(CH_2)_6CN$	75
13	$PhCOCH_2CO_2(CH_2)_7CH_3$	16	$Ph(CH_2)_2CO_2(CH_2)_7CH_3$	Trace

[a] Reaction solutions were 0.2 *M* in the carbonyl compound, 0.8 *M* in $NaBH_3CN$ in a 1:1 mixture of DMF and sulfolane acidified with 500 mg of *p*-toluenesulfonic acid monohydrate per 100 ml of solvent unless specified otherwise. [b] Yields of products were determined by glpc using internal standards and detector response factors. [c] 1.6 *M* in $NaBH_3CN$, 1.00 g of *p*-toluenesulfonic acid per 100 ml of solvent.

maximum yields. The rate plots for 2-undecanone tosylhydrazone (Figure 1) illustrate that increasing the acid concentration markedly accelerates the rate of reduction, but destruction of cyanoborohydride apparently competes with reduction at greater acid concentrations and lowers the final yield. The prior preparation of tosylhydrazones is unnecessary since the slow rate of carbonyl reduction[7] permits the generation of these intermediates *in situ* from the carbonyl compound and the *p*-toluenesulfonylhydrazide.

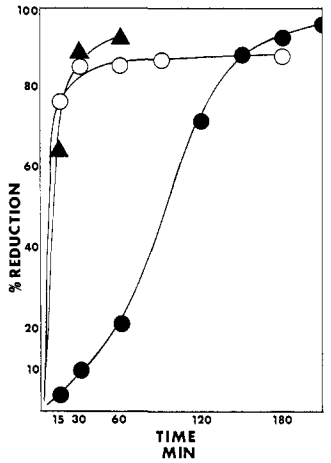

Figure 1. Reduction of 2-undecanone and cholestan-3-one tosylhydrazones with sodium cyanoborohydride in 1:1 dimethylformamide–sulfolane at 100°. All solutions were 0.2 *M* in tosylhydrazone and 0.8 *M* in sodium cyanoborohydride. The per cent reduction was determined by glpc analysis using internal standards: ●, 2-undecanone tosylhydrazone, solvent contained 500 mg of *p*-toluenesulfonic acid monohydrate per 100 ml, pH *ca.* 1.4; ○, 2-undecanone tosylhydrazone, solvent contained 1000 mg of *p*-toluenesulfonic acid monohydrate per 100 ml, pH *ca.* 0.8; ▲, cholestan-3-one tosylhydrazone, solvent contained 500 mg of *p*-toluenesulfonic acid monohydrate per 100 ml, pH *ca.* 1.4.

With the above in mind, the following general synthetic procedure was developed to effect a number of reductions which are shown in Table I. The aldehyde or ketone (1 mmol) and *p*-toluenesulfonylhydrazide (1.25 mmol) were dissolved in 5 ml of 1:1 DMF–sulfolane containing 25 or 50 mg of *p*-toluenesulfonic acid (see Table I). To this was added $NaBH_3CN$ (4 mmol), and the solution was heated at 100–105°. After completion,[9] the reactions were worked up by simply diluting with water and extracting with cyclohexane. Isolation of products is easily accomplished by washing with water to remove residual sulfolane and DMF followed by evaporation of the cyclohexane.

Several noteworthy features of the procedure are apparent from Table I. First, the yields of deoxygenated products are good to excellent (62–98% in 1–4 hr). Furthermore, in no cases studied were alkene or other side products detected by glpc or nmr. The superior selectivity possible is demonstrated by the conversions of keto esters (entries 8–11) and a cyano keto ester (entry 12) to the corresponding esters and cyano ester, respectively.[10] In fact, this procedure is so mild that aromatic ketones are not affected (entry 13), thus allowing aliphatic ketones to be removed in their presence. A wide variety of other functional groups should also be inert toward cyanoborohydride, and we are currently exploring the scope of possible selective conversions.

In conclusion, the procedure described offers a convenient, high-yield, relatively mild, and rapid method for the selective reduction of aliphatic ketones and aldehydes to hydrocarbons and should be applicable to a wide scope of structural types.

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(9) The reductions were conveniently monitored by adding an internal standard and 10 ml of cyclohexane to the reactions. At appropriate intervals, small samples of cyclohexane solution were removed and analyzed by glpc.

(10) For other procedures used to convert β-keto esters to saturated esters, see R. M. Coates and J. E. Shaw, *J. Org. Chem.*, 35, 2601 (1970), and references cited therein. These authors used a two-step procedure involving methoxymethylation followed by lithium-in-ammonia reduction to the esters in 23–61% yields.

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Acidity of Hydrocarbons. XXXV. Equilibrium Acidities of Phenylacetylene and *tert*-Butylacetylene in Cyclohexylamine

Sir:

Measures of the equilibrium acidity of acetylenes are presently available only for phenylacetylene in